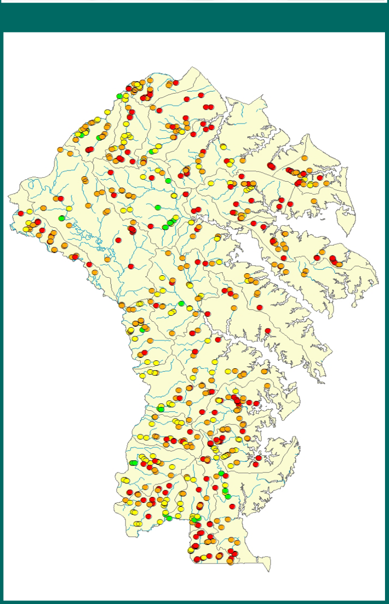


Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: Round Three 2017-2021

Anne Arundel County, Maryland
Department of Public Works
Bureau of Watershed Protection and Restoration

Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland

Round Three — 2017-2021

July 2022

Prepared for:

Anne Arundel County
Department of Public Works
Bureau of Watershed Protection and Restoration
Ecological Assessment and Evaluation Program

2664 Riva Road, 4th Floor/MS 7409
Annapolis, Maryland 21401

Prepared by:

KCI Technologies, Inc.
936 Ridgebrook Road
Sparks, Maryland 21152

Executive Summary

In 2004, a Countywide Biological Monitoring and Assessment Program for Anne Arundel County, Maryland was developed to assess the biological condition of the County's streams at multiple scales (i.e., site-specific, primary sampling unit (PSU), and countywide). Under the Countywide Biological Monitoring and Assessment program, biology (i.e., benthic macroinvertebrates) and stream habitat, as well as geomorphological and water quality parameters, are assessed at approximately 240 sites throughout the entire County over a 5-year period using a probabilistic, rotating-basin design. Round One of the County's Biological Monitoring and Assessment Program occurred between 2004 and 2008 and Round Two occurred between 2009 and 2013. This effort summarizes the findings of Round Three (2017 – 2021) of the County's Biological Monitoring and Assessment Program, with a discussion of the results at both countywide and smaller primary sampling unit (PSU) scales.

Prior to beginning Round Three of the program, a technical advisory group was convened to provide suggestions to Anne Arundel County on modifications to the sampling program. Recommendations from the advisory group which were incorporated into Round Three included partial replacement of fixed revisit sites, reduction of sites per PSU from ten to eight, addition of small stream sites, collection of grab samples for analysis by a water quality laboratory, and adding a summer visit for the collection of fish data and summer habitat assessments (Southerland et al., 2016).

Based on the Benthic Index of Biotic Integrity (BIBI) for Coastal Plain streams, Anne Arundel County stream sites during the Round Three assessment period were generally in poor biological condition. Countywide BIBI results indicate that only 6% of the sites in the County were in "Good" condition, 30% were rated "Fair", 41% were rated "Poor", and 23% were classified as "Very Poor", which is consistent with findings of both the Round One and Round Two surveys (Hill and Pieper, 2011b; Hill et al., 2014). There was no significant difference in average biological conditions between Round One and Round Three or between Round Two and Round Three surveys. Fish Index of Biotic Integrity (FIBI) scores for sites were generally poor, with 15% of the sites in "Good" condition, 24% in "Fair" condition, 31% "Poor", and 29% were classified as "Very Poor". Physical habitat conditions in County streams were generally rated "Partially Degraded" using the MBSS Physical Habitat Index (PHI) method, and "Partially Supporting" using the U.S. EPA's Rapid Bioassessment Protocol (RBP), which are also similar to both Round One and Round Two results.

Biological conditions of the benthic macroinvertebrate community at the PSU scale resulted in five PSUs, out of 24 total, rated as "Fair," and 19 rated "Poor". Only five PSUs saw significant differences in BIBI scores between Round One and Round Three. Upper Magothy River and Upper North River both saw BIBI scores decrease, possibly due to increased specific conductivity. Three PSUs (West River, Sawmill Creek, and Stony Run) saw BIBI scores increase between Rounds One and Three. Only two PSUs (Upper Magothy River and West River) had significant changes in mean BIBI scores between Rounds Two and Three, with both decreasing between the rounds. Biological conditions of the fish community at the PSU scale were similar to the conditions of the benthic macroinvertebrate communities with six PSUs rated "Fair", 15 rated "Poor", and three were rated "Very Poor". Physical habitat results using the PHI resulted in 15 PSUs rated as "Partially Degraded," and nine rated as "Degraded." RBP physical habitat rated 13 PSUs as "Partially Supporting," seven as "Supporting," and four were rated "Non-Supporting." Geomorphic assessment data indicate that the majority of streams assessed were classified as Rosgen "E" type (30%), "F" type (26%), or "G" type (17%) channels followed by "C" (11%), "B" (8%), and "DA"

(3%) type channels with the remaining 5% of streams either classified as "Transitional" or the stream type could not be determined.

Water quality data suggest that elevated specific conductivity measurements are a concern across the County as the vast majority of PSUs (75%; 18 of 24) had elevated spring conductivity levels, with mean conductivity greater than the 247 µS/cm threshold for impairment derived from the MBSS dataset. PSU mean concentrations of copper, lead, and zinc did not reach the EPA acute or chronic thresholds. Comparing Round Three results to water quality categories developed from the state-wide MBSS data set, PSU mean total nitrogen fell in the low category for the majority of PSUs (17 of 24), and PSU mean total phosphorus was in the moderate category for half the PSUs (12 of 24) and in the high category for nearly 38% (9 of 24) of PSUs. Analysis of land use and imperviousness show 11 PSUs having predominantly developed land use and the remaining 13 PSUs dominated by forested land use. Impervious surface percentages at the PSU scale ranged from 2.0% to 32.7%.

Nonparametric Kendall rank correlations found significant correlations between a number of biotic and abiotic variables. Both the BIBI and FIBI were positively correlated with the RBP physical habitat index, while neither was significantly correlated to the PHI index. BIBI scores were moderately correlated (negatively) to percent imperviousness ($p < 0.05$) and percent developed ($p < 0.05$) land use variables and correlated (positively) with percent forested ($p < 0.05$) and percent agriculture ($p < 0.05$) variables. FIBI was only moderately correlated to a single land cover variable, percent open ($p < 0.05$).

Specific conductivity and chloride were moderately negatively correlated to several benthic metrics including Percent Ephemeroptera, Number of Ephemeroptera and Percent Intolerant but not with the BIBI. Several water quality parameters were positively correlated with the FIBI, although none were highly significantly correlated and most were only weakly correlated, including ammonia and TKN (weakly negatively correlated) and water temperature, calcium, and hardness (weakly positively correlated). Several geomorphic variables were significantly correlated with biotic variables, but the findings may be an artifact of intercorrelation with drainage area. Numerous biological and physical habitat variables demonstrated strong positive correlations with drainage area, suggesting BIBI, FIBI, and RBP index scores are influenced by drainage area size. This evaluation is useful for understanding factors that affect stream quality, for improving water-quality management programs, for predicting stream response, and for documenting changing conditions over time in Anne Arundel County.

Acknowledgements

The principal authors of this document were Colin Hill, Robert Owen, Andy Becker and Michael Pieper of KCI Technologies, Inc. Cole Ecological, Inc. completed benthic macroinvertebrate sample sorting and primary identification and Ellen Friedman of Maryland Department of Natural Resources (2017-2018) and ESFriedman Lab (2019-2021). County staff instrumental in program management and quality assurance are Janis Markusic and Christopher Victoria in the Department of Public Works, Ecological Assessment and Evaluation Program. Annual sampling, data preparation, and reporting were conducted by KCI Technologies, Inc. and Coastal Resources, Inc.

The appropriate citation for this report is:

Hill, C. R., Owen, R.A., Becker, A.J., and M.J. Pieper. 2022. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: Round Three 2017 – 2021. Anne Arundel County Department of Public Works, Ecological Assessment and Evaluation Program, Annapolis, Maryland. 118 pp., plus appendices.

For more information about this report, please contact:
Christopher Victoria
Ecological Assessment and Evaluation Program
Bureau of Watershed Protection and Restoration
Department of Public Works
Anne Arundel County
2662 Riva Road / MS 7409
Annapolis, Maryland 21401
410.222.0545
pwvict16@aacounty.org

Table of Contents

List of Tables

List of Figures

1. Introduction

In 2003, the Anne Arundel County Office of Environmental & Cultural Resources (now the Department of Public Works, Bureau of Watershed Protection and Restoration) 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 development of the stream assessment tool (SAT) and related watershed management tool (WMT). However, the County found that information necessary to adequately characterize the biological condition of its major watersheds and to satisfy the needs and goals of the County's planning and management efforts were lacking. A comprehensive biological monitoring and assessment program would allow managers to:

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

Consequently, a Biological Monitoring and Assessment Program for Anne Arundel County, Maryland was developed by Hill and Stribling (2004) with the input of County staff and a technical advisory group comprised of local, State, and Federal government officials as well as representatives from academia. Under the Countywide Biological Monitoring and Assessment Program, biology and stream habitat, as well as geomorphological and water quality parameters, were assessed at approximately 240 sites throughout the entire County (i.e., 10 sites in each of 24 Primary Sampling Units or PSUs) over a 5-year period using a randomized rotating-basin design. Each 5-year period of sampling is referred to as a round. Stream sites were selected from a 1:100,000 scale stream reach file. These methods remained consistent for Round One and Round Two. Further information describing the Countywide Biological Monitoring and Assessment Program design during Round One and Round Two can be found in Hill and Stribling (2004).

Prior to beginning Round Three, a technical advisory group was again convened to provide suggestions to Anne Arundel County on modifications to the sampling program. Recommendations from the advisory group incorporated into Round Three included partial replacement of fixed revisit sites, reduction of sites per PSU from ten to eight, addition of small stream sites, collection of water quality grab samples for analysis by a water quality laboratory, and adding a summer visit for the collection of fish data and summer habitat assessments (Southerland et al., 2016).

Partial replacement with the addition of repeat sites from Round One and Round Two was added to improve trend detection by reducing the between site variability in the dataset related to the proportion of repeat sites visited in Round Three. A sampling design containing from 25% to 50% repeat sites is suggested as an ideal balance between trend detection and representative assessment with new sites (Cochran, 1977). Sites per PSU were reduced from ten to eight based on the results of a power analysis (Southerland et al, 2016) which showed less variability in sites located in the western Coastal Plain reference streams.

Small stream sites falling only on Anne Arundel County's high-resolution stream reach file were added to inform the County about ecological and habitat conditions of small streams not assessed during Round One and Round Two. Maryland's Benthic Index of Biotic Integrity (BIBI) was developed using data from sites larger than what are included in the small sites added to Round Three, so there exists a research question about the applicability of BIBI for small streams. Small site data were analyzed separate from the large stream sites in this Round Three report until this research question is answered.

Water quality grab samples were added to the data collected from each site during Round Three to provide additional abiotic data for analysis and description of stressors at the site and subwatershed level.

Anne Arundel County added a second summer field sampling visit to each large stream site to collect data on the ecological health of the fish communities, and to assess and describe habitat conditions present at the low-flow limiting conditions present during summertime. Analysis of the statewide MBSS dataset show little correlation between the benthic macroinvertebrate and fish indices, suggesting that each community is affected by and responds differently to stressors present in the watershed. Having a second ecological health index score will provide the County with a more complete understanding of ecological condition and may help describe different stressor gradients than would be possible with a single index score.

Sites were selected during Round Three from two stream strata; the large stream strata using the 1:100,000 scale stream reach file, and a small stream strata consisting of streams from the County's high-resolution stream reach file (estimated to be 1:2,400 scale) not also reflected in the large stream strata. For the Round Three large stream strata sites, eight sites were sampled in each PSU with 50% revisits of previously sampled Round One or Round Two sites, and 50% newly selected random sites. Eight random sites were selected from the small stream strata for each PSU.

This report summarizes the results of Round Three (2017 – 2021) of the County's Biological Monitoring and Assessment Program and compares stream health conditions with the conditions described from data collected during Round One (2004 – 2008) and Round Two (2009 – 2013). 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 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 at the time of program development (Hill and Stribling, 2004). Primary data collected from each site include site location (latitude and longitude), pH, dissolved oxygen, water temperature and specific conductivity, benthic macroinvertebrates, and physical habitat assessments following MBSS protocols (DNR, 2007; Stranko et al., 2019) as well as additional habitat assessment following USEPA's Rapid Bioassessment Protocols (RPB; Barbour et al., 1999) for Low Gradient streams. 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). New sampling components added to Round Three (Southerland et al., 2016) were water quality grab samples collected during the spring visit at all sites (e.g., small and large strata), and a second summer visit at the large stream sites where fish community was surveyed following MBSS protocols (Stranko et al., 2019) along with summer-collected habitat assessment data following MBSS and RBP habitat protocols. Biological data were analyzed using the revised (2005) version of the MBSS Coastal Plain Benthic Index of Biotic Integrity (BIBI) and Coastal Plain Fish Index of Biotic Integrity (FIBI; Southerland et al., 2005; Table 1). Habitat assessment data from each season were analyzed according to methods described in Barbour et al. (1999) for the RBP assessments (Table 2) and using MBSS' Physical Habitat Index (PHI; Paul et al., 2003; Table 3) developed for Maryland's streams.

Table 1. MBSS Biological Condition Rating

BIBI and FIBI Score	Narrative Rating
4.00 – 5.00	Good
3.00 – 3.99	Fair
2.00 – 2.99	Poor
1.00 – 1.99	Very Poor

Table 2. EPA RBP Scoring

Score	Narrative
151 +	Comparable
126-150	Supporting
101-125	Partially Supporting
0-100	Non Supporting

Table 3. MBSS PHI Scoring

Score	Narrative
81-100	Minimally Degraded
66-80.9	Partially Degraded
51-65.9	Degraded
0-50.9	Severely Degraded

A more detailed description of the sampling and analysis methods can be found in the annual Biological Monitoring and Assessment Program Annual Reports for each year of Round Three (Becker, et al., 2022; Becker, et al., 2020; Becker, et al., 2020; Becker, et al., 2018; Carvalho, et al., 2018). Specific information regarding the sampling and analysis methods, including the standard operating procedures (SOPs), can be found in the Documentation of Method Performance Characteristics for the Anne Arundel County Biological Monitoring Program (Hill and Pieper, 2017; Hill and Pieper, 2011a) and the Quality Assurance Project Plan for Anne Arundel County Biological Monitoring and Assessment Program (Anne Arundel County, 2017).

2.2 Quality Assurance/Quality Control

A primary goal of the County is to produce biological assessments of its water resources with objective and defensible data. As a result, a comprehensive Quality Assurance Project Plan (QAPP) for ensuring the collection of such data was developed simultaneously with the Countywide Biological Monitoring and Assessment Program initially by Tetra Tech in 2004, updated by KCI in 2011, and updated again at the beginning of Round Three sampling in early 2017 (Anne Arundel County, 2017). The QAPP followed U. S. Environmental Protection Agency requirements for developing project plans (USEPA, 1995) and describes the biological stream assessment protocol including data collection methods (SOPs), the technical rationale behind the procedures, and the series of activities and reporting procedures that are used to document and communicate data quality.

To provide a guideline for ongoing data quality assessments associated with the County's Biological Monitoring Program and to help enhance defensibility of data and assessments, a method performance characteristic framework was developed and outlined in Documentation of Method Performance Characteristics for the Anne Arundel County Biological Monitoring Program (Hill et al., 2005; Hill and Pieper, 2010; Hill and Pieper, 2011a). 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 Three monitoring year can be found in the Biological Monitoring and Assessment Program's Annual Reports (Becker et al., 2022; Becker et al., 2020; Becker et al., 2020; Becker et al., 2018; Carvalho, et al., 2018).

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 Three sampling year using geospatial data using ESRI's ArcMap (Version 10.5.x) or ArcGIS Pro (Version 2.9.0) geographic information system (GIS). The County's land cover GIS data is a hybrid land use/land cover dataset, but primarily represents land cover and is referred to in this report as such. The County's impervious GIS data is a polygon file that represents roadways, building footprints, and parking lots. From these data, the land cover and impervious surfaces in each sampling site's drainage area were calculated. Area and percent area of land cover and imperviousness for each sampling site's drainage area was calculated. Land cover and imperviousness for each PSU was determined following the same procedures. The calculation of impervious area did not account for treated vs. untreated imperviousness nor connected vs. disconnected impervious area.

For those sites sampled in 2017 and 2018, land cover was evaluated using countywide land cover and impervious data layers from 2014. Sites sampled from 2019 through 2021 were evaluated using 2017 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 4. 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 4. Combined Land Use Classes

Land Use Class	Land Cover Type
Developed	Airport, Commercial, Industrial, Mining, Transportation, Utility, Residential (1/8-ac., ¼-ac., ½-ac., 1-ac., and 2-ac.)
Forested	Forested wetland, Residential woods, Woods
Agriculture	Pasture/hay, Row crops
Open	Open space, Open wetland, Water

2.4 Data Analysis

Round Three data were analyzed to investigate associations between chemical, physical, and biological, parameters 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, 2022) to show the distribution of values for each PSU including the following summary statistics; minimum, first quartile (i.e., value for which 25% of the values are less), median, mean, third quartile (i.e., value for which 75% of the values are less), and maximum, as well as anomalous values including outliers, and extreme outliers. Generally, an outlier is a data point that lies an abnormal distance from other values in a random sample from a population (NIST/SEMATECH, 2011). A standard outlier is a value that falls within the lower and upper limits of the distribution; the lower limit being the lower quartile minus 1.5 times the interquartile range, and the upper limit being the upper quartile plus 1.5 times the interquartile range. Similarly, an extreme outlier is a value that falls beyond the upper and lower limits and within the range between the lower quartile minus three times the interquartile range and the upper quartile plus three times the interquartile range.

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

2.4.2 Correlations

Correlation, one of the most commonly used techniques for investigating the relationship between two quantitative variables, quantifies the strength of the relationship between a pair of variables (Bewick et al., 2003). Simple linear correlation analysis relies on assumptions that both variables being compared are normally distributed and the linear plot is homoscedastic (i.e., uniform variance). However, a Shapiro-Wilk goodness of fit test (Shapiro and Wilk, 1965) revealed that the BIBI and FIBI data do not fit normal distributions (p 0.001, $\alpha = 0.05$). Consequently, a non-parametric correlation analysis using the Kendall rank correlation coefficient (Kendall, 1955), was performed on the data set using XLSTAT version 2022.1.1 (Addinsoft, 2022). 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., 99.9% probability) defined highly significant correlations. For a simplified discussion of results, correlations are defined as weak ($\tau < 0.1$), moderate ($\tau = 0.1$ to 0.3), or strong ($\tau > 0.3$).

2.4.3 Benthic Macroinvertebrate Taxa Analysis

Analysis was performed on the raw benthic macroinvertebrate taxa data to evaluate which, if any, taxa may be unique to sites categorized as ‘good’ by the BIBI. A taxa list was assembled for all sites that received BIBI scores of 4.00 or greater, representing the taxa present in minimally-impaired sites. A taxa list was also assembled for all sites that received BIBI scores of less than 3.00, which represented the taxa observed in impaired sites. The two lists were then compared for overlap and taxa were selected that were unique to only minimally-impaired sites. Taxa from the minimally-impaired list that occurred at only a single site with a BIBI score <3.00 were added to the list. The final list was then comprised of taxa that either remained unique to unimpaired sites (BIBI scores of 4.00 or greater) or those that occurred at only a single impaired site. Thus, the final list is comprised only of genera that are unique, or relatively unique, to unimpaired streams. Taxa that were found to be unique but were identified to a higher taxonomic level than the genus level target (e.g., family, tribe) were not omitted from the list as was done during the Round Two taxa analysis. Complete lists of taxa observed during Round Three are presented in Appendix E.

2.4.4 Comparison of Results between Sampling Rounds

To compare statistical differences between mean index values from two time periods (e.g., Round Two and Round Three), the analysis uses the method recommended by Schenker and Gentleman (2001). This is the same method used by the MBSS to evaluate changes in condition over time and is considered a more robust test than the commonly used method, which examines the overlap between the associated confidence intervals around two means (Roseberry Lincoln et al., 2007). In this method, the 95% confidence interval for the difference in mean values Q1 − Q2 is estimated using the following formula:

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

where Q1 and Q2 are two independent estimates of the mean of a variable (i.e., BIBI, RBP, PHI) and SE1 and SE2 are the associated standard errors. The null hypothesis that (Q1 − Q2) is equal to zero was tested (at the 5 percent nominal level) by examining whether the 95 percent confidence interval contains zero. The null hypothesis that the two means are equal was rejected if and only if the interval did not contain zero (Schenker and Gentleman, 2001), resulting in a statistically significant difference between those two values.

3 Round Three Results

Results of Round Three sampling in Anne Arundel County from 2017 to 2021 are discussed by parameter (i.e., land use/land cover, biology, physical habitat, water quality, and geomorphology) at two different scales, the Countywide scale and PSU scale, in the following sections. Individual site assessment results are reported in the Biological Monitoring and Assessment Program's annual reports (Becker, et al., 2022, 2020, 2020, and 2018; Carvalho, et al., 2018).

3.1 Primary Sampling Unit Characterization

As outlined in Design of the Biological Monitoring and Assessment Program for Anne Arundel County, Maryland, the County was subdivided into 24 subwatershed PSUs (Hill and Stribling, 2004). To better understand the PSUs discussed in the following sections, a table containing summary characteristics for each PSU (i.e., drainage area, land use types, year sampled, etc.) has been compiled (Table 5.). In addition, Countywide results are also included to provide a way to compare individual PSU results with overall conditions observed in the County throughout Round Three sampling. Countywide land use and imperviousness are calculated based on County level data. Condition ratings for the County are based on mean values for all Countywide sites located on the large stream strata (n = 192). Percentage and proportion results at the Countywide scale (e.g., total proportion of Rosgen stream types, percentage of biological conditions, percentage of physical habitat conditions, etc.) are based on the individual site results (n = 192). Graphical presentation of PSU summary data are available for each of the 24 PSUs in Appendix C.

3.2 Land Use/Land Cover and Imperviousness

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

Figure 1 shows the proportion of land use classes for each PSU. A total of 11 PSUs were predominantly comprised of developed land use, ranging from 46.6% in Piney Run to 70.4 % in Upper Magothy. Similar to land use results from Round Two, only two PSUs, Upper Patuxent and Cabin Branch were less than 20% developed. Forested land use was dominant in the remaining 13 PSUs, which ranged from 34.7% in Lyons Creek to 69.80% in Upper Patuxent. Three PSUs had the smallest proportion of forested land (less than 25%) including Sawmill Creek, Lower Patapsco, and Upper Magothy, (20.1, 23.7, and 24.5 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 (33.8%), followed by Rock Branch (24.7%), Cabin Branch (24.3%), Hall Creek (22.5%), and West River (22.3%). Open land use was the least dominant, with the highest proportions observed in Sawmill Creek (17.3%) and Stony Run (16.7%), due in large part to the open space surrounding Baltimore-Washington International (BWI) Airport in addition to Cabin Branch (14.8%), which is largely due to Jug Bay Wetland Sanctuary acreage. A map displaying land use throughout the County, based on the 2017 Land Cover layer, is shown in Figure 2.

Within each PSU, the dominant land use type (i.e., the largest land use category, by percent, found in the upstream drainage area) representing each site sampled is shown, as a percentage of total sites, in Figure 3. Similar to Round Two results, one hundred percent of sites sampled in Upper Magothy, Stony Run, and Lower Magothy have predominantly developed land use along with the addition of Marley Creek and Lower Patapsco in the current round. Seven of eight sites in Bodkin Creek and Piney Run were also dominated by developed land use. There were no PSUs with 100% of sites dominated by forested land use. One PSU had seven of eight sites that were predominantly forested (Upper Patuxent). Seventy-five percent of sites in Lyons Creek were dominated by agricultural land use. The proportions of dominant land use types sampled differ slightly from the proportions that characterize each PSU, as shown in Figure 1, suggesting that land use within site-specific drainage areas may be more useful in explaining the overall biological condition of each PSU as opposed to land use at the PSU scale.

Table 5. Characterization of Anne Arundel County Primary Sampling Units from 2017-2021.

PSU Name	PSU Code	Year Sampled	Drainage Area (acres)	Percent Impervious	Percent Developed	Percent Forested	Percent Agriculture	Percent Open	BIBI Rating	FIBI Rating	PHI Rating	RBP Rating
COUNTYWIDE	-	2017-2021	266,024	15.0	46.4	37.3	7.4	8.8	P	P	PD	PS
Bodkin Creek	6	2017	5,872	13.6	53.4	35.7	0.9	10.0	P	P	PD	S
Cabin Branch	23	2021	6,443	2.0	18.4	42.6	24.3	14.8	P	P	PD	NS
Ferry Branch	21	2021	8,038	3.8	25.4	41.7	21.5	11.4	F	F	D	PS
Hall Creek	24	2021	3,168	3.0	34.6	40.1	22.5	2.7	P	P	PD	NS
Herring Bay	15	2021	14,595	4.7	30.5	50.1	10.3	9.0	F	VP	D	PS
Little Patuxent	17	2019	28,196	18.0	39.9	44.5	2.9	12.6	P	P	D	PS
Lower Magothy	8	2018	12,697	19.9	64.8	27.4	1.1	6.7	P	P	PD	S
Lower North River (South River)	12	2019	23,681	16.4	54.8	33.3	4.9	7.0	P	P	PD	PS
Lower Patapsco	3	2018	4,040	31.5	64.9	23.7	0.0	11.4	P	P	D	NS
Lyons Creek	22	2021	6,154	3.2	27.1	34.7	33.8	4.3	F	F	PD	PS
Marley Creek	5	2018	19,425	28.3	65.4	26.4	0.4	7.8	P	P	D	PS
Middle Patuxent	18	2019	6,332	6.3	30.1	38.1	20.1	11.7	P	P	PD	PS
Piney Run	1	2018	4,868	23.5	46.6	41.4	0.2	11.7	P	F	D	NS
Rhode River	13	2017	8,737	6.1	28.4	51.5	13.7	6.4	P	VP	PD	S
Rock Branch	20	2020	6,131	3.8	26.7	40.4	24.7	8.1	P	P	PD	PS
Sawmill Creek	4	2019	11,044	32.7	62.2	20.1	0.4	17.3	P	F	PD	S
Severn River	10	2017	28,920	19.9	58.5	31.1	2.8	7.6	P	P	PD	S
Severn Run	9	2017	15,424	19.6	52.6	37.1	2.9	7.4	P	P	D	S
Stocketts Run	19	2018	8,714	5.8	35.3	39.4	19.7	5.6	F	P	PD	PS
Stony Run	2	2020	6,203	18.3	53.5	29.8	0.0	16.7	F	F	D	PS
Upper Magothy	7	2020	10,031	13.9	70.4	24.5	0.3	4.8	P	P	D	PS
Upper North River (South River)	11	2017	12,797	7.0	37.6	48.9	9.3	4.2	P	F	PD	PS
Upper Patuxent	16	2019	6,957	6.9	19.0	69.8	0.5	10.8	P	P	PD	S
West River	14	2020	7,558	4.9	29.7	42.6	22.3	5.4	P	VP	PD	PS

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

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

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

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

The percentage of impervious cover was quite variable, ranging from a maximum of 32.7% in Sawmill Creek to a minimum of 2.0% in Cabin Branch (Table 5.). One other PSU, Lower Patapsco, had impervious cover equal to or exceeding 30%, comprising 31.5% of its drainage area. Two PSUs had impervious cover between 20% and 30% (Marley Creek and Piney Run), and seven more PSUs exceeded 13% (Lower Magothy, Severn River, Severn Run, Little Patuxent, Lower North River, Upper Magothy, and Bodkin Creek). The remaining 12 PSUs all had impervious cover that was below 10%, seven of which had less than five percent impervious cover (Cabin Branch, Hall Creek, Lyons Creek, Rock Branch, Ferry Branch, Herring Bay, and West River). A map of impervious cover throughout the County, based on the 2017 impervious cover layer, is displayed in Figure 4.

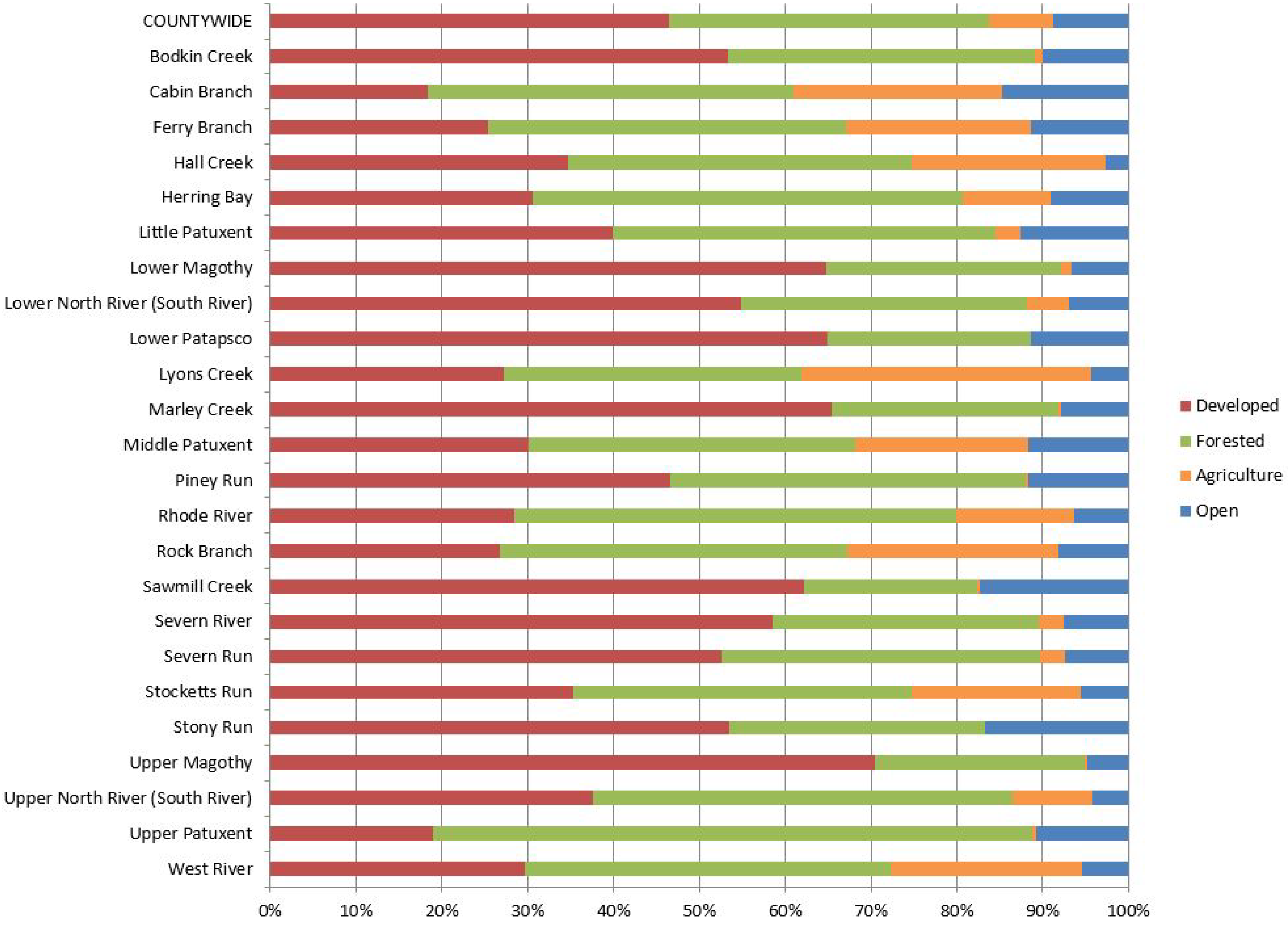


Figure 1. Percentage of Land Use Types for each PSU

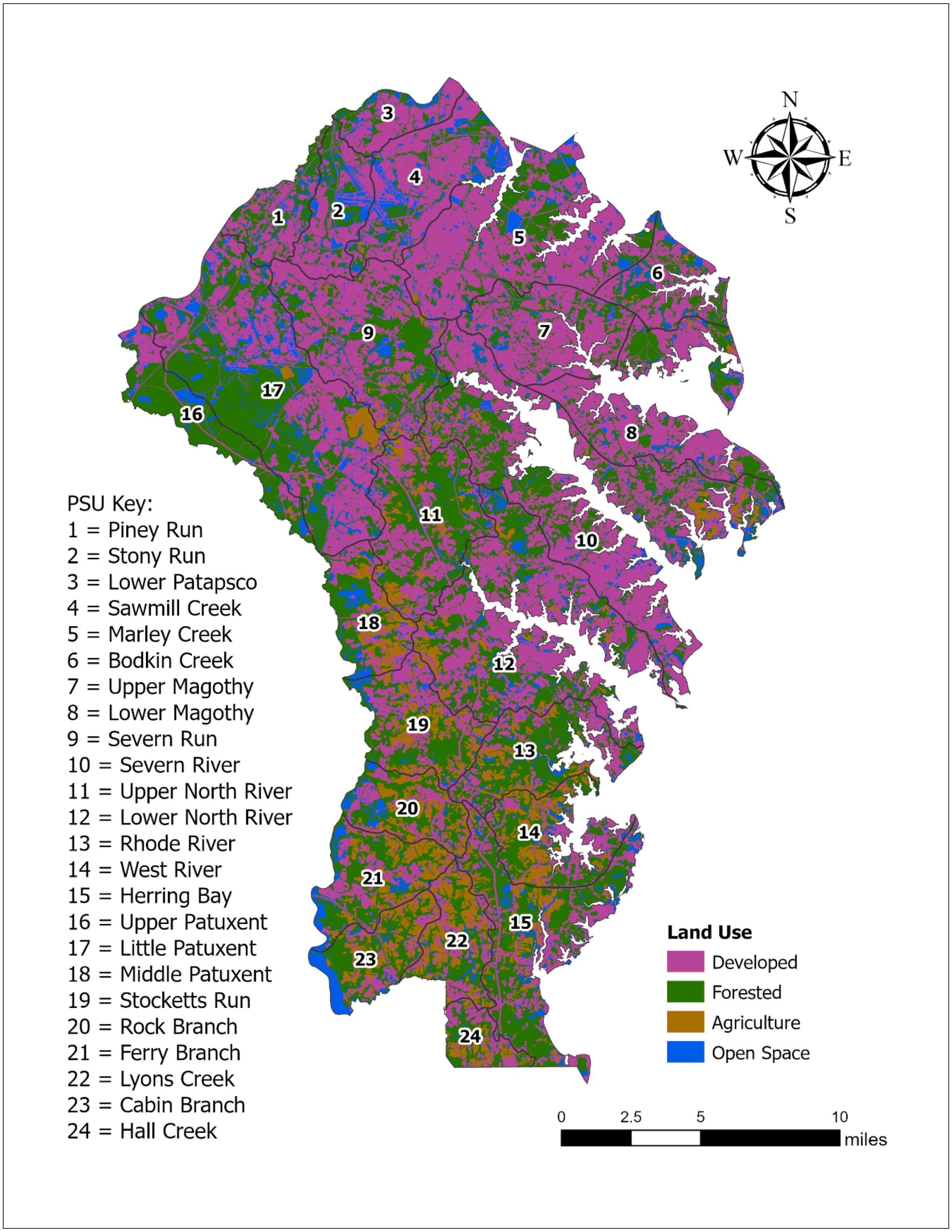


Figure 2. Anne Arundel County Land Use from 2017

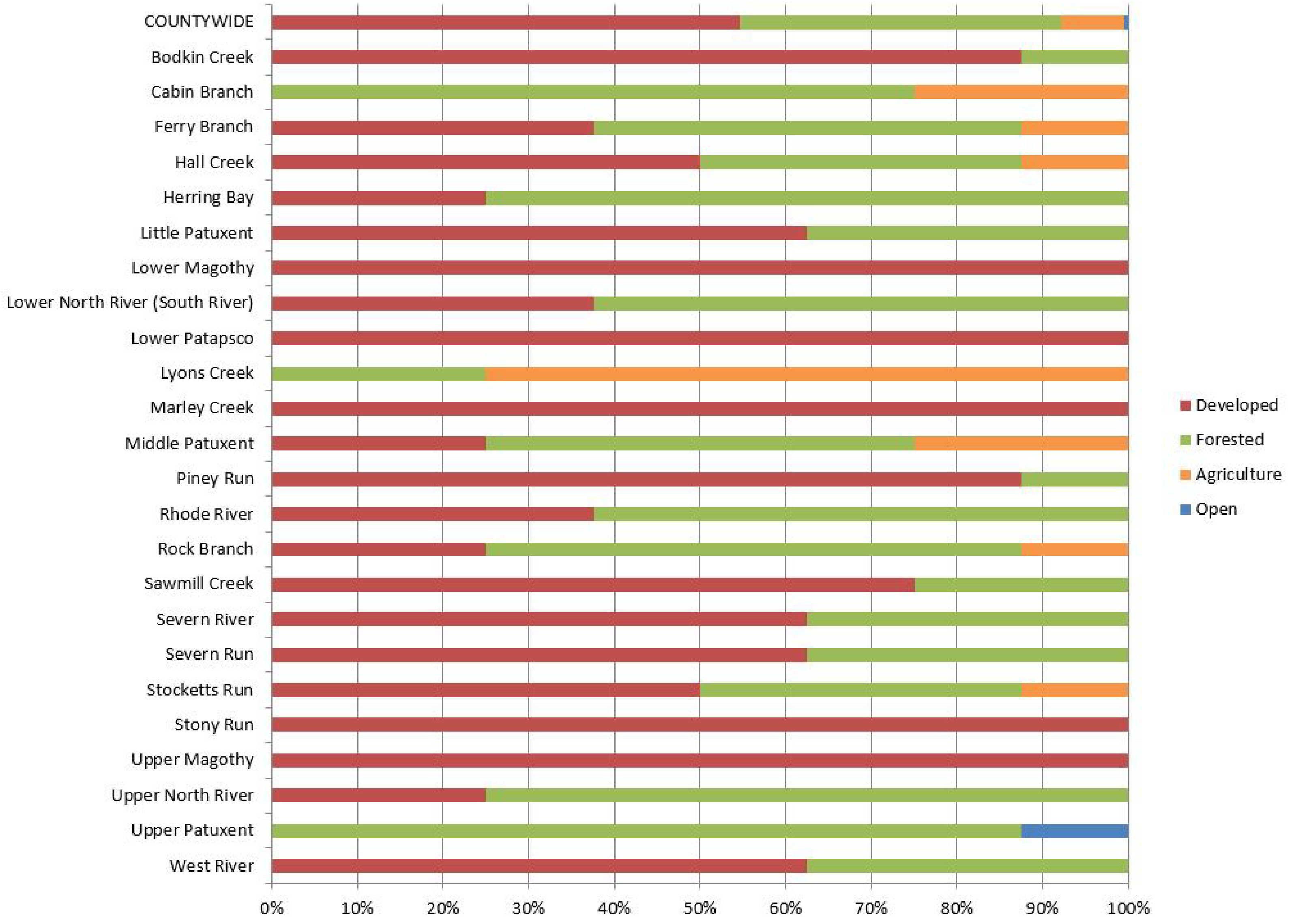


Figure 3. Dominant Land Use Draining to Each Site as a Proportion of Total Sites Sampled in Each PSU.

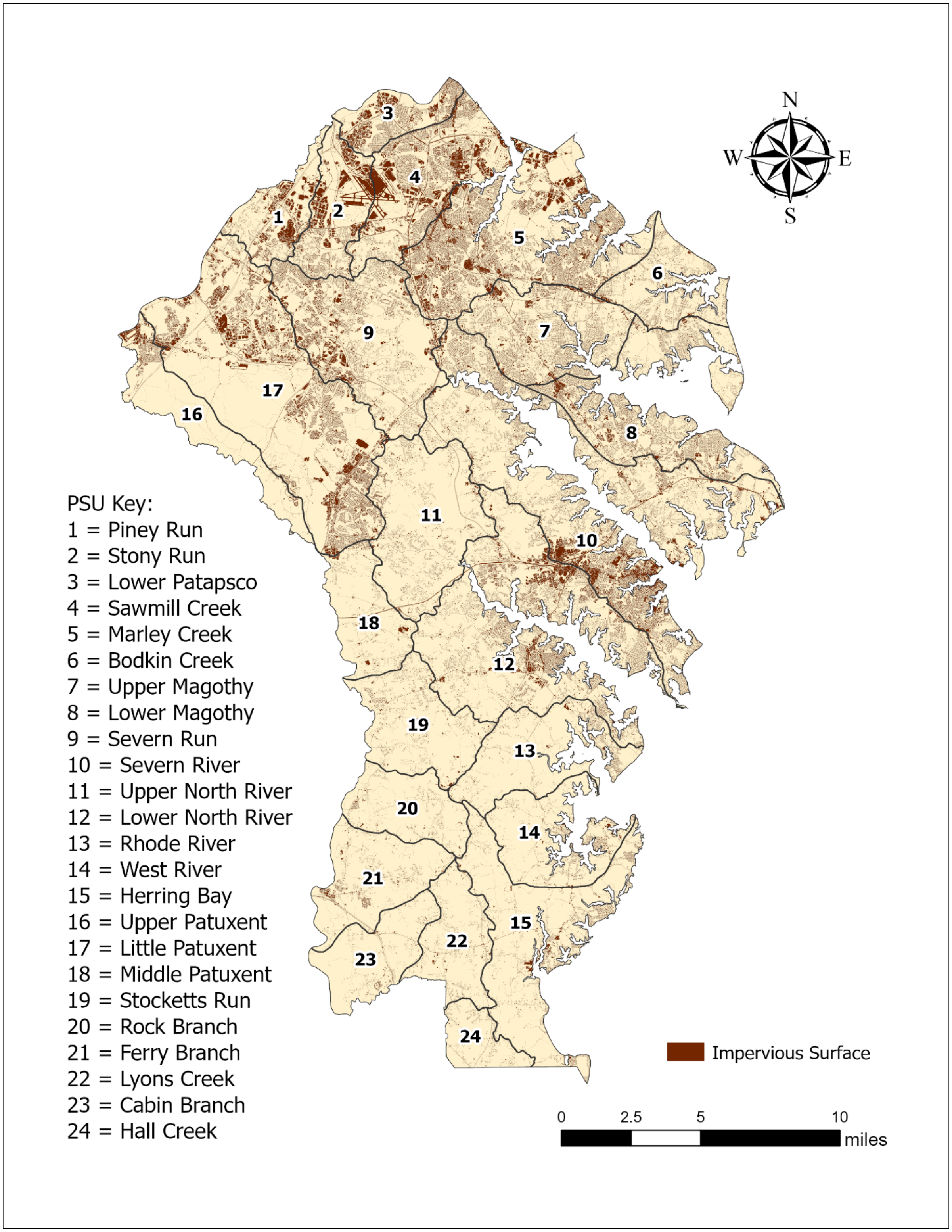


Figure 4. Anne Arundel County Impervious Surface from 2017

3.3 Biological Conditions

3.3.1 BIBI Scores

Since the inception of the Countywide program, the biological condition of Anne Arundel County's large streams has been 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 6. The overall condition of Anne Arundel County streams during the Round Three assessment period (2017-2021) was "Poor", with a mean BIBI score of 2.59 (standard deviation [SD] = 0.81).

Table 6. Mean BIBI Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2017-2021

PSU	Sample	Mean BIBI	Std Dev	Rating	Rank
COUNTYWIDE	192	2.59	0.81	Poor	-
Ferry Branch	8	3.29	0.55	Fair	1
Lyons Creek	8	3.14	0.86	Fair	2
Stocketts Run	8	3.11	1.18	Fair	3
Stony Run	8	3.07	0.50	Fair	4
Herring Bay	8	3.00	1.08	Fair	5
Sawmill Creek	8	2.93	1.17	Poor	6
Rock Branch	8	2.89	0.70	Poor	7
Cabin Branch	8	2.82	0.67	Poor	8
Severn Run	8	2.82	1.17	Poor	9
Upper North River	8	2.68	0.74	Poor	10
Middle Patuxent	8	2.68	0.84	Poor	11
Piney Run	8	2.61	0.43	Poor	12
Severn River	8	2.57	0.51	Poor	13
Bodkin Creek	8	2.54	0.51	Poor	14
Lower North River	8	2.39	0.74	Poor	15
Rhode River	8	2.36	0.52	Poor	16
West River	8	2.36	0.56	Poor	17
Marley Creek	8	2.32	0.92	Poor	18
Hall Creek	8	2.18	0.69	Poor	19
Lower Magothy	8	2.14	0.53	Poor	20
Lower Patapsco	8	2.14	0.98	Poor	21
Upper Magothy	8	2.14	0.65	Poor	22
Upper Patuxent	8	2.07	0.52	Poor	23
Little Patuxent	8	2.00	0.48	Poor	24

A total of five PSUs were rated "Fair" (21%), and nineteen were rated "Poor" (79%, Figure 5). Ferry Branch had the highest mean BIBI score of 3.29, followed by Lyons Creek (3.14), Stockett's Run (3.11), Stony Run (3.07), and Herring Bay (3.00), all of which were rated as having "Fair" biological conditions. On the opposite end of the spectrum, Little Patuxent had the lowest BIBI score of 2.00, which one of nineteen rated as "Poor." There were no PSUs rated in the 'Good' or 'Very Poor' categories by the BIBI.

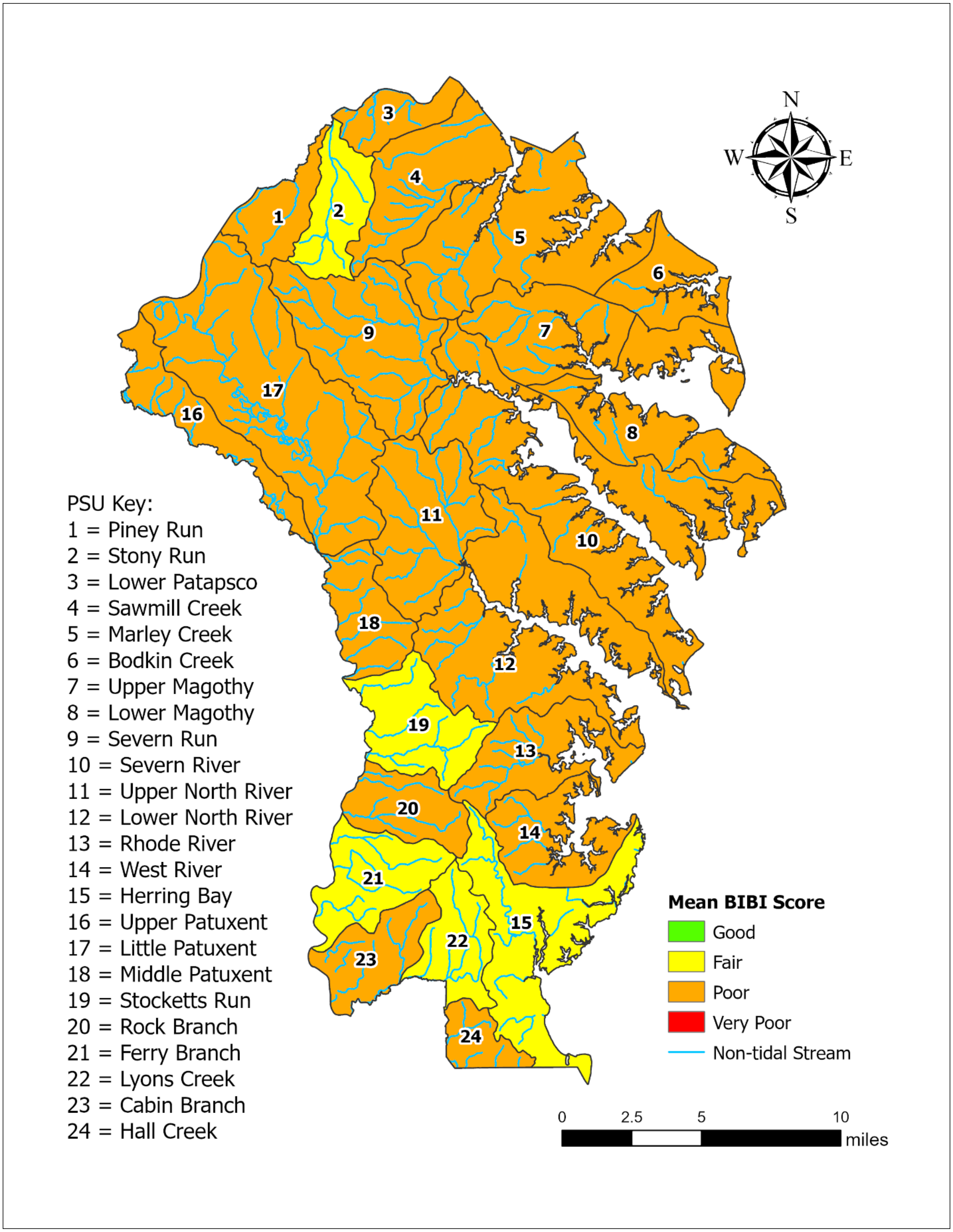


Figure 5. Average Biological (BIBI) Conditions for Primary Sampling Units.

At the Countywide scale, BIBI scores indicate that only 6% of the streams in the County were in “Good” condition, 30% were rated “Fair”, 41% were rated “Poor”, and 23% were classified as “Very Poor” (Figure 6). These results are somewhat similar to findings from the Maryland Department of Natural Resources’ MBSS sampling efforts during their Round Four sampling period (2015-2017) for sites sampled in Anne Arundel County. The countywide assessment classified the majority of streams as being in either “Poor” or “Fair” biological condition; however, MBSS classified more streams as being in “Good” condition and less stream s in “Very Poor” condition (34% vs. 6% and 11% vs. 23%, respectively).

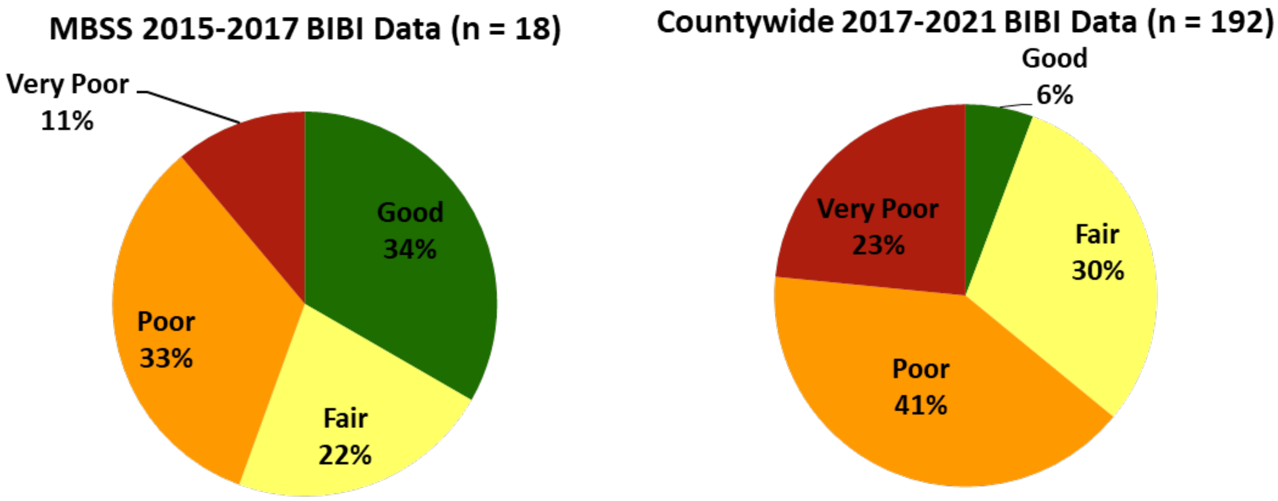


Figure 6. Comparison of Biological Conditions (BIBI) in Anne Arundel County Between MBSS Round 4 (2015-2017) and Countywide Round Three (2017-2021) Assessments.

A summary of site-specific biological condition ratings as a percentage of total sites within each PSU is displayed (Figure 7) and the distribution of sampling sites with their corresponding biological condition rating is displayed in Figure 8. Four PSUs (Herring Bay, Lyons Creek, Severn Run and Stocketts Run) had 25 percent of sites rated “Good” while three more PSUs had 13 percent of sites rated as “Good” (Ferry Branch, Middle Patuxent, and Sawmill Creek). Two PSUs (Ferry Branch and Stony Run) had no sites rated as “Very Poor.” Conversely, nine PSUs had 25 percent or more of sites rated as “Very Poor” and no sites rated as “Good.” Moreover, one PSU (Little Patuxent) had 100 percent of sites rated as either “Poor” or “Very Poor”.

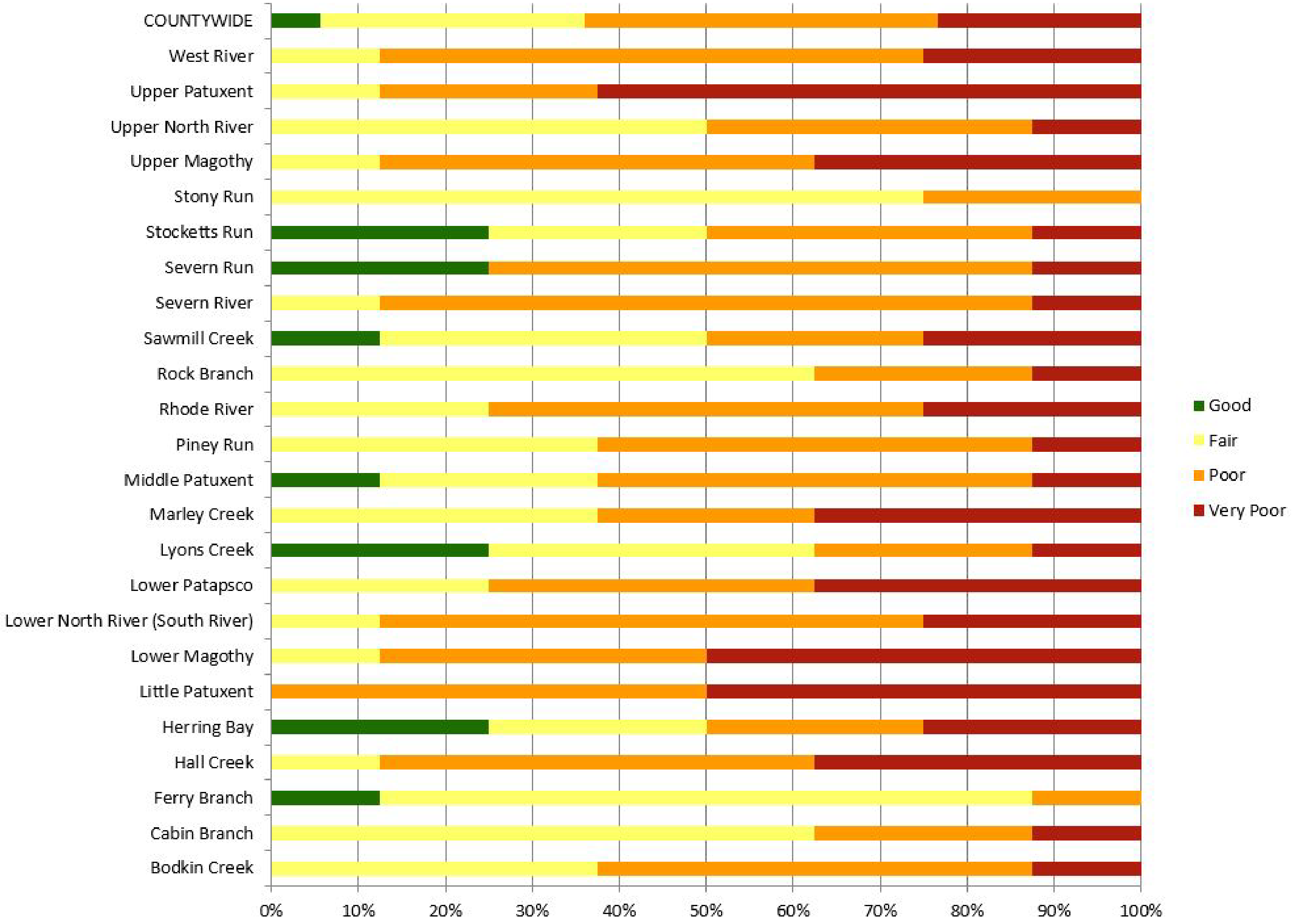


Figure 7. Biological Condition Ratings (BIBI) as a Percentage of Total Sites Within Each PSU.

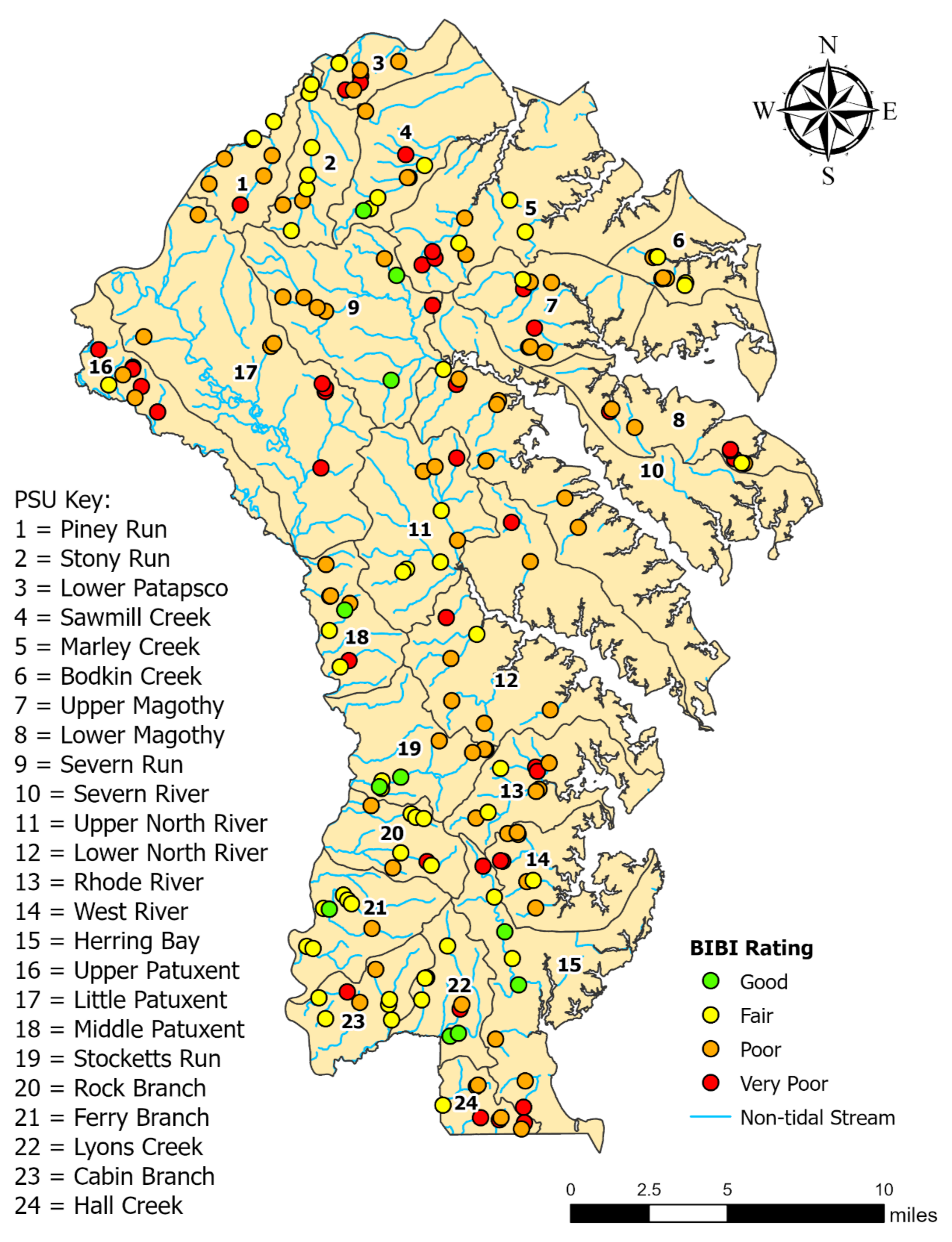


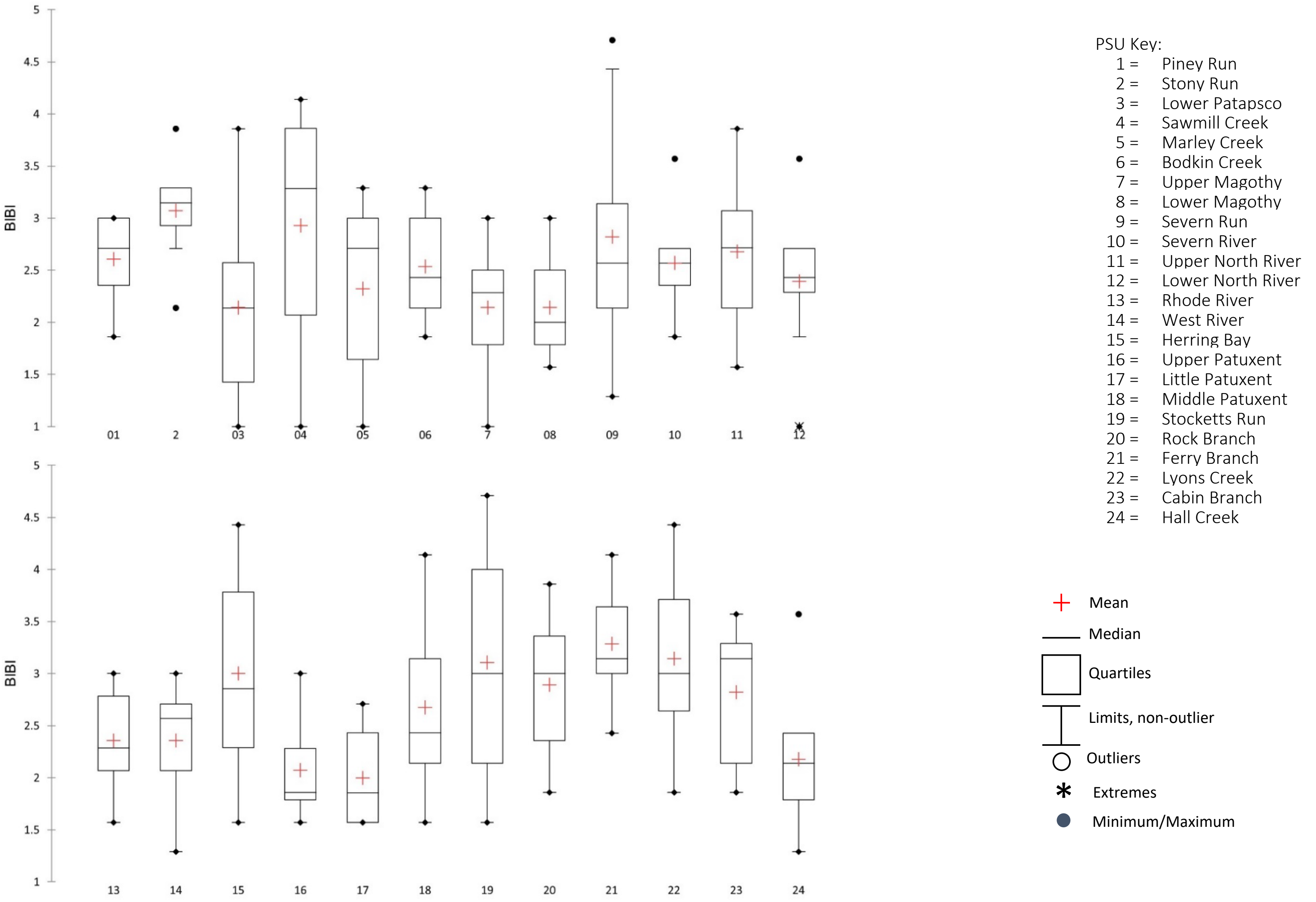
Figure 8. Countywide Biological Assessment (BIBI) Results from 2017-2021.

Box plots showing the distribution of BIBI scores for each PSU sampled during Round Three (n = 192) are shown in Figure 9. For the Countywide analysis, scores ranged from a minimum of 1.00 (i.e., the lowest attainable score) to a maximum of 4.71 (maximum attainable is 5.00). Sixty-four percent (64%) of sites had BIBI scores of less than or equal to 3.00, the threshold between "Fair" and "Poor" classifications. Sites rated as "Good" were primarily concentrated in the less developed southern portion of the County (Stockett's Run, Ferry Branch, Lyons Creek and Herring Bay; Figure 8). The broadest range of BIBI scores (i.e., where the difference between the maximum and minimum values was greater than 2.5) occurred in Lower Patapsco (PSU 03), Sawmill Creek (04), Severn Run (09), Lower North River (12), Herring Bay (15), Middle Patuxent (18), and Lyons Creek (22) PSUs, indicating greater variability between sites. The lowest variability between sites within a PSU was located in Piney Run (01) and Little Patuxent (17), where the range in BIBI scores was 1.14 for both PSUs.

3.3.2 FIBI Scores

In Round Three, the biological condition of Anne Arundel County's large streams was also assessed using fish indicators, namely the Fish Index of Biotic Integrity (FIBI) developed by MBSS and specifically calibrated for Coastal Plain streams (Southerland et al., 2005). A comparison of mean FIBI scores along with relative rankings (1 = best, 24 = worst) for each PSU is included in Table 7. The overall condition of Anne Arundel County streams during the Round Three assessment period (2017-2021) was "Poor", with a mean FIBI score of 2.52 (standard deviation [SD] = 1.1).

A total of six PSUs were rated "Fair" (25%), fifteen were rated "Poor" (63%), and three were rated "Very Poor" (13%, Figure 5). There were no PSUs rated in the 'Good' category by the FIBI. Ferry Branch had the highest mean FIBI score of 3.79, followed by Stony Run (3.37), Sawmill Creek (3.28), Piney Run (3.25), Upper North River (3.08), and Lyons Creek (3.00), all of which were rated as having "Fair" biological conditions. On the opposite end of the spectrum, West River (1.29), Rhode River (1.46), and Herring Bay (1.71), had the lowest FIBI scores and were all rated as "Very Poor".



PSU Key:
1 = Piney Run
2 = Stony Run
3 = Lower Patapsco
4 = Sawmill Creek
5 = Marley Creek
6 = Bodkin Creek
7 = Upper Magothy
8 = Lower Magothy
9 = Severn Run
10 = Severn River
11 = Upper North River
12 = Lower North River
13 = Rhode River
14 = West River
15 = Herring Bay
16 = Upper Patuxent
17 = Little Patuxent
18 = Middle Patuxent
19 = Stocketts Run
20 = Rock Branch
21 = Ferry Branch
22 = Lyons Creek
23 = Cabin Branch
24 = Hall Creek

Figure 9. Box Plots of BIBI Scores.

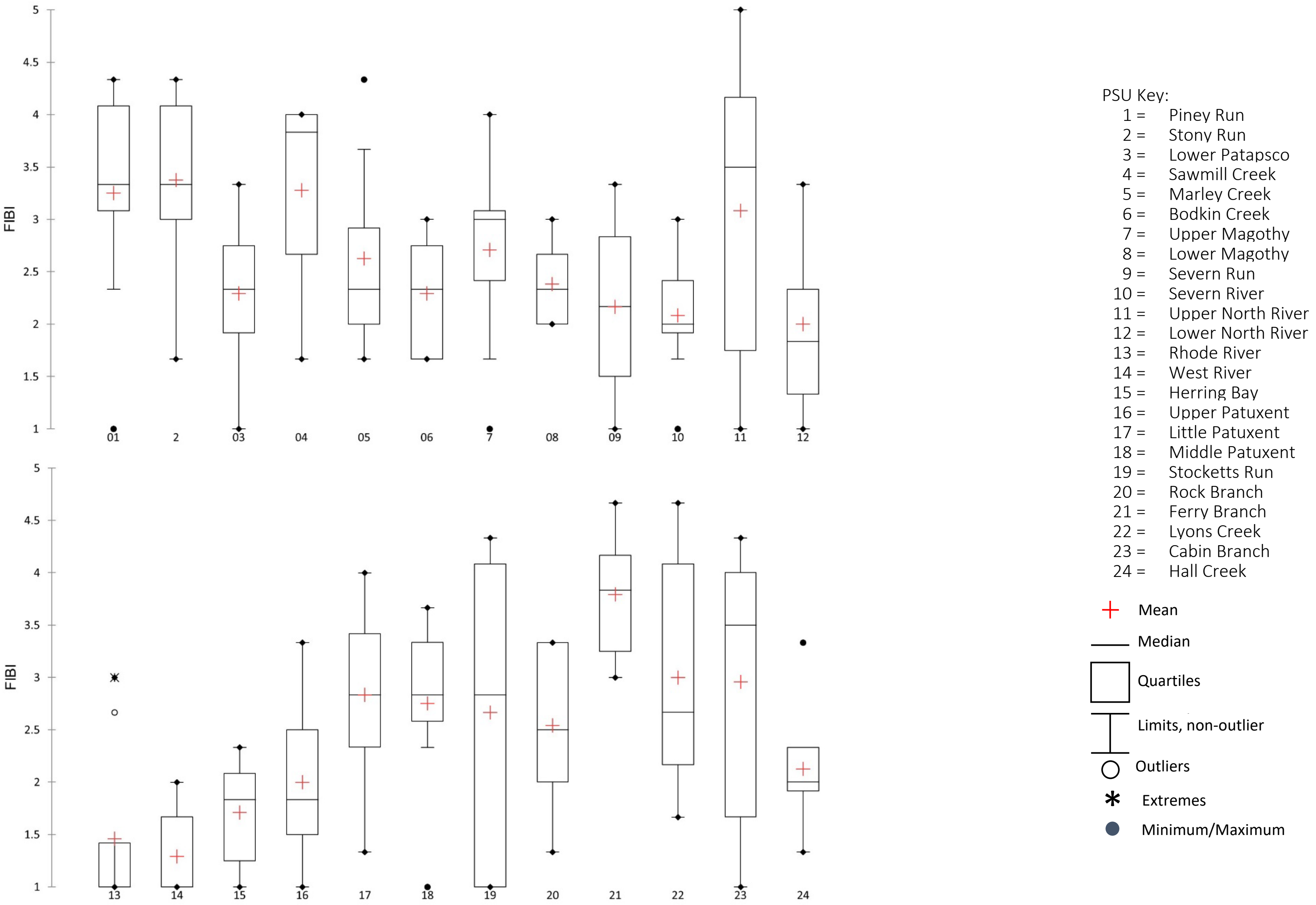


Figure 10. Box Plots of FIBI Scores.

Table 7. Mean FIBI Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2017-2021

PSU	Sample	Mean FIBI	Std Dev	Rating	Rank
COUNTYWIDE	189	2.52	1.1	Poor	-
Ferry Branch	8	3.79	0.7	Fair	1
Stony Run	8	3.37	0.9	Fair	2
Sawmill Creek	6	3.28	1.0	Fair	3
Piney Run	8	3.25	1.1	Fair	4
Upper North River	8	3.08	1.6	Fair	5
Lyons Creek	8	3.00	1.2	Fair	6
Cabin Branch	8	2.96	1.3	Poor	7
Little Patuxent	8	2.83	0.9	Poor	8
Middle Patuxent	8	2.75	0.8	Poor	9
Upper Magothy	8	2.71	1.0	Poor	10
Stocketts Run	8	2.67	1.5	Poor	11
Marley Creek	8	2.63	0.9	Poor	12
Rock Branch	8	2.54	0.8	Poor	13
Lower Magothy	7	2.38	0.4	Poor	14
Bodkin Creek	8	2.29	0.6	Poor	15
Lower Patapsco	8	2.29	0.7	Poor	16
Severn Run	8	2.17	0.9	Poor	17
Hall Creek	8	2.13	0.6	Poor	18
Severn River	8	2.08	0.6	Poor	19
Upper Patuxent	8	2.00	0.9	Poor	20
Lower North River	8	2.00	0.9	Poor	21
Herring Bay	8	1.71	0.5	Very Poor	22
Rhode River	8	1.46	0.9	Very Poor	23
West River	8	1.29	0.4	Very Poor	24

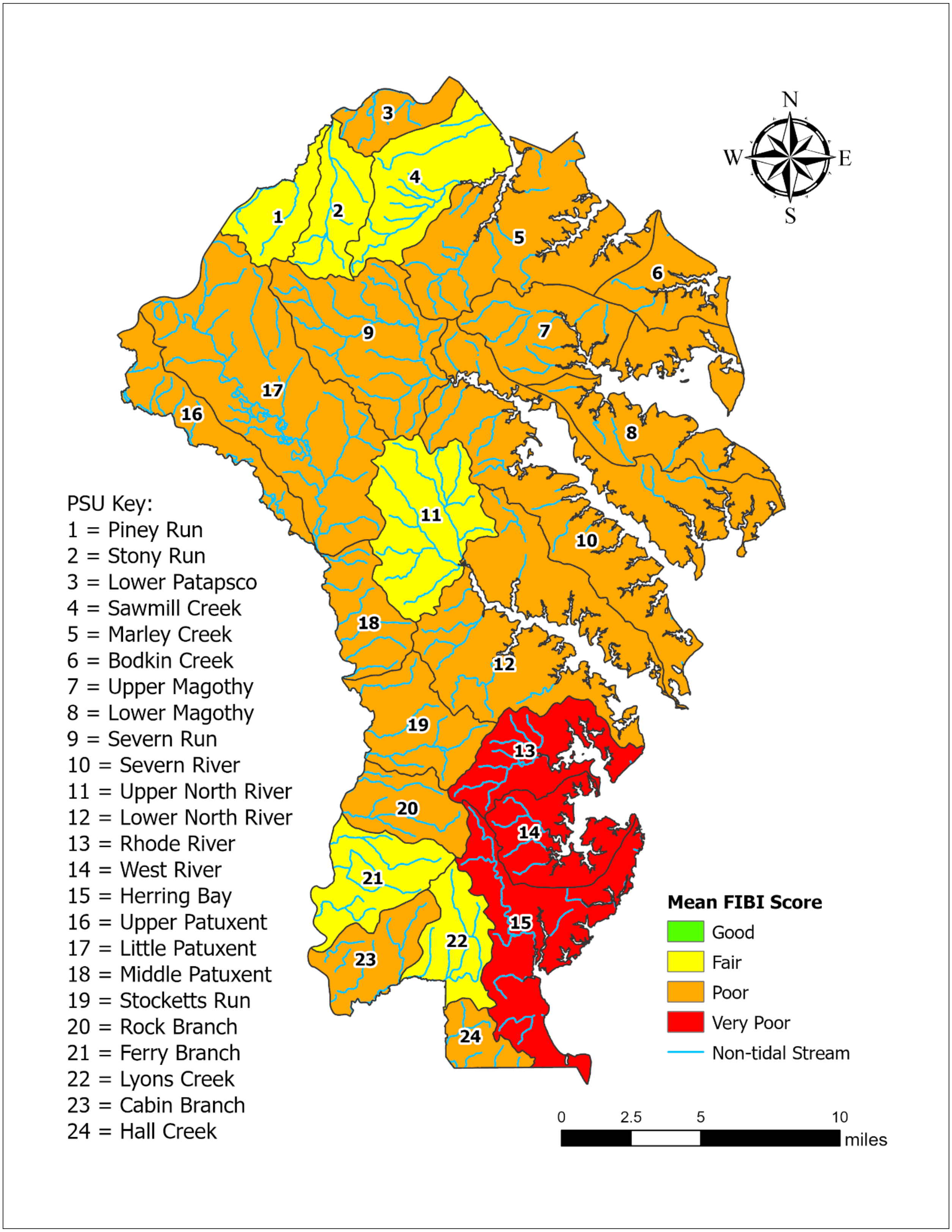
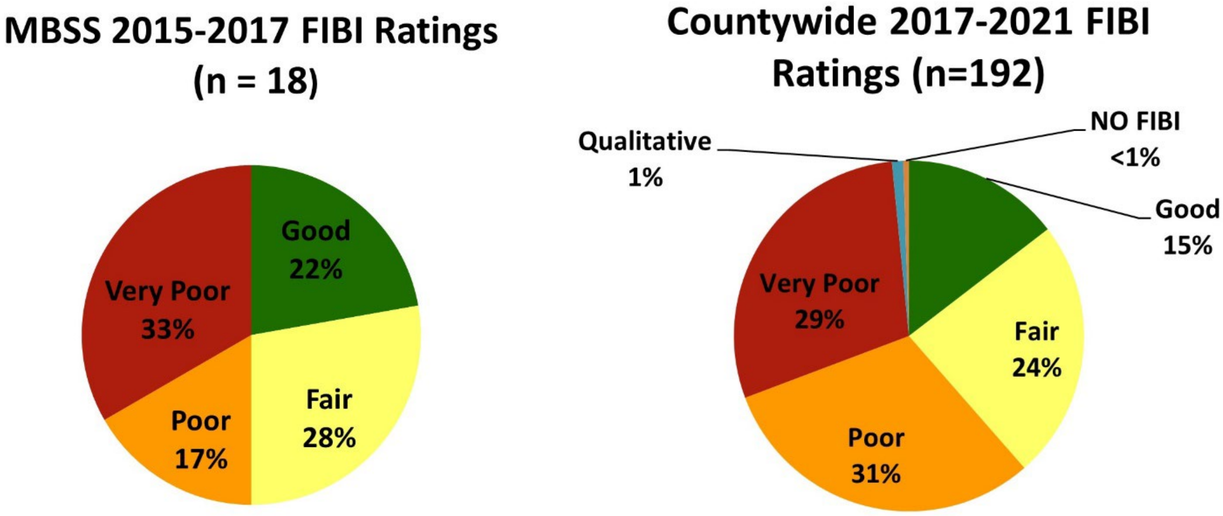


Figure 11. Average Biological (FIBI) Conditions for Primary Sampling Units.

Countywide fish assessment results indicate that 15% of the streams in the County were in “Good” condition, 24% were rated “Fair”, 31% were rated “Poor”, and 29% were classified as “Very Poor” (Figure 12). Two sites (1%) were sampled qualitatively, while one site (<1%) was not classified using FIBI scores. Countywide results are comparable to findings from the Maryland DNR MBSS sampling efforts during their Round Four sampling period (2015-2017) for sites sampled in Anne Arundel County. However, the countywide assessment classified the majority of streams (60%) as being in either “Poor” or “Very Poor” biological condition, while MBSS classified 50% of streams as being “Poor” or “Very Poor” and 50% as “Good” or “Fair” biological condition.


MBSS 2015-2017 FIBI Ratings (n = 18)

Countywide 2017-2021 FIBI Ratings (n=192)

Figure 12. Comparison of Biological Conditions (FBI) in Anne Arundel County Between MBSS Round 4 (2015-2017) and Countywide Round Three (2017-2021) Assessments.

A summary of site-specific biological condition ratings as a percentage of total sites within each PSU is displayed (Figure 12) and the distribution of sampling sites with their corresponding biological condition rating, based on FIBI scores, is displayed in Figure 14. Ferry Branch had 50% of sites rated as “Good”. Seven PSUs (Cabin Branch, Lyons Creek, Piney Run, Sawmill Creek, Stocketts Run, Stony Run, and Upper North River), had 37.5 percent of sites rated “Good” while three more PSUs had 13 percent of sites rated as “Good” (Little Patuxent, Marley Creek, and Upper Magothy). Two PSUs (Ferry Branch and Lower Magothy) had no sites rated as “Very Poor.” Conversely, eleven PSUs had 25 percent or more of sites rated as “Very Poor” and no sites rated as “Good.” Moreover, two PSUs (Herring Bay and West River) had 100 percent of sites rated as either “Poor” or “Very Poor”.

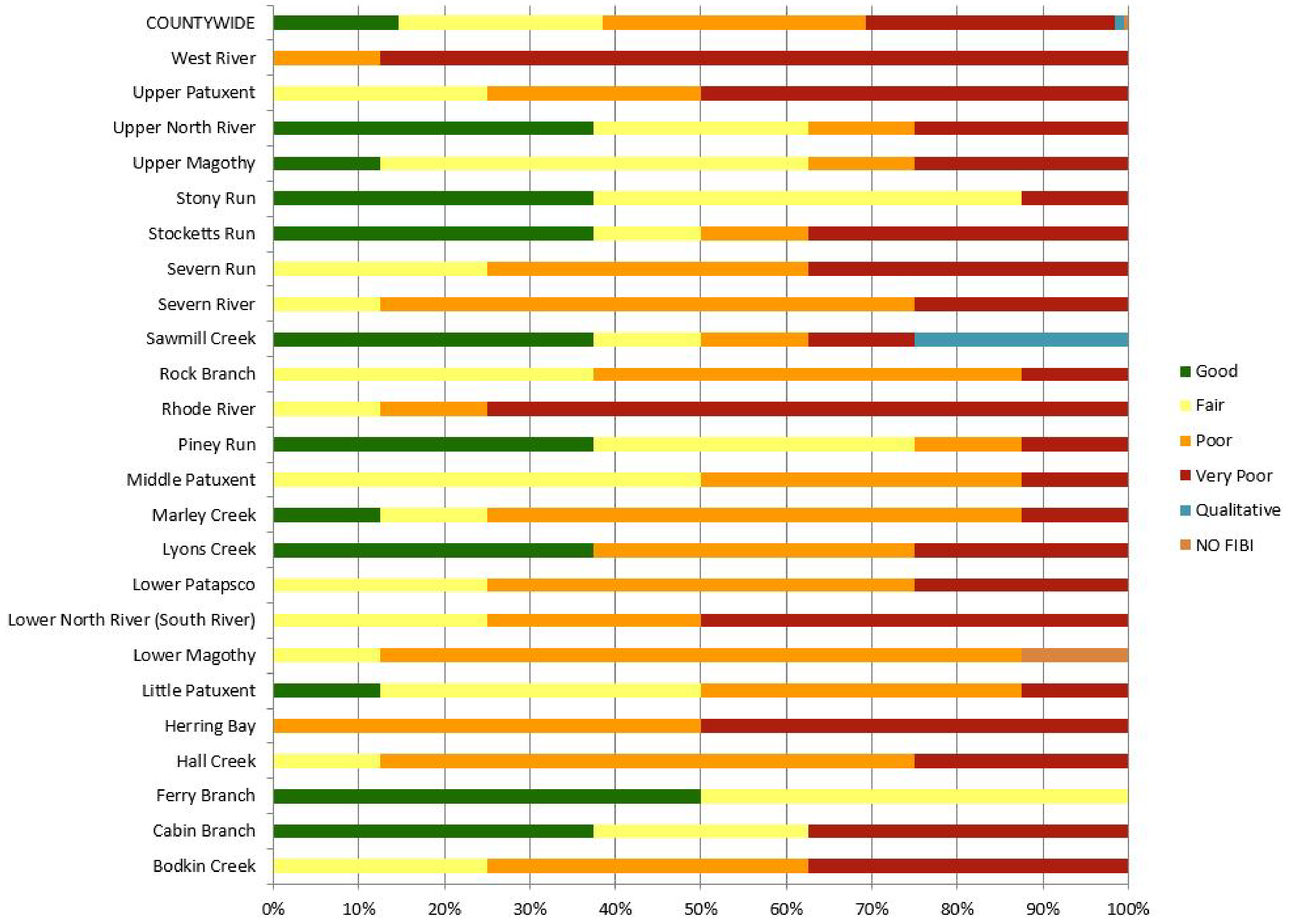


Figure 13. Biological Condition Ratings (FIBI) as a Percentage of Total Sites Within Each PSU.

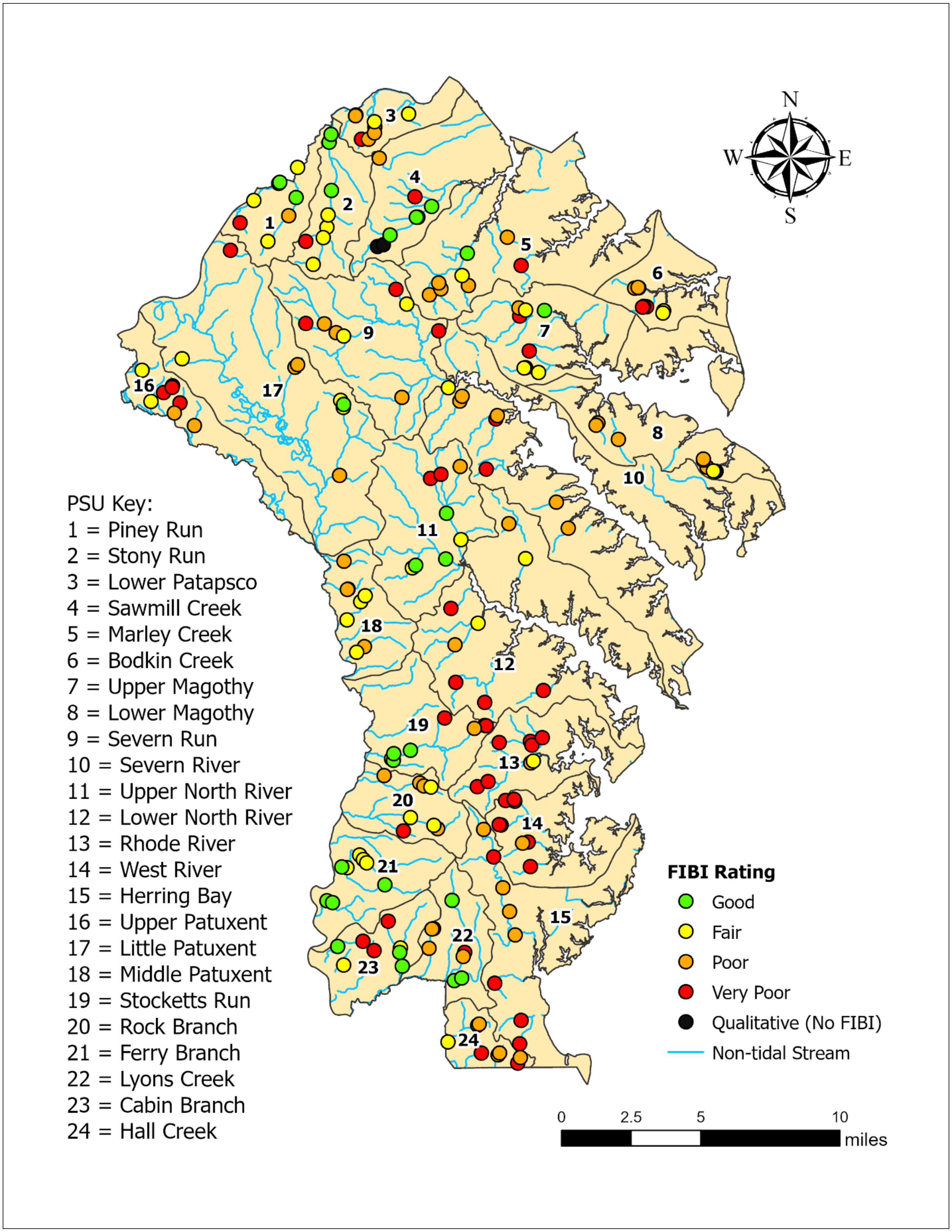


Figure 14. Countywide Biological Assessment (FIBI) Results from 2017-2021.

Box plots showing the distribution of FIBI scores for each PSU sampled during Round Three (n = 192) are shown in Figure 10. For the Countywide analysis, scores ranged from a minimum of 1.00 (i.e., the lowest attainable score) to a maximum of 5.00 (maximum attainable is 5.00). Sixty percent of sites had FIBI scores of less than or equal to 3.00, the threshold between “Fair” and “Poor” classifications. Sites rated as “Good” were primarily concentrated in the less developed southern portion of the County (Stocketts Run, Ferry Branch, Lyons Creek, and Cabin Branch) or along the northern portion of the County (Piney Run, Stony Run, and Sawmill Creek, Figure 14). The broadest range of FIBI scores (i.e., where the difference between the maximum and minimum values was greater than 2.5) occurred in Piney Run (PSU 01), Stony Run (02), Marley Creek (05), Upper Magothy (07), Little Patuxent (17), Middle Patuxent (18), Stocketts Run (19), Lyons Creek (22), and Cabin Branch (23) PSUs, indicating greater variability between sites. Six of those ten PSUs also had at least one site that was dry and receiving a FIBI score of 1.00. In contrast, Lower Magothy (08) and West River (14) had the smallest range of FIBI scores (i.e., equal to 1.0), indicating less variability between sites.

3.4 Physical Habitat Conditions

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

3.4.1 RBP Habitat

Mean RBP habitat scores and relative rankings (1 = best, 24 = worst) for each PSU based on the large stream strata are presented in

Table 8. The overall physical habitat conditions in Anne Arundel County streams were rated “Partially Supporting” by the RBP (mean = 117.3, SD = 18.77). The majority of PSUs, 13 total, were rated as “Partially Supporting” (54%), seven were rated “Supporting” (29%), and four were rated “Non-Supporting” (17%, Figure 15). There were no PSUs with a mean physical habitat condition rating of “Comparable.”

Table 8. Mean RBP Habitat Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2017-2021

PSU	Sample Size	Mean RBP	Std Dev	Rating	Rank
COUNTYWIDE	192	117.3	18.77	Partially Supporting	-
Bodkin Creek	8	138.6	12.74	Supporting	1
Rhode River	8	133.8	10.91	Supporting	2
Severn River	8	133.5	17.46	Supporting	3
Lower Magothy	8	131.4	11.26	Supporting	4
Upper Patuxent	8	128.6	13.85	Supporting	5
Severn Run	8	127.5	13.63	Supporting	6
Sawmill Creek	8	126.1	19.77	Supporting	7
Stony Run	8	124.9	7.92	Partially Supporting	8
Stocketts Run	8	123.6	19.08	Partially Supporting	9
Lower North River	8	122.6	17.48	Partially Supporting	10
Middle Patuxent	8	121.0	10.65	Partially Supporting	11
Upper North River	8	119.0	21.40	Partially Supporting	12
Herring Bay	8	118.1	12.33	Partially Supporting	13
Little Patuxent	8	115.5	12.52	Partially Supporting	14
Rock Branch	8	113.8	12.15	Partially Supporting	15
Marley Creek	8	111.8	16.93	Partially Supporting	16
West River	8	111.0	9.06	Partially Supporting	17
Lyons Creek	8	110.6	13.86	Partially Supporting	18
Upper Magothy	8	108.9	18.69	Partially Supporting	19
Ferry Branch	8	104.1	11.33	Partially Supporting	20
Piney Run	8	100.9	22.62	Non-Supporting	21
Cabin Branch	8	97.6	10.08	Non-Supporting	22
Hall Creek	8	97.6	9.02	Non-Supporting	23
Lower Patapsco	8	93.8	22.47	Non-Supporting	24

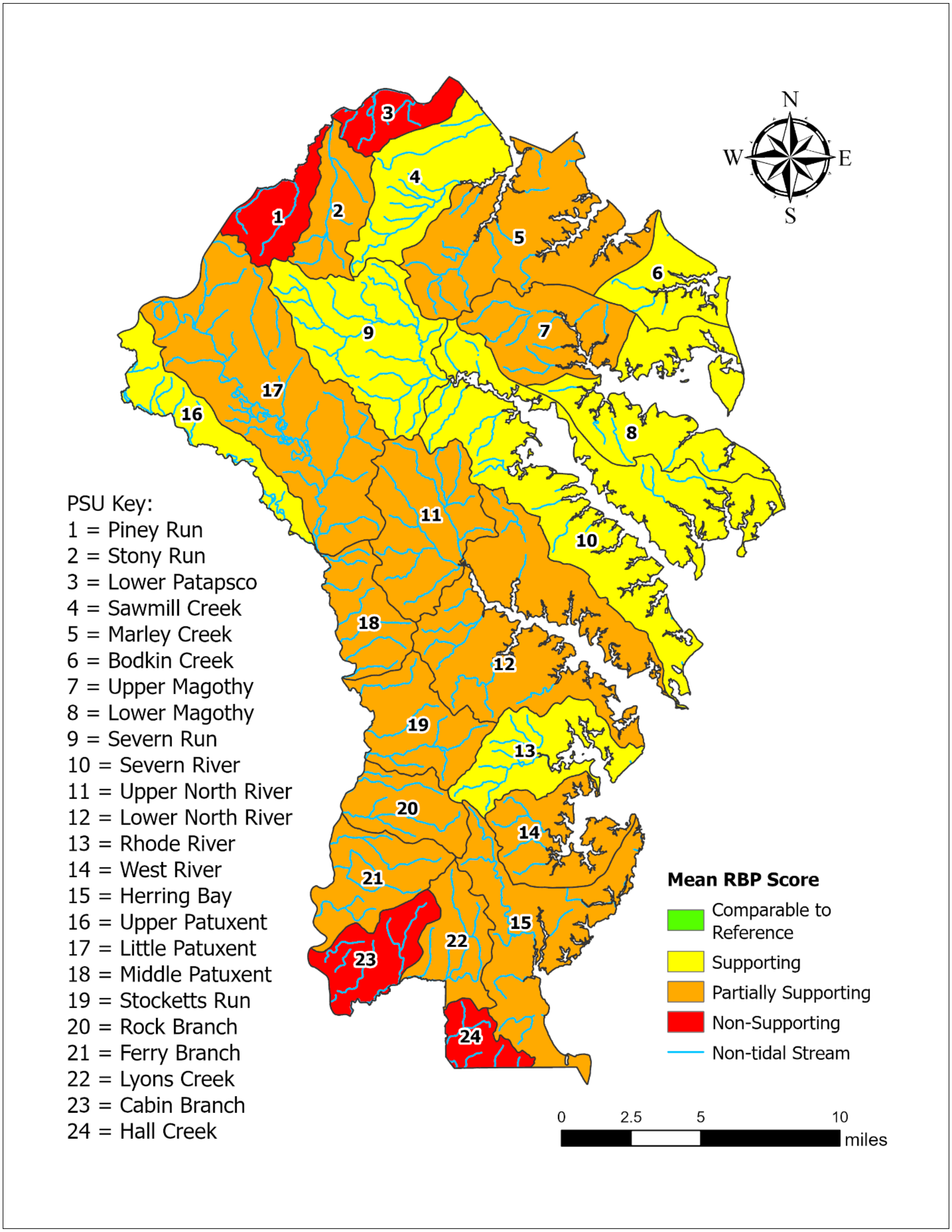


Figure 15. Average RBP Physical Habitat Conditions for Primary Sampling Units.

Bodkin Creek had the highest mean RBP score of 138.6 with a physical habitat condition rating of “Supporting.” Six additional PSUs received a “Supporting” rating including Rhode River (RBP = 133.8), Severn River (133.5), Lower Magothy (131.4), Upper Patuxent (128.6), Severn Run (127.5), and Sawmill Creek (126.1). Conversely, Lower Patapsco received the lowest RBP score of 93.8 and was classified as “Non-Supporting” along with Hall Creek (97.6), Cabin Branch (97.6), and Piney Run (100.9).

Countywide RBP physical habitat assessment results indicate that only 2% of the streams in the County were rated “Comparable to Reference”, 32% were rated “Supporting”, 48% were rated “Partially Supporting”, and 18% were classified as “Non-Supporting” (Figure 16).

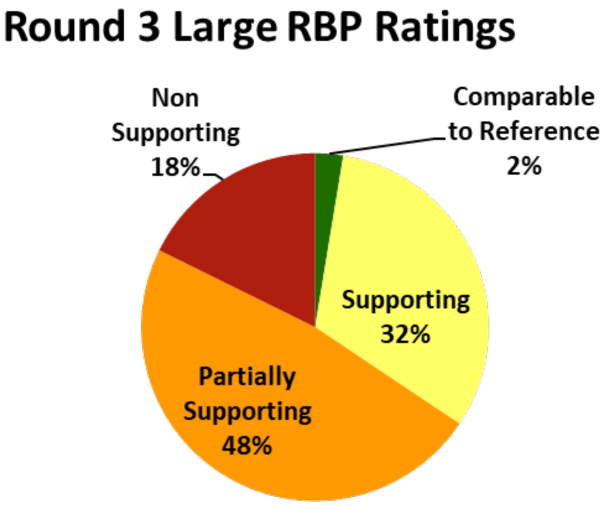


Figure 16. Countywide RBP Physical Habitat Conditions (2017-2021; n=192).

A summary of site-specific physical habitat conditions, as a percentage of total sites within each PSU, is displayed in Figure 17. A total of nine PSUs (Bodkin Creek, Herring Bay, Lower Magothy, Middle Patuxent, Severn River, Severn Run, Stockett’s Run, Stony Run and Upper Patuxent), had all sites rated as either “Comparable”, “Supporting”, or “Partially Supporting.” Five PSUs had one site rated as “Comparable” (Bodkin Creek, Lower North River, Severn River, Stockett’s Run, and Upper Patuxent). On the other hand, five PSUs (Cabin Branch, Ferry Branch, Hall Creek, Lower Patapsco and Piney Run), had all sites rated as either “Non-Supporting” or “Partially Supporting”. Figure 18 shows the distribution of sampling sites with their corresponding RBP physical habitat condition rating.

Figure 19 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 Stoney Run (PSU 02), West River (14), Middle Patuxent (18), Cabin Branch (23), and Hall Creek (24). The broadest range of RBP scores (i.e., greater than or equal to 60 points between lowest and highest scores) were observed in Sawmill Creek (PSU 04), Upper Magothy (07), and Upper North River (11) PSUs.

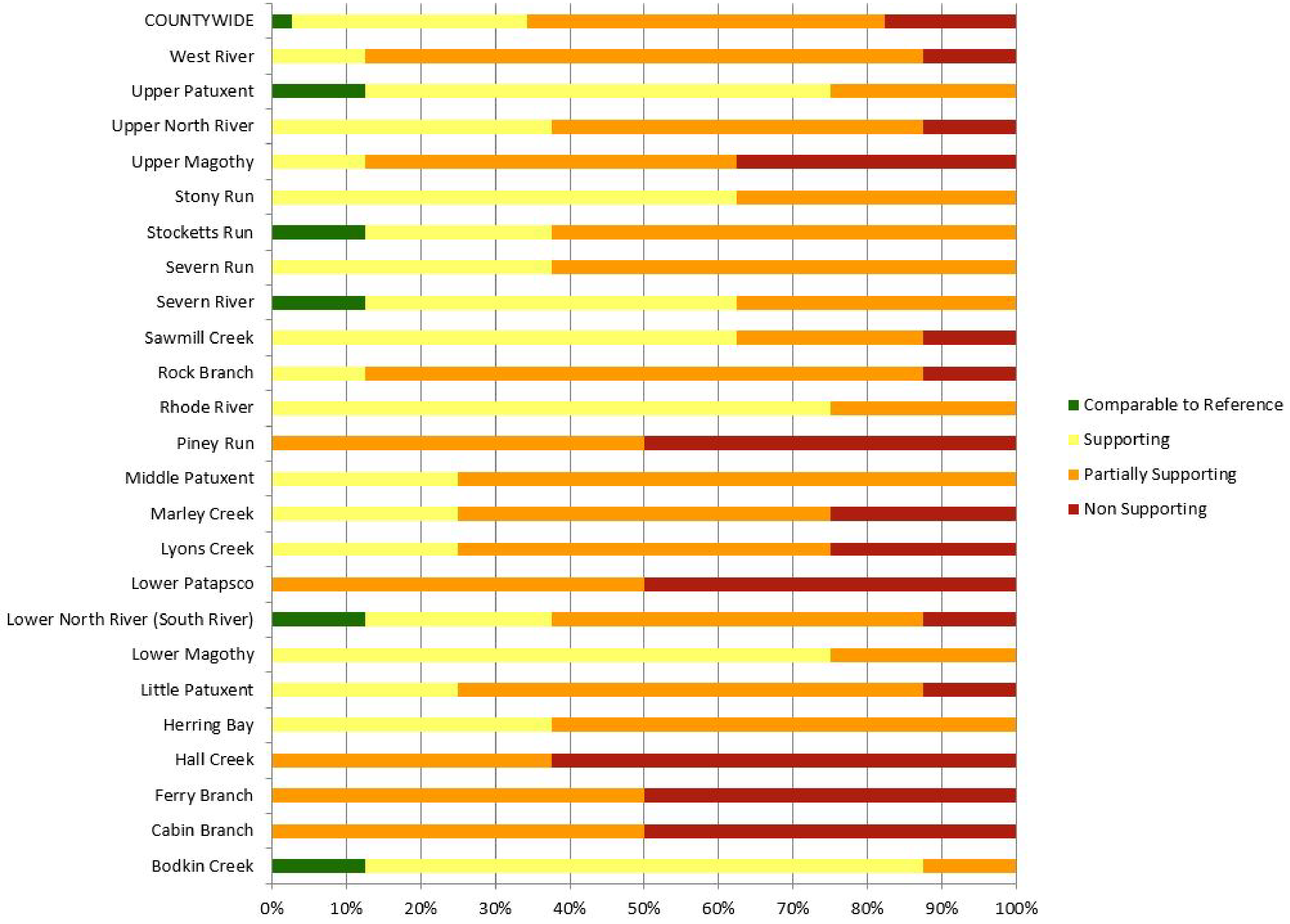


Figure 17. RBP Physical Habitat Conditions as a Percentage of Total Sites Within Each PSU.

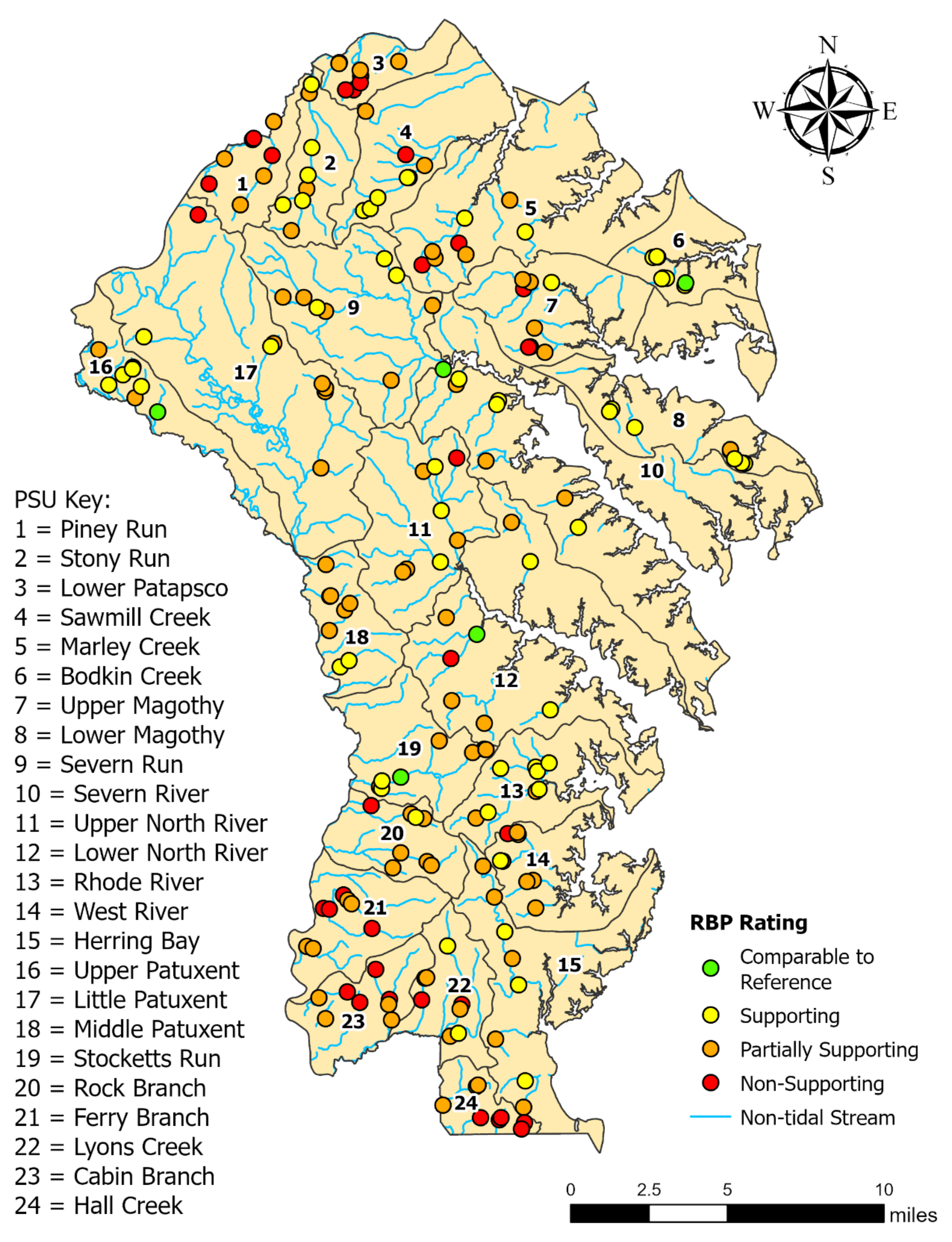


Figure 18. Countywide Physical Habitat Assessment (RBP) Results from 2017-2021.

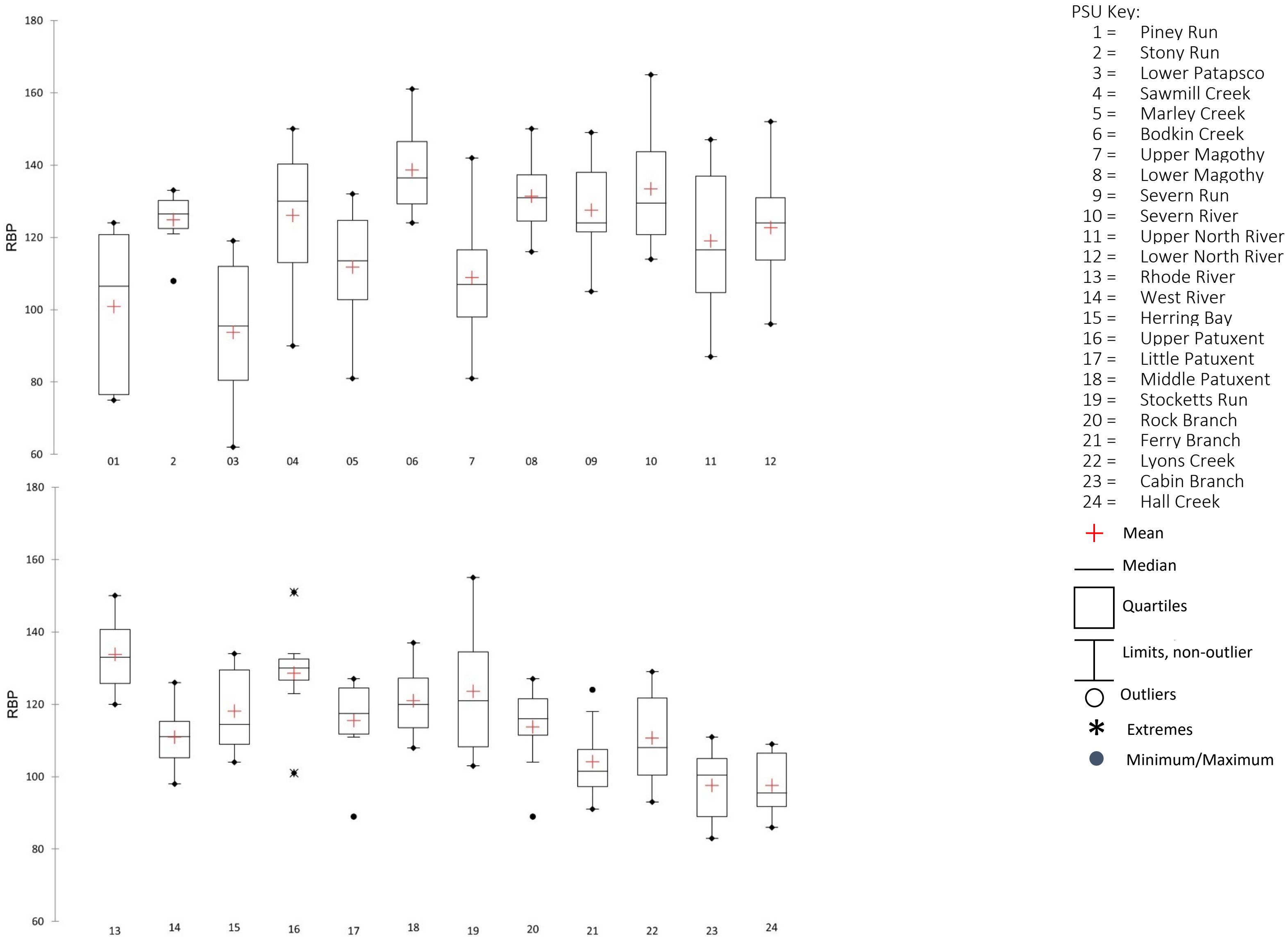


Figure 19. Box Plot of RBP Scores.

3.4.2 PHI Habitat

Physical habitat conditions of streams in Anne Arundel County are also assessed using the Physical Habitat Index (PHI) developed by MBSS and specifically calibrated for Coastal Plain streams (Paul et al., 2003). In Round Three, PHI was scored during both the spring and summer index periods for sites in the large stream strata. Results presented here are limited to the summer index period PHI data to be consistent with the Annual Reports that reported results using summer PHI data. As a result, sites that were dry during the summer visit were not rated using the PHI, and the sample size was reduced to 183 sites of the 192 visited. A comparison of mean PHI scores, along with relative rankings (1 = best, 24 = worst), for each PSU is displayed in Table 9. Overall physical habitat conditions in Anne Arundel County streams were rated “Partially Degraded” by the PHI, with a mean score of 67.6 (SD = 9.5). Fifteen PSUs were rated as “Partially Degraded”, while nine were considered “Degraded” (Figure 20). Bodkin Creek had the highest mean PHI score of 79.8 and was rated “Partially Degraded”, followed by Upper Patuxent (PHI = 75.6) and Sawmill Creek (PHI = 74.6), both classified as “Partially Degraded”. The lowest PHI score of 55.8 occurred in Lower Patapsco, which was classified as “Degraded”. Piney Run (59.6), Ferry Branch (61.1), Upper Magothy (61.4), and Marley Creek (61.7) were also classified as “Degraded” and round out the bottom five worst rated PSUs.

Table 9. Mean Physical Habitat Index Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2017-2021

PSU	Sample Size	Mean PHI	Std Dev	Rating	Rank
COUNTYWIDE	183	67.6	9.5	Partially Degraded	-
Bodkin Creek	8	79.8	9.7	Partially Degraded	1
Upper Patuxent	8	75.6	6.7	Partially Degraded	2
Sawmill Creek	8	74.6	7.8	Partially Degraded	3
Severn River	7	73.1	9.5	Partially Degraded	4
Stocketts Run	8	71.8	6.3	Partially Degraded	5
Rock Branch	8	71.5	9.7	Partially Degraded	6
Rhode River	5	70.9	12.3	Partially Degraded	7
Upper North River	6	70.0	7.8	Partially Degraded	8
Cabin Branch	8	69.8	8.2	Partially Degraded	9
Lower North River	8	69.2	7.1	Partially Degraded	10
Lower Magothy	8	69.2	5.7	Partially Degraded	11
Middle Patuxent	8	68.1	7.5	Partially Degraded	12
West River	7	67.9	4.6	Partially Degraded	13
Lyons Creek	8	67.5	8.7	Partially Degraded	14
Hall Creek	8	66.9	3.7	Partially Degraded	15
Severn Run	6	65.3	8.3	Degraded	16
Stony Run	8	65.1	7.6	Degraded	17
Little Patuxent	8	64.3	11.7	Degraded	18
Herring Bay	8	64.2	6.6	Degraded	19
Marley Creek	8	61.7	8.7	Degraded	20
Upper Magothy	8	61.4	11.0	Degraded	21
Ferry Branch	8	61.1	8.0	Degraded	22
Piney Run	8	59.6	9.5	Degraded	23
Lower Patapsco	8	55.8	8.1	Degraded	24

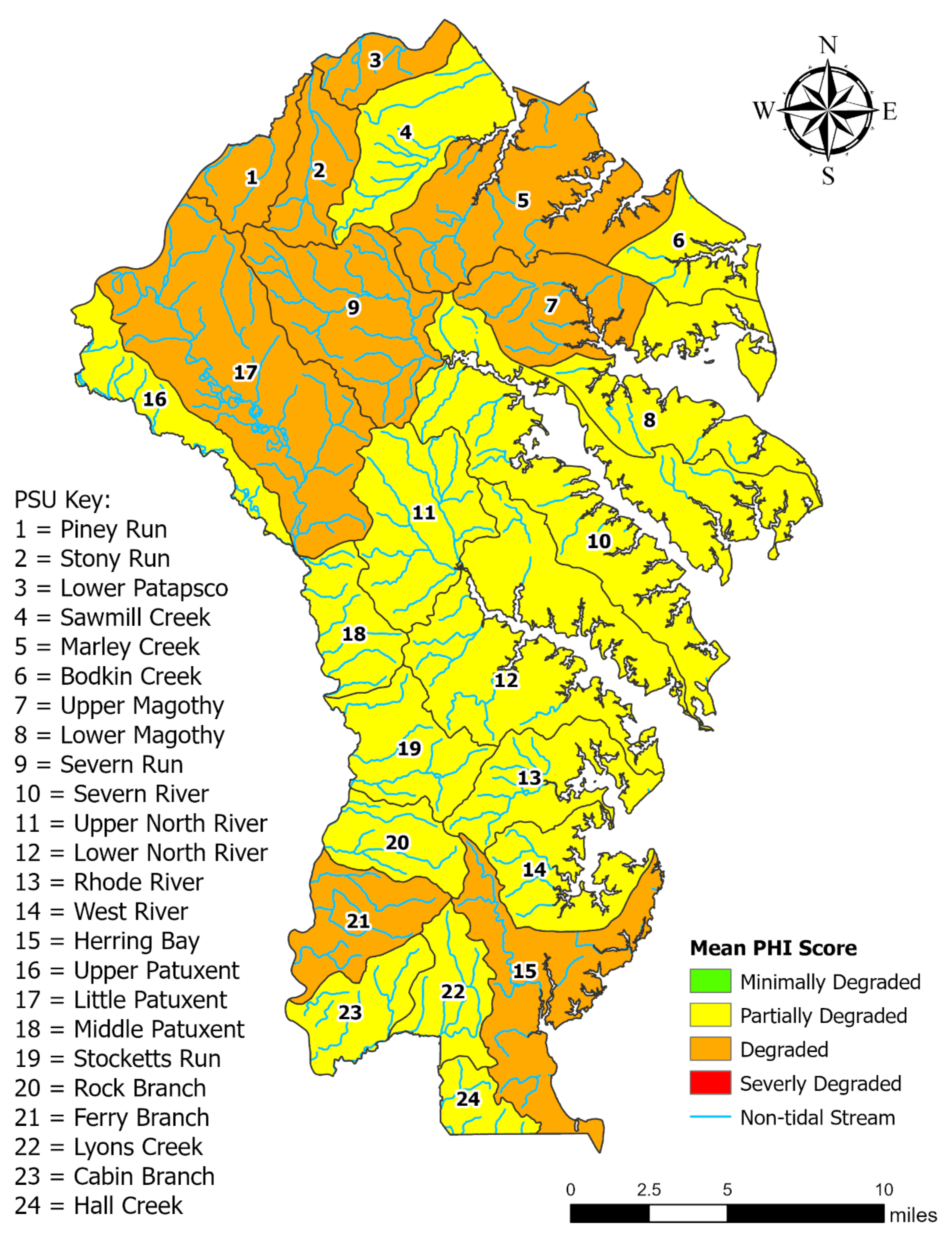


Figure 20. Average PHI Physical Habitat Conditions for Primary Sampling Units.

Countywide results indicate that 9% of the streams in Anne Arundel County had “Minimally Degraded” habitat, 48% had “Partially Degraded” habitat, 35% had “Degraded”, 4% had “Severely Degraded” habitat and 4% were considered “Other” due to dry site conditions (Figure 21).

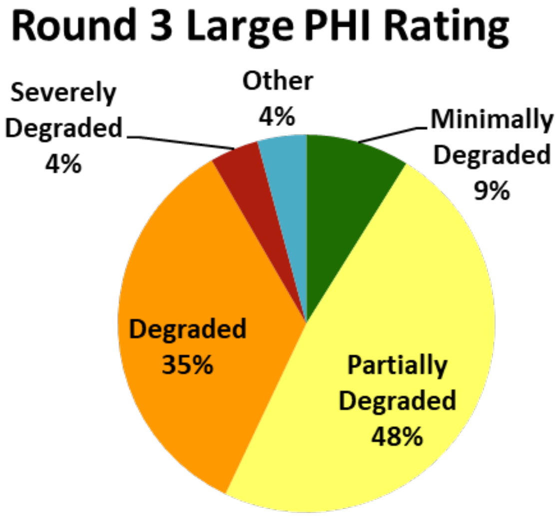


Figure 21. Countywide PHI Physical Habitat Conditions (2017-2021; n=192).

A summary of site-specific physical habitat conditions, as a percentage of total sites within each PSU, is displayed in Figure 22. Bodkin Creek was the only PSU with more than two sites (3) rated as “Minimally Degraded”. Eleven PSUs had at least one or 13% of sites rated as “Minimally Degraded”. Only four PSUs had one site rated as “Degraded” (Bodkin Creek, Severn Run, Stockett’s Run, and Upper Patuxent), while the 19 others had more than one site as “Degraded”. Seven PSUs (Ferry Branch, Little Patuxent, Lower Patapsco, Lyons Creek, Marley Creek, Piney Run, and Upper Magothy), had at least one site rated as “Severely Degraded”. Figure 23 shows the distribution of sampling sites with their corresponding physical habitat condition ratings for the PHI. Sites rated by the PHI as “Minimally Degraded” were spread evenly throughout the County with the most sites located in the Bodkin Creek watershed with 3 sites total

Box plots displaying the distribution of PHI scores within each PSU are included in Figure 24. Countywide PHI scores ranged from minimum of 37.3 to a maximum of 91.6 on a 100-point scale. The broadest range of PHI scores (i.e., the difference between the maximum and minimum values was greater than 70) were observed in Severn Run (PSU 09), Severn River (10), Upper North River (11), Rhode River (13), and West River (14) PSUs; however, all five of these PSUs had at least one PHI rating of 0.00 due to being dry during summer sampling. The smallest range of PHI scores (i.e., less than 20) were observed in Lower Magothy (08), Lower North River (12), Upper Patuxent (16) and Hall Creek (24), indicating less variability between sites.

Figure 22. PHI Physical Habitat Conditions as a Percentage of Total Sites Within Each PSU

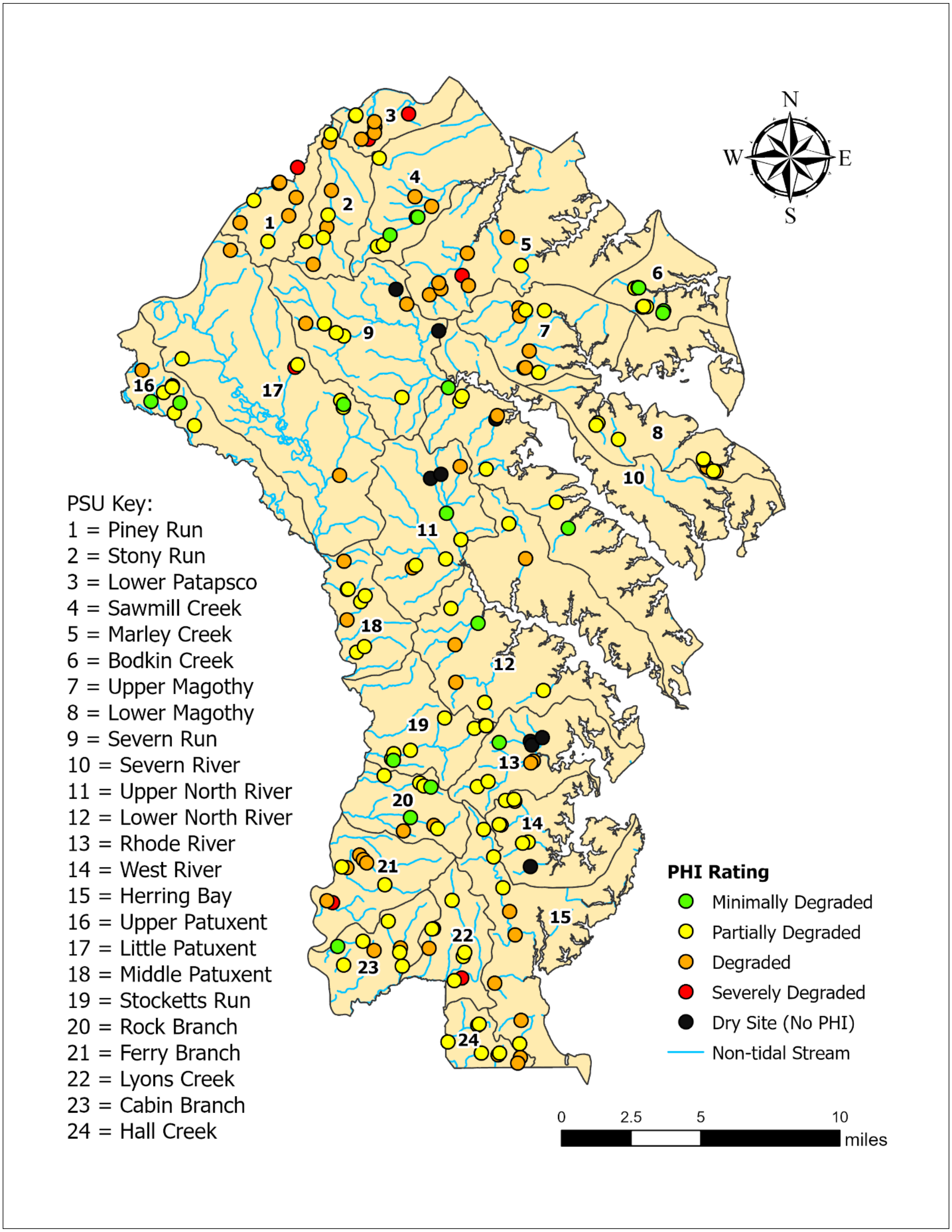


Figure 23. Countywide Physical Habitat Assessment (PHI) Results from 2017-2021.

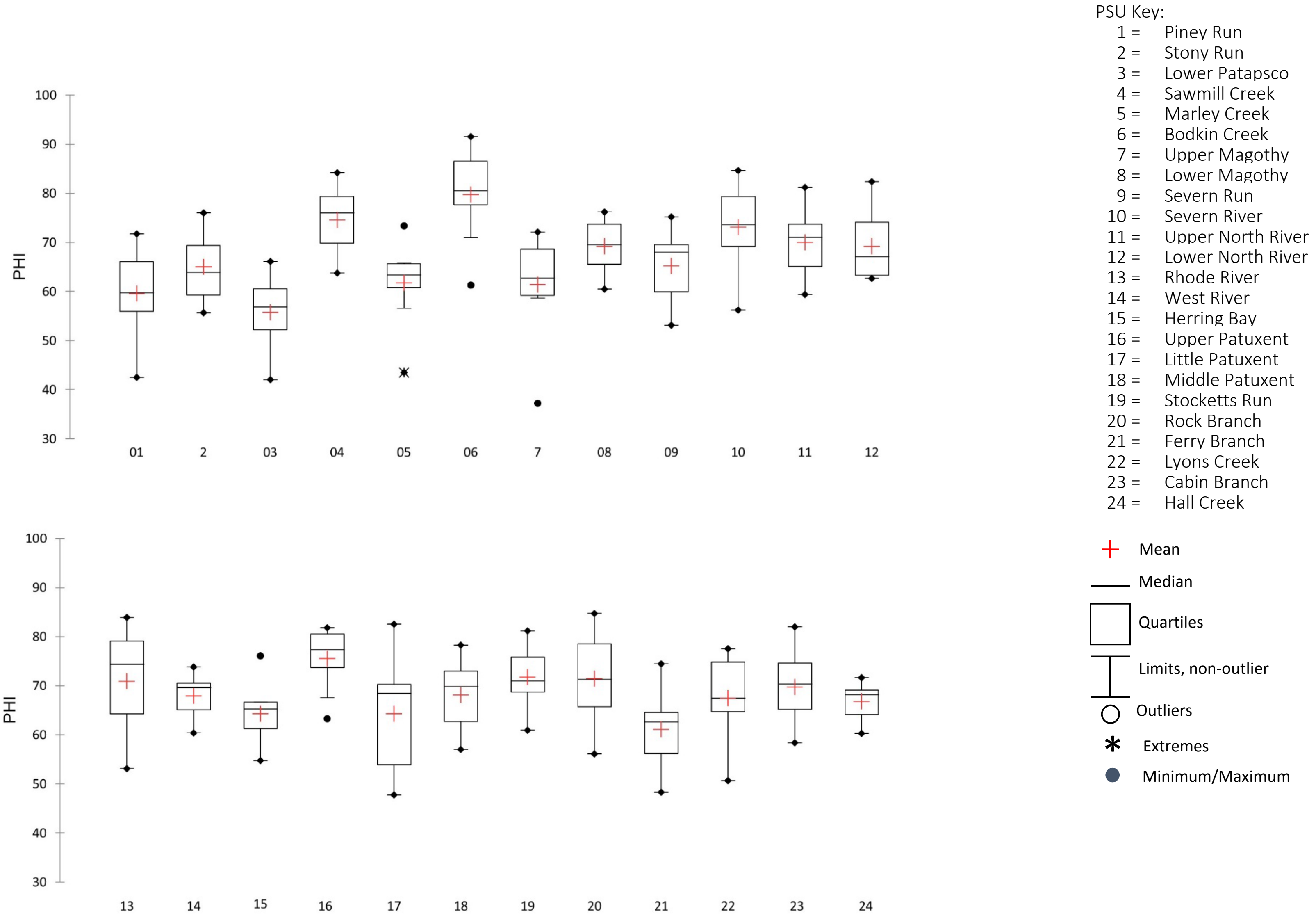


Figure 24. Box plot of PHI Scores.

3.5 Water Quality Conditions

Round Three was the first round where comprehensive water quality grab sampling was completed at each site during spring sampling within the monitoring program along with supplemental *in situ* water quality measurements during both spring and summer index periods (water temperature, pH, dissolved oxygen (DO), specific conductivity, and turbidity). A full list of parameters analyzed from grab samples is found below:

- Total Nitrogen
- Ammonia-N
- TKN (calculated)
- Nitrate-Nitrogen
- Nitrite-Nitrogen
- Orthophosphate
- Total Phosphorus
- Dissolved Organic Carbon
- Total Organic Carbon
- Total Copper
- Total Lead
- Total Zinc
- Chloride
- Calcium
- Magnesium
- Total Hardness
- Turbidity

Details on the field sampling and laboratory methods, including method detection limits, can be found in the QAPP and also each Annual Report for Round Three. For the water quality results and analysis, both small and large site data were combined from each PSU in order to increase the sample size from n=8 to n=16 and the total countywide dataset from 192 to 384 samples over the entire round.

The addition of grab samples allows for heavy metal analysis, specifically looking at exceedances of water quality standards for copper, zinc, and lead (COMAR, Table 10). Mean total copper concentrations ranged from a high of 3.49 µg/L at Stony Run to the low of 0.23 µg/L at Upper North River. Although no PSU mean concentration was above the acute or chronic criteria for total copper, there were four sites through Round Three that were above the chronic criteria of 9 µg/L and two of those sites were also above the acute criteria of 13 µg/L. These sites were located in the Marley Creek (10.09 µg/L), West River (16.00 µg/L), Little Patuxent (11.96 µg/L), and Stony Run (20.00 µg/L) PSUs.

Total lead mean concentrations ranged from a high of 1.317 µg/L at Little Patuxent to a low of 0.134 µg/L at Piney Run. A total of nine sites within seven PSUs (Bodkin Creek, Little Patuxent, Lower Patapsco, Rock Branch, Upper Magothy, Upper Patuxent (2), and Stony Run (2)), exceeded the EPA chronic criteria for lead of 2.5 µg/L. The exceedance values ranged from 2.94 µg/L at Lower Patapsco, to 12.25 µg/L at Little Patuxent.

Table 10. Water Quality Criteria

Parameter	Criteria	
	Acute	Chronic
Chloride (mg/L)*	860	230
Total Copper (µg/L)**	13	9
Total Zinc (µg/L)**	120	120
Total Lead (µg/L)**	65	2.5
Turbidity (NTU)**	150	50

* EPA National Recommended Water Quality Criteria for Aquatic Life
** COMAR 26.08.02.03-2: Numerical Criteria for Toxic Substances in Surface Waters

Only two sites had zinc concentrations exceed the EPA acute/chronic criteria of 120 µg/L. One site in West River had a concentration of 140.00 µg/L, while one site in Lower North River had a concentration of 190.58 µg/L of zinc. PSU mean concentrations of total zinc concentrations ranged from 4.67 µg/L at Hall Creek to 31.31 µg/L at Lower North River. Lead and zinc are of concern due to human health impacts, and copper because of its lethal effects on aquatic life.

Specific conductivity values were consistently high for the majority of PSUs (18 of 24), with mean values at or above the published 247 µS/cm informal County threshold for biological impairment (Morgan et al., 2007; Figure 26). Of the 18 PSUs with means above the threshold, the range was from 247µS/cm at Ferry Branch, to 1,025µS/cm at Lower Patapsco. All 18 PSUs with mean exceedances above the threshold had at least one site below the 247µS/cm level from Morgan et al. Six PSUs had means below 247µS/cm with a range of 241µS/cm at Lyons Creek down to 61µS/cm at Upper Patuxent. Of these six PSUs, only one (Hall Creek) did not have a single site with a reading above 247µS/cm. It is important to note that five of the six PSUs with the highest specific conductance means also had a high percent imperviousness ranging from 19.6% to 32.7% (Figure 32). There was a strong positive correlation between specific conductivity and chloride concentration for all sites sampled in Round Three (R^2 = 0.897; Figure 25). Elevated levels of chloride and magnesium are commonly associated with either runoff from roadways, particularly following winter roadway de-icing periods, or runoff carrying fertilizers (Williams 2001; Stranko et al. 2013).

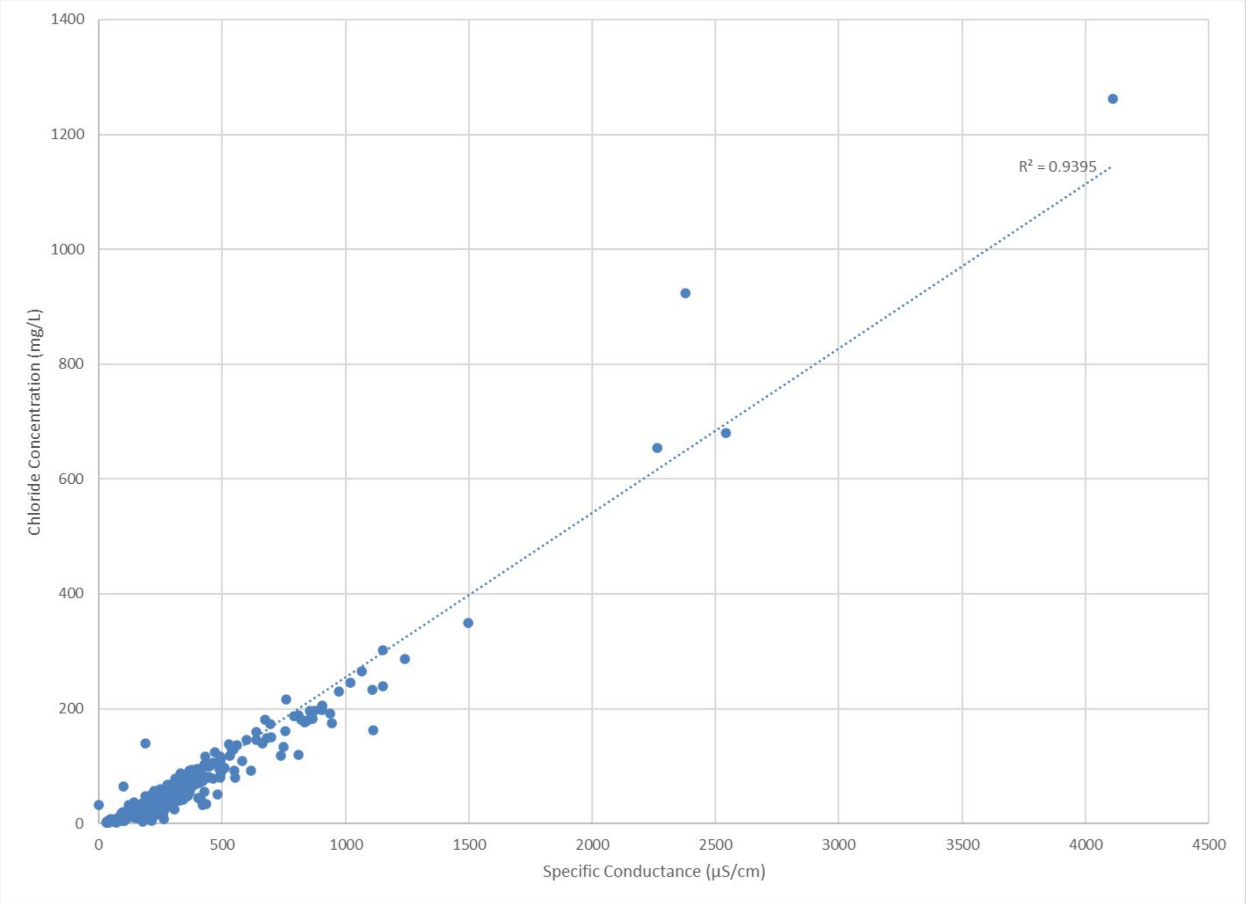


Figure 25. Relationship between in situ specific conductance and chloride concentrations for all Round Three sites (n=384).

Chloride concentrations measured in Round Three exceeded EPA's acute threshold at two (2) sites, both of which were rated "Poor" or "Very Poor", and the chronic threshold at nine (9) additional sites, all but one of which was rated "Poor" or "Very Poor". Both sites that exceeded the acute threshold were also sampled in the summer for fish and were also rated "Poor" or "Very Poor", with one site reporting no fish as being observed during sampling. However, it should also be noted that the sites sampled during the summer index period exhibited significantly lower specific conductivity values in the summer (i.e., <300 µS/cm) compared to the spring (i.e., >2000 µS/cm), suggesting that chloride concentrations were not likely to remain high for an extended period of time. Only one PSU, Lower Patapsco, had mean chloride concentrations above the chronic threshold (Figure 27), although it should be noted that the mean was skewed by several extreme outlier values.

Total nitrogen, nitrite, nitrate, and ammonia concentrations were varied across PSUs during Round Three. Since many samples were reported below the method detection limit for the nitrogen species, box plots were limited to total nitrogen (Figure 28). The MBSS water quality categories developed from the statewide MBSS dataset at the end of MBSS Round Two in 2005 (DNR, 2005; Table 11.) were used to analyze all nutrient species. For total nitrogen, no PSUs fell in the high category used by MBSS, seventeen PSUs (70.8%) fell in the low category, and seven PSUs (29.2%) fell within the moderate category (Figure 30). For nitrite, due to the detection limit of the laboratory procedures being within the 'moderate' category, 20 of the 24 PSUs were rated as 'moderate'. Four PSUs, Rock Branch, Stony Run, Upper Magothy, and West River had mean concentrations in the 'High' category for nitrite. For mean nitrate concentrations, the majority of PSUs were in the 'low' category (17 PSUs, 70.8%), while seven (29.2%) were in the 'moderate' category. No PSUs had mean nitrate concentrations within the 'high' category.

Table 11. MBSS Water Quality Categories for Nutrients

Parameter	Low	Moderate	High
Nitrate (NO3)	< 1.0	1.0 – 5.0	> 5.0
Nitrite (NO2)	< 0.0025	0.0025 – 0.01	> 0.01
Ammonia (NH3)	< 0.03	0.03 – 0.07	> 0.07
TN	< 1.5	1.5 – 7.0	>7.0
TP	< 0.025	0.025 – 0.070	> 0.070
Ortho-PO4	< 0.008	0.008 – 0.03	> 0.03

(DNR, 2005). All units are in mg/L.

Total ammonia mean concentrations were in the high category for nine PSUs (37.5%) and moderate for 12 PSUs (50%). Three (12.5%) PSUs were in the low category for total ammonia: Ferry Branch, Lyons Creek, and Upper Patuxent. Nitrogen is of concern because of its effect on eutrophication in the Chesapeake Bay (EPA, 1982; Kemp et al., 2005). Excess nitrogen can lead to blooms of algae in the downstream receiving waters and the Bay. Algae blooms consume large amounts of dissolved oxygen in the deeper portions of the Bay when the algae die off, sink to the bottom, and decay. Sources of nitrogen pollution include atmospheric deposition, residential fertilizer, urban stormwater runoff, agricultural runoff, and wastewater treatment plants. Ammonia is a concern because at high enough concentrations it can be toxic to aquatic life.

Total phosphorus concentrations were quite variable across the County (Figure 29). Mean PSU concentrations were found to be mostly in the moderate category, with 12 PSUs (50%) rated as moderate during Round Three. Three PSUs (12.5%)-- Sawmill Creek, Severn Run, and Upper Patuxent-- were in the low category. Nine PSUs (37.5%) were in the high category with West River, Rock Branch and Herring Bay having the highest mean concentrations (Figure 31). Orthophosphate concentrations had the majority of PSUs, 10 of 24 (41.7%), in the low category. Five PSUs (20.8%) had mean concentrations in the moderate category while nine PSUs (37.5%) fell into the high category. Phosphorus is of concern because of its effect on eutrophication in lakes and reservoirs, and to a lesser extent in the Chesapeake Bay (EPA, 1982; Kemp et al., 2005). Excess phosphorus can lead to blooms of algae in freshwater which consume large amounts of dissolved oxygen when the algae die off, sink to the bottom, and decay. Sources of phosphorus pollution include residential fertilizer, urban stormwater runoff, agricultural runoff, and wastewater treatment plants.

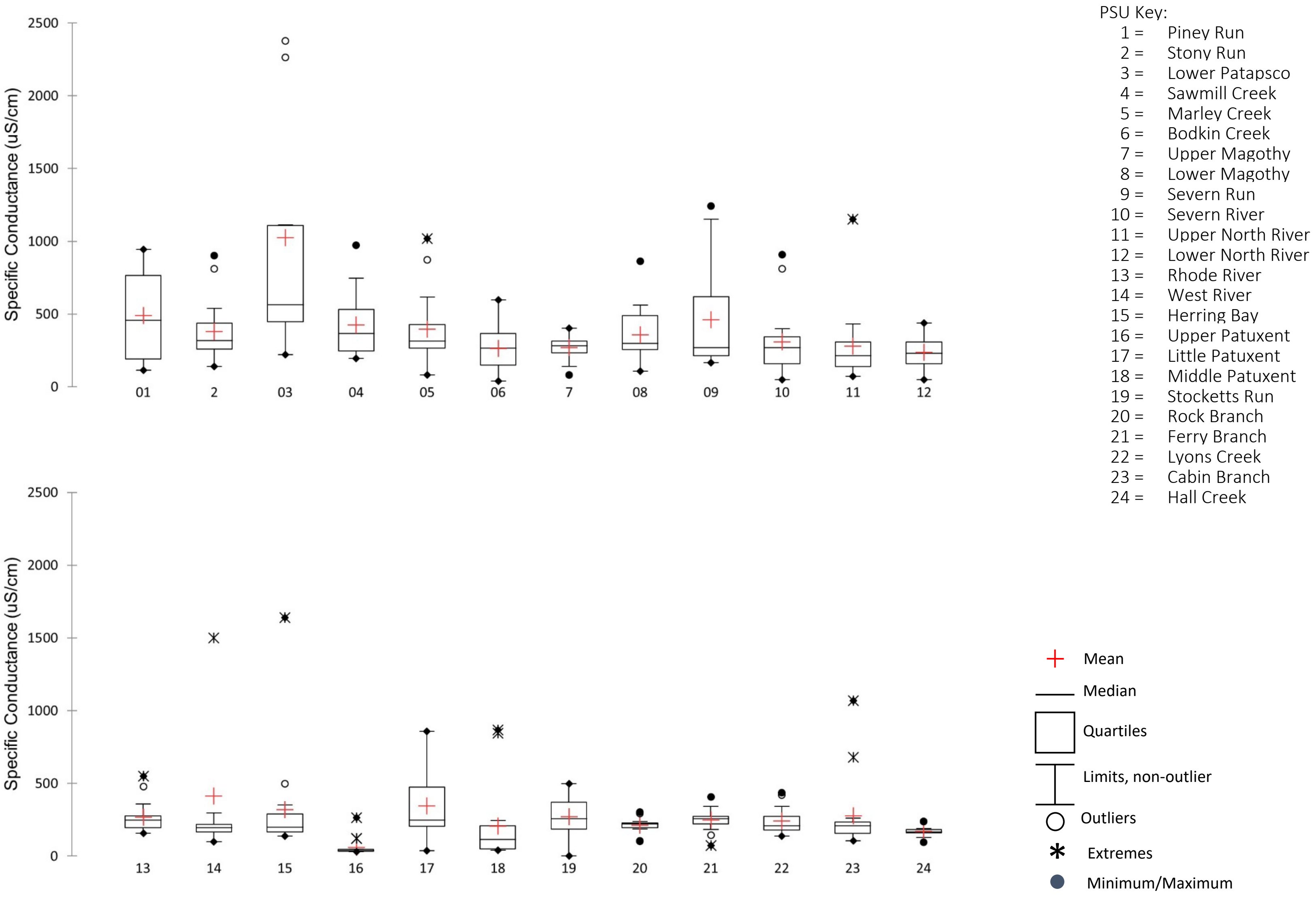
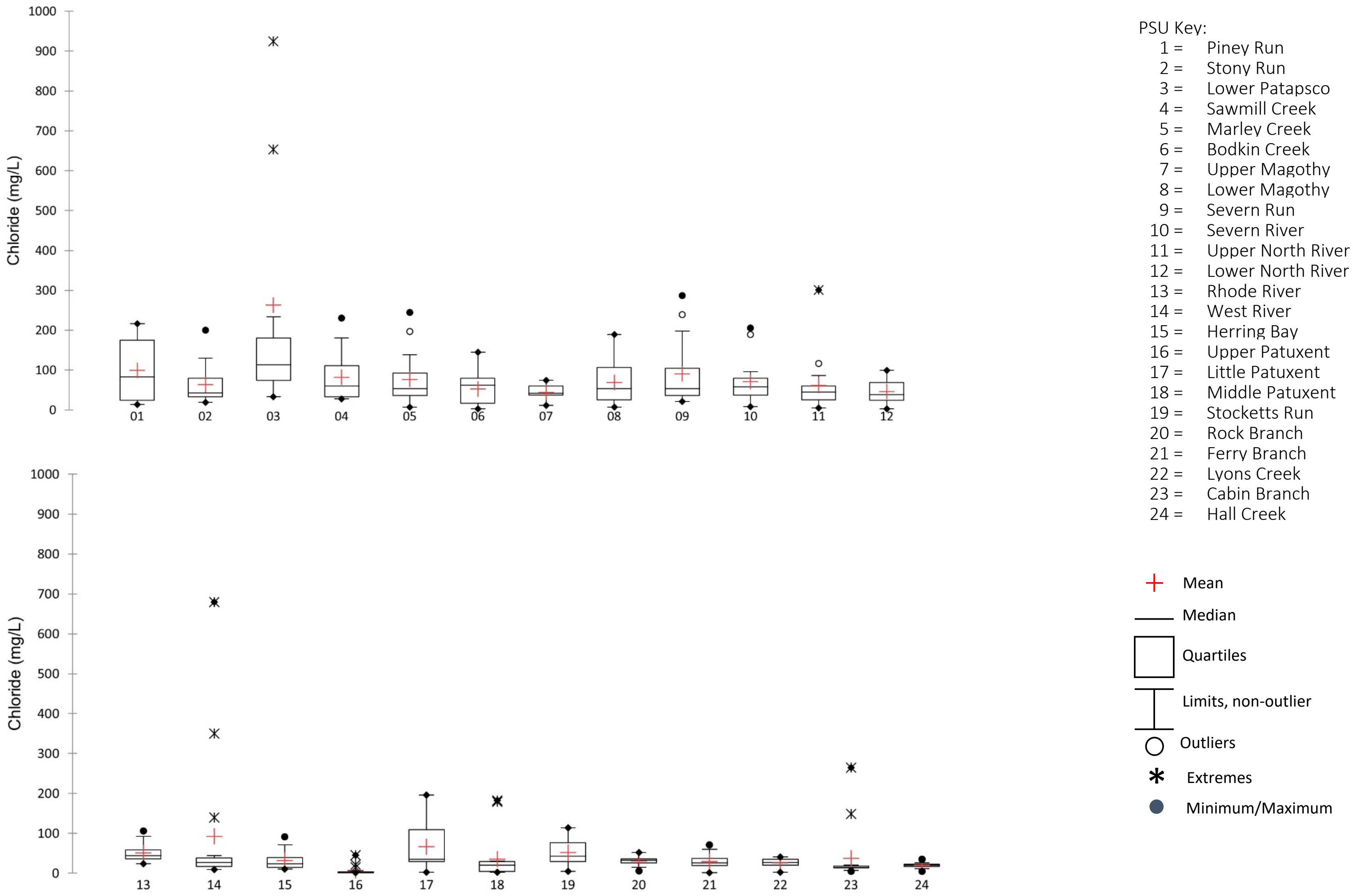


Figure 26. Box Plot of In Situ Specific Conductance values from Spring Index Period.



PSU Key:
1 = Piney Run
2 = Stony Run
3 = Lower Patapsco
4 = Sawmill Creek
5 = Marley Creek
6 = Bodkin Creek
7 = Upper Magothy
8 = Lower Magothy
9 = Severn Run
10 = Severn River
11 = Upper North River
12 = Lower North River
13 = Rhode River
14 = West River
15 = Herring Bay
16 = Upper Patuxent
17 = Little Patuxent
18 = Middle Patuxent
19 = Stocketts Run
20 = Rock Branch
21 = Ferry Branch
22 = Lyons Creek
23 = Cabin Branch
24 = Hall Creek

Figure 27. Box Plot of Chloride concentrations.

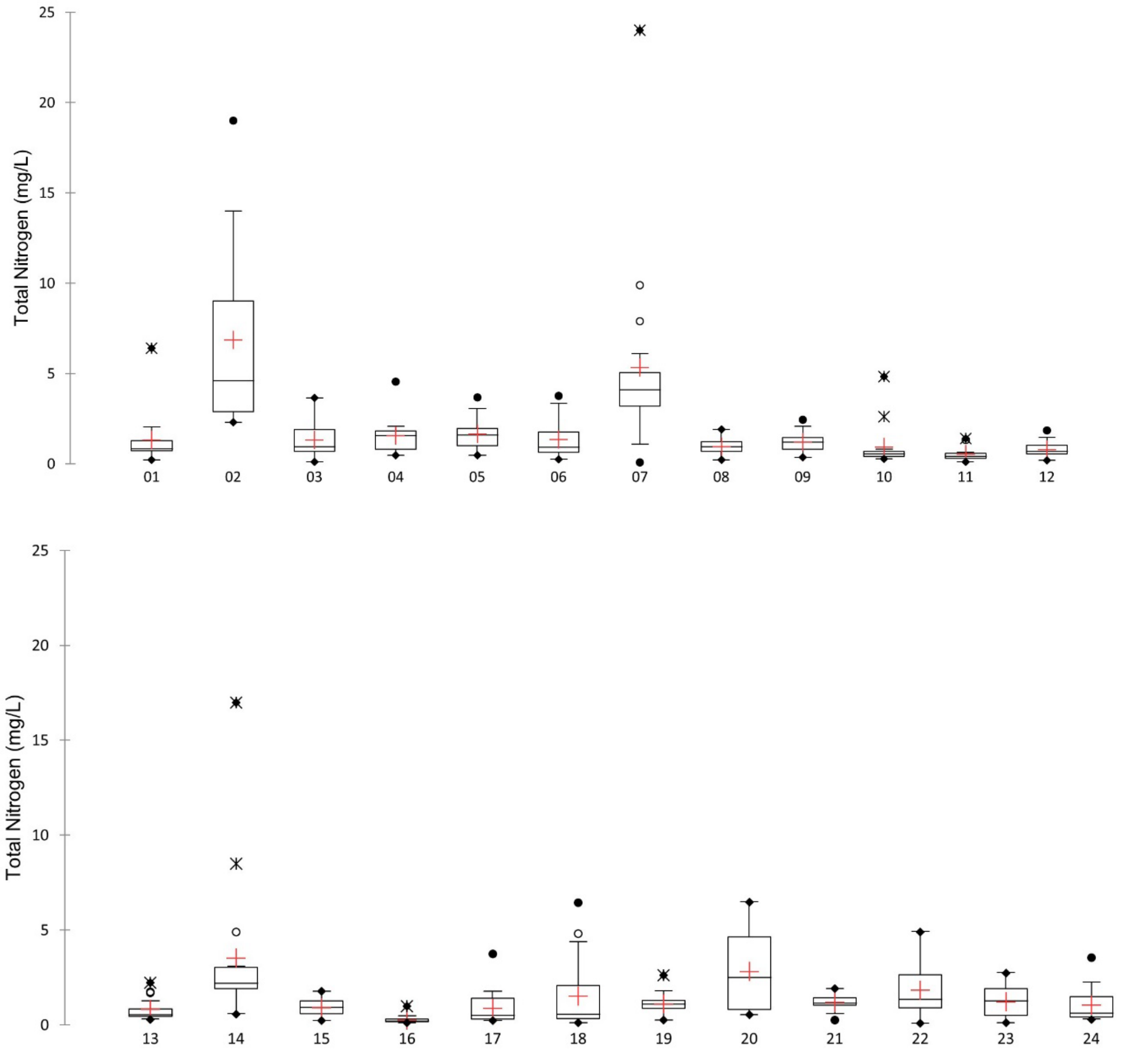


Figure 28. Box Plot of Total Nitrogen concentrations.

PSU Key:
1 = Piney Run
2 = Stony Run
3 = Lower Patapsco
4 = Sawmill Creek
5 = Marley Creek
6 = Bodkin Creek
7 = Upper Magothy
8 = Lower Magothy
9 = Severn Run
10 = Severn River
11 = Upper North River
12 = Lower North River
13 = Rhode River
14 = West River
15 = Herring Bay
16 = Upper Patuxent
17 = Little Patuxent
18 = Middle Patuxent
19 = Stocketts Run
20 = Rock Branch
21 = Ferry Branch
22 = Lyons Creek
23 = Cabin Branch
24 = Hall Creek

+ Mean
— Median
□ Quartiles
⊥ Limits, non-outlier
○ Outliers
* Extremes
● Minimum/Maximum

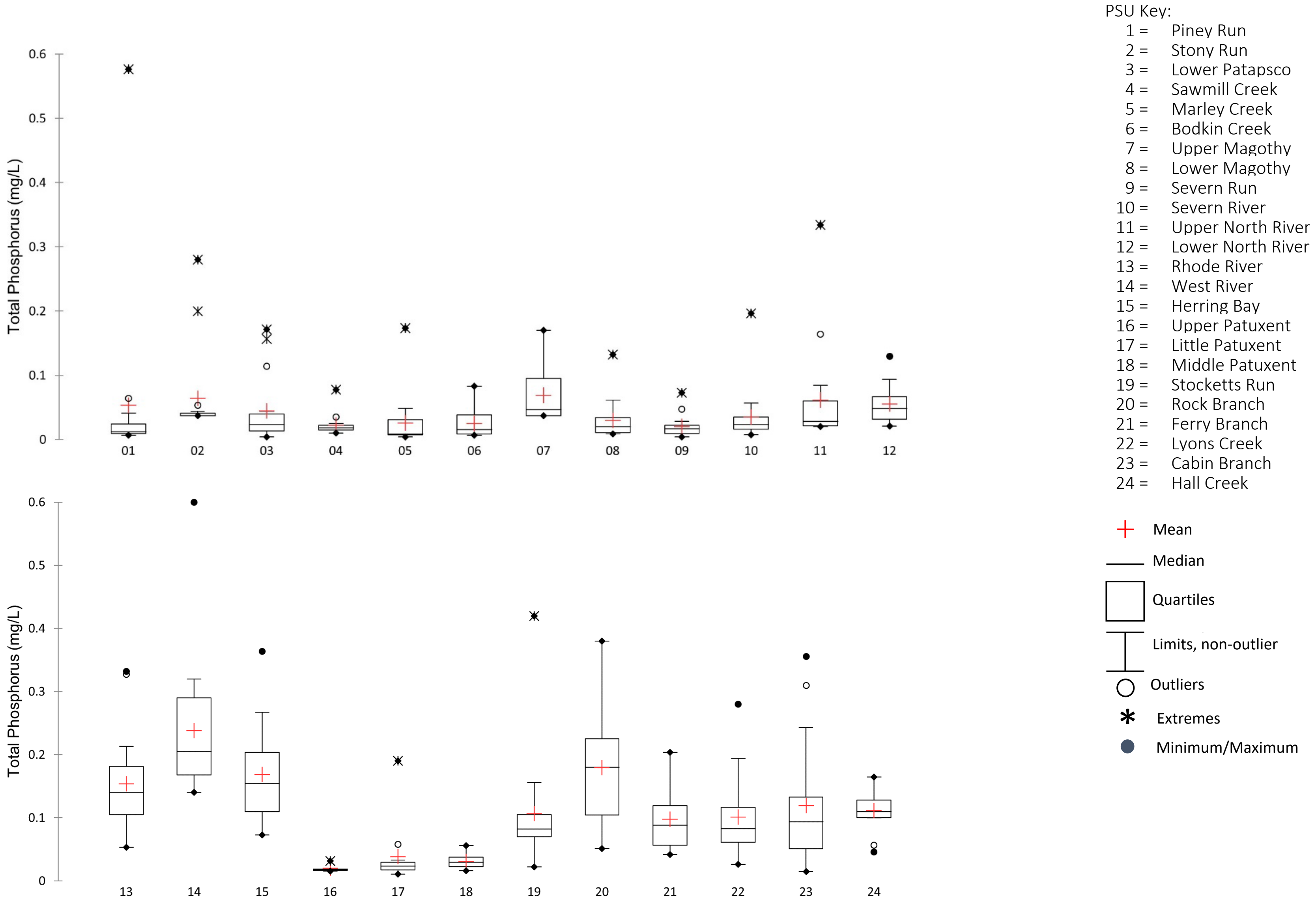


Figure 29. Box Plot of Total Phosphorus concentrations.

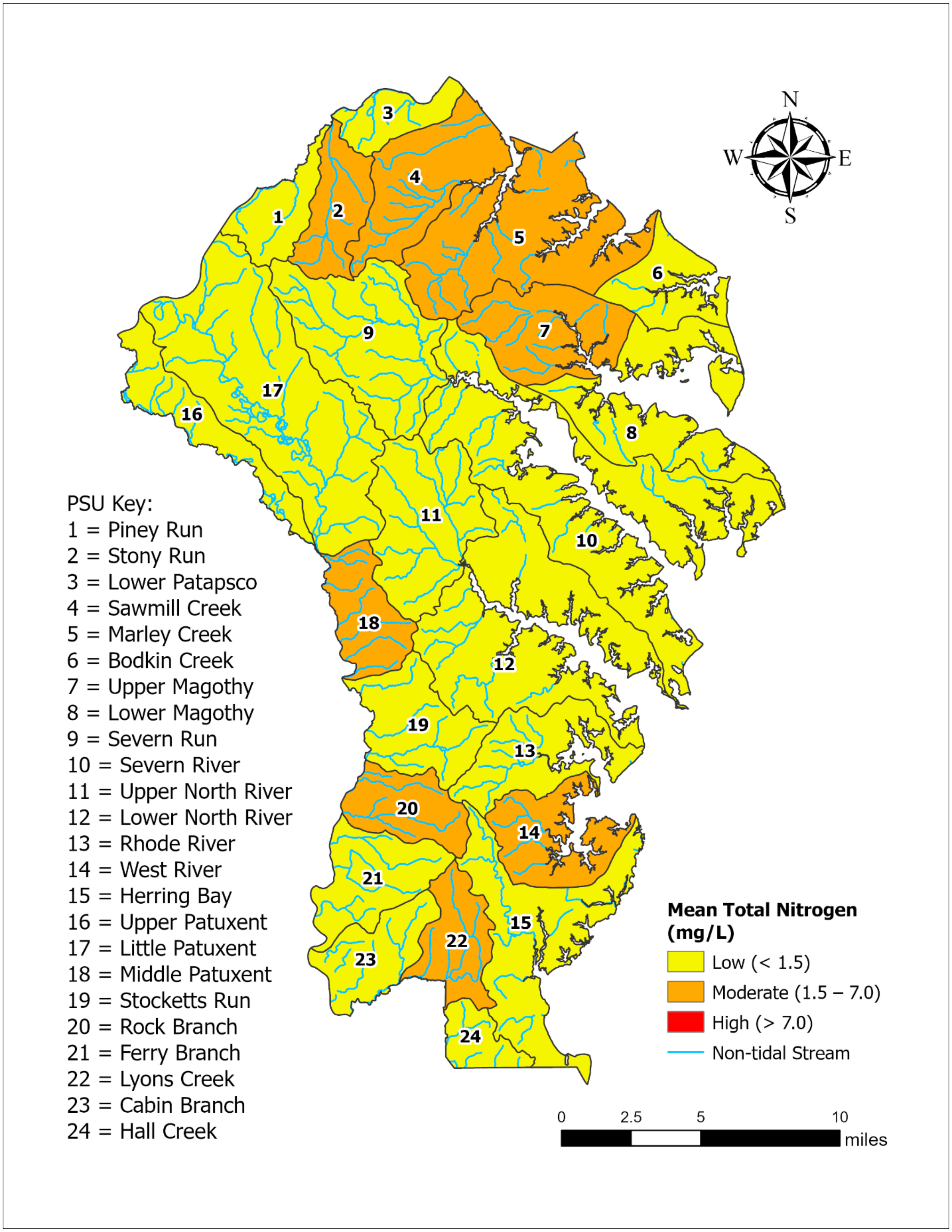


Figure 30. Average Total Nitrogen Values for Primary Sampling Units.

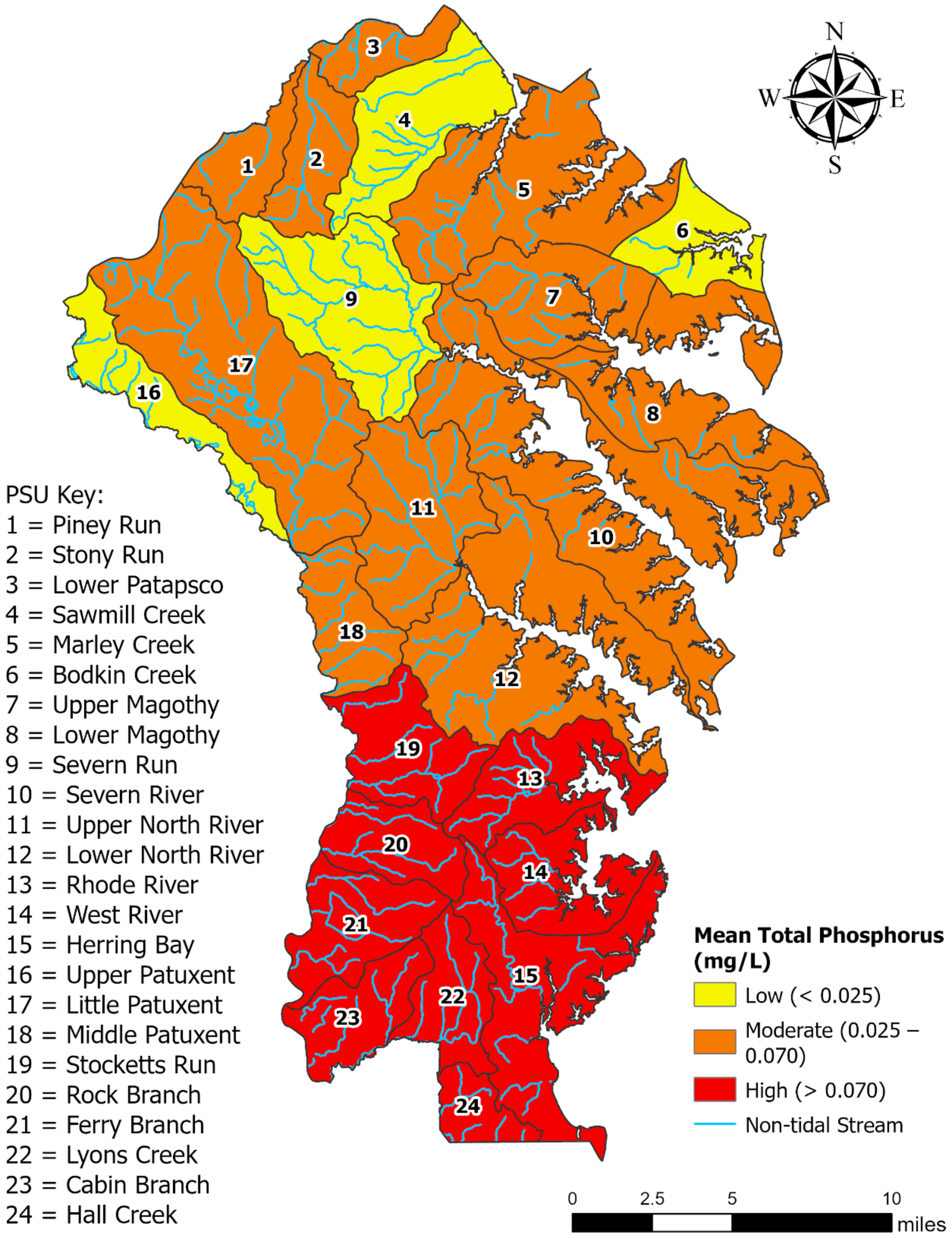
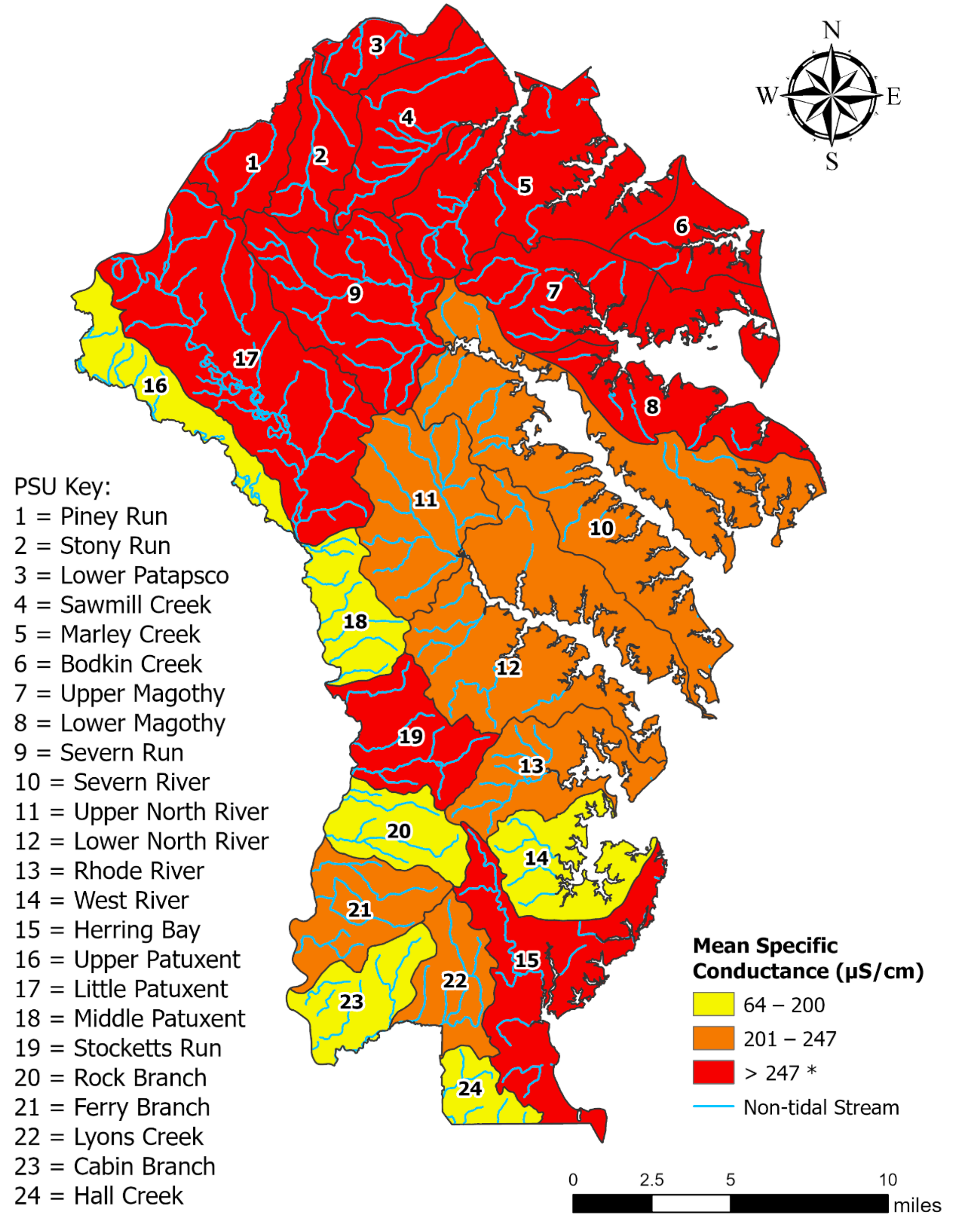


Figure 31. Average Total Phosphorus Values for Primary Sampling Units



*247 µS/cm is the critical threshold between 'Fair' and 'Poor' stream quality for Maryland streams as identified by Morgan et al. (2007)

Figure 32. Average Conductivity Values for Primary Sampling Units.

3.6 Fluvial Geomorphology

The geomorphological characteristics of Anne Arundel County streams were primarily characterized using the Rosgen stream classification system for natural rivers (Rosgen, 1994 and 1996). A map of Rosgen classification results for all large stream strata sites assessed during Round Three is displayed in Figure 34. In Round Three, Rosgen channel type was not determined (i.e., classified as ND) for seven sites because either geomorphic assessments were unable to be completed in the field due to anthropogenic constraints (e.g., pipe culvert, armored banks) or the resulting data were not sufficient, or representative, to allow for an accurate classification. Additionally, one site was considered 'Other', as the site was actively transitioning between two Rosgen channel types and could not be classified as a single stream type. Of the remaining 184 sites that were surveyed and assessed, the majority were classified as "E" type (30%), "F" (26%), and "G" (17%) channels followed by "C" (11%), "B" (8%), and "DA" (3%) channels (Figure 33). There were no large stream strata sites classified as "A" or "D" types during the Round Three sampling effort.

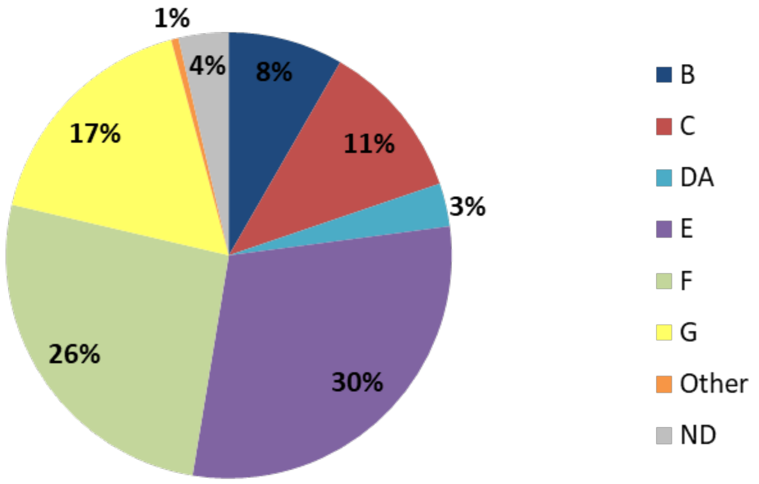


Figure 33. Distribution of Rosgen Stream Types in Sites Sampled from 2017-2021 (n=192)

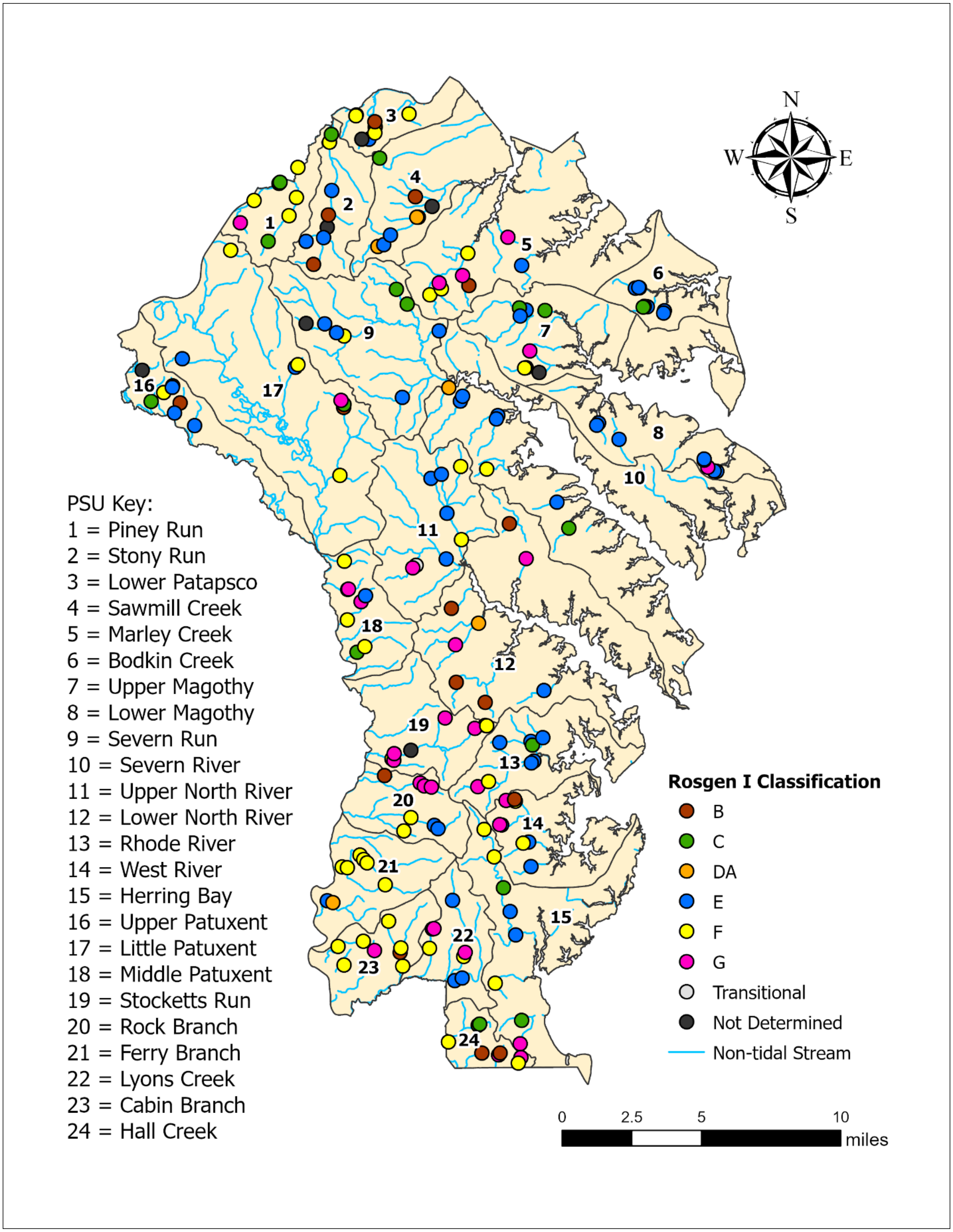


Figure 34. Countywide Geomorphic Classification (Rosgen) Results from 2017-2021

The proportion of Rosgen stream types within each PSU is presented in Figure 35. 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, Lower Magothy, Rhode River, Severn River, Severn Run, and Upper North River PSUs, where they comprised at least 50% of sites sampled. Other PSUs with predominantly “E” type channels include Stony Run, Upper Patuxent and West River. As the second most dominant channel type observed in Round Three, entrenched “F” type channels comprised at least 50% of sites in Cabin Branch, Ferry Branch, and Piney Run PSUs. Streams sampled in Herring Bay, Little Patuxent, and Lower Patapsco PSUs were also predominantly “F” type channels. “G” type channels, typically considered very sensitive to disturbance with a tendency to make significant adverse channel adjustments to changes in flow regime and sediment supply (Rosgen, 1996), comprised at least 50% of sites in only Stockett’s Run PSU, which consisted of 63%. The “G” type channel was also the predominant stream type identified in Rock Branch PSU. The “B” type channel was observed in 11 PSUs with Lower North River having the most sites at 38%. Anastomosed “DA” type channels, were observed in only 4 PSUs with the most sites in Sawmill Creek.

Figure 36 displays box plots of the four primary delineative parameters (i.e., entrenchment ratio, width/depth ratio, sinuosity, water surface slope) used in the Rosgen classification system. The box plots display the similarities and differences in the delineative parameter values measured throughout Anne Arundel County by channel type. As expected, entrenchment ratio and width/depth ratio were the most useful delineative parameters for classifying channels into different stream types. Channel sinuosity and water surface slope, on the other hand, showed a high degree of overlap between the different stream types.

The geomorphic assessment field data were compared to the Maryland Coastal Plain (MCP) regional relationships of bankfull channel geometry (McCandless, 2003) in order to determine how bankfull characteristics observed in the field compare to those predicted by the MCP. Comparisons of bankfull cross-sectional area, bankfull width, and mean bankfull depth are shown in Figure 37, Figure 38, and Figure 39, respectively. Although bankfull cross-sectional area values indicate that the field data points fall above and below the MCP curve, the field data trendline closely follows the MCP curve, especially where drainage area exceeds two square miles. A similar trend was observed for bankfull depth values, where the field data fell both above and below the MCP curve, but the overall trendline resembled the MCP predictions, although not as closely as bankfull cross-sectional area values. Field data of mean bankfull width, on the other hand, were far more variable with many points falling further above and below the MCP than bankfull cross-sectional area and bankfull depth even though both trendlines closely resembled one another. Overall, it appears that the field bankfull data are fairly consistent with the MCP relationships for sites with larger drainage areas (i.e., greater than two square miles); however, field measured bankfull width dimensions were more often larger than the MCP predictions while mean depth measurements were more often slightly smaller than the MCP predictions.

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

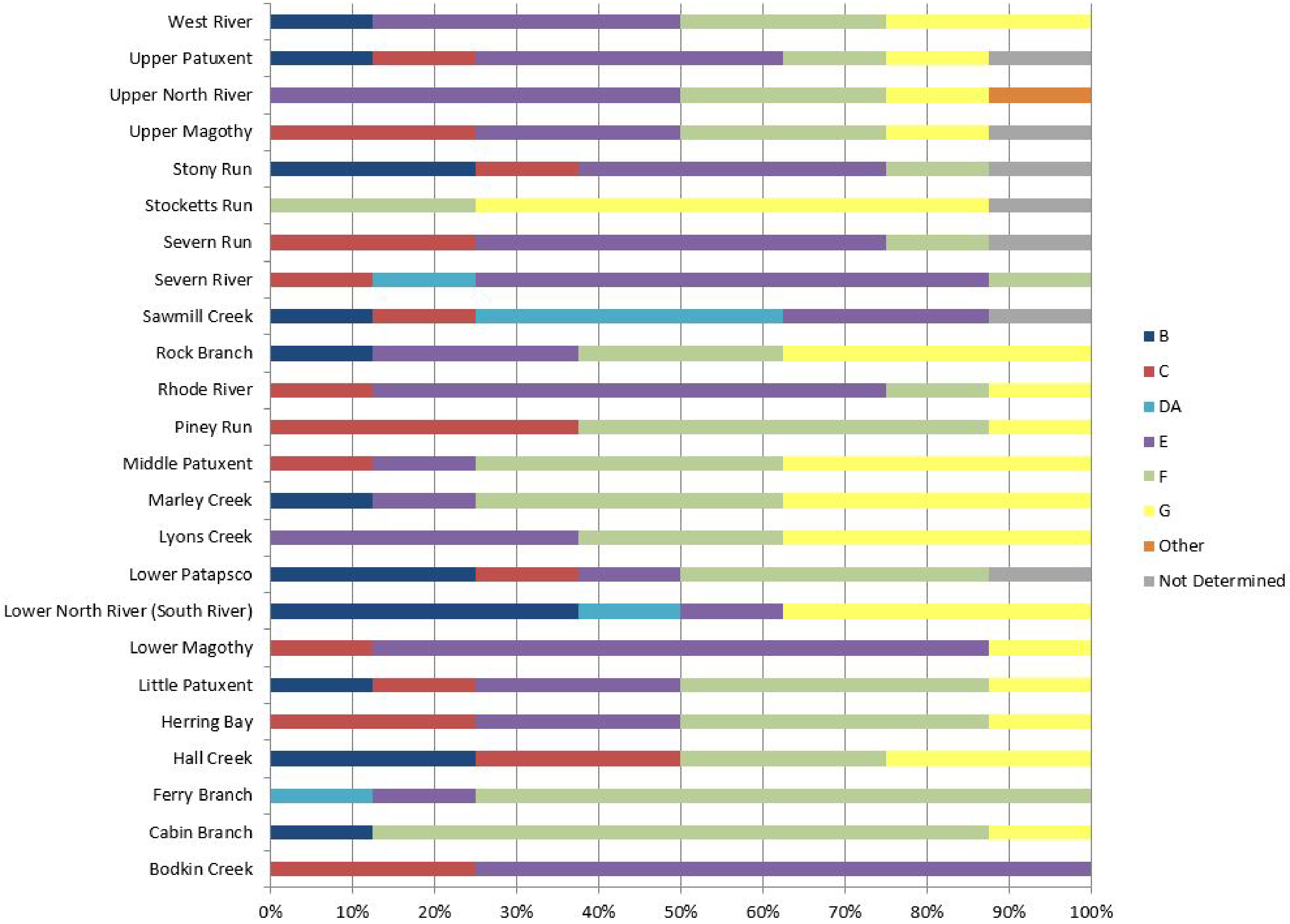


Figure 35. Proportion of Rosgen stream types identified within each PSU. ND indicates that Rosgen stream type was not determined.

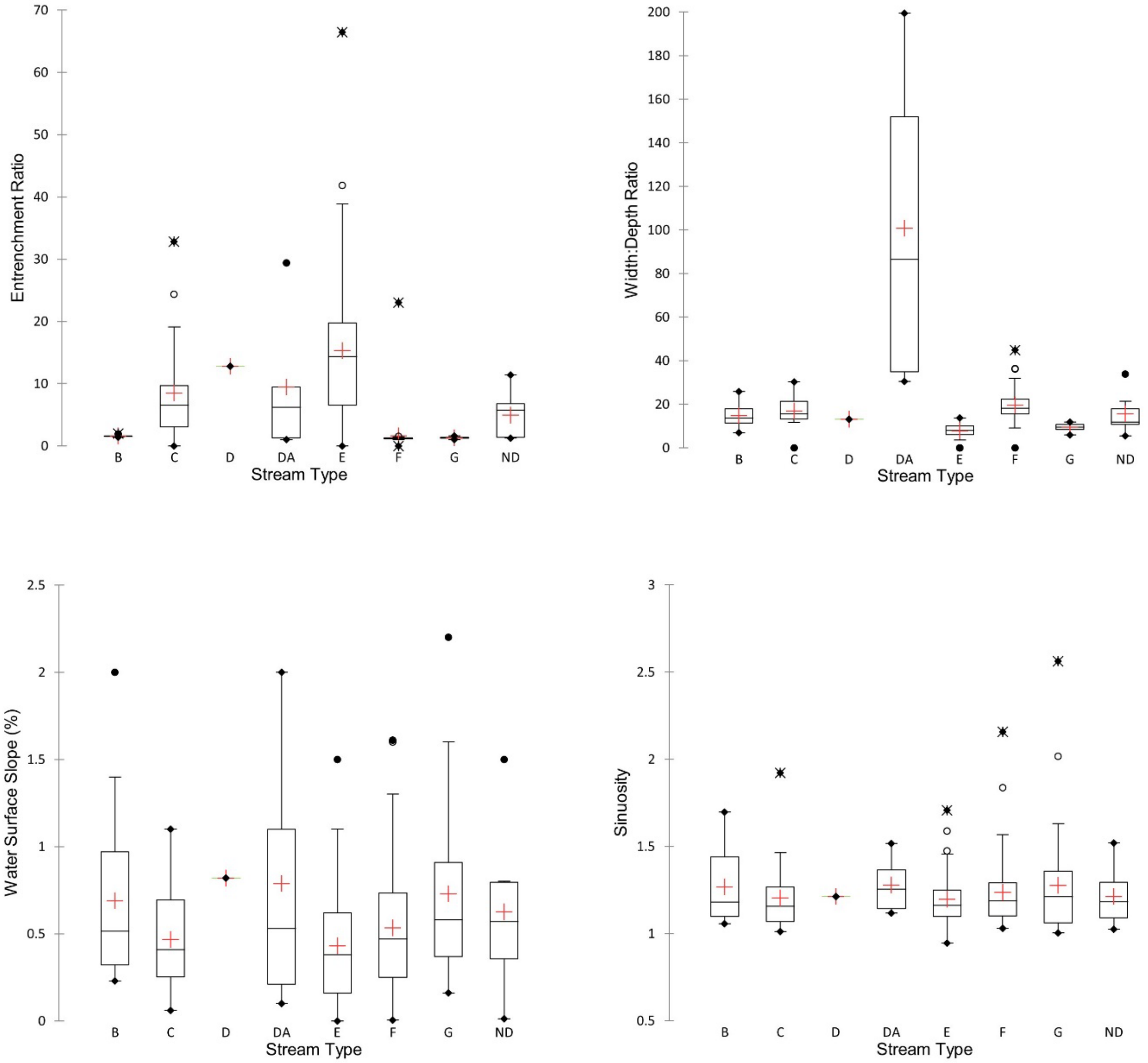


Figure 36. Box Plots of Geomorphic Parameters Used for Rosgen Stream Classification.

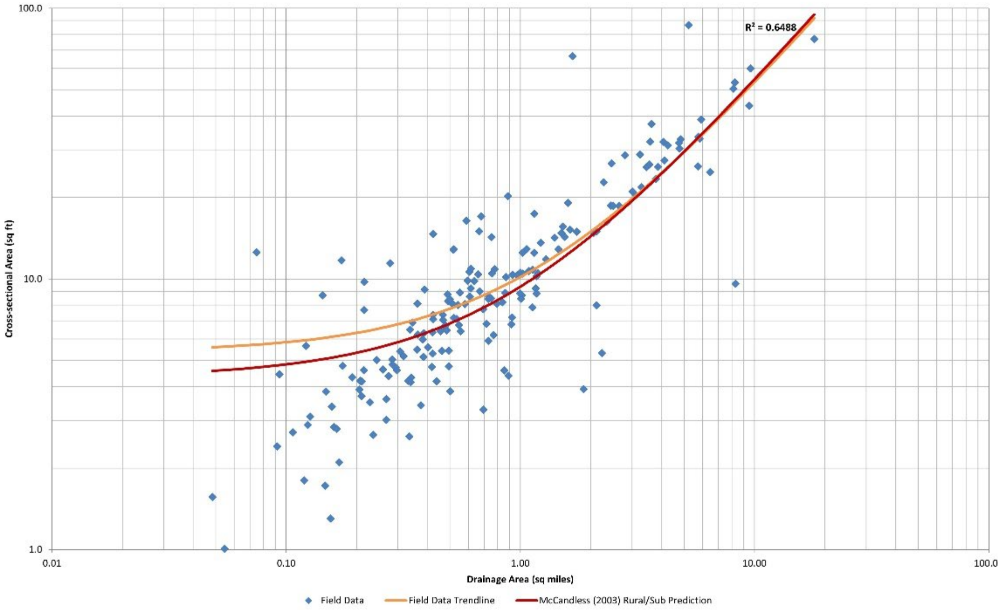


Figure 37. Comparison of the Bankfull Cross-Sectional Area - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

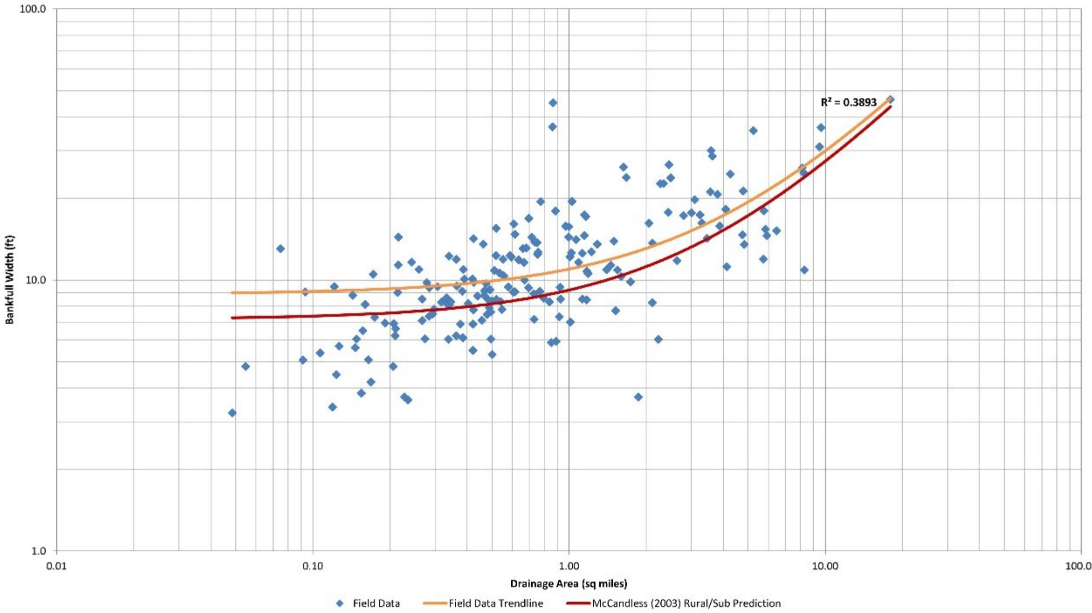


Figure 38. Comparison of the Bankfull Width - Drainage Area Relationship between Field Data and Regional Relationship Curve Data

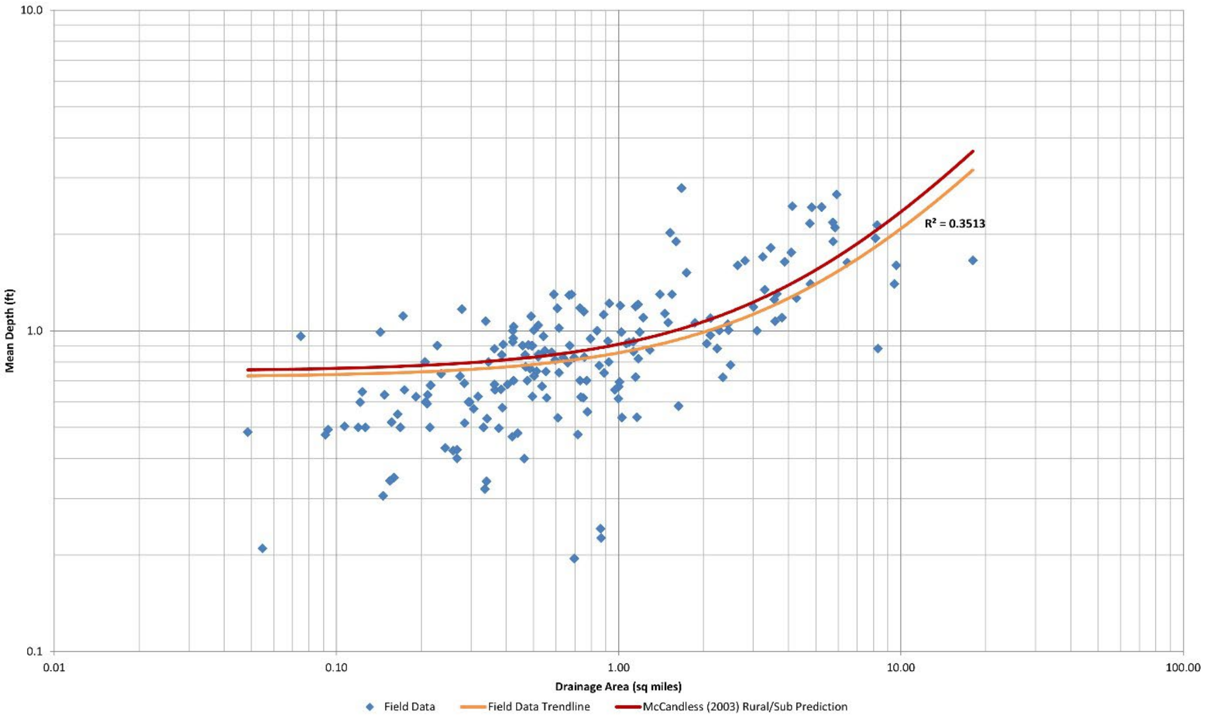


Figure 39. Comparison of the Mean Bankfull Depth - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

4 Round Three Data Analysis

4.1 Exploratory Trend Analysis

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

Stratification by dominant land use class, at the scale of drainage area to each individual sampling location, showed a considerable overlap of interquartile ranges and highly similar mean and median BIBI scores (Figure 40). Sites dominated by agriculture and forested land cover show an increased potential for higher BIBI scores as shown by the higher 3rd quartile values. In contrast, sites in the developed class have a decreased potential for higher BIBI scores and an increased potential for lower BIBI scores as shown by the lower 1st quartile values as compared to agriculture or forested sites. FIBI data stratified by dominant land use class show sites with predominantly agricultural land use have higher mean and median FIBI scores compared to sites dominated by developed and forest land use (Figure 41). These results suggest that dominant land use class alone is not a primary driver of biological condition. This is likely because 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 proportion of forested land. Furthermore, the proximity of land use types with respect to the sample station location may have a greater influence on the biota.

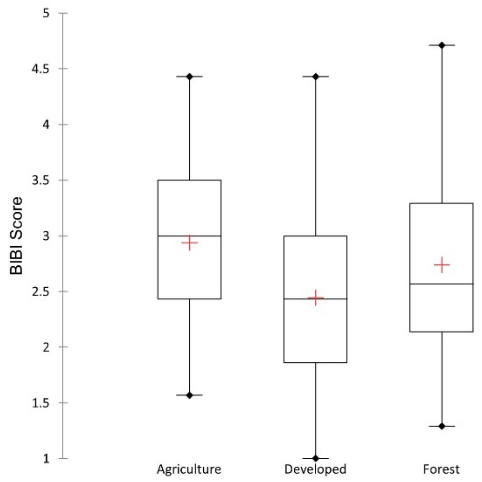


Figure 40. BIBI Data Stratified by Dominant Land Use Class.

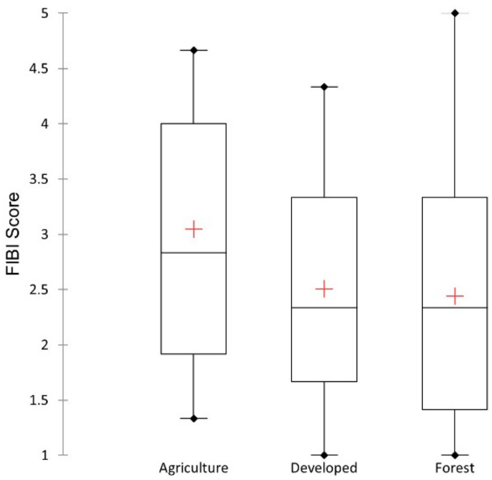


Figure 41. FIBI Data Stratified by Dominant Land Use Class.

To examine the influence of drainage area on BIBI and FIBI scores, sites were stratified by drainage area classes with small drainages classified as less than 200 acres, medium drainages as 200 – 500 acres, large drainages as 500 – 1000 acres, and very large drainages as >1000 acres. 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 42). An even more distinct upward trend can be observed for FIBI scores with increasing drainage area, where discrete separation in interquartile ranges can be seen between very large drainages and small drainages (Figure 43). This pattern in BIBI scores is consistent with that observed in both Round One (Hill and Pieper, 2011b) and Round Two (Hill et al., 2014), which suggests drainage area is likely influencing BIBI scores with a potential for streams with larger drainage areas to score higher than streams with smaller drainage areas. Furthermore, the addition of FIBI data in Round 3 suggests that this drainage area influence is not limited to BIBI scoring and also occurs with FIBI scoring.

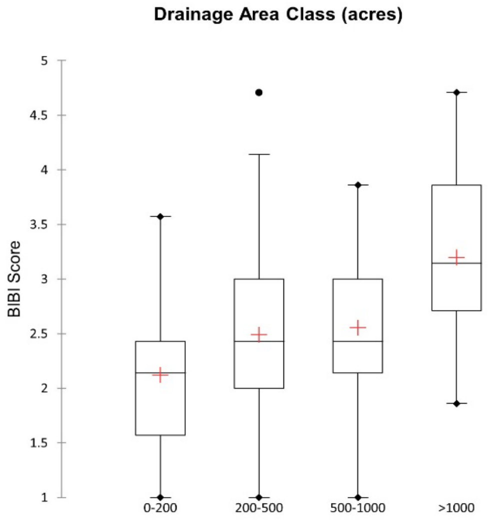


Figure 42. BIBI Data Stratified by Drainage Area Class.

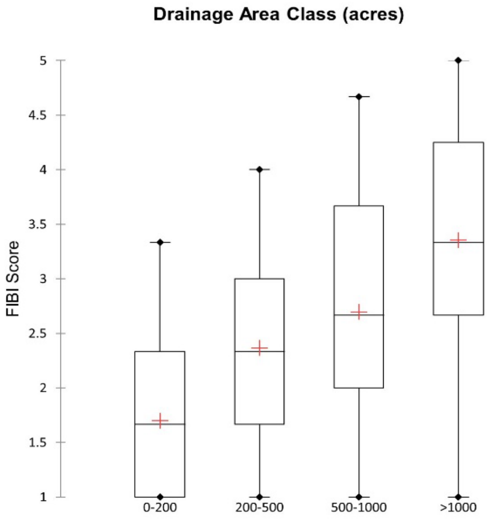


Figure 43. FIBI Data Stratified by Drainage Area Class.

Box plots of individual benthic macroinvertebrate metrics show a similar drainage area influence, especially for number of Ephemeroptera and percent Ephemeroptera metrics (Figure 44). For sites with less than 500 acres of drainage, a single Ephemeroptera taxon is considered an extreme outlier and mean percent Ephemeroptera values are less than one percent. A similar trend is observed with scraper taxa, whereby watersheds less than 200 acres have mean values below one and more than two taxa are considered extreme outliers. 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).

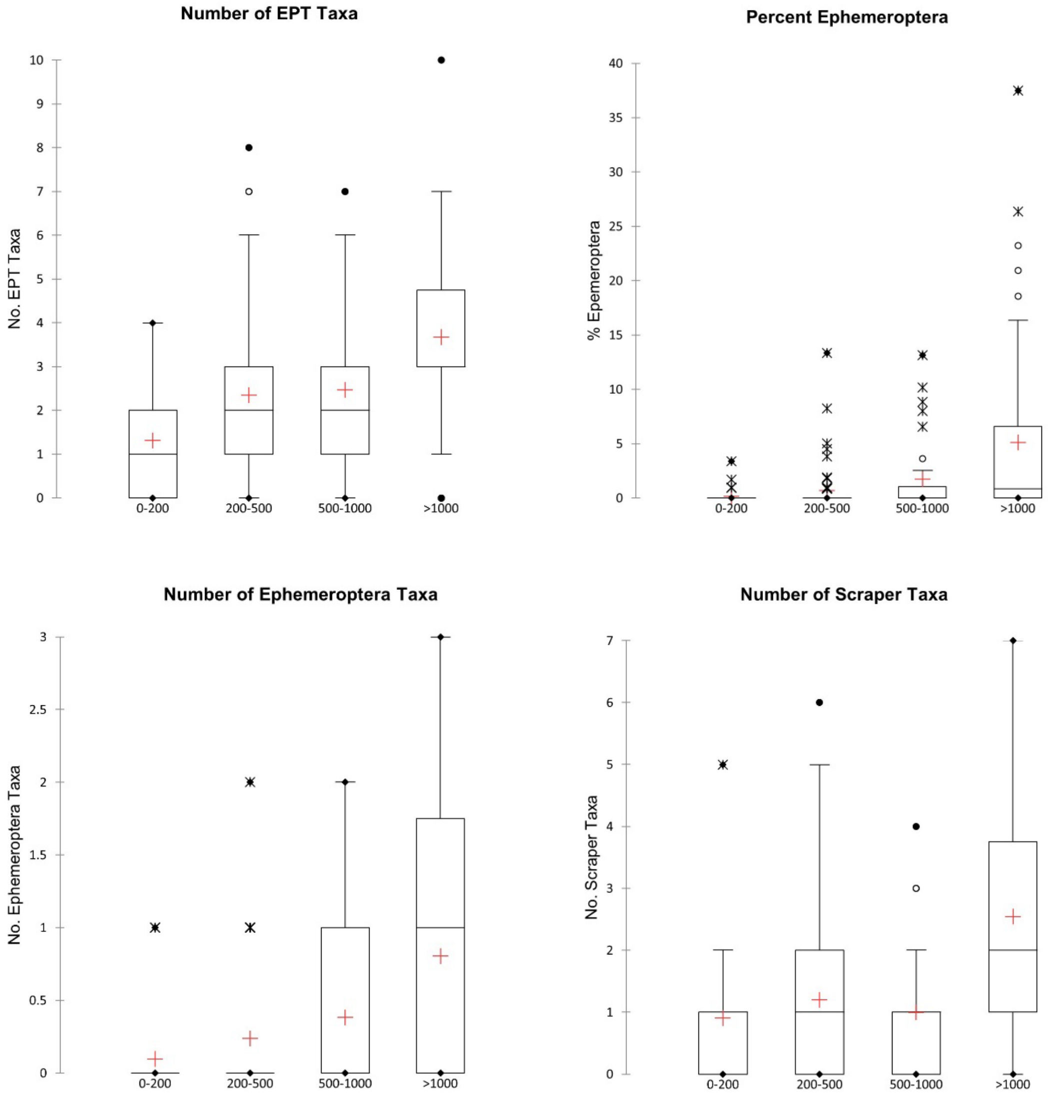


Figure 44. Box Plots of Benthic Macroinvertebrate Metrics Stratified by Drainage Area Class.

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 nearly one half received scores of ‘1’ for scraper taxa. Consequently, sites having drainage areas less than 500 acres frequently score lower than sites with larger drainage areas primarily due to the absence of these two ‘rare’ taxa groups, which may result in a bias toward lower BIBI scores for smaller streams since the BIBI is not scaled to drainage area as is MBSS’s FIBI.

Box plots of individual fish metrics show a similar drainage area influence to those observed with the BIBI (Figure 45). Despite the coastal plain FIBI containing one metric scaled to drainage area (i.e., Adjusted Number of Benthic Species), the overall FIBI does appear to be skewed towards sites with larger drainage areas. Not only does the Adjusted Number of Benthic Species metric fail to adequately correct for drainage area, but it can inadvertently cause sites with one or more benthic species to receive negative metric values when below a certain drainage area (94 acres), automatically resulting in a metric score of ‘1’ and skewing the FIBI downward by a value of 0.67. The metric adjustment formula also erroneously causes inflated metric values (sometimes exceeding 100) for sites with one or more benthic species when sites fall within a drainage area of 94 – 150 acres. For example, one headwaters stream received a score of 100.9 which skewed the mean for the 0-100 class, and subsequently was omitted from the plot in Figure 45. There were 12 sites in Round 3 (6.25%) with a drainage area below 94 acres, four of which contained no fish. None of the remaining eight sites contained benthic species; however, this metric should be closely evaluated in future Rounds for sites matching this criteria.

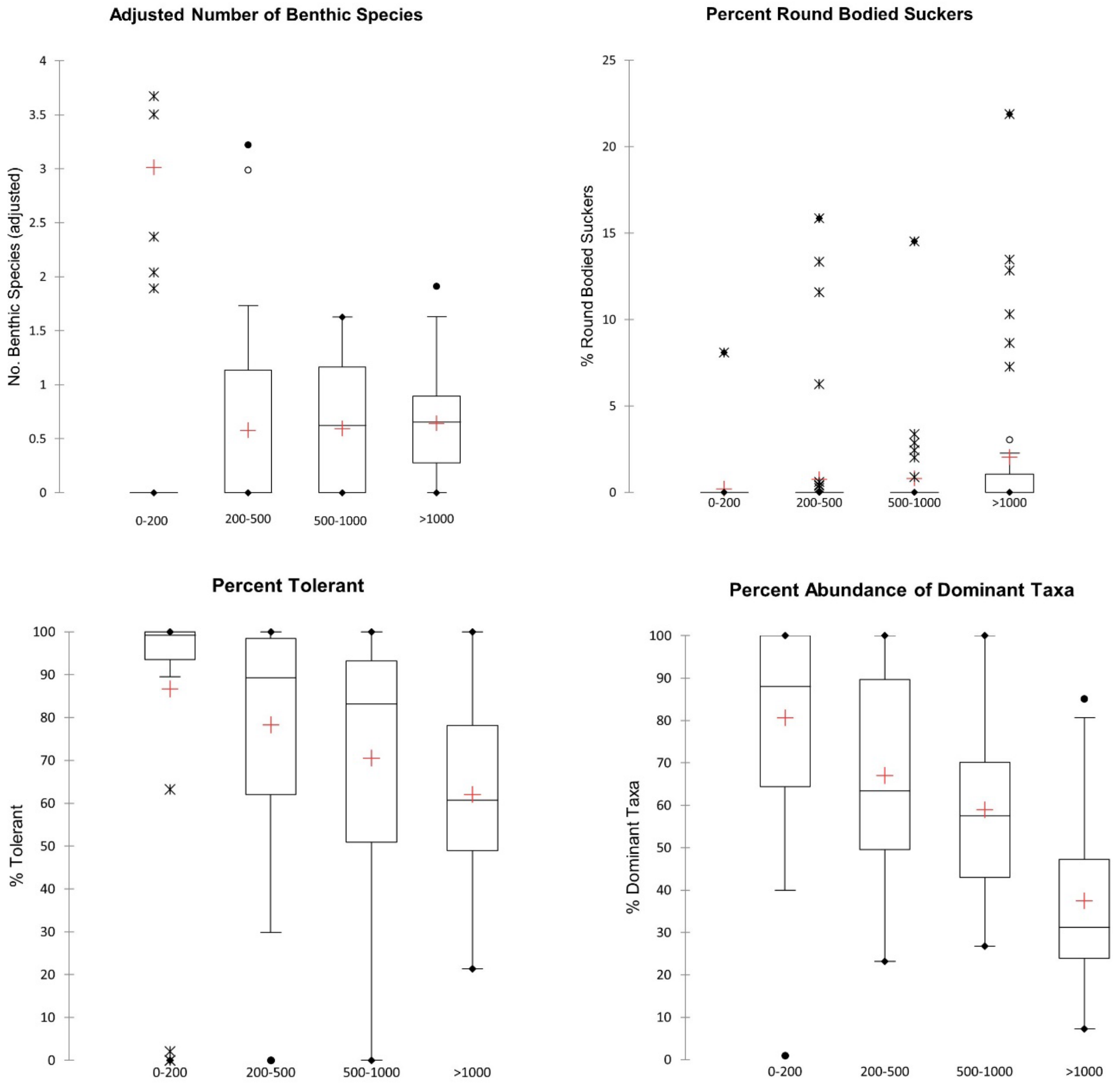


Figure 45. Box Plots of Fish Metrics Stratified by Drainage Area Class.

The Percent Round Bodied Suckers metric shows sites with less than 100 acres lacking any round bodied suckers, while the mean scores increase consistently with each larger drainage area class. Percent

Tolerant and Percent Abundance of Dominant Taxa metrics both tend to increase with increasing anthropogenic disturbance; therefore, lower values are indicative of healthier fish assemblages compared to higher values. For both of these metrics, mean values steadily decrease with each larger drainage area class. This is likely the result of larger sites generally having a greater diversity of overall species, which tends to offset the impact of one or two tolerant or dominant species on the overall metric scores.

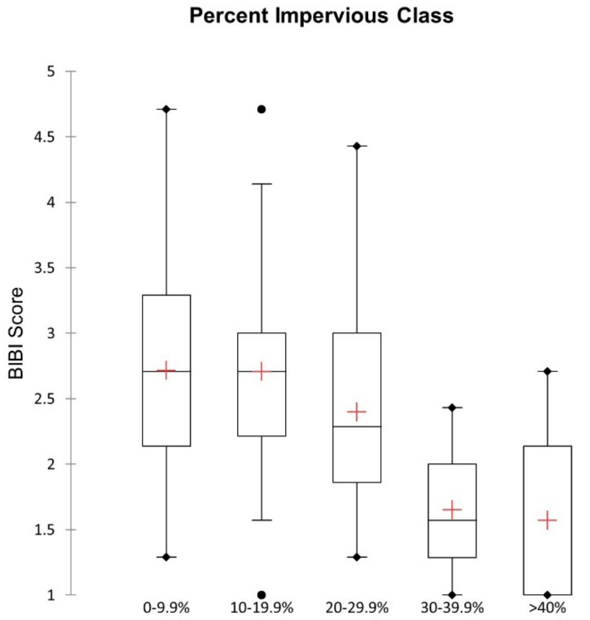


Figure 46. BIBI Data Stratified by Percent Impervious Class.

Stratification of BIBI data by percent impervious class showed a reduction in BIBI scores (mean, max, and 3rd quartile) among sites where imperviousness exceeded 20%, and a further reduction across the board above 30% (Figure 46), indicating a pronounced influence of drainage area imperviousness on biota. No sites exceeding 30% imperviousness achieved a BIBI score greater than 3.00, which is the general threshold for biological impairment designation. A closer look at individual benthic macroinvertebrate metrics shows the percentage of intolerant (i.e., pollution sensitive) taxa decline sharply as imperviousness exceeds 20% (Figure 47). Number of EPT taxa declines as imperviousness exceeds 30%, although not as sharply until imperviousness exceeds 40%. These findings are consistent with both the Round One report (Hill and Pieper, 2011b) and Round Two report (Hill et al., 2014) as well as 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. The Round Three data 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.

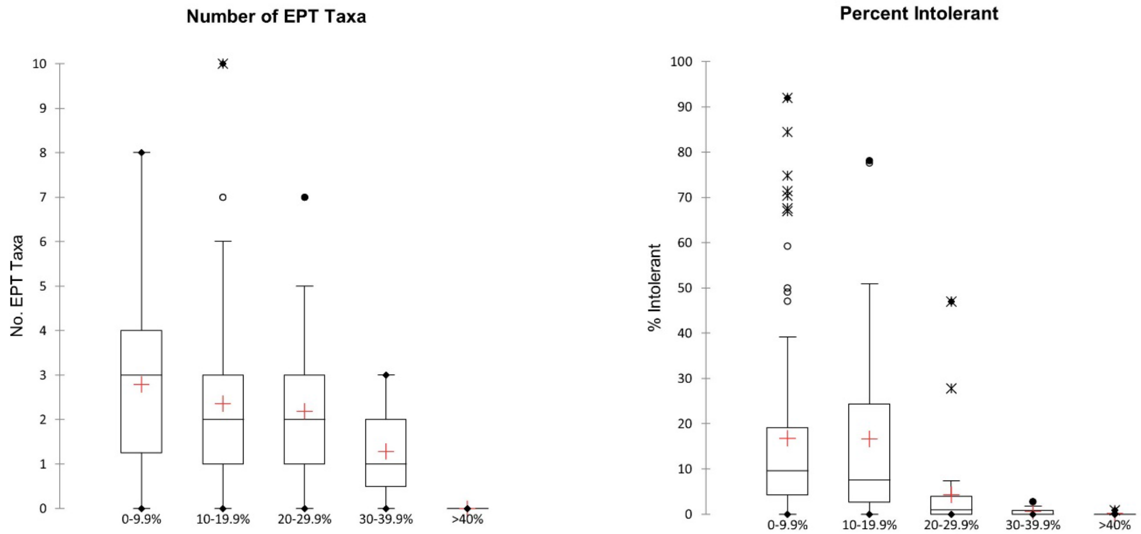


Figure 47. Box Plots of Percent Intolerant and EPT Taxa Metrics Stratified by Imperviousness Class.

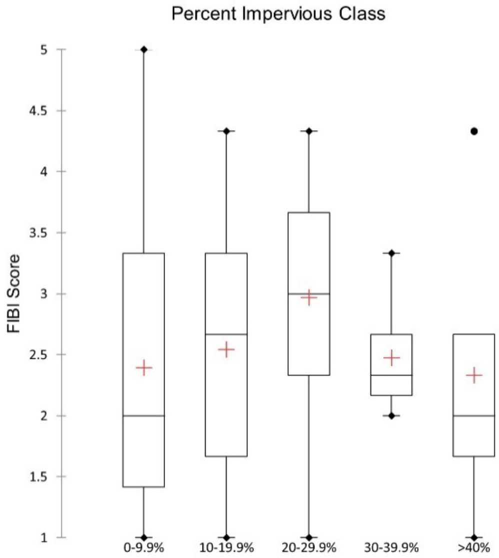


Figure 48. FIBI Data Stratified by Percent Impervious Class.

Stratification of FIBI data by percent impervious class showed a less consistent pattern with regard to increasing imperviousness as did the BIBI (Figure 48). Although maximum FIBI scores were highest among the sites with less than 10% imperviousness as expected, 1st quartile, mean, and 3rd quartile FIBI scores were highest among sites in the 20 – 29.9% class. Furthermore, median FIBI scores in this class were 3.00, which is the threshold for biological impairment, indicating half of the sites would be considered unimpaired based on FIBI scores. FIBI scores did drop off notably above 30% imperviousness, although maximum scores above 3.00 were still possible even above 40% imperviousness. Reviewing the relationships between individual metrics (Figure 49) yielded results that were less in line with the BIBI results. For example, the Percent Tolerant metric showed higher mean and median values for sites with less than 30% imperviousness compared to sites with greater than 40% imperviousness. The Percent Dominant Taxa also showed an inconsistent pattern with imperviousness, whereby sites in the 20 - 29.9% class and >40% class had far lower mean and median percentages for dominant taxa compared to sites with less than 10% imperviousness. These results suggest that FIBI scores are much less predictable based on drainage area imperviousness compared to BIBI scores. For example, Figure 48 shows an inconsistent relationship between impervious cover and FIBI scores, whereby there is very little difference in the mean FIBI scores across the different impervious classes. This is different than the pattern observed in MBSS Coastal Plain dataset and could be particular to AA Co streams.

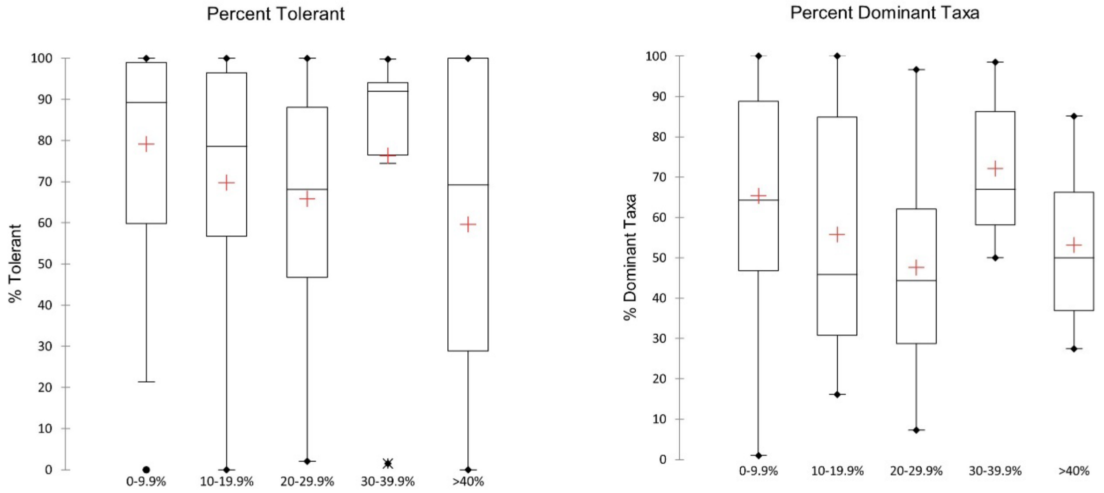


Figure 49. Box Plots of Percent Tolerant and Percent Dominance Metrics Stratified by Imperviousness Class.

A comparison of BIBI scores and FIBI 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 showed a large amount of overlap between channel types with similar mean BIBI scores across all of the major stream types (Figure 50). It should be noted that there was a very small sample size for ‘A’ (n=1) and ‘D’ (n=2) stream types, which excludes these stream types from meaningful comparisons. All stream types had maximum scores above 4.00, or “Good” biological conditions. This does not support the notion that both “F” and “G” type streams, which are incised channels with little to no floodplain access and are considered the least stable stream types in terms of erosion potential, have a reduced potential for BIBI scores compared the more stable stream types (i.e., “B”, “C”, “E” and “DA”). These results suggest that Rosgen stream class alone is not a good predictor of biological conditions based on BIBI scores, which is consistent with findings from both the Round One report (Hill and Pieper, 2011b), and Round Two report (Hill et al., 2014).

Stratification of FIBI scores by Rosgen Level I stream type showed less overlap between channel types compared to BIBI scores (Figure 50). FIBI scores were notably higher among DA stream types, although it should be noted that this stream type had a relatively small sample size (n=6) compared to the other stream types shown and may be skewed as a result. Mean, 1st quartile, and 3rd quartile FIBI scores were lowest for ‘G’ type streams, which are considered incised and generally unstable. This is largely due to the fact that numerous ‘G’ streams received the lowest possible score of 1.00 since no fish were observed or captured during sampling. These results suggest that Rosgen stream type may be a better predicter of fish assemblage health than benthic community health, at least for certain stream types.

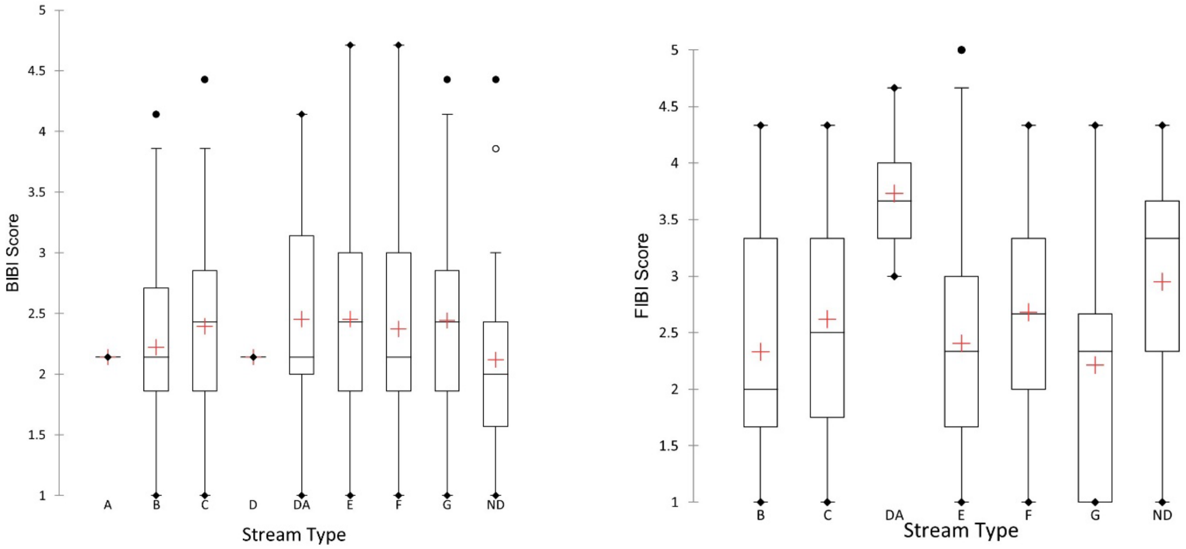


Figure 50. BIBI and FIBI Scores Stratified by Rosgen Stream Type.

4.2 Correlations

The following section describes the results of the correlation analysis with a discussion of the associations between biotic and abiotic variables. 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., 99.9% probability) defined highly significant correlations. For a simplified discussion of results, correlations are defined as weak (τ <0.1), moderate (τ = 0.1 to 0.3), or strong (τ >0.3). Complete correlation matrices are included in Appendix B.

4.2.1 Physical Habitat Variables

4.2.1.1 RBP Habitat Index

The coastal plain BIBI and individual benthic macroinvertebrate metrics were compared to RBP and PHI habitat scores collected during the spring index period. The BIBI score was highly significantly correlated (p-values less than 0.001) with several individual habitat metrics including epifaunal substrate/available cover, pool substrate, and pool variability (Table 12.). The overall RBP habitat index score (τ = 0.16, p <0.05) and riparian zone width were also moderately positively correlated. Percent Intolerant was the only individual macroinvertebrate metric highly significantly correlated (τ = 0.18, p <0.001), while three additional metrics including Number of Taxa, EPT Taxa, and Scraper Taxa were also correlated positively with RBP index score. Pool Variability was consistently correlated with all macroinvertebrate metrics, with the exception of Percent Intolerant.

Table 12. Correlation coefficients (Kendall τ) for spring 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	0.05	0.01	-0.12	-0.12	0.01	0.06	-0.02	-0.02
Vegetative Protection	0.07	-0.06	**-0.22**	**-0.23**	0.07	-0.01	-0.05	-0.05
Channel Flow	0.12	0.09	0.01	0.02	**0.22**	0.10	-0.08	0.14
Channel Alteration	0.02	0.05	0.09	0.09	0.12	-0.03	0.00	0.07
Channel Sinuosity	0.02	0.04	0.09	0.06	0.06	0.00	0.03	0.05
Pool Substrate	**0.14**	**0.27**	0.14	0.14	0.10	**0.21**	0.01	**0.23**
Pool Variability	**0.14**	**0.20**	**0.26**	**0.26**	0.00	**0.22**	**0.15**	**0.26**
Riparian Zone Width	0.11	**0.16**	0.10	0.10	**0.20**	0.06	0.02	**0.15**
Sediment Deposition	0.05	0.05	-0.09	-0.08	**0.17**	0.08	-0.08	0.05
Epi. Substrate/Avail. Cover	**0.15**	**0.29**	0.15	0.15	**0.16**	**0.15**	0.08	**0.24**
RBP Score	**0.16**	**0.16**	0.02	0.02	**0.18**	**0.15**	0.00	**0.16**
PHI Habitat Variables								
Instream Habitat	0.11	**0.23**	0.12	0.12	0.09	**0.17**	0.06	**0.19**
Epifaunal Substrate	0.13	**0.31**	0.15	0.15	**0.21**	0.13	0.04	**0.24**
Bank Stability	0.04	-0.01	-0.12	-0.12	0.04	0.06	-0.10	-0.04
Percent Shading	-0.01	-0.01	-0.05	-0.05	0.09	**-0.19**	0.00	-0.06
Remoteness	-0.01	0.08	0.07	0.07	**0.18**	-0.10	-0.02	0.05
# Woody Debris/Rootwads	-0.02	0.06	0.06	0.08	0.06	0.03	-0.02	0.07
Instream Habitat Score	0.01	0.06	-0.05	-0.05	0.04	0.04	0.02	0.02
Epifaunal Substrate Score	0.08	**0.22**	0.06	0.07	**0.17**	0.04	0.02	**0.14**
Bank Stability Score	0.04	-0.01	-0.12	-0.12	0.03	0.06	-0.10	-0.03
Shading Score	0.00	-0.01	-0.06	-0.06	0.09	**-0.18**	0.00	-0.05
Remoteness Score	-0.01	0.08	0.07	0.07	**0.18**	-0.10	-0.02	0.05
Woody Debris Score	-0.13	-0.12	-0.10	-0.09	0.00	-0.10	-0.05	-0.10
PHI Score	0.00	0.07	-0.07	-0.06	**0.16**	-0.05	-0.03	0.01

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

Highlighted values indicate significance at 0.001 level

The coastal plain FIBI and all fish macroinvertebrate metrics were compared to RBP and PHI habitat scores collected during the summer index period. The FIBI score was highly significantly correlated (p-values less than 0.001) with the overall RBP habitat index score along with several individual habitat metrics including channel flow, channel sinuosity, pool substrate, pool variability, and epifaunal substrate/available cover (Table 13.). Riparian zone width was also moderately positively correlated. Two individual fish metrics, Percent Tolerant and Percent Abundance of Dominant Taxon, were both moderately negatively correlated to the overall RBP score. Epifaunal substrate/available cover was significantly correlated with all fish metrics; negatively correlated with Percent Tolerant, Percent Generalist, Omnivores, Insectivores and Percent Abundance of Dominant Taxon; positively correlated with Abundance per Square Meter, Adjusted Number of Benthic Species, and Percent Round-bodied Suckers.

Table 13. Correlation coefficients (Kendall τ) for summer physical habitat variables versus fish metric and index scores.

Variable	**Abundance Per m^2**	**Adjusted No. Benthic Species**	**Percent Tolerant**	**Percent Generalist,**	**Percent Round-bodied Suckers**	**Percent Abundance**	**FIBI**
RBP Habitat Variables							
Bank Stability	**-0.12**	-0.08	-0.10	-0.08	-0.06	-0.03	0.03
Vegetative Protection	0.04	**-0.21**	-0.03	0.04	-0.08	0.01	0.07
Channel Flow	0.00	0.01	-0.08	-0.05	0.09	**-0.12**	**0.22**
Channel Alteration	-0.01	**0.13**	0.07	0.02	-0.07	**0.12**	0.07
Channel Sinuosity	**0.27**	**0.13**	0.06	-0.01	0.03	0.06	**0.25**
Pool Substrate	**0.12**	**0.16**	-0.10	**-0.16**	**0.24**	**-0.25**	**0.41**
Pool Variability	**0.17**	0.10	**-0.12**	-0.01	**0.30**	**-0.20**	**0.40**
Riparian Zone Width	**0.11**	0.01	-0.04	0.01	0.03	0.07	**0.14**
Sediment Deposition	-0.05	-0.07	-0.04	-0.05	-0.05	-0.02	0.07
Epi. Substrate/Avail. Cover	**0.12**	**0.22**	**-0.15**	**-0.20**	**0.27**	**-0.29**	**0.47**
RBP Score	0.09	0.04	**-0.11**	-0.10	0.10	**-0.12**	**0.29**
PHI Habitat Variables							
Instream Habitat	**0.16**	**0.21**	**-0.13**	**-0.17**	**0.31**	**-0.29**	**0.50**
Epifaunal Substrate	0.10	**0.22**	**-0.15**	**-0.20**	**0.21**	**-0.27**	**0.43**
Bank Stability	-0.05	**-0.14**	**-0.10**	-0.11	-0.07	**-0.12**	0.04
Percent Shading	**-0.16**	**-0.12**	**0.14**	0.11	**-0.30**	**0.24**	**-0.21**
Remoteness	0.01	0.01	0.02	0.05	-0.06	0.08	0.01
# Woody Debris/Rootwads	**0.11**	**0.15**	0.00	-0.05	0.11	-0.04	**0.29**
Instream Habitat Score	**0.21**	**0.13**	0.01	-0.09	**0.17**	**-0.10**	**0.30**
Epifaunal Substrate Score	**0.12**	**0.18**	-0.07	**-0.16**	0.10	**-0.16**	**0.30**
Bank Stability Score	-0.05	**-0.14**	**-0.10**	-0.11	-0.07	**-0.12**	0.04
Shading Score	**-0.15**	**-0.12**	**0.12**	**0.11**	**-0.28**	**0.23**	**-0.20**
Remoteness Score	0.01	0.01	0.02	0.05	-0.06	0.08	0.01
Woody Debris Score	**0.12**	0.00	**0.16**	0.08	-0.11	**0.15**	0.01
PHI Score	0.07	0.03	0.00	-0.03	-0.07	-0.01	0.08

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

Other than drainage area, the overall RBP index score was significantly correlated with only one land use variable, percent impervious cover (Table 14.), although this is likely due to intercorrelation between drainage area and percent impervious cover (Appendix B, page B-5). Two individual habitat parameters, channel alteration and epifaunal substrate/available cover, were significantly correlated with numerous land use characteristics (Table 14.). Both parameters were negatively correlated ($p < 0.05$) with percent developed and positively correlated ($p < 0.05$) with percent forested. Three individual habitat variables were highly significantly correlated ($p < 0.001$) with drainage area including pool substrate, pool variability and epifaunal substrate/available cover, while two additional variables, channel flow and riparian zone width were moderately positively correlated ($p < 0.05$) with drainage area. These results are generally consistent with findings from the Round One Report (Hill and Pieper, 2011b) and Round Two Report (Hill et al., 2014), which found the strongest correlations were with drainage area.

The RBP as well as individual parameters were compared against geomorphic variables to determine which geomorphic measures are most strongly associated with physical habitat conditions (Table 15.). It should be noted however, that numerous geomorphic measures were highly significantly correlated with drainage area, as were numerous habitat parameters. Therefore, to avoid potentially significant correlations that may be the result of covariance, this discussion will focus on dimensionless geomorphic variables (i.e., entrenchment ration and width/depth ratio) and sinuosity, which were not correlated with drainage area. Entrenchment ratio was strongly positively correlated with RBP score as well as several individual parameters including bank stability, sediment deposition, and channel flow, and moderately positively correlated with vegetative protection. Width/depth ratio was highly significantly negatively correlated with channel flow ($p < 0.001$) and also negatively correlated ($p < 0.05$) with sediment deposition. While a strong positive correlation between measured sinuosity and the visually assessed channel sinuosity parameter was expected, sinuosity was also significantly correlated ($p < 0.05$) with overall RBP score as well as pool substrate, riparian zone width, and epifaunal substrate.

Table 14. Correlation coefficients (Kendall τ) for physical habitat variables versus land use variables.

Variable	**% Impervious**	**%Developed**	**%Forested**	**%Open**	**%Agriculture**	**Drainage area**
RBP Habitat Variables						
Bank Stability	**0.17**	0.09	-0.04	0.05	-0.07	-0.07
Vegetative Protection	**0.23**	**0.10**	-0.03	0.09	**-0.11**	-0.05
Channel Flow	0.01	-0.06	**0.12**	0.03	-0.04	**0.12**
Channel Alteration	**-0.23**	**-0.13**	**0.14**	**-0.22**	**0.16**	0.01
Channel Sinuosity	0.10	0.00	-0.01	0.06	**-0.11**	0.09
Pool Substrate	0.08	-0.01	0.06	**0.13**	**-0.11**	**0.29**
Pool Variability	-0.04	**-0.12**	0.07	0.07	**0.11**	**0.36**
Riparian Zone Width	-0.08	**-0.13**	**0.21**	-0.06	0.02	**0.14**
Sediment Deposition	0.04	0.00	0.04	**0.13**	**-0.12**	-0.03
Epi. Substrate/Avail. Cover	0.01	**-0.12**	**0.12**	**0.12**	-0.01	**0.32**
RBP Score	**0.10**	-0.03	0.09	0.08	-0.07	**0.18**
PHI Habitat Variables						
Instream Habitat	0.06	-0.08	0.08	**0.17**	-0.05	**0.37**
Epifaunal Substrate	-0.03	**-0.16**	**0.16**	0.10	0.01	**0.28**
Bank Stability	**0.21**	**0.10**	-0.04	0.06	**-0.15**	-0.06

Variable	**% Impervious**	**%Developed**	**%Forested**	**%Open**	**%Agriculture**	**Drainage area**
Percent Shading	**-0.15**	**-0.13**	**0.10**	-0.10	**0.14**	**-0.21**
Remoteness	**-0.26**	**-0.27**	**0.21**	**-0.12**	**0.18**	-0.05
# Woody Debris/Rootwads	-0.02	-0.06	0.01	0.10	0.01	**0.13**
Instream Habitat Score	0.02	**-0.11**	0.08	**0.10**	-0.04	0.01
Epifaunal Substrate Score	-0.06	**-0.17**	**0.16**	0.05	0.02	0.06
Bank Stability Score	**0.21**	**0.10**	-0.04	0.06	**-0.15**	-0.06
Shading Score	**-0.12**	**-0.12**	0.09	-0.09	**0.14**	**-0.20**
Remoteness Score	**-0.26**	**-0.27**	**0.21**	**-0.12**	**0.18**	-0.05
Woody Debris Score	-0.09	-0.07	-0.02	-0.02	0.06	**-0.27**
PHI Score	-0.08	**-0.18**	**0.14**	0.02	0.03	**-0.11**

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

4.2.1.2 PHI Habitat Index

The PHI score was strongly correlated with RBP score ($\tau = 0.42$, $p < 0.001$), but was not significantly correlated with BIBI score (Appendix B, page B-3). Two individual PHI parameters, epifaunal substrate and instream habitat, were highly significantly correlated with BIBI score (Table 12.). 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 14.. Remoteness was highly significantly correlated with the Percent Intolerant metric, which is not surprising given that the percentage of intolerant individuals tends to increase as sites become more remote.

Although the PHI score was not significantly correlated with FIBI score, several individual PHI metrics were highly significantly correlated (Table 13.). Epifaunal substrate, instream habitat, and number of woody debris and rootwads were all positively correlated ($p < 0.001$) with the FIBI score, while percent shading was negatively correlated. The relationship to shading is likely due to the fact that shading is negatively correlated with drainage area (Table 14.), while FIBI is positively correlated with drainage area.

Land use characteristics correlated better with the PHI habitat index, as compared to the RBP index (Table 14.), which is consistent with findings from Round One (Hill and Pieper, 2011b) and Round Two (Hill et al., 2014). The overall PHI score was negatively correlated ($p < 0.001$) with percent developed land and drainage area ($p < 0.05$) and positively correlated ($p < 0.05$) with percent forested land cover. These results are somewhat expected given that remoteness, which is an indirect measure of proximity to roads, is highly significantly correlated with percent developed, percent forested, and percent imperviousness. In addition to remoteness, percent shading was also correlated with nearly all land use characteristics, with percent impervious and percent developed being negatively correlated, and percent forested and percent agriculture being positively correlated. It is also worth noting that bank stability is the only metric that showed a significant negative correlation ($p < 0.05$) with percent agriculture. In contrast, bank stability showed a highly significant positive correlation to percent impervious, which further supports the notion that bank stability scores can be easily skewed by artificial hardening and stabilization efforts while providing little biological benefit as demonstrated by the negative correlations with macroinvertebrate metrics (Table 12.).

The PHI as well as individual parameters were compared against geomorphic variables to determine which geomorphic measures are most strongly associated with physical habitat conditions (Table 15.). Because numerous geomorphic measures were significantly correlated with drainage area, as were numerous habitat parameters, this discussion will focus primarily on the dimensionless geomorphic variables, (i.e., entrenchment ration and width/depth ratio) sinuosity and D50, which were not correlated with drainage area, as well as metric scores that have been scaled to drainage area and were not also correlated with drainage area (i.e., instream habitat, epifaunal substrate, bank stability, remoteness). The overall PHI score was not significantly correlated with any geomorphic variables other than those correlated to drainage area. Instream habitat and epifaunal substrate metrics were both moderately positively correlated with sinuosity. Instream habitat was highly significantly correlated with D50, although epifaunal substrate was only moderately positively correlated with D50. Bank stability was strongly positively correlated ($p < 0.001$) with both flood-prone width and entrenchment ratio, while being moderately negatively correlated with D50.

Table 15. Correlation coefficients (Kendall τ) for physical habitat variables versus geomorphic variables.

Variable	**Entrenchment Ratio**	**Bankfull Width**	**Mean Depth**	**Width: Depth Ratio**	**Bankfull Area**	**Water Surface Slope**	**Bankfull Discharge**	**Sinuosity**	**Flood-Prone Width**	**D50**
RBP Habitat Variables										
Bank Stability	**0.23**	-0.04	**-0.14**	0.04	**-0.10**	-0.04	**-0.13**	-0.09	**0.23**	**-0.22**
Vegetative Protection	**0.15**	**-0.10**	-0.08	-0.06	**-0.11**	-0.03	-0.09	0.02	**0.13**	**-0.11**
Channel Flow	**0.30**	-0.07	**0.11**	**-0.24**	0.03	**-0.16**	-0.03	-0.05	***0.27***	***-0.25***
Channel Alteration	0.00	-0.04	-0.03	0.00	-0.04	**-0.12**	-0.10	0.02	0.01	-0.06
Channel Sinuosity	0.00	0.04	0.01	0.04	0.02	0.07	-0.03	**0.60**	0.04	**0.15**
Pool Substrate	0.07	***0.27***	***0.21***	0.05	***0.30***	-0.04	***0.22***	**0.11**	***0.25***	***0.19***
Pool Variability	0.01	***0.27***	***0.28***	-0.02	***0.35***	**-0.15**	***0.27***	0.02	**0.15**	0.09
Riparian Zone Width	0.00	0.08	0.03	0.06	0.07	-0.08	-0.02	**0.16**	0.10	-0.03
Sediment Deposition	**0.22**	**-0.13**	0.00	**-0.17**	-0.09	0.08	-0.07	0.01	**0.14**	**-0.14**
Epi. Substrate/Avail. Cover	0.05	***0.26***	***0.21***	0.02	***0.28***	-0.07	***0.25***	**0.15**	***0.21***	***0.18***
RBP Score	**0.24**	0.08	0.08	-0.05	**0.10**	**-0.11**	0.04	**0.10**	***0.32***	-0.08
PHI Habitat Variables										
Instream Habitat	0.01	***0.29***	***0.23***	0.02	***0.32***	**-0.14**	***0.24***	**0.17**	***0.20***	**0.20**
Epifaunal Substrate	0.03	***0.25***	**0.16**	0.04	***0.24***	-0.04	***0.23***	**0.13**	***0.18***	**0.17**
Bank Stability	**0.21**	-0.04	**-0.14**	0.04	**-0.10**	-0.06	**-0.17**	-0.05	**0.20**	**-0.14**
Percent Shading	**-0.13**	**-0.13**	**-0.14**	0.02	**-0.16**	0.03	-0.04	-0.05	***-0.18***	-0.05
Remoteness	-0.03	-0.09	-0.04	-0.06	-0.08	0.03	-0.08	0.09	-0.07	-0.06
# Woody Debris/Rootwads	0.04	**0.11**	**0.12**	-0.03	**0.14**	-0.07	**0.12**	**0.12**	0.09	0.08
Instream Habitat Score	-0.03	0.04	-0.02	0.01	0.03	0.02	0.07	**0.16**	0.01	**0.12**
Epifaunal Substrate Score	0.00	**0.11**	0.02	0.04	0.07	0.07	**0.14**	**0.12**	0.07	**0.14**
Bank Stability Score	**0.21**	-0.04	**-0.14**	0.04	**-0.10**	-0.06	**-0.17**	-0.05	**0.20**	**-0.14**

Shading Score	**-0.11**	**-0.13**	**-0.13**	0.01	**-0.15**	0.02	-0.04	-0.05	**-0.17**	-0.05
Remoteness Score	-0.03	-0.09	-0.04	-0.06	-0.08	0.03	-0.08	0.09	-0.07	-0.06
Woody Debris Score	0.01	**-0.15**	**-0.17**	0.00	***-0.18***	**0.13**	-0.09	0.06	**-0.11**	-0.02
PHI Score	0.00	-0.06	**-0.13**	0.01	**-0.10**	0.04	-0.04	0.09	-0.01	0.02
Drainage Area	0.07	**0.47**	**0.47**	0.00	**0.63**	**-0.34**	**0.36**	0.03	**0.36**	**0.13**

Values in bold are different from 0 with a significance level alpha=0.05
Highlighted values indicate significance at 0.001 level
Italicized values indicate both variables are strongly correlated with drainage area

4.2.2 Water Chemistry Variables

Water chemistry variables, both those measured *in situ* during the spring index period and those collected from grab sampling during the spring, were compared to land use and landcover characteristics to determine relationships between instream water quality and surrounding land use. Water quality sampling data from both the large stream strata and small stream strata were combined to increase the sample size (n=384) and better represent the conditions occurring in all the County's streams. It should also be noted that the method detection limit values were applied to all samples that were reported as non-detects, since non-numerical data cannot be used in correlational analyses.

Both *in situ* specific conductivity (spring) and chloride were highly significantly correlated to all land use and land cover variables (Table 16.). Both were strongly positively correlated with percent impervious cover and percent developed and moderately correlated with percent open land. Both were negatively correlated to percent forested and percent agriculture, although not as strongly as with impervious and developed land cover. The similarities between the response to land cover parameters is not surprising given that specific conductivity and chloride were strongly and highly significantly correlated ($\tau = 0.762$, $p < 0.001$). Magnesium, calcium, and hardness are also strongly correlated with *in situ* specific conductivity, and thus show similar patterns whereby they are positively correlated with impervious and developed land cover but negatively correlated with percent forested and often percent agriculture as well. Conductivity has previously shown a strong link with land use characteristics in Anne Arundel County (Hill and Pieper, 2011b; Hill et al., 2014). Conductivity is often observed in elevated levels in developed, or urbanized, watersheds and has been shown to be strongly correlated with urban land use (Rasmussen et al., 2009). Furthermore, the results are consistent with a study examining the relationship between stream chemistry and watershed land cover in the Mid-Atlantic region, where concentrations of chloride and base cations, which collectively influence conductivity, were strongly related to watershed land cover (Herlihy et al. 1998).

Correlations among nutrients were slightly more variable. Total phosphorus was strongly negatively correlated to percent impervious ($\tau = -0.315$, $p < 0.001$) and moderately correlated to percent developed and percent open, while being positively correlated with percent agriculture. While it was also negatively correlated with drainage area, this is likely due to intercorrelation with percent open, given the moderate correlation ($\tau = 0.246$, $p < 0.001$) between these two variables. A similar pattern was observed for orthophosphate, albeit with slightly weaker associations. On the other hand, total nitrogen was moderately positively correlated to percent impervious cover and percent developed ($p < 0.001$), which appears to be largely driven by ammonia nitrogen and total Kjeldahl nitrogen that are also positively correlated. Interestingly, nitrate was highly significantly correlated ($p < 0.001$) with percent developed but not significantly correlated to percent impervious, suggesting its presence is likely due to lawn-based fertilizer applications as opposed to impervious surface runoff. Nitrate was also moderately positively correlated to percent agriculture, suggesting its presence is likely due to fertilizer applications. Total nitrogen was strongly negatively correlated to percent forested land cover, and all nitrogen species with the exception of TKN were also negatively correlated with high significance. Organic carbon, both total (TOC) and dissolved (DOC), were moderately negatively correlated with percent agriculture ($p < 0.001$). Metals including copper and zinc were positively correlated with percent impervious, while copper and lead were negatively correlated with percent agriculture.

Water chemistry variables were also compared to biological index (i.e., BIBI, FIBI) and individual metric scores. Due to the unknown certainty of using the BIBI on the small stream strata, the results included herein are focused on the relationships observed in the large streams strata (n=192). The BIBI was not highly significantly correlated with any individual water quality parameters, but significant positive correlations were observed for *in situ* turbidity, total phosphorus, and nitrate (

Table 17.). Magnesium was the only parameter negatively correlated to BIBI. The BIBI was not negatively correlated to specific conductivity among the large streams; however, conductivity was found to be moderately negatively correlated among the small stream strata ($\tau = -0.147$, $p < 0.05$). Specific conductivity and chloride were moderately negatively correlated to several individual metrics including Percent Ephemeroptera, Number of Ephemeroptera and Percent Intolerant.

Except for total phosphorus, nutrients generally did not correlate well with benthic metrics. Total phosphorus was positively correlated ($p < 0.001$) with Percent Ephemeroptera and Number of Ephemeroptera as well as the BIBI ($p < 0.05$), which is possibly the result of nutrient enrichment. Among the metals, copper and zinc showed the most meaningful relationships with individual metrics. Copper was negatively correlated ($p < 0.001$) with Percent Ephemeroptera, Number of Ephemeroptera, and Percent Climbers, and zinc was also negatively correlated ($p < 0.05$) with Percent Ephemeroptera and Number of Ephemeroptera.

For comparisons to the FIBI and fish metrics, *in situ* water quality measurements from the summer index period were used. It should be noted that metric and index scores from dry sites were omitted from this analysis. Only two water quality parameters were positively correlated with the FIBI, although none were highly significantly correlated (Table 18.). Water temperature nitrate were both moderately positively correlated ($p < 0.05$. Water temperature is positively correlated with both calcium and hardness; therefore, the positive correlation between temperature and FIBI is possibly due to intercorrelation with these two water quality parameters. Adjusted number of benthic species was highly positively correlated with dissolved oxygen and nitrate but negatively correlated to TKN. Chloride was negatively correlated to Percent Abundance of Dominant Taxa ($p < 0.001$) and Percent Tolerant ($p < 0.001$). Compared to benthic macroinvertebrates, fish metrics and IBI scores showed fewer significant correlations with laboratory analyzed parameters. This may be a result of the grab samples being collected during the spring index period and not representative of the water quality conditions at the time of sampling. Furthermore, relationships between fish metric scores may have been weakened by the numerous sites (n=14) that had no observed fish present and received an automatic 1.00 FIBI score. For example, sites without fish may have been due to an impassable culvert or blockage downstream, unsuitable habitat conditions, or insufficient drainage area, rather than unacceptable water quality conditions.

Table 16. Correlation coefficients (Kendall τ) for water chemistry and land use variables.

Variable	Drainage Area	%Impervious	%Developed	%Forested	%Open	%Agriculture
Conductivity (In Situ)	-0.013	**0.396**	**0.364**	**-0.306**	**0.123**	**-0.206**
Dissolved Oxygen (In Situ)	**0.218**	**-0.134**	**-0.105**	0.003	0.035	**0.254**
pH (In Situ)	**0.179**	**0.179**	**0.146**	**-0.102**	**0.092**	-0.040
Turbidity (In Situ)	-0.020	**-0.133**	**-0.078**	**0.096**	0.041	-0.026
Temperature (In Situ)	-0.073	**-0.079**	-0.022	0.058	-0.037	-0.009
Chloride	0.020	**0.453**	**0.380**	**-0.288**	**0.135**	**-0.227**
Total Phosphorus	**-0.112**	**-0.315**	**-0.127**	0.061	**-0.163**	**0.272**
Total Nitrogen	0.012	**0.122**	**0.221**	**-0.310**	-0.041	**0.088**
Orthophosphate	-0.057	**-0.254**	**-0.073**	0.007	**-0.122**	**0.188**
Ammonia N	0.044	**0.138**	**0.144**	**-0.129**	0.003	0.024
Nitrite-N	**0.105**	**0.107**	**0.074**	**-0.134**	**0.086**	-0.014
Nitrate-N	0.057	0.062	**0.190**	**-0.322**	**-0.068**	**0.208**
TKN	0.024	**0.160**	**0.114**	-0.042	**0.070**	**-0.102**
TOC	0.026	0.012	-0.037	**0.114**	**0.119**	**-0.198**
DOC	0.026	0.037	-0.035	**0.118**	**0.119**	**-0.207**
Magnesium	-0.021	**0.414**	**0.359**	**-0.277**	0.033	**-0.168**
Calcium	-0.036	**0.257**	**0.281**	**-0.296**	0.031	-0.037
Hardness	-0.031	**0.305**	**0.292**	**-0.290**	0.060	**-0.086**
Copper	-0.001	**0.278**	**0.142**	-0.054	**0.174**	**-0.358**
Zinc	**-0.115**	**0.135**	0.064	-0.065	-0.055	-0.069
Lead	**-0.137**	0.011	-0.029	0.057	0.043	**-0.204**
Turbidity	-0.072	**-0.103**	-0.064	**0.068**	-0.055	**0.074**

Table 17. Correlation coefficients (Kendall τ) for water chemistry and benthic macroinvertebrate metrics and BIBI scores. *In situ* measurements are from spring index period.

Variable	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% Climbers	BIBI
Conductivity (*In Situ*)	0.006	-0.092	**-0.145**	**-0.161**	**-0.268**	**0.189**	0.038	-0.047
Dissolved Oxygen (*In Situ*)	0.053	**0.106**	**0.177**	**0.182**	**-0.109**	0.021	**0.134**	0.098
pH (*In Situ*)	0.019	0.011	0.087	0.093	**-0.160**	**0.209**	0.019	0.074
Turbidity (*In Situ*)	0.037	-0.037	0.018	0.026	0.020	**0.206**	0.019	**0.110**
Temperature (*In Situ*)	-0.006	-0.060	-0.039	-0.040	0.085	-0.017	0.008	-0.014
Chloride	0.081	-0.079	**-0.214**	**-0.232**	**-0.256**	**0.190**	0.075	-0.047
Total Phosphorus	-0.028	0.041	**0.215**	**0.229**	0.074	0.011	0.075	**0.101**
Total Nitrogen	0.067	-0.023	0.069	0.057	**-0.141**	**0.126**	0.058	0.053
Orthophosphate	-0.064	0.008	**0.192**	**0.187**	0.095	0.046	-0.031	0.086
Ammonia-N	0.028	**-0.115**	-0.103	-0.095	-0.045	0.012	0.011	-0.053
Nitrite-N	-0.061	**-0.112**	-0.026	-0.034	**-0.105**	0.106	-0.048	-0.037
Nitrate-N	**0.134**	0.055	**0.123**	**0.122**	**-0.156**	**0.134**	**0.173**	**0.131**
TKN	0.001	**-0.116**	**-0.135**	**-0.139**	-0.030	**0.117**	-0.060	-0.041
TOC	-0.067	-0.061	-0.003	-0.003	0.072	**0.144**	**-0.167**	0.013
DOC	-0.057	-0.062	-0.021	-0.019	0.072	**0.136**	**-0.165**	0.011

Variable	**No. Taxa**	**No. EPT Taxa**	**% Ephem**	**No. Ephem Taxa**	**% Intolerant**	**No. Scraper Taxa**	**% Climbers**	**BIBI**
Magnesium	0.023	**-0.192**	**-0.228**	**-0.252**	**-0.282**	0.103	0.080	**-0.133**
Calcium	-0.059	**-0.162**	**-0.151**	**-0.143**	**-0.311**	**0.163**	0.091	-0.100
Hardness	-0.019	**-0.175**	**-0.179**	**-0.187**	**-0.311**	**0.186**	0.073	-0.096
Copper	-0.002	-0.090	**-0.200**	**-0.214**	-0.069	**0.132**	**-0.180**	-0.075
Zinc	0.007	-0.071	**-0.141**	**-0.159**	0.028	-0.035	-0.019	-0.071
Lead	0.013	-0.052	-0.087	-0.091	0.048	**0.132**	**-0.171**	0.008
Turbidity	0.054	-0.061	0.018	0.041	-0.069	0.056	**0.107**	0.037

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

Highlighted values indicate significance at 0.001 level

Table 18. Correlation coefficients (Kendall τ) for water chemistry and fish metrics and FIBI scores. *In situ* measurements are from the summer index period.

Variable	**Abundance Per m^2**	**Adjusted No. Benthic Species**	**Percent Tolerant**	**Percent Generalist, Omnivores,**	**Percent Round-bodied Suckers**	**Percent Abundance Dominant Taxa**	**FIBI**
Conductivity (*In Situ*)	-0.011	-0.015	**-0.116**	-0.064	**0.123**	**-0.164**	0.095
Dissolved Oxygen (*In Situ*)	**-0.155**	**0.243**	0.027	-0.086	-0.013	-0.069	0.062
pH (*In Situ*)	**-0.103**	0.046	-0.069	-0.010	0.105	**-0.106**	0.067
Turbidity (*In Situ*)	-0.004	**-0.138**	**0.114**	0.083	0.022	0.069	-0.082
Temperature (*In Situ*)	0.095	-0.043	-0.070	-0.023	**0.125**	-0.033	**0.106**
Chloride	-0.054	-0.013	**-0.148**	-0.063	0.052	**-0.190**	0.086
Total Phosphorus	**-0.106**	-0.017	-0.035	-0.064	0.034	-0.033	-0.095
Total Nitrogen	0.007	0.072	0.008	-0.088	0.068	-0.064	0.076
Orthophosphate	-0.072	-0.033	0.019	**-0.115**	0.095	-0.044	-0.061
Ammonia-N	**-0.128**	**-0.109**	-0.099	0.011	-0.003	-0.064	-0.043
Nitrite-N	**-0.121**	-0.020	-0.071	**-0.115**	0.110	**-0.121**	0.023
Nitrate-N	0.063	**0.221**	**0.110**	-0.035	0.051	0.027	**0.125**
TKN	**-0.119**	**-0.202**	**-0.130**	0.010	0.011	**-0.125**	-0.064
TOC	0.078	**-0.112**	0.030	0.068	0.061	0.018	0.021
DOC	0.077	**-0.114**	0.024	0.067	0.055	0.020	0.018
Magnesium	-0.032	0.021	**-0.197**	-0.070	0.027	**-0.193**	0.084
Calcium	**-0.140**	-0.033	**-0.123**	-0.021	0.033	-0.109	-0.032
Hardness	**-0.126**	0.000	**-0.137**	-0.025	0.031	**-0.128**	0.004
Copper	0.098	**-0.131**	-0.011	0.073	0.004	-0.039	0.028
Zinc	-0.084	0.011	-0.015	-0.025	-0.070	0.015	-0.009
Lead	0.045	**-0.118**	0.075	0.082	-0.016	0.031	-0.027
Turbidity	-0.062	-0.045	0.014	**0.109**	-0.023	0.034	-0.063

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

Highlighted values indicate significance at 0.001 level

4.2.3 Geomorphic Variables

Geomorphic data were compared to biological data (BIBI and FIBI) from the large stream strata due to concerns about the BIBI's applicability to small streams. Consistent with the Round Two report (Hill et al., 2014), geomorphic data yielded some significant correlations with the overall BIBI score as well as several individual macroinvertebrate metrics (Table 19.). Five variables (mean depth, bankfull area, bankfull width, flood-prone width, and estimated bankfull discharge) were highly significantly correlated with the overall BIBI score. Substrate D50 was also positively correlated ($p < 0.05$), while water surface slope was negatively correlated ($p < 0.05$). Four metrics, Number of EPT Taxa, Percent Ephemeroptera, Ephemeroptera Taxa, and Scraper Taxa, were either correlated ($p < 0.05$) or highly significantly correlated ($p < 0.001$) with at least five different geomorphic variables. However, it should be noted that these four macroinvertebrate metrics, as well as the BIBI score, are also highly significantly correlated with drainage area, and nearly all geomorphic variables are also very strongly correlated ($p < 0.001$) with drainage area (Table 21.), with the exception of entrenchment ratio, width/depth ratio, and sinuosity. This suggests the results are likely due to intercorrelation between drainage area and geomorphic variables given that they are not independent variables (i.e., mean depth, bankfull area, and bankfull discharge variables are dependent on catchment drainage area). Nonetheless, geomorphic variables such as width, depth, and estimated discharge are likely potential drivers of the drainage area effect observed with benthic macroinvertebrate metrics and the BIBI score. For instance, McCandless (2003) found that bankfull discharge, width, mean depth, and cross-sectional area are all significantly related to drainage area in coastal plain streams.

Table 19. Correlation coefficients (Kendall τ) for geomorphic, and land use variables versus benthic macroinvertebrate metric and index scores from large stream strata.

Variable	**No. Taxa**	**No. EPT Taxa**	**% Ephem**	**No. Ephem Taxa**	**% Intolerant**	**No. Scraper Taxa**	**% Climbers**	**BIBI**
Geomorphic Variables								
Entrenchment Ratio	0.085	0.028	0.007	-0.001	**0.132**	0.072	-0.037	0.089
Bankfull Width	**0.122**	**0.273**	**0.233**	**0.236**	-0.052	**0.263**	**0.180**	**0.268**
Mean Depth	**0.185**	**0.216**	**0.246**	**0.252**	0.067	**0.213**	**0.141**	**0.312**
Width: Depth Ratio	-0.045	0.080	0.033	0.027	**-0.123**	0.048	0.055	-0.014
Bankfull Area	**0.187**	**0.279**	**0.287**	**0.293**	-0.003	**0.298**	**0.195**	**0.343**
Water Surface Slope	-0.086	-0.061	**-0.160**	**-0.174**	-0.065	-0.073	0.001	**-0.123**
Bankfull Discharge	**0.175**	**0.307**	**0.209**	**0.219**	-0.025	**0.203**	**0.206**	**0.280**
Sinuosity	-0.043	0.044	0.082	0.059	0.024	-0.020	-0.012	0.002
Flood-Prone Width	**0.136**	**0.166**	**0.114**	0.106	**0.105**	**0.203**	0.025	**0.211**
D50	**0.117**	**0.170**	0.095	0.096	**-0.101**	**0.124**	0.060	**0.119**
Land Use/ Drainage Area Variables								
Drainage Area	**0.191**	**0.295**	**0.296**	**0.298**	0.051	**0.243**	0.087	**0.306**
%Impervious	0.028	**-0.185**	**-0.302**	**-0.318**	**-0.299**	**0.164**	-0.031	**-0.161**
%Developed	-0.028	**-0.206**	**-0.250**	**-0.259**	**-0.316**	**0.155**	-0.029	**-0.156**
%Forested	0.055	**0.196**	**0.146**	**0.149**	**0.343**	**-0.107**	-0.027	**0.128**
%Open	-0.019	0.042	-0.087	-0.101	-0.048	0.105	-0.063	-0.018
%Agriculture	0.098	0.101	**0.279**	**0.298**	0.082	-0.066	**0.211**	**0.177**

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

FIBI and fish metrics saw similar patterns when compared to geomorphic data (Table 20.). Mean depth, bankfull area, bankfull width, flood-prone width, estimated bankfull discharge and D50 were all highly significantly correlated with the overall FIBI score. Width/depth ratio and sinuosity were also positively correlated ($p < 0.05$), while water surface slope was negatively correlated ($p < 0.05$). Four individual metrics, Adjusted No. Benthic Species, Percent Tolerant, Percent Round-bodied Suckers, and Percent Abundance Dominant Taxa, were either correlated ($p < 0.05$) or highly significantly correlated ($p < 0.001$) with at least five different geomorphic variables. As with the benthic metrics, three of the four fish metrics and the FIBI score are also highly significantly correlated with drainage area, and nearly all geomorphic variables are also very strongly correlated ($p < 0.001$) with drainage area (Table 20), except for entrenchment ratio, width/depth ratio and sinuosity. This suggests the results are likely due to intercorrelation between drainage area and geomorphic variables as noted above. Geomorphic variables such as bankfull width, bankfull depth, and estimated discharge are strongly correlated with FIBI scores and are likely the primary drivers of the drainage area effect observed with numerous fish metrics and the overall FIBI score.

Table 20. Correlation coefficients (Kendall τ) for geomorphic, and land use variables versus fish metric and index scores.

Variable	**Abundance Per m^2**	**Adjusted No. Benthic Species**	**Percent Tolerant**	**Percent Generalist, Omnivores,**	**Percent Round-bodied Suckers**	**Percent Abundance Dominant Taxa**	**FIBI**
Geomorphic Variables							
Entrenchment Ratio	0.096	**-0.187**	-0.071	0.070	0.003	-0.020	-0.038
Bankfull Width	0.053	**0.308**	**-0.129**	**-0.170**	**0.307**	**-0.229**	**0.421**
Mean Depth	0.021	**0.120**	**-0.185**	-0.082	**0.241**	**-0.219**	**0.299**
Width: Depth Ratio	0.028	**0.160**	0.061	-0.078	0.049	-0.004	**0.108**
Bankfull Area	0.048	**0.237**	**-0.190**	**-0.138**	**0.329**	**-0.273**	**0.434**
Water Surface Slope	0.075	-0.088	**0.138**	**0.125**	**-0.117**	**0.166**	**-0.123**
Bankfull Discharge	0.042	**0.268**	-0.049	-0.120	**0.250**	**-0.136**	**0.327**
Sinuosity	**0.111**	0.086	0.035	-0.053	0.012	0.051	**0.123**
Flood-Prone Width	**0.133**	-0.047	**-0.172**	0.005	**0.178**	**-0.151**	**0.190**
D50	**0.100**	**0.268**	0.062	-0.041	**0.128**	-0.030	**0.258**
Land Use/ Drainage Area Variables							
Drainage Area	0.015	**0.171**	**-0.246**	**-0.149**	**0.318**	**-0.317**	**0.407**
%Impervious	0.012	-0.032	**-0.141**	0.013	-0.042	**-0.108**	0.094
%Developed	0.001	-0.040	**-0.151**	-0.038	-0.048	**-0.113**	0.045
%Forested	-0.005	-0.038	0.048	0.052	0.013	0.029	-0.098
%Open	-0.042	-0.095	-0.070	-0.087	-0.026	-0.097	**0.103**
%Agriculture	-0.023	**0.158**	0.075	-0.028	0.031	0.062	0.025

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

4.2.4 Land Use Variables

In Round Three, land use variables (i.e., percent developed, agriculture, forested, open) correlated well with benthic macroinvertebrate data from the large stream strata. Drainage area was positively correlated ($p < 0.001$) with all but two metrics (Percent Climbers and Percent Intolerant) including the

BIBI (Table 19.), which is consistent with findings from prior rounds (Hill and Pieper, 2011b; Hill et al., 2014). Percent impervious was strongly negatively correlated with Percent Ephemeroptera, Ephemeroptera Taxa, and Percent Intolerant metrics and moderately negatively correlated with EPT Taxa as well as the BIBI score. Percent developed yielded similar correlations with the aforementioned metrics and BIBI score. The similarity in associations is not surprising given the strong positive correlation between percent impervious and percent developed ($\tau = 0.59$). In contrast, percent forested was strongly positively correlated with the Percent Intolerant metric, and moderately positively correlated with EPT Taxa, Percent Ephemeroptera, Ephemeroptera Taxa and the BIBI score. Percent agriculture was highly significantly correlated (positively) with three metrics (i.e., Percent Ephemeroptera, Ephemeroptera Taxa, and Percent Climbers) and moderately positively correlated with the BIBI score. These findings are consistent with the previous studies concluding that streams draining developed, or urban, watersheds tend to be more degraded than those draining agricultural or forested watersheds (Crawford and Lenat 1989, Wang et al. 2000). Interestingly, Number of Scraper Taxa was negatively correlated with percent forested and positively correlated with percent developed and percent impervious, which is contrary to the expected response to increasing perturbation in Southerland et al. (2005). However, the four most prevalent scraper taxa found in the County (i.e., *Hydrobaenus, Stenelmis, Physa, Ancyronyx*) have tolerance values of 7 or greater and are considered tolerant taxa. Of the 25 scraper taxa found in the County during Round Three, 44% are considered tolerant, while only 16% are considered intolerant.

With the exception of drainage area, land use variables were generally weak predictors of fish conditions due to sparse significant correlations with the FIBI and individual fish metrics. Only percent open land cover was significantly correlated ($p < 0.05$) to FIBI scores, although the association was relatively weak ($\tau = 0.103$). Unlike the BIBI, the FIBI did not show negative correlations with percent impervious or percent developed land cover, nor positive correlations to percent forested or percent agriculture. Furthermore, Percent Tolerant and Percent Abundance Dominant Taxa metrics were negatively correlated ($p < 0.05$) to both percent impervious and percent developed, which was unexpected given that both metrics are expected to increase with increasing anthropogenic disturbance.

Significant correlations between land use variables and geomorphic variables were rather limited. Drainage area was the only variable highly significantly correlated to geomorphic variables. Strong positive correlations were identified with bankfull area, mean depth, bankfull width, bankfull discharge, and flood-prone width, while water surface slope was negatively correlated (Table 21.). Percent impervious was moderately positively correlated ($p < 0.05$) with flood-prone width and D50, and percent developed was weakly positively correlated ($p < 0.05$) with entrenchment ratio. This was somewhat unexpected given that entrenchment ratio is lower for more incised streams and higher for those with better floodplain connectivity, which are not typically associated with developed or urban streams. However, since the 1930's, when much of the agricultural land was converted to urban, suburban, commercial, or industrial development, streams in the older urban and suburban areas of the County have likely had sufficient time to rework legacy floodplain sediments between hard points like road culverts into more stable forms (Stribling et al., 2008). Percent agriculture was negatively correlated ($p < 0.05$) with sinuosity, flood-prone width, and D50. These results suggest persistent effects of legacy landuse such as channel straightening may still be present in portions of the County with heavy agricultural land use. Furthermore, agricultural dominated areas may be more prone to sedimentation, as indicated by the D50, when compared to areas with higher imperviousness.

Table 21. Correlation coefficients (Kendall τ) for geomorphic variables versus land use variables.

Variable	**Drainage area**	**%Impervious**	**%Developed**	**%Forested**	**%Open**	**%Agriculture**
Entrenchment Ratio	0.071	0.068	**0.058**	0.008	0.042	-0.064
Bankfull Width	**0.469**	0.086	0.009	0.008	**0.125**	-0.061
Mean Depth	**0.471**	0.042	0.005	0.001	**0.110**	0.029
Width: Depth Ratio	-0.001	0.031	0.017	-0.013	0.001	-0.060
Bankfull Area	**0.632**	0.078	0.001	-0.002	**0.138**	-0.017
Water Surface Slope	**-0.339**	0.004	-0.024	-0.051	0.016	0.010
Bankfull Discharge	**0.356**	0.030	-0.033	-0.023	0.103	0.069
Sinuosity	0.030	0.052	-0.025	0.024	**0.124**	**-0.106**
Flood-Prone Width	**0.355**	**0.119**	0.053	0.042	**0.126**	**-0.111**
D50	**0.132**	**0.103**	0.012	-0.046	**0.109**	**-0.124**

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

4.2.5 Biological Index Associations

In Round Three, several patterns between the biological data and other environmental variables that were observed in prior Rounds were further validated, while additional relationships were revealed due to the addition of fish sampling data and water quality grab sampling. Consistent with Round 2, land use variables appear to be good predictors of benthic macroinvertebrate conditions with moderate to strong associations with the BIBI and individual macroinvertebrate metrics. Percent forested and agriculture were positively correlated with BIBI scores and percent developed and percent impervious were negatively correlated, which were the expected responses, suggesting that these broad land use categories are generally useful predictors of overall biological conditions. Several individual macroinvertebrate metrics showed strong correlations with land use variables, which remain consistent with prior findings (Hill and Pieper, 2011b; Hill et al., 2014). Number of EPT Taxa and Percent Intolerant Urban metrics, specifically, continue to perform well. The Number of EPT Taxa metric (the number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (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 respond well to land use characteristics such as percent developed, which is associated with urban stressors and increased perturbation.

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

While benthic macroinvertebrate data showed good correlations with land use variables, they were rather weak predictors of fish FIBI and individual fish metrics. Aside from drainage area, only one land use characteristic, percent open land cover, was significantly correlated to the FIBI score. Individual fish metrics did not correlate well and provided little insight regarding surrounding land use impacts.

Consistent with Round Two, geomorphic data correlated well with the overall BIBI score as well as several individual macroinvertebrate metrics again in Round 3. Five variables were highly significantly correlated with the overall BIBI score and two more were negatively correlated at the 0.05 level. Similar results were observed for the overall FIBI score, where six variables were highly significantly correlated with the overall FIBI score and three more were negatively correlated at the 0.05 level. Bankfull area showed the strongest correlations with both BIBI and FIBI scores, while bankfull width, mean depth and bankfull discharge were strongly to moderately correlated with both indices. However, it should be noted that nearly all geomorphic variables are also strongly correlated with drainage area, which suggests these results are possibly due to intercorrelation between drainage area and geomorphic variables. What is not yet clear, however, is the influence drainage area has on the biological conditions and whether or not the instream geomorphic differences (e.g., depth, width, area) are driving the ‘drainage area effect’ or if it is simply unaccounted for in the IBI and metric scoring process.

Neither the BIBI nor FIBI was strongly correlated with any of the water chemistry variables. However, specific conductivity and chloride were moderately negatively correlated to several individual metrics including Percent Ephemeroptera, Number of Ephemeroptera and Percent Intolerant. The negative relationship between these benthic metrics and conductivity have been documented previously in Anne Arundel County (Hill and Pieper, 2011b; Hill et al., 2014). Given the close relationship between conductivity and chloride, it is probable that chloride concentrations are driving the *in-situ* conductivity values that have been negatively associated with benthic metrics. Magnesium and calcium are strongly positively correlated with conductivity; and therefore, they are likely contributors to instream conductivity throughout the County. Both magnesium and calcium are also strongly positively correlated with chloride, suggesting their presence, especially in urban areas, may be due to de-icing compounds (i.e., magnesium chloride, calcium chloride). Thus, it’s not surprising that both are negatively correlated with Percent Ephemeroptera, Number of Ephemeroptera and Percent Intolerant metrics.

Several physical habitat parameters were highly significantly correlated to both BIBI and FIBI. The individual RBP habitat variables that were most strongly correlated with both BIBI and FIBI scores included pool substrate, pool variability, and epifaunal substrate/available cover. Total RBP habitat score, which was highly significantly correlated with the BIBI score in the Round One report (Hill and Pieper, 2011b), was only correlated at the 0.05 level in Rounds Two and Three. However, the RBP score was highly significantly correlated with the FIBI score. Only two PHI habitat parameters, instream habitat and epifaunal substrate, were highly significantly correlated to the BIBI score, and the overall PHI was not significantly correlated in Round Three. FIBI scores were strongly positively correlated to instream habitat and epifaunal substrate and rootwads and woody debris, and moderately negatively correlated to percent shading, but the overall PHI was not significantly correlated. 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, as well as FIBI scores, in Anne Arundel County.

The highly significant correlation between drainage area and biological indicators was again observed in Round Three, with even stronger associations observed for the FIBI and several other fish metrics. The BIBI score and five other metrics were positively correlated with drainage area. Additionally, the FIBI score and five fish metrics were also significantly correlated with drainage area. These results support the notion that drainage area, or perhaps stream order, is exerting some influence on biological community composition, and ultimately metric and BIBI scoring. Since drainage area was also significantly correlated with numerous habitat metrics including the overall RBP score and a number of geomorphic variables, it is likely that physical habitat is more diverse, and heterogeneous in larger stream systems, which provides an increased potential for full colonization by benthic macroinvertebrates and fish communities. What is unclear is whether this influence of drainage area on the BIBI and FIBI is more widespread across Maryland, or more confined to the western coastal plain given the deficiency of larger stream networks due to the predominance of first order streams that drain directly to the flooded river valleys of the Chesapeake Bay (i.e., Magothy River, Severn River, South River, Rhode River, West River).

4.3 Benthic Macroinvertebrate Taxa Analysis

A review of benthic macroinvertebrate taxa found at all sites receiving a biological condition rating of 'Good' (BIBI score ≥ 4.00) was conducted to evaluate if there are taxa unique to high quality streams in the County. Sixteen taxa were found during Round Three that were truly unique to unimpaired sites and were not found at any site that had been classified as either 'Poor' or 'Very Poor' (Table 22.). Only seven unique taxa were found from the same analysis of Round Two data. All but two taxa, *Maccaffertium* and *Perlesta*, were present at only a single 'Good' site, and three of those taxa (i.e., Corixidae, Muscidae, *Wormaldia*) had only a single specimen present, which suggests that these three taxa may simply be very rare with regards to occurrence and abundance. Seven other taxa (i.e., *Conchapelopia*, *Ephemerella*, Hydroptilidae, Perlodidae, *Phylocentropus*, *Strophopteryx*, *Trissopelopia*) had two individuals present in the sample, suggesting these taxa may also be very rare taxa with a limited distribution. Only two macroinvertebrate taxa, *Tallaperla* and *Sweltsa*, both intolerant stoneflies, have been designated as cold water obligates by Maryland DNR (Kashiwagi & Prochaska, 2011). Cold water obligates are defined as genera with a 99th percentile of specimens occurring at or below a temperature threshold of 22° Celcius and are potential surrogate indicators for brook trout water temperatures (Kashiwagi & Prochaska, 2011). Even though *Swelta* was found at one site in Round Two, no observations of *Sweltsa* were recorded from Round Three sites.

Table 22. Taxa Unique to Unimpaired Sites.

Order	Family	Genus	Tolerance Value	No. of Organisms Found	No. of 'Good' Sites with Taxa Present
Diptera	Chironomidae	*Clinotanypus*	6.6	4	1
Diptera	Chironomidae	*Conchapelopia*	6.1	2	1
Hemiptera	Corixidae	*Corixidae*	5.6	1	1
Ephemeroptera	Ephemerellidae	*Ephemerella*	2.3	2	1
Ephemeroptera	Ephemerellidae	*Eurylophella*	4.5	3	1
Coleoptera	Dryopidae	*Helichus*	6.4	6	1
Amphipoda	Hyalellidae	*Hyalella*	4.2	7	1
Tricoptera	Hydroptilidae	*Hydroptilidae*	4.0	2	1
Ephemeroptera	Heptageniidae	*Maccaffertium*	3.0	100	7
Diptera	Muscidae	*Muscidae*	7.0	1	1
Plecoptera	Perlidae	*Perlesta*	1.6	6	2
Plecoptera	Perlodidae	*Perlodidae*	2.2	2	1
Tricoptera	Dipseudopsidae	*Phylocentropus*	5.0	2	1
Plecoptera	Taenioperygidae	*Strophoptertx*	3.3	2	1
Diptera	Chironomidae	*Trissopelopia*	4.1	2	1
Tricoptera	Philopotamidae	*Wormaldia*	1.8	1	1

An additional seven taxa were primarily unique to unimpaired sites but were found to occur at only one 'Poor' site (Table 23.). It should be noted that generally these taxa were found at sites with BIBI scores at or greater than 2.14. One taxon (Psychodidae) was observed at a site with a BIBI score of 1.57. While these taxa can be generally associated with unimpaired biological conditions, they are not unique to 'Good' sites as their presence has been observed, albeit rarely, in streams designated as having 'Poor' biological conditions.

Table 23. Taxa Primarily Occurring at Unimpaired Sites but Present at a Single Impaired Site.

Order	Family	Genus	Tolerance Value	No. of Organisms Found	No. of 'Good' Sites with Taxa Present
Ephemeroptera	Baetidae	Baetidae	2.3	33	1
Plecoptera	Chloroperlidae	Chloroperlidae	1.6	38	1
Ephemeroptera	Baetidae	*Cladotanytarsus*	6.6	3	1
Plecoptera	Perlodidae	*Isoperla*	2.4	35	5
Plecoptera	Perlidae	Perlidae	2.2	3	1
Diptera	Psychodidae	Psychodidae	4.0	4	1
Diptera	Chironomidae	*Stictochironomus*	9.2	9	2

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

4.4 Small Stream Strata Analysis

A comparison of BIBI data collected from the small stream strata (i.e., streams existing only on the County's 1:2,400 scale stream coverage) with the large stream strata used in Rounds One and Two (i.e., streams present on the County's 1:100,000 scale stream coverage) was performed to assess whether any notable differences exist between metric values and scoring. Benthic metrics and BIBI scores compared at the countywide level showed numerous differences between large streams (n=192) and small streams (n=192). Considerable differences can be observed for Percent Ephemeroptera, Ephemeroptera Taxa, and Scraper Taxa metrics, and to a smaller extent Total Taxa, with large streams having higher values as a whole compared to small streams (Figure 51). No notable differences were observed with Percent Intolerant to Urban and Percent Climber metrics. The difference between strata becomes even more stark when comparing metric scores, where large streams consistently score higher than small streams for a number of metrics (Figure 52). The most notable differences are observed for Percent Ephemeroptera and Ephemeroptera Taxa metrics, where small streams rarely score above a '1'. Given that numerous metrics are generally scored lower for small streams, compared to their large stream counterparts, the overall BIBI scores are also observed scoring lower for small streams (Figure 53).

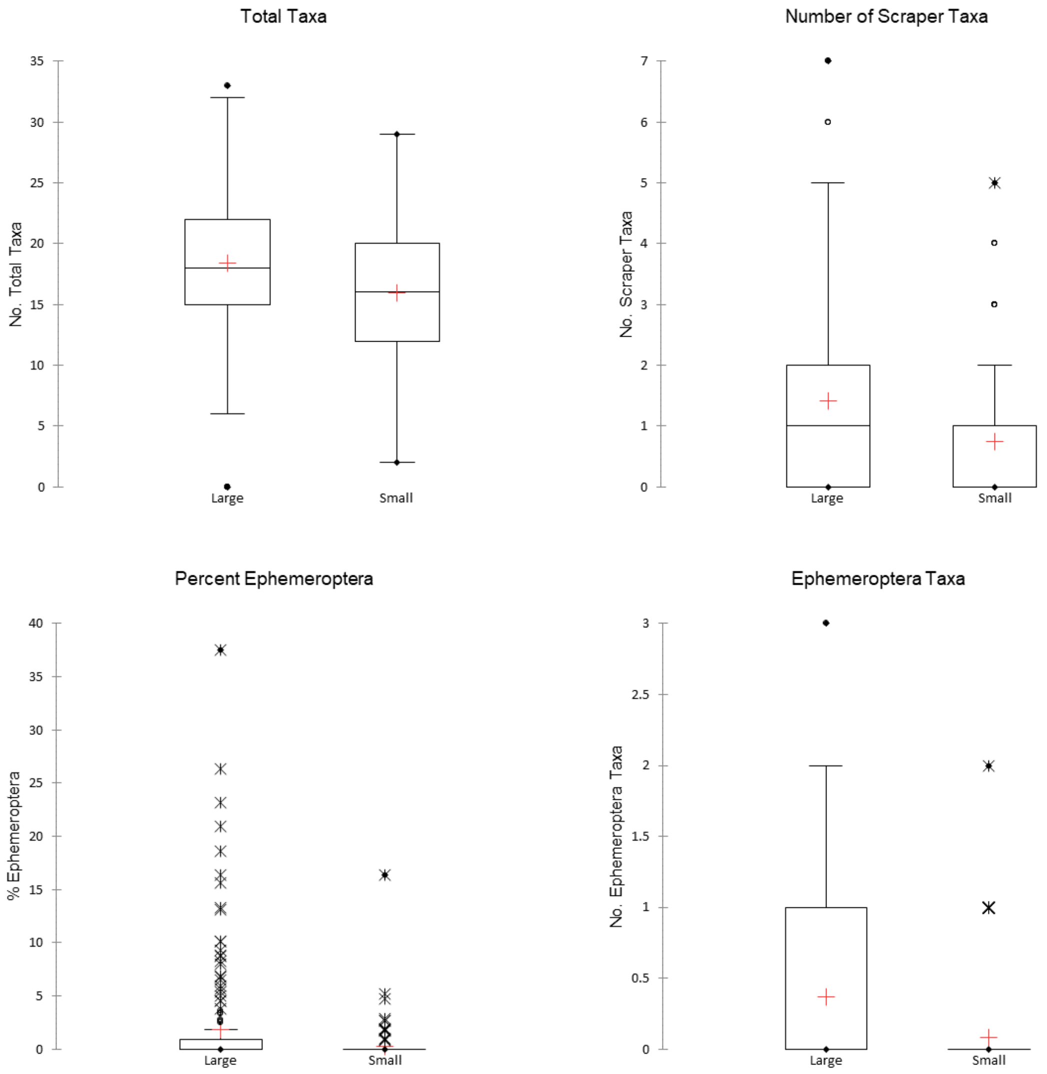


Figure 51. Comparison of benthic macroinvertebrate metric values between large streams and small streams.

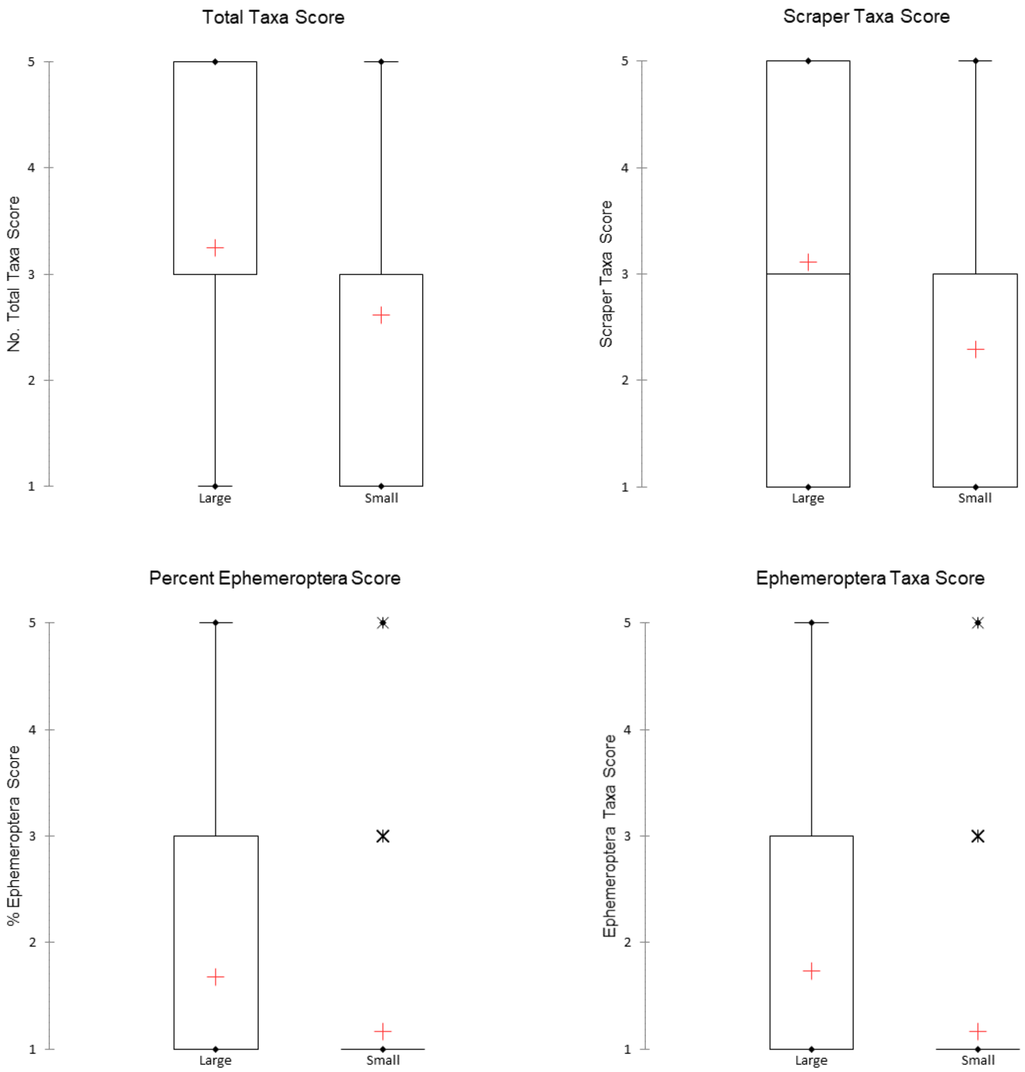


Figure 52. Comparison of benthic macroinvertebrate metric scores between large streams and small streams.

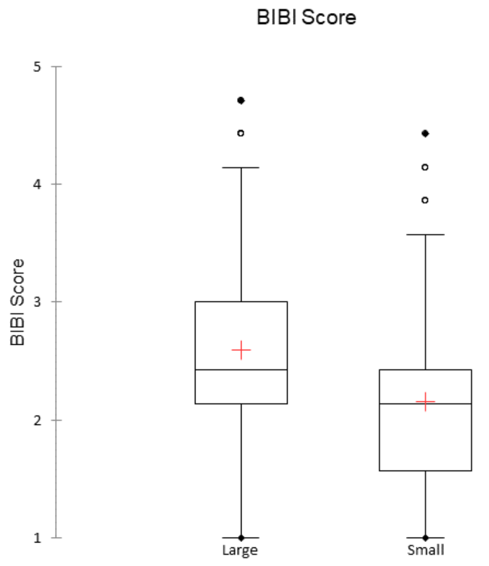


Figure 53. Comparison of BIBI scores between large streams and small streams.

Differences in metric scores between strata were tested for statistical significance using the non-parametric Mann-Whitney Two-tailed test, since metric and BIBI data were not normally distributed for both groups. All four metrics discussed above, in addition to the BIBI score, are significantly different between groups (Table 24). These results suggest that several metrics are influenced by stream size including the BIBI.

Table 24. Mann-Whitney Two-tailed test results for large vs. small stream benthic macroinvertebrate data.

Metric	U	U (standardized)	Expected value	Variance (U)	p-value (Two-tailed)	alpha
Total Taxa	23014	4.219	18432	1179426	<0.0001	0.050
Scraper Taxa	23565	4.991	18432	1057484	<0.0001	0.050
Ephemeroptera Taxa	22446	5.469	18432	538495	<0.0001	0.050
% Ephemeroptera	22460	5.470	18432	542218	<0.0001	0.050
BIBI Score	24565	5.681	18432	1165207	<0.0001	0.050

Comparisons at the PSU level were also investigated to determine the effects of combining small stream data with large stream data to determine mean BIBI scores. For three-quarters of PSUs, incorporating the small stream data resulted in decreased mean BIBI scores (Table 25.). Only six (6) PSUs saw an increase in mean BIBI scores from the inclusion of small stream data. Differences in mean PSU BIBI scores between large and small ranged from -0.89 to 1.18, with at least four (4) PSUs having a difference greater than 1.00. Overall, nine individual PSUs would exhibit a difference in biological classification (i.e., Good, Fair, Poor, Very Poor) if data were combined as compared to using the large stream data only. However, it should be noted that one PSU, Piney Run (01), would improve from 'Poor' to 'Fair' with the inclusion of small stream data. Side-by-side comparisons of mean PSU scores using small stream, large stream, and combined data are displayed in Figure 54.

Table 25. Comparison of PSU mean BIBI scores between small and large streams.

PSU	Combined Mean	Large Mean	Small Mean	Delta (Large-Small)	Difference between Combined and Large Classifications
01	3.05	2.61	3.50	-0.89	Yes
02	2.50	3.07	1.93	1.14	Yes
03	2.20	2.14	2.25	-0.11	No
04	2.34	2.93	1.75	1.18	No
05	2.25	2.32	2.18	0.14	No
06	2.38	2.54	2.21	0.32	No
07	1.97	2.14	1.79	0.36	Yes
08	1.89	2.14	1.64	0.50	Yes
09	2.79	2.82	2.75	0.07	No
10	2.23	2.57	1.89	0.68	No
11	2.70	2.68	2.72	-0.04	No
12	2.14	2.39	1.89	0.50	No
13	2.18	2.36	2.00	0.36	No
14	2.00	2.36	1.64	0.71	No
15	2.46	3.00	1.93	1.07	Yes
16	2.14	2.07	2.21	-0.14	No
17	2.18	2.00	2.36	-0.36	No
18	2.70	2.68	2.71	-0.04	No
19	2.75	3.11	2.39	0.71	Yes
20	2.45	2.89	2.00	0.89	No
21	2.70	3.29	2.11	1.18	Yes
22	2.71	3.14	2.29	0.86	Yes
23	2.34	2.82	1.86	0.96	No
24	1.98	2.18	1.79	0.39	Yes

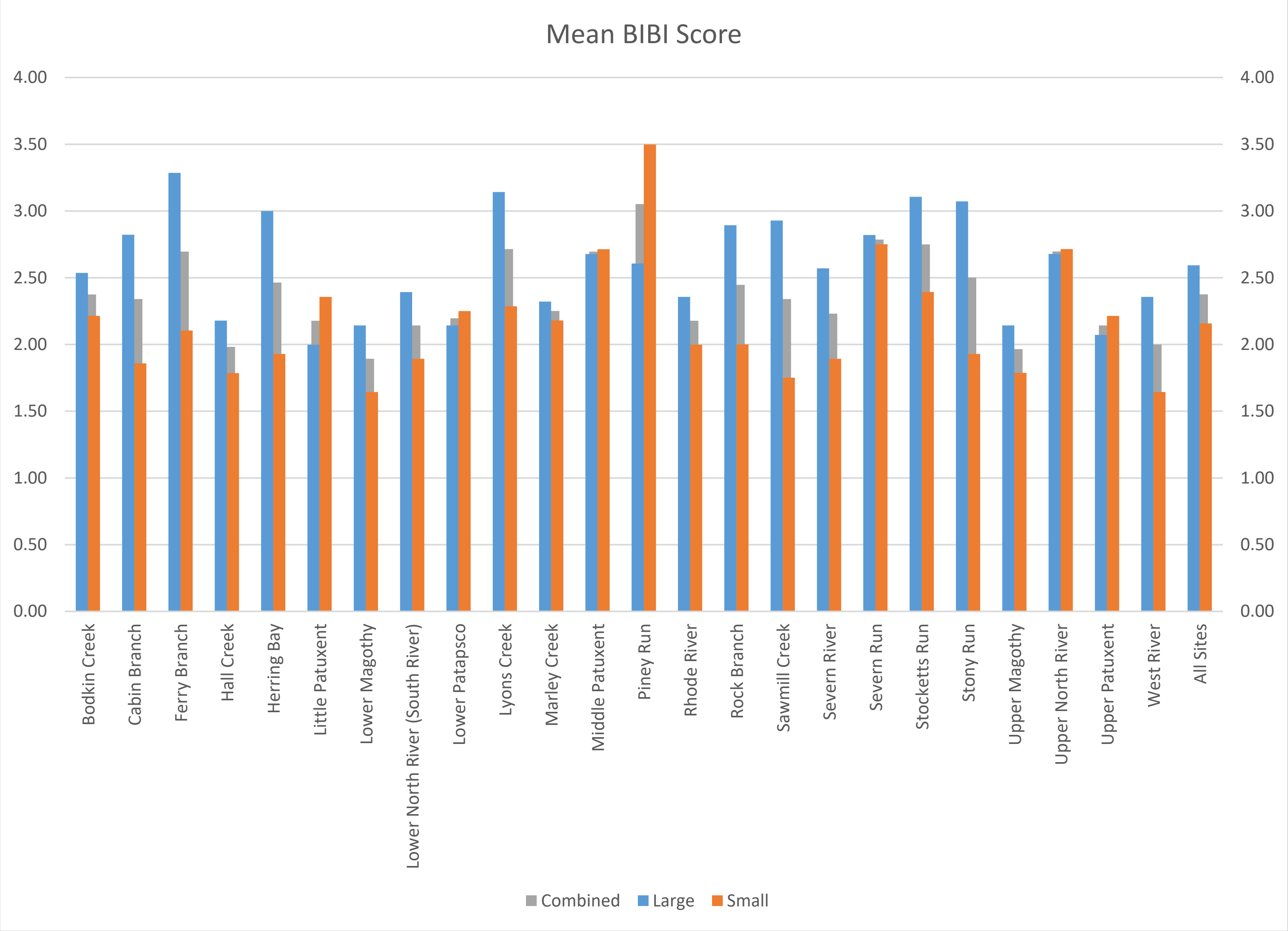


Figure 54. Comparison of mean BIBI scores using small, large, and combined sites

5 Comparison of Round One, Round Two and Round Three Results

5.1 Biological and Physical Habitat Comparison

This section presents a brief comparison of the biological and physical habitat assessment results between Round One and Round Three and also between Round Two and Round Three. Using procedures described in Roth et al. (2005), statistical comparisons of BIBI and RBP index scores between Rounds One and Two are shown in Table 26 and between Rounds Two and Three in Table 27. It should be noted that the overall number of samples collected in Round Three at 8 samples per PSU (n=192) differs from the number of samples collected during Round One (n=240) and Round Two (n=240) in which 10 samples were collected per PSU.

Table 26. Comparison of Biological and Physical Habitat Index Scores Between Round One and Round Three.

	Round Three		Round One		Upper	Lower	Significant Difference? (Direction)
Index	Mean	SE	Mean	SE	95% CI	95%CI	
BIBI	2.59	0.06	2.61	0.05	0.17	-0.13	No
RBP	117.3	1.35	115.87	1.35	2.35	-5.13	No
PHI	69.22	0.79	67.47	0.77	0.42	-3.91	No

Table 27. Comparison of Biological and Physical Habitat Index Scores Between Round One and Round Three.

	Round Three		Round Two		Upper	Lower	Significant Difference? (Direction)
Index	Mean	SE	Mean	SE	95% CI	95%CI	
BIBI	2.59	0.06	2.67	0.05	0.07	-0.23	No
RBP	117.3	1.35	120.31	1.55	0.98	-7.08	No
PHI	69.22	0.79	69.46	0.74	1.88	-2.37	No

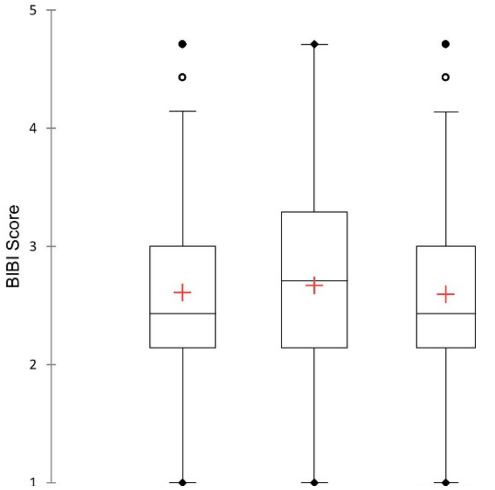


Figure 55. Comparison of Round 1, Round 2 and Round 3 BIBI Scores.

Mean BIBI scores for the County did not change significantly between sampling rounds. Although the median and third quartile values improved slightly in Round Two, the first quartile and mean BIBI score remained virtually unchanged (Figure 55). Round 3 scores resulted in nearly identical summary statistics compared to Round 1, despite 48 fewer samples collected. A statistically significant difference in the average RBP habitat scores for the County was observed between Round One and Round Two, but not between Round Two and Round Three. While the first quartile remained relatively unchanged, the mean, median, and third quartiles were all slightly higher in Round Two, even though minimum scores were considerably lower in

Round Two (Figure 57). Average PHI scores for the County did not significantly change between sampling rounds even though mean, median, and the first and third quartile values were all slightly higher in Rounds Two and Three (Figure 56). Given that neither the PHI nor the BIBI changed, it is likely that the small, but significant, change noted in RBP scores between Round One and Round Two does not reflect an improvement in the physical habitat conditions within the County's streams and riparian zones during this time span but rather is an artifact of the qualitative nature of a visually-based assessment methodology. In other words, the observed difference is more likely attributed to sampler bias that is inherent in any rapid, visually-based habitat assessment procedure.

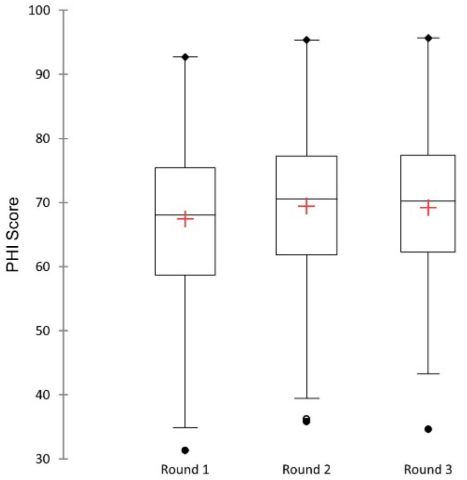


Figure 56. Comparison of Round 1, Round 2 and Round 3 PHI Scores.

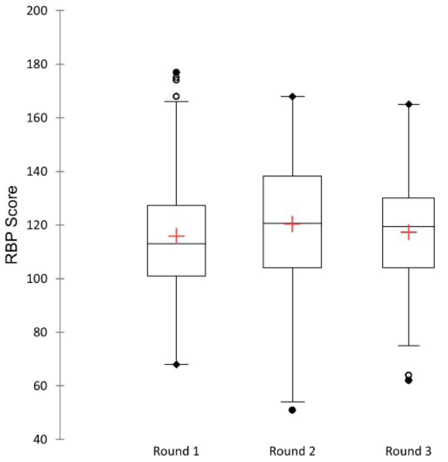


Figure 57. Comparison of Round 1, Round 2 and Round 3 RBP Scores.

At the PSU level, BIBI scores changed significantly for a total of five PSUs between Rounds One and Three (Table 28.). Three PSUs (i.e., West River, Sawmill Creek, and Stony Run) had mean BIBI scores that significantly increased since the first round of sampling began. Conversely, the Upper Magothy and Upper North River PSUs had mean BIBI scores that were significantly lower in Round Three. Stony Run was the only PSU that saw a significant difference in either RBP or PHI habitat scores among the PSUs with statistically significant changes in BIBI scores, suggesting that the randomly selected sites had better physical habitat conditions (based on RBP scores) as compared to Round 1. Observed changes in the other PSUs were likely due to factors other than improved or degraded physical habitat conditions.

Table 28. Comparison of PSU BIBI Scores Between Round One and Round Three.

PSU #		Round Three		Round One		Upper	Lower	Significant Difference? (Direction)
	PSU Name	Mean IBI	SE	Mean IBI	SE	95% CI	95%CI	
1	Piney Run	2.61	0.15	2.69	0.25	0.66	-0.49	No
2	Stony Run	3.07	0.18	2.37	0.22	-0.15	-1.26	Yes (Increase)
3	Lower Patapsco	2.14	0.35	2.69	0.19	1.32	-0.23	No
4	Sawmill Creek	2.93	0.41	1.92	0.13	-0.16	-1.86	Yes (Increase)

PSU #	PSU Name	Round Three Mean IBI	Round Three SE	Round One Mean IBI	Round One SE	Upper 95% CI	Lower 95%CI	Significant Difference? (Direction)
5	Marley Creek	2.32	0.32	2.57	0.17	0.97	-0.47	No
6	Bodkin Creek	2.54	0.18	2.43	0.19	0.40	-0.62	No
7	Upper Magothy	2.14	0.23	2.86	0.21	1.32	0.11	Yes (Decrease)
8	Lower Magothy	2.14	0.19	2.2	0.15	0.53	-0.41	No
9	Severn Run	2.82	0.41	2.80	0.23	0.91	-0.95	No
10	Severn River	2.57	0.18	3.09	0.27	1.15	-0.11	No
11	Upper North River	2.68	0.26	3.34	0.15	1.25	0.08	Yes (Decrease)
12	Lower North River	2.39	0.26	2.63	0.17	0.85	-0.38	No
13	Rhode River	2.36	0.19	1.97	0.11	0.04	-0.81	No
14	West River	2.36	0.20	1.86	0.10	-0.07	-0.93	Yes (Increase)
15	Herring Bay	3.00	0.38	2.80	0.34	0.80	-1.20	No
16	Upper Patuxent	2.07	0.18	2.37	0.12	0.73	-0.13	No
17	Little Patuxent River	2.00	0.17	2.09	0.25	0.68	-0.51	No
18	Middle Patuxent	2.68	0.30	2.94	0.22	1.00	-0.47	No
19	Stocketts Run	3.11	0.42	3.51	0.28	1.39	-0.58	No
20	Rock Branch	2.89	0.25	2.43	0.31	0.31	-1.24	No
21	Ferry Branch	3.29	0.19	3.20	0.26	0.54	-0.72	No
22	Lyons Creek	3.14	0.31	2.77	0.25	0.40	-1.15	No
23	Cabin Branch	2.82	0.24	2.31	0.16	0.05	-1.07	No
24	Hall Creek	2.18	0.24	2.77	0.24	1.26	-0.08	No

When comparing BIBI scores between Rounds Two and Three, only two PSUs saw significant changes during that time span (Table 29). Both the Upper Magothy and West River PSUs had mean BIBI scores that significantly decreased since the second round of sampling began. The Upper Magothy is the only PSU that has consistently seen decreasing BIBI scores since Round One. On the other hand, the West River first saw a significant increase in BIBI scores in Round Two, increasing from a mean of 1.86 in Round One to 2.89 in Round Two before dropping back down to 2.36 in Round Three. Even though the West River BIBI decreased since Round Two, it remains significantly higher than Round One.

For the two PSUs that saw statistically significant decreases in BIBI scores since Round One, we reviewed several additional abiotic variables that have been shown to be strongly associated with the BIBI score (i.e., percent impervious, drainage area, conductivity) to help explain the shift in BIBI scores. For the Upper Magothy PSU, we see a steady increase in specific conductivity values from Rounds One through Round Three (Figure 58). While the increase in specific conductivity values was not statistically significant between Round One and Round Three, mean values in Round Three (285.5 µs/cm) exceeded the benthic macroinvertebrate impairment threshold of 247 µs/cm, while mean values in Round One (231.0 µs/cm) did not. The Upper North River PSU also saw an increase in specific conductivity values from Rounds One through Round Three (Figure 58). Mean specific conductivity values saw a significant increase between Round One (136.6 µs/cm) and Round Two (233.6 µs/cm) before decreasing slightly in

Round Three (216.6 µs/cm). Although mean values did not exceed the benthic macroinvertebrate impairment threshold, maximum values 3rd quartile and maximum values exceeded 247 µs/cm in Rounds Two and Three. Therefore, it's likely that changes in water quality conditions, namely specific conductivity, are at least partially responsible for the decreasing BIBI scores in the Upper North River and Upper Magothy PSUs. Since neither PSU showed statistically significant differences in the percentage of impervious surface or drainage area to each sampling location, the changes in water quality conditions are not likely attributed to changes in land use between rounds.

Table 29. Comparison of PSU BIBI Scores Between Round Two and Round Three.

PSU #	PSU Name	Round Two Mean IBI	Round Two SE	Round Three Mean IBI	Round Three SE	Upper 95% CI	Lower 95%CI	Significant Difference? (Direction)
1	Piney Run	2.69	0.28	2.61	0.15	0.54	-0.71	No
2	Stony Run	2.69	0.31	3.07	0.18	1.09	-0.32	No
3	Lower Patapsco	2.43	0.23	2.14	0.35	0.53	-1.10	No
4	Sawmill Creek	2.35	0.16	2.93	0.41	1.45	-0.29	No
5	Marley Creek	1.83	0.15	2.32	0.32	1.19	-0.21	No
6	Bodkin Creek	2.40	0.29	2.54	0.18	0.80	-0.53	No
7	Upper Magothy	2.91	0.19	2.14	0.23	-0.19	-1.35	Yes (Decrease)
8	Lower Magothy	2.11	0.17	2.14	0.19	0.53	-0.46	No
9	Severn Run	3.14	0.33	2.82	0.41	0.72	-1.36	No
10	Severn River	2.77	0.2	2.57	0.18	0.33	-0.73	No
11	Upper North River	2.74	0.28	2.68	0.26	0.68	-0.81	No
12	Lower North River	2.60	0.19	2.39	0.26	0.42	-0.84	No
13	Rhode River	2.17	0.14	2.36	0.19	0.64	-0.27	No
14	West River	2.89	0.09	2.36	0.20	-0.10	-0.96	Yes (Decrease)
15	Herring Bay	3.17	0.32	3.00	0.38	0.80	-1.14	No
16	Upper Patuxent	2.34	0.16	2.07	0.18	0.21	-0.75	No
17	Little Patuxent River	2.34	0.09	2.00	0.17	0.03	-0.72	No
18	Middle Patuxent	3.32	0.19	2.68	0.30	0.05	-1.33	No
19	Stocketts Run	2.6	0.29	3.11	0.42	1.50	-0.49	No
20	Rock Branch	3.03	0.24	2.89	0.25	0.53	-0.80	No
21	Ferry Branch	2.91	0.15	3.29	0.19	0.85	-0.11	No
22	Lyons Creek	3	0.31	3.14	0.31	1.00	-0.71	No
23	Cabin Branch	3.34	0.25	2.82	0.24	0.16	-1.19	No
24	Hall Creek	2.2	0.26	2.18	0.24	0.68	-0.72	No

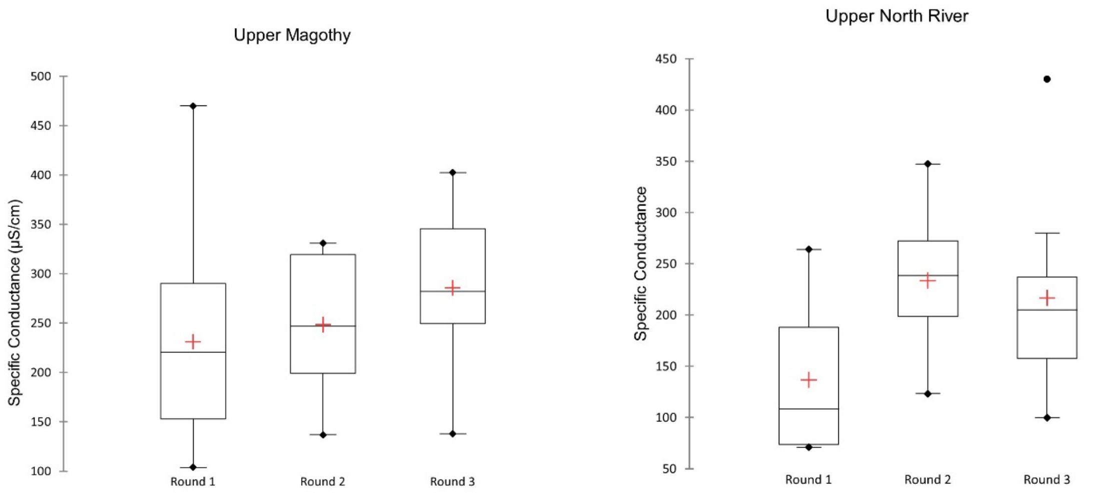


Figure 58. Comparison of Specific Conductivity Values between sampling Rounds.

Of the three PSUs where BIBI scores were observed to have increased significantly between Round One and Round Three, only Stony Run displayed meaningful trends regarding the aforementioned abiotic variables. Since Round One, mean conductivity values have decreased considerably from 633.9 µS/cm in Round One to 322.6 µS/cm in Round 3 (Figure 59). Additionally, Round Three RBP and PHI scores were significantly higher compared to those from Round One sites. While it's unlikely that physical habitat conditions improved over time, it is likely that sites sampled in Round Three simply had better physical habitat conditions than those sampled in Round One.

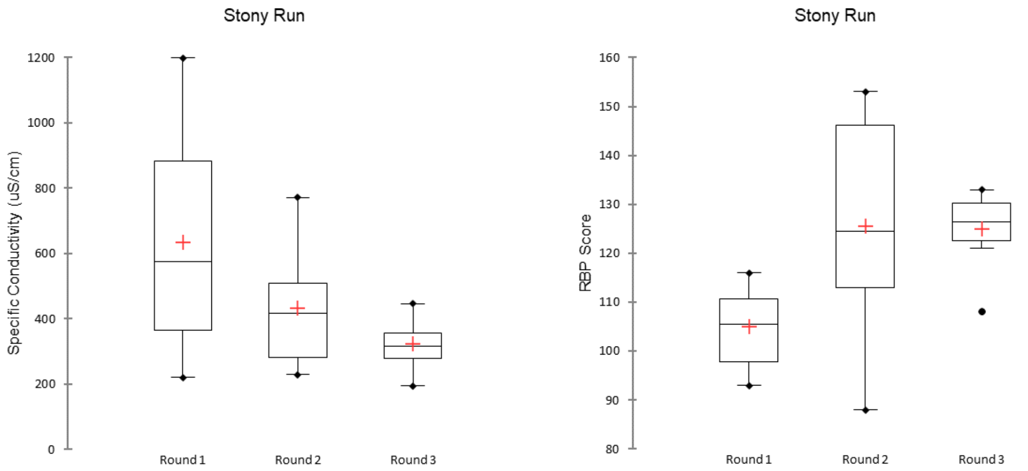


Figure 59. Comparison of Specific Conductivity Values and RBP Scores between sampling Rounds in Stony Run.

West River and Sawmill Creek were sampled in the same year (2008) during the Round One sampling effort. The spring 2008 sampling period was preceded by unusually low precipitation and flow conditions that persisted in Maryland through the fall and winter of 2007 and into the spring of 2008. In fact, Anne Arundel County was in a severe drought in October of 2007 with moderate drought conditions continuing into March, the start of the 2008 sampling season (NDMC, 2014). In October of 2007, USGS reported record low flows on numerous streams and rivers in central Maryland and the eastern shore including the Patuxent River, Piscataway Creek, Winters Run, the Choptank River and Nassawango Creek (Baltimore Sun, 2007). Furthermore, the aquatic biota at MBSS Sentinel Sites in the coastal plain (western shore) decreased slightly in 2008, a year after the 2007 drought (Becker et al., 2010), although the FIBI decreased more considerably than the BIBI. Given that BIBI scores also decreased, and more considerably during the same time period at MBSS Sentinel Sites in the coastal plain - eastern shore (Becker et al., 2010), it is highly plausible that BIBI scores were depressed in West River and Sawmill Creek PSUs as a result of the drought conditions. Becker et al. (2010) also noted that stream biota at Sentinel Sites typically recover quickly (i.e., within a year) once precipitation and flow conditions return to normal. Thus, it is even likely that West River, which was sampled in 2008 during Round One, could recover within a year and the mean BIBI score could significantly improve by 2009, when it was sampled again for Round Two.

5.2 Revisit Site Comparison

Revisit site data from Round Three was examined to determine any biological trends in sites where changes in geomorphic variables such as bankfull cross-sectional area, D50 particle size, and Rosgen stream classification were observed between Round One and Two assessments. Site specific comparisons for revisit sites can be found in the respective Annual Reports (Becker, et al., 2022; Becker, et al., 2020; Becker, et al., 2020; Becker, et al., 2018; Carvalho, et al., 2018). Comparisons of geomorphological data for revisit sites are presented in Appendix D. Kendall correlations were performed to determine if any significant correlations exist between the change in values, or delta (Δ), between time periods for geomorphic measures and BIBI scores. No significant correlations were observed between changes in BIBI scores and changes in bankfull area or changes in D50 (Table 30.). Furthermore, no significant correlations were observed between changes in bankfull area and changes in D50. Plots comparing changes in cross-sectional area versus change in BIBI scores and changes in D50 particle size versus changes in BIBI scores are shown in Figure 60 and Figure 61, respectively.

Table 30. Correlation coefficients (Kendall τ) for geomorphic variables versus BIBI score.

Variable	%Δ Bankfull Area	Δ D50	Δ BIBI
%Δ Bankfull Area	**1**	-0.082	0.098
Δ D50	-0.082	**1**	-0.004
Δ BIBI	0.098	-0.004	**1**

Significance level alpha=0.05

The revisit site dataset was also evaluated to determine if changes in Rosgen stream classification yielded predictable results with changes in BIBI scores. Between Rounds, 31% of revisit sites saw changes in the Rosgen Level I classification, 36% saw no change in classification, and 30% were unable to determine changes due a number of factors including inability to find the original cross-sectional monuments, differences in bankfull calls, geomorphic surveys not being performed in early years, etc.

Sites where a change in classification was observed had an average ΔBIBI of 0.27, while sites where no change occurred saw an average ΔBIBI of -0.08. No predictable patterns were observed where a change in Rosgen class yielded a predictable change in BIBI scores (e.g., Rosgen class shifted to less stable type resulting in lower BIBI score). The largest individual change in BIBI score that resulted in a shift from a "Good" rating 2010 to a "Poor" rating in 2019 occurred at a site with no change in Rosgen classification and a relatively small %Δ Bankfull Area (13.5). Of the 10 sites that saw a decrease in BIBI score of 1.0 or greater between visits, none saw changes in Rosgen classification from more stable type to a less stable type. In fact, two sites saw a shift to a more stable type (i.e., C5 to E5, F5 to B5c), and four (4) sites saw no change in classification. Furthermore, of the 15 sites that saw an increase in BIBI score of 1.0 or greater between visits none saw changes in Rosgen classification to a more stable stream type.

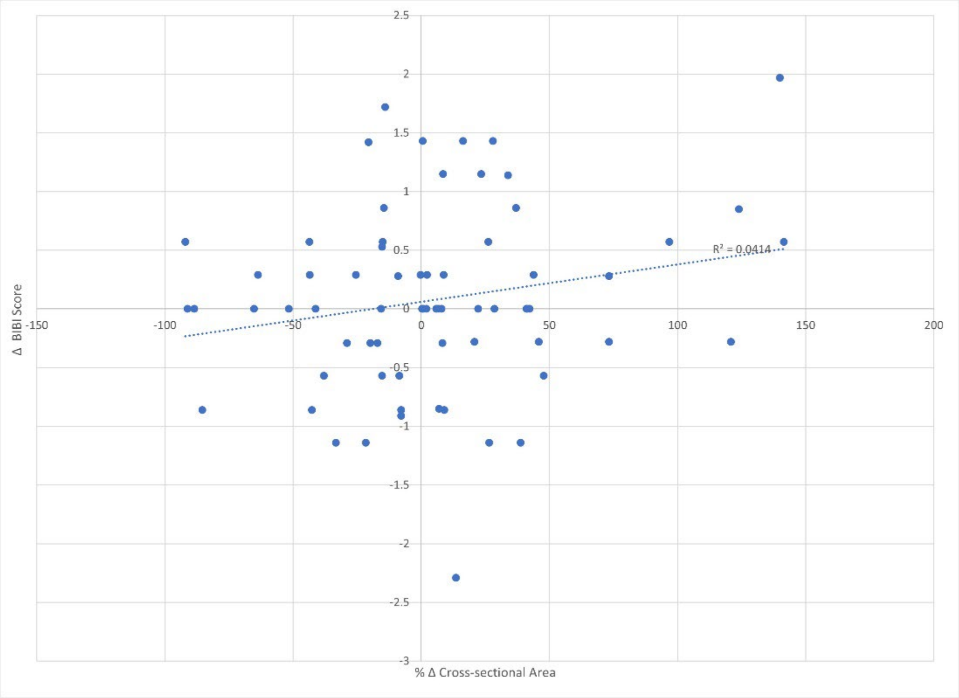


Figure 60. Comparison of change in cross-sectional area versus change in BIBI for all Round Three revisit sites.

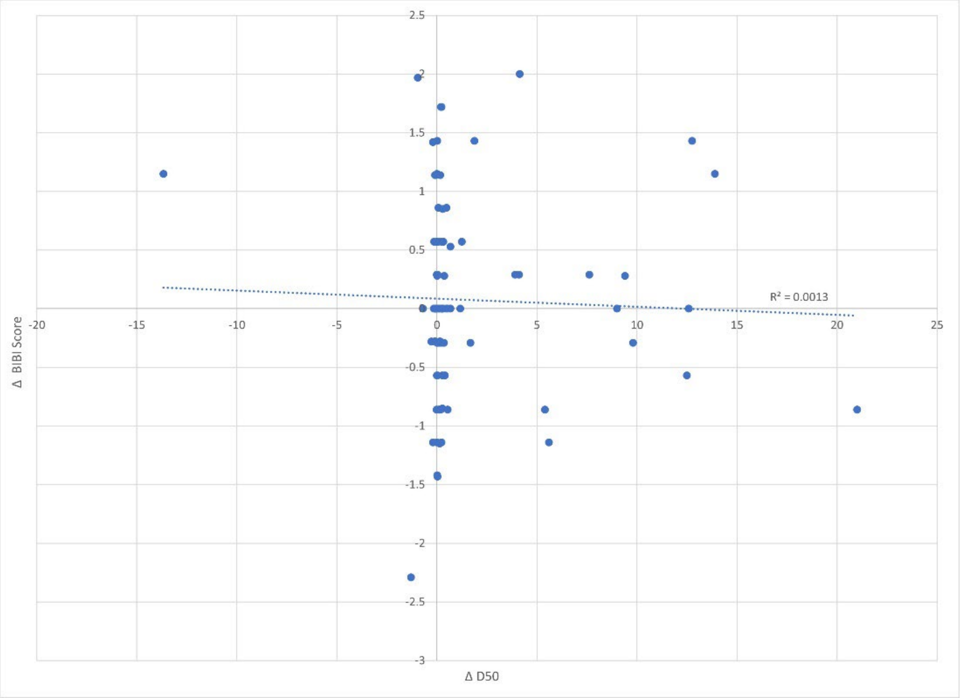


Figure 61. Comparison of change in D50 particle size versus change in BIBI for all Round Three revisit sites.

Collectively, these results suggest that changes in geomorphology, specifically changes in cross-sectional area, over time do not translate to predictable changes in biological condition, and conversely, changes in BIBI cannot be easily explained by changes in geomorphic variables as measured by the Rosgen classification scheme. Changes in bankfull cross-sectional area are based on a single cross section and may not accurately reflect changes occurring throughout the site, or even directly upstream of the established cross section. For example, the site may be experiencing bank erosion and degradation upstream of the cross section, leading to localized aggradation within the cross-section location and a subsequent decrease in bankfull area. And while Rosgen stream classification is intended to classify the stream based on representative, reach-wide characteristics, the majority of classification variables are based on a single cross-sectional survey. Therefore, reach wide changes in geomorphology may not be sufficiently captured by Rosgen stream classification or cross-sectional dimensions.

6 Conclusions and Recommendations

Round Three was the first sampling round to include more than one biological condition indicator with the addition of fish sampling and FIBI scoring. At the County scale, both biological indicators (i.e., BIBI, FIBI) yielded similar results regarding the ecological status of County streams at the conclusion of Round Three. Using the BIBI, the ecological status of County streams can best be described as poor with nearly two-thirds (64%) of the County's large streams in "Poor" or "Very Poor" condition, which is relatively consistent with what was observed during Rounds One (Hill and Pieper, 2011b) and Two (Hill et al., 2014).

The FIBI yielded similar results rating 60% of the County's large streams in "Poor" or "Very Poor" condition. Recent biological monitoring efforts by the MBSS from 2015-2017 yielded slightly different conclusions for the ecological status of Anne Arundel County streams, where 44% were rated “Poor” or “Very Poor” while 56% were rated “Good” or “Fair” using BIBI scores. However, previous MBSS monitoring efforts with a more robust number sampling sites yielded more similar results to the County’s Program (Millard et al., 2001; Kazyak et al., 2005; DNR, 2013). There was no statistically significant difference in the average biological condition, based on BIBI, of Anne Arundel County’s streams between Rounds One, Two, and Three (see Table 26, Table 27 & Table 28).

A total of 79% of the County’s PSUs are considered as being in an impaired biological condition, being rated as either “Poor” or “Very Poor” by the BIBI. However, the ecological status of individual PSU’s varies broadly throughout the County ranging from “Fair” to “Very Poor”, based on mean BIBI scores. The PSUs rated in the best biological condition by the BIBI are Ferry Branch, Lyons Creek, Stocketts Run, Stony Run, and Herring Bay. Both Herring Bay and Lyons Creek were also rated “Fair” in Round Two and Ferry Branch was rated “Fair” in Round One. There were no PSUs rated in the worst biological condition of “Very Poor” during Round Three. Little Patuxent and Upper Patuxent received the lowest BIBI scores in Round Three, just slightly above the threshold between “Poor” and “Very Poor”.

Using the FIBI, the ecological status of PSUs is comparable with 75% of the County’s PSUs are considered as being in an impaired biological condition. The PSUs rated in the best biological condition by the FIBI are Ferry Branch, Stony Run, Sawmill Creek, Piney Run, Upper North River, and Lyons Creek. Only three PSUs, Ferry Branch, Lyons Creek and Stony Run were rated “Fair” by both the BIBI and FIBI, while both Piney Run and Upper North River were rated “Poor” by the BIBI. Conversely, Herring Bay was rated “Fair” by the BIBI but “Very Poor” by the FIBI. This was the only instance where the mean biological condition rating at the PSU level deviated by more than one rating classification. Over 70% of PSUs (n=17) had matching biological condition ratings between BIBI and FIBI scores, while only seven (7) PSUs yielded different results. This suggests that both benthic macroinvertebrate and fish communities are useful indicators for assessing ecological conditions at the PSU scale.

The observed trend in PSU conditions can be partially explained by a general lack of adequate habitat for benthic macroinvertebrates resulting from past and current land use changes. Because Anne Arundel County lies within the Coastal Plain region, many stream bottoms are composed primarily of sand and silt, which, in general, make poor habitat for benthos, and productive habitats such as woody debris and rootwads have been significantly reduced due to logging practices (Millard et al., 2001). Furthermore, land use changes 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 can 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 or fish communities, which is often an indication of degraded water quality conditions. Additional water quality parameters were measured in Round Three; however, few water quality parameters added in Round Three yielded significant correlations with either the BIBI or FIBI and none were considered highly significant or strong correlations. Highly significant correlations were observed between water quality parameters and individual benthic macroinvertebrate metrics, although correlations were generally weak for fish metrics. As noted in previous Rounds (Hill and Pieper, 2011b; Hill et al., 2014), *in situ* specific conductivity continues to provide a useful measure of water quality impairment and correlated strongly with impervious cover. Stream conductivity is affected by inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations (Southerland et al., 2007), many of which are generally found at elevated concentrations in urban streams (Paul and Meyer, 2001). In fact, conductivity levels in the County were highest in PSUs with a high percentage of impervious surfaces (i.e., greater than 19%). Increased stream ion concentrations in urban systems typically results from runoff over impervious surfaces, passage through pipes, and exposure to other anthropogenic infrastructure (Cushman, 2006). While elevated conductivity may not directly affect stream biota, its constituents (e.g., chloride, metals, and nutrients) may be present at levels that can cause considerable biological impairment. For instance, chloride concentrations measured in Round Three exceeded acute or chronic thresholds at eleven sites, ten of which were rated as impaired by the BIBI. Similar results were observed for sites that exceeded chronic or acute criteria for copper, zinc, or lead, where all sites were rated as impaired by the BIBI.

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

6.1 Stressor Relationships

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

The cumulative effects of human activities within the County's watersheds often result in an alteration of at least one, if not several, of these factors with detrimental consequences for the aquatic biota. Determining which specific stressors are responsible for the observed degradation within a stream or PSU is a challenging task, given that many stressors co-exist and that both synergistic and antagonistic effects can occur among these stressors. Furthermore, an added challenge in identifying the stressors affecting stream biota is that the water quality and physical habitat data collected by the County's monitoring program are not comprehensive (i.e., they do not include all possible stressors), and virtually no data are available regarding biotic interactions and energy sources and only limited data regarding flow regime variables, such as land use and impervious cover. Stressor relationships with stream biotic components, and their derived indices (i.e., BIBI, FIBI), 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.

Impervious Cover

The numerous parameters measured as part of the Countywide Biological Monitoring and Assessment Program do address, at least in part, many common stressors, or stressor surrogates, to Maryland's streams such as impervious cover, sedimentation, and habitat degradation. As expected, the percentage of impervious cover draining to a sampling station appears to be a dominant stressor source affecting the biological condition of streams in Anne Arundel County. The relationship between imperviousness and ecological condition has been thoroughly studied and is well documented (Paul and Meyer, 2001; Schueler, 2008; Meyer et al., 2005; Walsh et al., 2005). While the relationship holds that high levels of imperviousness consistently lead to poor biological health, the contrary is not always true; low levels of imperviousness do not necessarily translate to good biological health. Other stressors not associated with imperviousness such as degraded physical habitat condition, siltation, or legacy land use may be factors limiting the biological community. As an example, Cabin Branch with only 2.0 percent imperviousness, suffers from 'Partially Degraded/Non-Supporting' physical habitat conditions which limits the biological potential of these streams in the absence of high imperviousness.

Many streams in Anne Arundel County, particularly in the well-developed northern and eastern portions of the County, exhibit many symptoms of the "Urban Stream Syndrome" including altered channel morphology, reduced biotic richness, decreased dominance of sensitive species, and elevated concentrations of contaminants (Paul and Meyer, 2001; Meyer et al., 2005). However, the biological response to impervious cover was not always consistent throughout the County. For instance, of the 11 sites rated "Good" for biological condition, three had drainage areas that exceeded 10% imperviousness, and one site in Severn Run had a drainage area with 21% imperviousness, although it should be noted that this site had a large drainage area that exceeded 1,000 acres. This unexpected response to high percentages of imperviousness can be explained by three primary factors: 1) impervious cover may be a source of different types of stressors (e.g., metals, oils, sediments) under different settings (e.g., rooftop, roadside, or parking lot runoff) resulting in considerable differences in water quality, or even quantity during storm events, depending on specific location; 2) hydrologic alteration affects may be partially mitigated by stormwater management facilities or other best management practices (BMPs), or even naturally occurring landscape features such as wetlands or forested buffers; and 3) the increased flow and overall volume of water in sites with large drainage areas may have an enhanced capacity to buffer the effects of stormwater runoff as compared to smaller streams, as implicated by the fact that all sites in Round Three with greater than 4,000 acres of drainage had biological condition ratings of "Good' or 'Fair' for both BIBI and FIBI despite conductivity values that exceeded the impairment threshold of 247 µS/cm. Further investigation into which factors enable certain streams with high imperviousness to maintain sufficient physical habitat quality and healthy benthic macroinvertebrate communities (e.g., stormwater management, wetland connectivity, continuous buffers, etc.) would be beneficial for watershed planners as it may shed some light onto which techniques are most effective at reducing the impacts of high imperviousness.

Legacy Effects

While impervious cover, and its associated stressors (e.g., toxic contaminants, nutrients, sediments, hydrologic alterations), can be used to explain the degraded biological conditions in the more developed PSUs, it is not a useful predictor in the rural, minimally developed southern and western portions of the County that includes the following PSUs: Middle Patuxent, Stocketts Run, Rhode River, Rock Branch, West River, Ferry Branch, Herring Bay, Cabin Branch, Lyons Creek, and Hall Creek. These PSUs are all categorized as having less than 30 percent developed land, greater than 10 percent agricultural land use, and less than 10 percent imperviousness. With the exception of the Rhode River PSU, physical habitat was rated as either "Non-Supporting" or "Partially Supporting" by the RBP, suggesting that physical habitat condition is a limiting factor to the biota in this region of the County. Furthermore, nearly two-thirds (63%) of the streams sampled in this region of the County were classified as incised "F" and "G" type streams, which are generally considered unstable stream types. In some of the more heavily forested PSUs with less than 30% developed land (e.g., Cabin Branch, Upper Patuxent, Rock Branch, Ferry Branch, Rhode River), this impaired physical habitat and geomorphic instability is likely a result of legacy effects, which are the consequences of past disturbances that continue to influence environmental conditions long after the initial appearance of the disturbance (Allan, 2004). Historically, nearly all of Anne Arundel County has experienced deforestation, followed by intensive agriculture which significantly altered the landscape (Schneider, 1996). These drastic land use changes likely altered the structure and function of the stream ecosystems to a considerable extent, some of which have yet to fully recover. This notion is supported by Harding and others (1998), who found that 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.

Chlorides

Chloride appears to be a predominant water quality stressor occurring throughout the County. Chloride showed significant negative correlations with multiple benthic macroinvertebrate metrics including

Percent Ephemeroptera, Number of Ephemeroptera and Percent Intolerant. Water quality samples from Round Three identified streams with chloride concentrations exceeding EPA's chronic (230 mg/L) and acute (860 mg/L) criteria across six (6) separate PSUs, extending from Lower Patapsco in the urban north to Cabin Branch in the rural south. Not surprisingly, all but one site that exceeded chloride thresholds were rated "Poor" or "Very Poor" by the BIBI. Both of the sites that exceeded the acute threshold were also rated "Poor" or "Very Poor" by the FIBI. While the number of sites exceeding national aquatic life criteria was relatively small throughout the County, chloride thresholds for more sensitive taxa such as Ephemeroptera (mayfly taxa) may be considerably lower. For instance, Miltner (2021) found a hazard concentration of 52 mg/L for chloride in Ohio streams. One-third (33.3%) of sites in the County sampled exceeded Ohio's hazard concentration during Round Three. However, MDE has yet to develop water quality standards for chlorides in Maryland streams.

6.2 Recommendations for Future Program Development

Stream Network for Sampling

In Round Three, sampling was extended from the original 1:100,000-scale stream network to include additional sites on the County's roughly 1:2,400-scale stream network layer increasing the length of streams assessed from 422 stream miles to approximately 1,500 stream miles. While this increases the target number of stream miles by approximately 250%, it is not statistically valid to compare the complete new stream network to Rounds One and Two, because the new network comprises a different population of streams (Southerland et al., 2016). Therefore, results of sampling between the large strata and small strata were reported separately throughout Round Three. Furthermore, Southerland and others (2016) evaluated whether County streams of different sizes vary naturally in biological condition to determine if the current coastal plain BIBI would be applicable to the small stream strata and found significant differences that may skew BIBI results. Fortunately, Maryland DNR is planning to further evaluate the applicability of current BIBIs to smaller streams, although the timeline for results and/or guidance is unknown. Since the Round Three analysis continues to show considerable differences in metric scoring and overall BIBI scores between large and small streams, it is currently recommended that the County continue to segregate data between large and small streams, at least until DNR releases results of the BIBI analysis. Combining data between strata to assess PSU conditions will likely result in depressed mean scores and may incorrectly identify streams as impaired when they are simply more biologically limited due to stream size.

Geomorphic Assessments

Data from geomorphic assessments across Anne Arundel County are useful to describe the variability of stream channel shape and form and begin to understand how shape and form have changed due to land use conversion over time. Geomorphic data may also prove useful to the County when identifying and prioritizing streams and subwatersheds for restoration, and to help guide future stream protection policy. 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. Streams originally surveyed in Rounds One and Two were re-surveyed in Round Three and relationships between geomorphic processes and biological responses were evaluated. Unfortunately, no consistent patterns were observed between changes in geomorphic variables and biological responses to measured changes. Therefore, quantitative geomorphic surveys do not appear to yield considerable data of value for predicting biological conditions or identifying predominant stressors.

For revisit sites where repeat cross-sectional data is available, it may be beneficial to evaluate changes in imperviousness and/or land use characteristics at sites where considerable changes have been observed over time. A review of historical changes overtime in impervious data and/or landuse in may help to explain observed changes in reach-level geomorphic conditions and potentially provide a valuable predictor for anticipated changes in stream morphology resulting from land use changes in the County.

Additional Stressor Analysis

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

BIBI Review and Revision

Multiple Rounds of data collection and analysis in the County show potential shortcomings with the BIBI scoring process, especially with regard to perceived limitations from drainage area to each site. While the FIBI attempts to adjust for drainage area for benthic species, the BIBI does not normalize any benthic macroinvertebrate metrics using drainage area despite many metrics showing significant correlations with DA in the Round Three Countywide dataset. While this occurrence may be unique to Anne Arundel County streams, it is recommended that the County pursue discussions with MBSS to address this concern as part of their commitment to supporting MS4 jurisdictions. This is likely to gain even greater importance as MS4 jurisdictions move toward sampling smaller streams using the recommended 1:24,000 stream scale, which could potentially bias BIBI scores downward on streams with smaller drainage areas. The County may want to collaborate with MBSS to pursue revisions to the BIBI scoring process for these smaller streams.

7 References

Abdi, H. 2007. Kendall rank correlation. In Salkind, N.J. Encyclopedia of Measurement and Statistics. Thousand Oaks (CA): Sage. http://www.utdallas.edu/~herve/Abdi-KendallCorrelation2007-pretty.pdf.

Addinsoft. 2022. XLSTAT statistical and data analysis solution, version 2022.1.1. New York, USA. https://www.xlstat.com/en.

Allan, J.D. 2004. Landscapes and Riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology and Evolutionary Systems 35:257-284.

Angermeier, P.L., and J.R. Karr. 1994. Biological integrity versus biological diversity as policy directives. Bioscience 44:690-697.

Anne Arundel County. 2017. Anne Arundel County Biological Monitoring and Assessment Program: Quality Assurance Project Plan. Revised May 2017. Prepared by KCI Technologies, Inc. for Anne Arundel County Department of Public Works, Watershed Ecosystem and Restoration Services.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Baltimore Sun. 2007. Maryland drought deepens – USGS. Maryland Weather Blog. October 18, 2007. Web page accessed on January 7, 2014. http://weblogs.marylandweather.com/2007/10/maryland_drought_deepens_usgs.html

Becker, A.J., Owen, R., Gring, J., and L. Nolan. 2022. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: 2021. Anne Arundel County Department of Public Works, Ecological Assessment and Evaluation Program, Annapolis, Maryland. 93 pp., plus appendices.

Becker, A.J., Fenwick, S., Gring, J., Nolan, L., and J. Saville. 2020. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: 2020. Anne Arundel County Department of Public Works, Ecological Assessment and Evaluation Program, Annapolis, Maryland. 86 pp., plus appendices.

Becker, A.J., Hill, C.R., Gring, J., Spradlin, D., and J. Saville. 2020. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: 2019. Anne Arundel County Department of Public Works, Ecological Assessment and Evaluation Program, Annapolis, Maryland.

Becker, A.J., Hill, C.R., Gring, J., Spradlin, D., and L. Edmond. 2018. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: 2018. Anne Arundel County Department of Public Works, Ecological Assessment and Evaluation Program, Annapolis, Maryland.

Becker, A.J., Stranko, S.A., Klauda, R.J., Prochaska, A.P., Schuster, J.D., Kashiwagi, M.T., and P.H. Graves. 2010. Maryland Biological Stream Survey's Sentinel Site Network: A Multi-purpose Monitoring Program. Prepared by the Maryland Department of Natural Resources, Resource Assessment Services, Monitoring and Non-tidal Assessment Division, Annapolis, MD. Prepared for the Maryland Department of Natural Resources, Wildlife and Heritage Service, Natural Heritage Program, Annapolis, MD.

Bewick, V., L. Cheek, and J. Ball. 2003. Statistics review 7: Correlation and regression. Critical Care 7(6): 451-459.

Carvalho, B.B., Becker, A.J., Hill, C.R., Gring, J., and S. Sipple. 2018. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: 2017. Anne Arundel County Department of Public Works, Ecological Assessment and Evaluation Program, Annapolis, Maryland.

Center for Watershed Protection (CWP). 2003. Impacts of impervious cover on aquatic ecosystems. Center for Watershed Protection, Ellicott City, Maryland. 142p.

Cochran, W.G. 1977. Sampling Techniques. John Wiley & Sons, New York, NY.

Code of Maryland Regulations (COMAR). 2010. Code of Maryland Regulations, Title 26- Department of the Environment, Subtitle 08 – Water Pollution. 26.08.02.02- Designated Uses, 26.08.02.03- Water Quality Criteria Specific to Designated Uses. Maryland Department of the Environment. (February 10, 2022). http://www.dsd.state.md.us/comar/subtitle_chapters/26_Chapters.aspx#Subtitle08

Crawford, J.K. and D.R. Lenat. 1989. Effects of land use on the water quality and biota of three streams in the Piedmont Province of North Carolina. In: Water Resources Investigation Report 89-4007. US Geological Survey, Raleigh, NC.

Crunkleton, M.C. and S.E. Gresens. 2012. A different perspective: A multivariate analysis approach for biomonitoring data collected in Anne Arundel County, Maryland. Poster presented at the 2012 Annual Meeting and Workshop for the Association of Mid-Atlantic Aquatic Biologists. Towson University, Towson, MD.

Cushman, S.F. 2006. Fish movement, habitat selection, and stream habitat complexity in small urban streams. Dissertation submitted to the Faculty of the Graduate School of the University of Maryland, College Park, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Harding, J.S., E.F. Benfield, P.V. Bolstad, G.S. Helfman and E.B.D. Jones, III. 1998. Stream biodiversity: the ghost of land use past. Proc. Natl. Acad. Sci. 95: 14843-14847.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. Gen. Tech. Rep. RM-245. U.S. Department of Agriculture, Forest Service, Rocky Mtn Forest and Range Experimental Station. 61 pp.

Helms B.S., Feminella J.W., and S. Pan. 2005. Detection of biotic responses to urbanization using fish assemblages from small streams of western Georgia, USA. Urban Ecosystems 8:39–57

Herlihy, A.T., J.L Stoddard, and C.B. Johnson. 1998. The relationship between stream chemistry and watershed land cover data in the Mid-Atlantic region, US. Water, Air, and Soil Pollution 105:377-386.

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

Hill, C.R., and M. J. Pieper. 2011a. Documentation of Method Performance Characteristics for the Anne Arundel County Biological Monitoring Program. Revised, August 2011. Prepared by KCI Technologies, Sparks, MD for Anne Arundel County, Department of Public Works, Watershed, Ecosystem, and Restoration Services. Annapolis, MD.

Hill, C. R., and M.J. Pieper. 2011b. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: Round One 2004 – 2008. Anne Arundel County Department of Public Works, Watershed, Ecosystem, and Restoration Services, Annapolis, Maryland.

Hill, C.R., and M. J. Pieper. 2011c. Quality Assurance Project Plan for Anne Arundel County Biological Monitoring and Assessment Program. Revised, May 2011. Prepared by KCI Technologies, Sparks, MD for Anne Arundel County, Department of Public Works, Watershed, Ecosystem, and Restoration Services. Annapolis, MD.

Hill, C. R., and J.B. Stribling. 2004. Design of the Biological Monitoring and Assessment Program for Anne Arundel County, Maryland. Prepared by Tetra Tech, Inc., Owings Mills, Maryland, for the Anne Arundel County Office of Environmental & Cultural Resources, Annapolis, Maryland.

Hill, C.R., J.B. Stribling, and A.C. Gallardo. 2005. Documentation of Method Performance Characteristics for the Anne Arundel County Biological Monitoring Program. Prepared by Tetra Tech, Inc., Owings Mills, MD for Anne Arundel County Office of Environmental & Cultural Resources. Annapolis, MD.

Hill, C.R., and M. J. Pieper. 2010. Documentation of Method Performance Characteristics for the Anne Arundel County Biological Monitoring Program. Revised, December 2010. Prepared by KCI Technologies, Sparks, MD for Anne Arundel County, Department of Public Works, Watershed, Ecosystem, and Restoration Services. Annapolis, MD.

Fend, S.V., Carter, J.L., and Kearns, F.R. 2005. Relationships of field habitat measurements, visual habitat indices, and land cover to benthic macroinvertebrates in urbanized streams of the Santa Clara Valley, California: in Brown, L.R., Gray, R.H., Hughes, R.M., and Meador, M.R., eds., Effects of urbanization on stream ecosystems: American Fisheries Society, Symposium 47, Bethesda, Maryland, p. 193-212.

Kaller, M. D., & Hartman, K. J. 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. Hydrobiologia, 518, 95-104.

Karr, J.R. and E.W. Chu. 1998. Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Washington, DC.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5. Champaign, Illinois.

Kashiwagi, M. and T. Prochaska. 2011. Improving the thermal protection for Maryland streams: Getting the most out of designated uses. Proceedings of the 2011 Maryland Streams Symposium. Maryland Department of Natural Resources.

Kazyak, P.F., Brindley, A., and M. Southerland. 2005. Maryland Biological Stream Survey 2000-2004, Volume 8: County Results. Published by the Maryland Department of Natural Resources, Annapolis, MD. Publication # DNR-12-0305-0107.

Kemp, W.M., Boynton, W.R., Adolf, J.E., Boesch, D.F., Boicourt, W.C., Brush, G., Cornwell, J.C., Fisher, T.R., Glibert, P.M., Hagy, J.D., Harding, L.W., Houde, E.D., Kimmel, D.G., Miller, W.D., Newell, R.I.E., Roman, M.R., Smith, E.M., and J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series, 303, 1-29 - November 2005.

Kendall, M.G. 1955. Rank Correlation Methods. New York: Hafner Publishing Co.

Kennen, J.G., Chang, M., and Tracy, B.H., 2005, Effects of landscape change on fish assemblage structure in a rapidly growing metropolitan area in North Carolina, USA, in Brown, L.R., Gray, R.H., Hughes, R.M., and Meador, M.R., eds., Effects of urbanization on stream ecosystems: Bethesda, Maryland, American Fisheries Society Symposium, v. 47, p. 39–52.

Kerans, B. L., and J. R. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4:768–785.

Maryland Department of Natural Resources (DNR). 2007. Maryland Biological Stream Survey Sampling Manual: Field Protocols. CBWP-MANTA-EA-07-01. Published by the Maryland Department of Natural Resources, Annapolis, MD. Publication # 12-2162007-190.

Maryland Department of Natural Resources (DNR). 2005. Maryland Biological Stream Survey 2000-2004. Volume 14: Stressors Affecting Maryland Streams. CBWP-MANTA-EA-05-11. Published by the Maryland Department of Natural Resources, Annapolis, MD. Publication # 12-0305-0101.

Maryland Department of Natural Resources (DNR). 2013. Data from Round 3 of the Maryland Biological Stream Survey (2007 – 2009). Maryland Department of Natural Resources, Resource Assessment Services, Monitoring and Non-tidal Assessment Division, Annapolis, MD.

McCandless, T.L. 2003. Maryland stream survey: Bankfull discharge and channel characteristics of streams in the Coastal Plain hydrologic region. U.S. Fish and Wildlife Service, Annapolis, MD. CBFO-S03-02.

Meyer, J.L., M.J. Paul, and W.K. Taulbee. 2005. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society 24:602-612.

Millard, C.J., P.F. Kazyak, and A.P. Prochaska. 2001. Anne Arundel County. Results of the 1994-1997 Maryland Biological Stream Survey: County-Level Assessments. Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. Annapolis, MD. CBWP-MANTA-EA-01-12.

Miltner, R. 2021. Assessing the Impacts of Chloride and Sulfate Ions on Macroinvertebrate Communities in Ohio Streams. Water 2021, 13, 1815. https://doi.org/10.3390/w13131815

Miltner R.J., White D., and C. Yoder. 2004. The biotic integrity of streams in urban and suburbanizing landscapes. Landscape and Urban Planning 69:87–100

Minshall, G. W., K. W. Cummins, R. C. Petersen, C. E. Cushing, D. A. Bruns, J. R. Sedell & R. L. Vannote, 1985. Developments in stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences 42: 1045–1055.

Morgan R.P., and S.F. Cushman. 2005. Urbanization effects on stream fish assemblages in Maryland, USA. Journal of the North American Benthological Society 24:643–655

Morgan R.P., K.M. Kline, and S.F. Cushman. 2007. Relationships among nutrients, chloride, and biological indices in urban Maryland streams. Urban Ecosystems 10:153-177

National Drought Mitigation Center (NDMC). 2014. U.S. Drought Monitor for Maryland. Web page accessed on January 7, 2014. http://droughtmonitor.unl.edu/DataArchive/MapArchive.aspx

NIST/SEMATECH. 2011. e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, accessed March 1, 2022.

Paul, M.J. and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333-365.

Paul, M.J., Stribling, J.B., Klauda, R.J., Kazyak, P.F., Southerland, M.T., and N.E. Roth. 2003. A Physical Habitat Index for Freshwater Wadeable Streams in Maryland. Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. Annapolis, MD. CBWP-MANTA-EA-03-4.

Rasmussen, T.J., Poulton, B.C., and Graham, J.L., 2009, Quality of streams in Johnson County, Kansas, and relations to environmental variables, 2003–07: U.S. Geological Survey Scientific Investigations Report 2009–5235, 84p. with appendices.

Roesner, L.A., and B.P. Bledsoe. 2003. Physical Effects of Wet Weather Flow on Aquatic Habitats: Present Knowledge and Research Needs, Water Environment Research Foundation Report 00-WSM-4.

Roseberry Lincoln, A., R. Klauda, and E.K. Barnum. 2007. Maryland Biological Stream Survey 2000-2004, Volume 12: Changes in Condition. DNR-12-0305-0103. Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. Annapolis, MD. CBWP-MANTA-EA-05-9.

Rosgen, D.L. 1994. A Classification of Natural Rivers. Catena 22:169-199.

Rosgen, D.L. 1996. Applied River Morphology (Second Edition). Wildland Hydrology. Pagosa Springs, CO.

Roth, N., J. Vølstad, L. Erb, E. Weber, P. Kazyak, S. Stranko, and D. Boward. 2005. Maryland Biological Stream Survey 2000-2004, Volume 6: Laboratory, Field, and Analytical Methods. Prepared by Versar, Incorporated, Columbia, Maryland, and the Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division, Annapolis, Maryland. Publication No. DNR 12-0305-0108-EA-05-3

Schenker, N. and J. F. Gentleman. 2001. On Judging the Significance of Differences by Examining the Overlap Between Confidence Intervals. The American Statistician 55(3):182–186.

Schneider, D.W. 1996. Effects of European settlement and land use on regional patterns of similarity among Chesapeake forests. Bulletin of the Torrey Botanical Club 123(3):223-239.

Schueler, T. 1994. The importance of imperviousness. Watershed Protection Techniques, 1(3), 100-111.

Schueler, T. 2008. Chesapeake Stormwater Network Technical Bulletin No.3 - Implications of the Impervious Cover Model: Stream classification, urban subwatershed management and permitting. Version 1. Chesapeake Stormwater Network. Baltimore, MD www.chesapeakestormwater.net

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984. Incised Channels: Morphology, Dynamics, and Control. Water Resources Publications, Littleton, CO.

Shapiro S. S. and Wilk M. B. 1965. An analysis of variance test for normality. Biometrika, 52, 3 and 4, 591-611.

Simon, A., and C.R. Hupp. 1986. Channel Evolution in Modified Tennessee Streams. In: Proceedings of the 4th Federal Interagency Sedimentation Conference, Las Vegas, Nevada. US Government Printing Office, Washington, DC, 5.71-5.82.

Simon, A. 1989. A Model of Channel Response in Disturbed Alluvial Channels. Earth Surface Processes and Landforms: 14, 11-26.

Southerland, M., G. Rogers, M. Kline, R. Morgan, D. Boward, P. Kazyak, and S. Stranko. 2005. Development of New Fish and Benthic Macroinvertebrate Indices of Biotic Integrity for Maryland Streams. Report to Monitoring and Non-Tidal Assessment Division, Maryland Department of Natural Resources, Annapolis, MD.

Southerland, M., J. Volstad, E. Weber, R. Morgan, L. Currey, J. Holt, and C. Poukish. 2007. Using MBSS Data to Identify Stressors for Streams That Fail Biocriteria in Maryland. Maryland Department of the Environment, Baltimore, Maryland.

Southerland, M., G. Rogers, N. Roth and D. Zaveta. 2016. Design Update of the Anne Arundel County Biological Monitoring Program. Prepared for the Anne Arundel County Department of Public Works, Watershed Protection and Restoration Program, Annapolis, Maryland. Prepared by Versar, Inc., Columbia, Maryland, and AKRF, Inc., Hanover, Maryland. 37pp.

Stranko, S., D. Boward, J. Kilian, A. Becker, M. Ashton, M. Southerland, B. Franks, W. Harbold, and J. Cessna. 2015. Maryland Biological Stream Survey: Round Four Field Sampling Manual. Revised January 2019. Published by the Maryland Department of Natural Resources, Annapolis, MD. Publication # 12-Resource Assessment Service-3142014-700.

Stranko, S., R. Bourquin, J. Zimmerman, M. Kashiwagi, M. McGinty, and R. Klauda. 2013. Do Road Salts Cause Environmental Impacts? Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division, Resources Assessment Service. Annapolis, MD.

Stribling, J.B., B. Jessup, and C.J.Victoria. 2008. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: 2006. Anne Arundel County Department of Public Works, Watershed, Ecosystem and Restoration Services [now the Bureau of Watershed Assessment and Restoration], Annapolis, Maryland. 34 pp. plus Appendices.

Tetra Tech, Inc. 2004. Quality Assurance Projects Plan for Anne Arundel County Biological Monitoring and Assessment Program. Revision 1. Report to Anne Arundel County Office of Environmental and Cultural Resources. Annapolis, MD.

U.S. Environmental Protection Agency (USEPA). 2000. Stressor Identification Guidance Document. EPA 822-B-00-025. U.S. Environmental Protection Agency, Office of Water, Office of Research and Development, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1995. EPA Requirements for Quality Assurance Project Plans. U.S. Environmental Protection Agency, Quality Staff, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1982. Chesapeake Bay Program Technical Studies: A Synthesis. U.S. Environmental Protection Agency, Washington, D.C. https://www.chesapeakebay.net/content/publications/cbp_13280.pdf

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushin, 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130–137.

Volstad J.H., Roth N.E., Mercurio G., Southerland M.T., and D.E. Strebel. 2003. Using environmental stressor information to predict the ecological status of Maryland non-tidal streams as measured by biological indicators. Environmental Monitoring and Assessment 84:219–242

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

Wang, L., J. Lyons, P. Kanehl, R. Bannerman and E. Emmons. 2000. Watershed urbanization and changes in fish communities in Southeastern Wisconsin streams. Journal of the American Water Resources Association 36(5): 1173-1189.

Williams, W.D. 2001. Anthropogenic salinization of inland waters. Hydrobiologia, 466:329-337.

Appendix A: Land Use and Land Cover Data

Table A-1. Total Acres Per Land Cover Type for Each Primary Sampling Unit and Countywide Based on 2017 Anne Arundel County Land Cover Layer. Note: PSUs shaded gray were calculated using 2014 land cover data.

Primary Sampling Unit	**PSU Code**	**Airport**	**Commercial**	**Forested Wetlands**	**Industrial**	**Mining**	**Open Space**	**Open Wetland**	**Pasture/Hay**	**Residential 1/2-ac**	**Residential 1/4-ac**	**Residential 1/8-ac**	**Residential 1-ac**	**Residential 2-ac**	**Row Crops**	**Transportation**	**Utility**	**Water**	**Woods-Coniferous**	**Woods- Decidiuous**	**Woods-Mixed**	**Total Acres**
COUNTYWIDE	-	1256.8	14452.8	8458.4	3974.8	686.3	16167.7	3663.2	8706.4	12023.2	23141.6	16329.5	12425.8	27370.2	11090.7	9670.8	2102.3	3618.9	4135.7	1067.0	85640.4	265982.5
Piney Run	1		448.6	13.2	313.2		509.2	15.3	11.9	73.2	122.7	359.3	302.5	307.3		337.7	5.0	46.4	64.2		1935.5	4865.2
Stony Run	2	519.3	530.7	15.4	384.5	4.5	847.5	161.4		301.7	493.6	369.3	169.9	86.7	1.7	447.5	10.7	26.1	129.4		1702.8	6202.9
Lower Patapsco	3		406.6	12.4	361.7	109.3	239.9	99.4		50.3	588.6	632.7	109.2	47.5		272.9	43.0	121.4	8.1	7.1	928.3	4038.5
Sawmill Creek	4	624.4	1101.6	44.8	729.5		1785.7	76.3	37.5	159.2	1312.5	1581.3	238.6	218.9	7.7	813.6	82.7	52.5	184.7		1984.3	11036.0
Marley Creek	5		1510.4	22.5	882.1		1096.8	116.2	13.0	1024.6	2546.2	4559.1	615.6	421.1	63.7	964.1	189.2	300.5	219.8	11.3	4867.6	19423.7
Bodkin Creek	6		232.1	92.6	1.5		307.5	84.3	29.2	738.1	458.1	89.3	953.7	543.3	21.2	120.2		195.1	71.4		1934.2	5871.7
Upper Magothy	7		663.6	53.0	12.9		399.2	26.9	17.7	1530.5	1995.3	303.9	1213.0	898.0	7.9	443.4		57.7	178.0		2230.4	10031.4
Lower Magothy	8		618.9	138.4	7.8		545.5	117.3	84.2	2277.8	2718.2	784.1	570.9	833.7	57.4	415.2		192.0	127.2	62.9	3145.9	12697.3
Severn Run	9		805.9	34.1	407.8		1006.1	91.3	274.4	631.2	1680.8	1577.9	926.3	1261.2	173.4	720.5	95.0	47.6	671.6	167.3	4851.8	15424.3
Severn River	10		2090.3	428.0	182.8		1563.7	295.6	604.9	2437.1	4574.1	1077.9	2333.4	3019.6	219.0	1143.0	50.3	343.1	106.9	49.4	8400.7	28919.7
Upper North River	11		200.8	1447.9	25.3		362.7	106.7	719.5	101.4	90.3	129.8	1436.4	2211.1	467.2	383.6	236.3	63.7	89.9	131.1	4593.7	12797.3
Lower North River	12	24.9	1381.3	1251.1	100.9		1142.5	263.1	579.7	1348.5	2943.9	816.3	1722.9	3682.8	573.6	765.9	188.5	263.5	57.8		6574.2	23681.3
Rhode River	13		159.5	363.0	26.6		273.2	192.2	753.4	303.6	314.0	2.8	209.8	1267.7	439.5	147.2	47.1	96.6	76.1	4.8	4059.8	8736.8
West River	14		174.5	157.5	0.9		204.8	139.8	984.0	351.6	144.7	215.9	274.1	890.3	698.7	141.1	51.0	63.9	30.7	17.9	3016.1	7557.6
Herring Bay	15	6.5	306.2	1358.1	24.6		510.9	628.5	541.6	241.7	361.1	617.1	294.0	1980.1	968.4	303.7	321.2	175.3	94.6		5860.8	14594.6
Upper Patuxent	16	14.2	232.2	687.2	13.2		586.0	74.9	9.7	3.5	460.3	113.8	2.9	109.9	22.2	185.7	183.7	87.5	633.9	137.5	3392.7	6950.9
Little Patuxent	17	67.4	2879.2	794.5	451.2	255.1	2671.8	365.9	328.7	182.5	2188.5	2798.4	278.1	476.0	499.1	1209.7	468.1	521.1	969.0	470.1	10321.7	28195.9
Middle Patuxent	18		189.5	264.5	18.3	22.4	594.2	33.3	532.6	86.1	66.2	11.1	33.1	1343.6	741.3	135.2		112.9	197.7		1949.6	6331.5
Stocketts Run	19		150.7	548.4	18.4		414.5	14.7	983.7	139.7			235.1	2274.9	734.2	162.6	94.8	56.2	93.0	1.6	2791.0	8713.4
Rock Branch	20		69.9	343.2		240.4	339.4	70.3	536.4	6.2	71.0		11.4	1163.3	976.5	77.4		84.7	53.3	1.2	2077.9	6122.5
Ferry Branch	21		152.6	109.6	1.0	54.5	365.9	304.6	651.7	11.4	6.2	217.1	176.0	1300.7	1075.3	179.2		193.1	50.8	4.5	3183.5	8037.7
Lyons Creek	22		89.6	182.2	3.2		190.3	58.3	503.3	16.9	4.3		259.3	1191.4	1576.5	104.8		16.6	5.1	0.3	1945.5	6147.7
Cabin Branch	23		23.2	49.3	7.5		151.1	307.7	324.4		0.9	72.3	25.7	936.1	1238.7	117.7		495.2	14.8		2678.6	6443.1
Hall Creek	24		35.0	47.6			59.3	19.3	184.8	6.4			33.9	905.3	527.5	78.8	35.7	6.4	7.6		1213.8	3161.4

Footnotes:

* Some water not included in LC classification, following acres were added manually to Water - Cabin Branch 450.07 ac, Ferry Branch 86.32 ac

Table A-2. Percentage of Land Cover Type for Each Primary Sampling Unit and Countywide Based on 2017 Anne Arundel County Land Cover Layer. Note: PSUs shaded gray were calculated using 2014 land cover data.

Primary Sampling Unit	PSU Code	Airport	Commercial	Forested Wetlands	Industrial	Mining	Open Space	Open Wetland	Pasture/Hay	Residential 1/2-ac	Residential 1/4-ac	Residential 1/8-ac	Residential 1-ac	Residential 2-ac	Row Crops	Transportation	Utility	Water	Woods-Coniferous	Woods- Decidiuous	Woods-Mixed
COUNTYWIDE	-	0.5%	5.4%	3.2%	1.5%	0.3%	6.1%	1.4%	3.3%	4.5%	8.7%	6.1%	4.7%	10.3%	4.2%	3.6%	0.8%	1.4%	1.6%	0.4%	32.2%
Piney Run	1	0.0%	9.2%	0.3%	6.4%	0.0%	10.5%	0.3%	0.2%	1.5%	2.5%	7.4%	6.2%	6.3%	0.0%	6.9%	0.1%	1.0%	1.3%	0.0%	39.8%
Stony Run	2	8.4%	8.6%	0.2%	6.2%	0.1%	13.7%	2.6%	0.0%	4.9%	8.0%	6.0%	2.7%	1.4%	0.0%	7.2%	0.2%	0.4%	2.1%	0.0%	27.5%
Lower Patapsco	3	0.0%	10.1%	0.3%	9.0%	2.7%	5.9%	2.5%	0.0%	1.2%	14.6%	15.7%	2.7%	1.2%	0.0%	6.8%	1.1%	3.0%	0.2%	0.2%	23.0%
Sawmill Creek	4	5.7%	10.0%	0.4%	6.6%	0.0%	16.2%	0.7%	0.3%	1.4%	11.9%	14.3%	2.2%	2.0%	0.1%	7.4%	0.7%	0.5%	1.7%	0.0%	18.0%
Marley Creek	5	0.0%	7.8%	0.1%	4.5%	0.0%	5.6%	0.6%	0.1%	5.3%	13.1%	23.5%	3.2%	2.2%	0.3%	5.0%	1.0%	1.5%	1.1%	0.1%	25.1%
Bodkin Creek	6	0.0%	4.0%	1.6%	0.0%	0.0%	5.2%	1.4%	0.5%	12.6%	7.8%	1.5%	16.2%	9.3%	0.4%	2.0%	0.0%	3.3%	1.2%	0.0%	32.9%
Upper Magothy	7	0.0%	6.6%	0.5%	0.1%	0.0%	4.0%	0.3%	0.2%	15.3%	19.9%	3.0%	12.1%	9.0%	0.1%	4.4%	0.0%	0.6%	1.8%	0.0%	22.2%
Lower Magothy	8	0.0%	4.9%	1.1%	0.1%	0.0%	4.3%	0.9%	0.7%	17.9%	21.4%	6.2%	4.5%	6.6%	0.5%	3.3%	0.0%	1.5%	1.0%	0.5%	24.8%
Severn Run	9	0.0%	5.2%	0.2%	2.6%	0.0%	6.5%	0.6%	1.8%	4.1%	10.9%	10.2%	6.0%	8.2%	1.1%	4.7%	0.6%	0.3%	4.4%	1.1%	31.5%
Severn River	10	0.0%	7.2%	1.5%	0.6%	0.0%	5.4%	1.0%	2.1%	8.4%	15.8%	3.7%	8.1%	10.4%	0.8%	4.0%	0.2%	1.2%	0.4%	0.2%	29.0%
Upper North River (South River)	11	0.0%	1.6%	11.3%	0.2%	0.0%	2.8%	0.8%	5.6%	0.8%	0.7%	1.0%	11.2%	17.3%	3.7%	3.0%	1.8%	0.5%	0.7%	1.0%	35.9%
Lower North River (South River)	12	0.1%	5.8%	5.3%	0.4%	0.0%	4.8%	1.1%	2.4%	5.7%	12.4%	3.4%	7.3%	15.6%	2.4%	3.2%	0.8%	1.1%	0.2%	0.0%	27.8%
Rhode River	13	0.0%	1.8%	4.2%	0.3%	0.0%	3.1%	2.2%	8.6%	3.5%	3.6%	0.0%	2.4%	14.5%	5.0%	1.7%	0.5%	1.1%	0.9%	0.1%	46.5%
West River	14	0.0%	2.3%	2.1%	0.0%	0.0%	2.7%	1.8%	13.0%	4.7%	1.9%	2.9%	3.6%	11.8%	9.2%	1.9%	0.7%	0.8%	0.4%	0.2%	39.9%
Herring Bay	15	0.0%	2.1%	9.3%	0.2%	0.0%	3.5%	4.3%	3.7%	1.7%	2.5%	4.2%	2.0%	13.6%	6.6%	2.1%	2.2%	1.2%	0.6%	0.0%	40.2%
Upper Patuxent	16	0.2%	3.3%	9.9%	0.2%	0.0%	8.4%	1.1%	0.1%	0.1%	6.6%	1.6%	0.0%	1.6%	0.3%	2.7%	2.6%	1.3%	9.1%	2.0%	48.8%
Little Patuxent	17	0.2%	10.2%	2.8%	1.6%	0.9%	9.5%	1.3%	1.2%	0.6%	7.8%	9.9%	1.0%	1.7%	1.8%	4.3%	1.7%	1.8%	3.4%	1.7%	36.6%
Middle Patuxent	18	0.0%	3.0%	4.2%	0.3%	0.4%	9.4%	0.5%	8.4%	1.4%	1.0%	0.2%	0.5%	21.2%	11.7%	2.1%	0.0%	1.8%	3.1%	0.0%	30.8%
Stocketts Run	19	0.0%	1.7%	6.3%	0.2%	0.0%	4.8%	0.2%	11.3%	1.6%	0.0%	0.0%	2.7%	26.1%	8.4%	1.9%	1.1%	0.6%	1.1%	0.0%	32.0%
Rock Branch	20	0.0%	1.1%	5.6%	0.0%	3.9%	5.5%	1.1%	8.8%	0.1%	1.2%	0.0%	0.2%	19.0%	15.9%	1.3%	0.0%	1.4%	0.9%	0.0%	33.9%
Ferry Branch	21	0.0%	1.9%	1.4%	0.0%	0.7%	4.6%	3.8%	8.1%	0.1%	0.1%	2.7%	2.2%	16.2%	13.4%	2.2%	0.0%	2.4%	0.6%	0.1%	39.6%
Lyons Creek	22	0.0%	1.5%	3.0%	0.1%	0.0%	3.1%	0.9%	8.2%	0.3%	0.1%	0.0%	4.2%	19.4%	25.6%	1.7%	0.0%	0.3%	0.1%	0.0%	31.6%
Cabin Branch	23	0.0%	0.4%	0.8%	0.1%	0.0%	2.3%	4.8%	5.0%	0.0%	0.0%	1.1%	0.4%	14.5%	19.2%	1.8%	0.0%	7.7%	0.2%	0.0%	41.6%
Hall Creek	24	0.0%	1.1%	1.5%	0.0%	0.0%	1.9%	0.6%	5.8%	0.2%	0.0%	0.0%	1.1%	28.6%	16.7%	2.5%	1.1%	0.2%	0.2%	0.0%	38.4%

<u>Footnotes:</u>

* Some water not included in LC classification, following acres were added manually to Water - Cabin Branch 450.07 ac, Ferry Branch 86.32 ac

Appendix B: Kendall Correlation Matrices

Kendall Correlation Matrix: Fish Variables Versus Geomorphic Variables

Variables	Entrenchment Ratio	Bankfull Width	Bankfull Area	Mean Depth	Width:Depth Ratio	Water Surface Slope (%)	Water Surface Slope (ft)	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50	**Abundance Per m^2**	**Adjusted No. Benthic Species**	**Percent Tolerant**	**Percent Generalist, Omnivores, Insectivores**	**PercentRound-bodied Suckers**	**Percent Abundance Dominant Taxa**	**FIBI**
Entrenchment Ratio	**1**																	
Bankfull Width	-0.079	**1**																
Bankfull Area	0.057	**0.661**	**1**															
Mean Depth	**0.216**	**0.295**	**0.635**	**1**														
Width:Depth Ratio	**-0.245**	**0.430**	0.091	**-0.275**	**1**													
Water Surface Slope (%)	-0.053	**-0.164**	**-0.231**	**-0.198**	0.052	**1**												
Water Surface Slope (ft)	-0.058	**-0.172**	**-0.238**	**-0.206**	0.043	**0.887**	**1**											
Bankfull Discharge	0.006	**0.443**	**0.630**	**0.581**	0.022	0.104	0.063	**1**										
Sinuosity	-0.025	0.050	0.041	0.043	0.044	**0.100**	0.096	0.064	**1**									
Flood-Prone Width	**0.612**	**0.310**	**0.360**	**0.326**	0.004	**-0.159**	**-0.159**	**0.171**	-0.009	**1**								
D50	**-0.228**	**0.247**	**0.200**	**0.102**	**0.150**	**0.110**	0.087	**0.234**	**0.163**	**-0.101**	**1**							
Abundance Per m^2	0.096	0.053	0.048	0.021	0.028	0.075	**0.107**	0.042	**0.111**	**0.133**	**0.100**	**1**						
Adjusted No. Benthic Species	**-0.187**	**0.308**	**0.237**	**0.120**	**0.160**	-0.088	-0.071	**0.268**	0.086	-0.047	**0.268**	0.096	**1**					
Percent Tolerant	-0.071	**-0.129**	**-0.190**	**-0.185**	0.061	**0.138**	**0.155**	-0.049	0.035	**-0.172**	0.062	**0.132**	0.029	**1**				
Percent Generalist, Omnivores, Insectivores	0.070	**-0.170**	**-0.138**	-0.082	-0.078	**0.125**	**0.154**	-0.120	-0.053	0.005	-0.041	**0.135**	**-0.251**	**0.349**	**1**			
PercentRound-bodied Suckers	0.003	**0.307**	**0.329**	**0.241**	0.049	**-0.117**	-0.082	**0.250**	0.012	**0.178**	**0.128**	**0.121**	**0.207**	**-0.201**	**-0.126**	**1**		
Percent Abundance Dominant Taxa	-0.020	**-0.229**	**-0.273**	**-0.219**	-0.004	**0.166**	**0.185**	**-0.136**	0.051	**-0.151**	-0.030	**0.150**	**-0.122**	**0.474**	**0.409**	**-0.260**	**1**	
FIBI	-0.038	**0.421**	**0.434**	**0.299**	**0.108**	**-0.123**	**-0.104**	**0.327**	**0.123**	**0.190**	**0.258**	**0.267**	**0.477**	**-0.255**	**-0.304**	**0.471**	**-0.364**	**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: Fish Variables Versus Land Use Variables

Variables	Drainage area	% Impervious	Impervious acres	Airport %	Commercial %	Forested wetland %	Industrial %	Open space	Wetland %	Pasture %	Residential 1/8-ac. %	Residential 1/2-ac. %	Residential 1/4-ac. %	Residential 1-ac. %	Residential 2-ac. %	Right-of-Way %	Transportation %	Utility %	Water %	Woods %	Woods coniferous %	Woods deciduous %	Woods mixed %	%Developed	%Agriculture	%Forested	%Open	Abundance Per m^2	Adjusted No. Benthic Species	Percent Tolerant	Percent Generalist, Omnivores, Insectivores	PercentRound-bodied Suckers	Percent Abundance Dominant Taxa	FIBI
Drainage area	**1**																																	
% Impervious	**0.095**	**1**																																
Impervious acres	**0.568**	**0.491**	**1**																															
Airport %	**0.173**	**0.175**	**0.224**	**1**																														
Commercial %	**0.193**	**0.537**	**0.486**	**0.174**	**1**																													
Forested wetland %	**0.251**	**-0.145**	0.085	-0.017	-0.041	**1**																												
Industrial %	**0.347**	**0.344**	**0.485**	**0.315**	**0.383**	0.025	**1**																											
Open space	**0.102**	**0.252**	**0.220**	**0.239**	**0.234**	**-0.128**	**0.262**	**1**																										
Wetland %	**0.428**	**0.189**	**0.433**	**0.142**	**0.233**	**0.269**	**0.409**	**0.122**	**1**																									
Pasture %	0.079	**-0.369**	**-0.165**	**-0.155**	**-0.198**	**0.249**	**-0.214**	**-0.209**	-0.046	**1**																								
Residential 1/8-ac. %	**0.187**	**0.484**	**0.428**	0.108	**0.375**	-0.095	**0.264**	**0.191**	**0.307**	**-0.357**	**1**																							
Residential 1/2-ac. %	**0.227**	**0.303**	**0.373**	0.103	**0.279**	0.008	**0.281**	0.050	**0.298**	**-0.260**	**0.348**	**1**																						
Residential 1/4-ac. %	**0.185**	**0.544**	**0.465**	0.091	**0.434**	**-0.198**	**0.331**	**0.184**	**0.275**	**-0.401**	**0.625**	**0.390**	**1**																					
Residential 1-ac. %	**0.226**	**0.285**	**0.370**	-0.025	**0.238**	**0.109**	**0.238**	0.043	**0.242**	**-0.133**	**0.171**	**0.460**	**0.241**	**1**																				
Residential 2-ac. %	-0.008	**-0.378**	**-0.235**	**-0.173**	**-0.312**	**0.248**	**-0.237**	**-0.234**	-0.088	**0.476**	**-0.461**	**-0.217**	**-0.469**	-0.043	**1**																			
Right-of-Way %	0.036	**-0.570**	**-0.270**	-0.109	**-0.342**	**0.171**	**-0.267**	**-0.252**	**-0.114**	**0.434**	**-0.400**	**-0.208**	**-0.435**	**-0.154**	**0.443**	**1**																		
Transportation %	0.089	**0.428**	**0.343**	**0.185**	**0.411**	**-0.122**	**0.371**	**0.216**	**0.176**	**-0.246**	**0.336**	**0.277**	**0.324**	**0.254**	**-0.157**	**-0.336**	**1**																	
Utility %	0.070	-0.063	0.020	0.043	-0.101	**0.132**	0.048	0.107	0.052	-0.059	-0.022	-0.058	-0.070	-0.043	-0.024	-0.090	-0.010	**1**																
Water %	**0.236**	0.087	**0.254**	0.035	**0.162**	**0.182**	**0.246**	**0.113**	**0.330**	-0.009	**0.168**	**0.185**	0.094	**0.205**	-0.023	0.015	**0.148**	0.013	**1**															
Woods %	0.100	**0.118**	**0.112**	-0.093	-0.059	**0.149**	-0.040	**-0.128**	0.077	-0.026	-0.015	**0.185**	-0.048	**0.297**	0.050	-0.085	-0.073	-0.012	0.037	**1**														
Woods coniferous %	**0.210**	0.063	**0.135**	**0.188**	-0.008	0.070	**0.139**	**0.261**	**0.214**	-0.089	0.098	**0.159**	0.010	**0.120**	**-0.171**	**-0.109**	0.072	**0.133**	0.030	0.107	**1**													
Woods deciduous %	**0.187**	0.030	**0.158**	-0.075	-0.010	-0.053	0.010	-0.067	0.069	0.005	0.083	0.052	0.074	0.013	-0.067	-0.037	0.095	**0.245**	-0.065	0.100	0.091	**1**												
Woods mixed %	**0.062**	**-0.374**	**-0.209**	**-0.127**	**-0.321**	**0.077**	**-0.076**	**-0.088**	**-0.082**	**0.112**	**-0.252**	**-0.190**	**-0.327**	**-0.133**	**0.138**	**0.154**	**-0.288**	**0.113**	**-0.081**	0.065	**0.158**	0.097	**1**											
%Developed	0.021	**0.592**	**0.385**	0.042	**0.394**	**-0.128**	**0.231**	**0.102**	**0.172**	**-0.319**	**0.412**	**0.347**	**0.518**	**0.332**	**-0.108**	**-0.431**	**0.410**	**-0.085**	**0.111**	**0.105**	**-0.134**	-0.043	**-0.524**	**1**										
%Agriculture	-0.019	**-0.476**	**-0.263**	**-0.163**	**-0.216**	**0.182**	**-0.310**	**-0.240**	**-0.178**	**0.600**	**-0.396**	**-0.245**	**-0.368**	**-0.168**	**0.402**	**0.712**	**-0.332**	**-0.170**	-0.054	**-0.115**	**-0.180**	-0.092	0.085	**-0.381**	**1**									
%Forested	0.028	**-0.404**	**-0.256**	-0.090	**-0.369**	**0.171**	**-0.138**	**-0.119**	-0.077	**0.114**	**-0.266**	**-0.224**	**-0.382**	**-0.149**	**0.125**	**0.170**	**-0.336**	**0.187**	-0.097	**0.136**	**0.212**	**0.128**	**0.782**	**-0.577**	0.051	**1**								
%Open	**0.115**	**0.244**	**0.229**	**0.248**	**0.241**	-0.064	**0.305**	**0.885**	**0.222**	**-0.197**	**0.228**	0.081	**0.162**	0.073	**-0.236**	**-0.256**	**0.225**	0.098	**0.201**	-0.074	**0.250**	-0.080	**-0.112**	**0.102**	**-0.241**	**-0.131**	**1**							
Abundance Per m^2	0.015	0.012	0.054	-0.085	0.012	**-0.113**	-0.012	-0.046	-0.001	-0.083	**0.136**	0.035	**0.132**	-0.049	**-0.127**	0.028	-0.031	-0.082	-0.048	0.040	-0.043	**0.176**	-0.009	0.001	-0.023	-0.005	-0.042	**1**						
Adjusted No. Benthic Species	**0.171**	-0.032	**0.117**	**0.138**	-0.013	0.068	0.043	-0.079	0.082	**0.208**	0.056	0.003	-0.009	-0.022	**0.115**	**0.198**	0.045	**-0.129**	0.020	-0.106	0.048	0.094	-0.024	-0.040	**0.158**	-0.038	-0.095	0.096	**1**					
Percent Tolerant	**-0.246**	**-0.141**	**-0.244**	-0.025	**-0.176**	-0.105	**-0.160**	-0.070	**-0.162**	-0.062	-0.108	-0.062	**-0.155**	**-0.172**	0.026	**0.188**	**-0.147**	-0.032	-0.023	-0.053	-0.012	-0.014	0.018	**-0.151**	0.075	0.048	-0.070	**0.132**	0.029	**1**				
Percent Generalist, Omnivores, Insectivores	**-0.149**	0.013	-0.100	**-0.141**	0.080	-0.072	-0.104	-0.062	-0.081	**-0.163**	0.019	0.038	0.049	-0.097	**-0.162**	-0.042	-0.078	-0.047	-0.075	0.018	-0.052	0.002	0.039	-0.038	-0.028	0.052	-0.087	**0.135**	**-0.251**	**0.349**	**1**			
PercentRound-bodied Suckers	**0.318**	-0.042	**0.216**	**0.236**	0.030	0.025	**0.205**	-0.036	**0.211**	0.087	0.106	0.111	0.108	0.044	-0.051	0.069	0.059	0.017	0.055	**-0.144**	0.053	**0.224**	0.063	-0.048	0.031	0.013	-0.026	**0.121**	**0.207**	**-0.201**	**-0.126**	**1**		
Percent Abundance Dominant Taxa	**-0.317**	**-0.108**	**-0.303**	**-0.130**	**-0.167**	**-0.138**	**-0.275**	-0.061	**-0.258**	-0.084	**-0.128**	**-0.110**	**-0.129**	**-0.169**	-0.023	**0.116**	**-0.192**	-0.034	**-0.160**	0.000	-0.065	-0.018	-0.020	**-0.113**	0.062	0.029	-0.097	**0.150**	**-0.122**	**0.474**	**0.409**	**-0.260**	**1**	
FIBI	**0.407**	0.094	**0.378**	**0.171**	**0.184**	0.088	**0.279**	0.080	**0.278**	0.061	**0.259**	**0.130**	**0.219**	**0.119**	**-0.110**	0.046	**0.164**	-0.038	**0.133**	**-0.133**	0.098	**0.126**	-0.075	0.045	0.025	-0.098	**0.103**	**0.267**	**0.477**	**-0.255**	**-0.304**	**0.471**	**-0.364**	**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: Summer Physical Habitat Versus Fish Variables (Large Sites)

Variables	**Abundance Per m2**	**Adjusted No. Benthic Species**	**Percent Tolerant**	**Percent Generalist, Omnivores, Insectivores**	**PercentRound-bodied Suckers**	**Percent Abundance Dominant Taxa**	**FIBI**	**Instream Habitat**	**Bank Stability**	**Epifaunal Substrate**	**Remoteness**	**Percent Shading**	**# Woody Debris/Rootwads**	**Remoteness Score**	**Epifaunal Substrate Score**	**Shading Score**	**Instream Habitat Score**	**Bank Stability Score**	**Woody Debris Score**	**PHI Score**	**Bank Stability (LB)**	**Bank Stability (RB)**	**Bank Stability (combined)**	**Vegetative Protection (LB)**	**Vegetative Protection (RB)**	**Vegetative Protection (combined)**	**Channel Flow**	**Channel Alteration**	**Channel Sinuosity**	**Pool Substrate**	**Pool Variability**	**Riparian Zone Width (LB)**	**Riparian Zone Width (RB)**	**Riparian Zone Width (combined)**	**Sediment Deposition**	**Epi. Substrate/Avail. Cover**	**RBP Score**
Abundance Per m2	**1**																																				
Adjusted No. Benthic Species	0.10	**1**																																			
Percent Tolerant	**0.13**	0.03	**1**																																		
Percent Generalist, Omnivores, Insectivores	**0.14**	**-0.25**	**0.35**	**1**																																	
PercentRound-bodied Suckers	**0.12**	**0.21**	**-0.20**	**-0.13**	**1**																																
Percent Abundance Dominant Taxa	**0.15**	**-0.12**	**0.47**	**0.41**	**-0.26**	**1**																															
FIBI	**0.27**	**0.48**	**-0.26**	**-0.30**	**0.47**	**-0.36**	**1**																														
Instream Habitat	**0.16**	**0.21**	**-0.13**	**-0.17**	**0.31**	**-0.29**	**0.50**	**1**																													
Bank Stability	-0.05	**-0.14**	**-0.10**	-0.11	-0.07	**-0.12**	0.04	**0.14**	**1**																												
Epifaunal Substrate	0.10	**0.22**	**-0.15**	**-0.20**	**0.21**	**-0.27**	**0.43**	**0.77**	**0.19**	**1**																											
Remoteness	0.01	0.01	0.02	0.05	-0.06	0.08	0.01	0.09	0.01	**0.13**	**1**																										
Percent Shading	**-0.16**	**-0.12**	**0.14**	0.11	**-0.30**	**0.24**	**-0.21**	**-0.19**	0.07	**-0.11**	**0.21**	**1**																									
# Woody Debris/Rootwads	**0.11**	**0.15**	0.00	-0.05	0.11	-0.04	**0.29**	**0.43**	0.05	**0.39**	**0.22**	0.00	**1**																								
Remoteness Score	0.01	0.01	0.02	0.05	-0.06	0.08	0.01	0.09	0.01	**0.13**	**1.00**	**0.21**	**0.22**	**1**																							
Epifaunal Substrate Score	**0.12**	**0.18**	-0.07	**-0.16**	0.10	**-0.16**	**0.30**	**0.61**	**0.19**	**0.81**	**0.19**	-0.02	**0.36**	**0.19**	**1**																						
Shading Score	**-0.15**	**-0.12**	**0.12**	**0.11**	**-0.28**	**0.23**	**-0.20**	**-0.18**	0.07	-0.09	**0.20**	**0.97**	0.01	**0.20**	-0.01	**1**																					
Instream Habitat Score	**0.21**	**0.13**	0.01	-0.09	**0.17**	**-0.10**	**0.30**	**0.67**	**0.14**	**0.57**	**0.15**	-0.06	**0.38**	**0.15**	**0.63**	-0.05	**1**																				
Bank Stability Score	-0.05	**-0.14**	**-0.10**	-0.11	-0.07	**-0.12**	0.04	**0.14**	**1.00**	**0.19**	0.01	0.07	0.05	0.01	**0.19**	0.07	**0.14**	**1**																			
Woody Debris Score	**0.12**	0.00	**0.16**	0.08	-0.11	**0.15**	0.01	**0.13**	0.03	**0.12**	**0.28**	**0.21**	**0.62**	**0.28**	**0.23**	**0.20**	**0.30**	0.03	**1**																		
PHI Score	0.07	0.03	0.00	-0.03	-0.07	-0.01	0.08	**0.35**	**0.29**	**0.43**	**0.42**	**0.27**	**0.40**	**0.42**	**0.54**	**0.26**	**0.51**	**0.29**	**0.47**	**1**																	
Bank Stability (LB)	**-0.14**	-0.09	-0.08	-0.06	-0.08	-0.03	0.00	0.09	**0.68**	**0.17**	0.05	0.10	0.03	0.05	**0.17**	0.10	0.10	**0.68**	0.01	**0.24**	**1**																
Bank Stability (RB)	-0.08	-0.07	**-0.11**	-0.09	-0.05	-0.01	0.05	**0.15**	**0.66**	**0.20**	0.07	0.08	0.08	0.07	**0.21**	0.07	**0.15**	**0.66**	0.04	**0.29**	**0.76**	**1**															
Bank Stability (combined)	**-0.12**	-0.08	-0.10	-0.08	-0.06	-0.03	0.03	**0.12**	**0.70**	**0.19**	0.05	0.09	0.05	0.05	**0.19**	0.09	**0.12**	**0.70**	0.02	**0.26**	**0.90**	**0.90**	**1**														
Vegetative Protection (LB)	0.03	**-0.22**	-0.01	0.04	-0.08	0.00	0.06	**0.23**	**0.34**	**0.27**	0.09	**0.17**	**0.13**	0.09	**0.25**	**0.17**	**0.21**	**0.34**	0.10	**0.31**	**0.32**	**0.29**	**0.31**	**1**													
Vegetative Protection (RB)	0.06	**-0.19**	-0.03	0.04	-0.08	0.02	0.08	**0.25**	**0.33**	**0.29**	0.09	**0.15**	**0.14**	0.09	**0.27**	**0.16**	**0.22**	**0.33**	**0.11**	**0.32**	**0.28**	**0.29**	**0.29**	**0.89**	**1**												
Vegetative Protection (combined)	0.04	**-0.21**	-0.03	0.04	-0.08	0.01	0.07	**0.24**	**0.33**	**0.27**	0.08	**0.16**	**0.13**	0.08	**0.26**	**0.17**	**0.21**	**0.33**	0.10	**0.31**	**0.30**	**0.28**	**0.29**	**0.95**	**0.95**	**1**											
Channel Flow	0.00	0.01	-0.08	-0.05	0.09	**-0.12**	**0.22**	**0.42**	**0.22**	**0.47**	0.06	-0.06	**0.28**	0.06	**0.42**	-0.05	**0.35**	**0.22**	**0.14**	**0.26**	**0.18**	**0.16**	**0.17**	**0.30**	**0.34**	**0.32**	**1**										
Channel Alteration	-0.01	**0.13**	0.07	0.02	-0.07	**0.12**	0.07	0.03	-0.03	0.10	**0.37**	**0.24**	**0.13**	**0.37**	**0.12**	**0.23**	0.03	-0.03	**0.17**	**0.20**	0.03	0.03	0.03	0.04	0.04	0.04	0.01	**1**									
Channel Sinuosity	**0.27**	**0.13**	0.06	-0.01	0.03	0.06	**0.25**	**0.20**	0.07	**0.21**	**0.15**	0.00	**0.16**	**0.15**	**0.20**	0.01	**0.19**	0.07	**0.13**	**0.16**	0.01	0.06	0.03	**0.16**	**0.16**	**0.15**	-0.02	**0.19**	**1**								
Pool Substrate	**0.12**	**0.16**	-0.10	**-0.16**	**0.24**	**-0.25**	**0.41**	**0.61**	**0.19**	**0.63**	0.05	-0.06	**0.31**	0.05	**0.54**	-0.05	**0.46**	**0.19**	0.10	**0.31**	**0.15**	**0.15**	**0.15**	**0.24**	**0.24**	**0.24**	**0.36**	0.02	**0.19**	**1**							
Pool Variability	**0.17**	0.10	**-0.12**	-0.01	**0.30**	**-0.20**	**0.40**	**0.65**	**0.11**	**0.54**	0.03	**-0.13**	**0.34**	0.03	**0.43**	**-0.12**	**0.50**	**0.11**	**0.11**	**0.25**	0.08	**0.11**	0.09	**0.22**	**0.23**	**0.22**	**0.36**	0.02	**0.18**	**0.50**	**1**						
Riparian Zone Width (LB)	0.06	0.05	-0.01	0.01	-0.02	0.09	**0.13**	**0.15**	0.05	**0.19**	**0.32**	**0.22**	**0.20**	**0.32**	**0.17**	**0.22**	0.10	0.05	**0.16**	**0.24**	0.06	0.04	0.05	**0.18**	**0.14**	**0.16**	0.05	**0.51**	**0.32**	**0.14**	**0.13**	**1**					
Riparian Zone Width (RB)	**0.15**	-0.01	-0.05	0.00	0.04	0.04	**0.15**	**0.21**	**0.14**	**0.29**	**0.38**	**0.14**	**0.25**	**0.38**	**0.29**	**0.14**	**0.18**	**0.13**	**0.20**	**0.33**	**0.13**	**0.15**	**0.15**	**0.26**	**0.32**	**0.29**	**0.21**	**0.40**	**0.19**	**0.19**	**0.17**	**0.37**	**1**				
Riparian Zone Width (combined)	**0.11**	0.01	-0.04	0.01	0.03	0.07	**0.14**	**0.19**	0.10	**0.27**	**0.39**	**0.20**	**0.22**	**0.39**	**0.26**	**0.20**	**0.13**	0.10	**0.17**	**0.32**	0.10	0.09	0.10	**0.25**	**0.25**	**0.25**	**0.13**	**0.48**	**0.27**	**0.19**	**0.15**	**0.75**	**0.73**	**1**			
Sediment Deposition	-0.05	-0.07	-0.04	-0.05	-0.05	-0.02	0.07	**0.20**	**0.21**	**0.27**	0.06	0.00	**0.12**	0.06	**0.28**	0.00	**0.21**	**0.21**	0.07	**0.18**	**0.18**	**0.17**	**0.17**	**0.30**	**0.32**	**0.30**	**0.45**	0.01	0.00	**0.25**	**0.18**	0.04	**0.15**	**0.11**	**1**		
Epi. Substrate/Avail. Cover	**0.12**	**0.22**	**-0.15**	**-0.20**	**0.27**	**-0.29**	**0.47**	**0.89**	**0.17**	**0.90**	**0.12**	**-0.14**	**0.40**	**0.12**	**0.72**	**-0.13**	**0.63**	**0.17**	**0.12**	**0.40**	**0.14**	**0.18**	**0.16**	**0.26**	**0.27**	**0.26**	**0.45**	0.07	**0.21**	**0.65**	**0.60**	**0.18**	**0.25**	**0.24**	**0.26**	**1**	
RBP Score	0.09	0.04	**-0.11**	-0.10	0.10	**-0.12**	**0.29**	**0.55**	**0.35**	**0.64**	**0.15**	-0.03	**0.33**	**0.15**	**0.58**	-0.01	**0.45**	**0.35**	**0.14**	**0.43**	**0.34**	**0.35**	**0.35**	**0.50**	**0.52**	**0.51**	**0.53**	**0.17**	**0.21**	**0.53**	**0.48**	**0.27**	**0.36**	**0.37**	**0.43**	**0.62**	**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: Fish Variables (Large Sites) Versus Water Quality (Summer In Situ). Sites dry during summer have been excluded.

Variables	Chloride	Total Phosphorus	Total Nitrogen	Orthophosphate	Ammonia N	Nitrite-N	Nitrate-N	TKN	TOC	DOC	Magnesium	Calcium	Hardness	Copper	Zinc	Lead	Turbidity (Lab)	Abundance Per m3	Adjusted No. Benthic Species	Percent Tolerant	Percent Generalist, Omnivores, Insectivores	PercentRound-bodied Suckers	Percent Abundance Dominant Taxa	FIBI	Conductivity (In Situ)	Dissolved Oxygen (In Situ)	pH (In Situ)	Turbidity (In Situ)	Water Temperature
Chloride	**1**																												
Total Phosphorus	**-0.181**	**1**																											
Total Nitrogen	0.070	**0.168**	**1**																										
Orthophosphate	**-0.202**	**0.579**	**0.307**	**1**																									
Ammonia N	**0.172**	**0.101**	**0.182**	0.090	**1**																								
Nitrite-N	0.016	**0.214**	**0.380**	**0.361**	**0.281**	**1**																							
Nitrate-N	0.070	0.091	**0.619**	**0.124**	-0.027	**0.152**	**1**																						
TKN	**0.149**	**0.181**	**0.220**	**0.260**	**0.406**	**0.363**	**-0.124**	**1**																					
TOC	**-0.114**	**0.110**	0.060	**0.272**	0.069	**0.208**	**-0.127**	**0.343**	**1**																				
DOC	**-0.106**	0.088	0.045	**0.246**	0.079	**0.210**	**-0.140**	**0.345**	**0.937**	**1**																			
Magnesium	**0.599**	**-0.172**	**0.133**	**-0.264**	**0.209**	**0.112**	0.078	**0.184**	**-0.192**	**-0.186**	**1**																		
Calcium	**0.421**	**0.137**	**0.209**	0.062	0.072	**0.224**	**0.141**	**0.264**	-0.023	-0.036	**0.391**	**1**																	
Hardness	**0.516**	0.051	**0.169**	0.027	**0.134**	**0.200**	**0.137**	**0.218**	-0.024	-0.031	**0.522**	**0.869**	**1**																
Copper	**0.168**	**-0.119**	**0.116**	0.034	0.074	**0.169**	-0.062	**0.328**	**0.445**	**0.462**	0.070	0.086	**0.101**	**1**															
Zinc	**0.143**	**-0.192**	0.050	**-0.197**	**0.132**	-0.025	0.039	-0.055	**-0.107**	-0.094	**0.169**	**-0.112**	-0.036	0.078	**1**														
Lead	-0.015	0.039	0.073	**0.136**	**0.133**	**0.147**	-0.074	**0.275**	**0.504**	**0.509**	**-0.164**	-0.057	-0.042	**0.512**	0.069	**1**													
Turbidity (Lab)	0.011	**0.230**	-0.063	0.005	**0.215**	0.068	-0.044	**0.097**	0.076	0.083	-0.017	**0.107**	0.069	-0.045	-0.032	**0.162**	**1**												
Abundance Per m3	-0.054	-0.106	0.007	-0.072	-0.128	-0.121	0.063	-0.119	0.078	0.077	-0.032	-0.140	-0.126	0.098	-0.084	0.045	-0.062	**1**											
Adjusted No. Benthic Species	-0.013	-0.017	0.072	-0.033	-0.109	-0.020	**0.221**	**-0.202**	-0.112	-0.114	0.021	-0.033	0.000	-0.131	0.011	-0.118	-0.045	0.096	**1**										
Percent Tolerant	**-0.148**	-0.035	0.008	0.019	-0.099	-0.071	0.110	-0.130	0.030	0.024	**-0.197**	-0.123	**-0.137**	-0.011	-0.015	0.075	0.014	0.132	0.029	**0.9997**									
Percent Generalist, Omnivores, Insectivores	-0.063	-0.064	-0.088	-0.115	0.011	-0.115	-0.035	0.010	0.068	0.067	-0.070	-0.021	-0.025	0.073	-0.025	0.082	0.109	0.135	**-0.251**	**0.349**	**0.9999**								
PercentRound-bodied Suckers	0.052	0.034	0.068	0.095	-0.003	0.110	0.051	0.011	0.061	0.055	0.027	0.033	0.031	0.004	-0.070	-0.016	-0.023	0.121	**0.207**	**-0.201**	-0.126	**1**							
Percent Abundance Dominant Taxa	**-0.190**	-0.033	-0.064	-0.044	-0.064	-0.121	0.027	-0.125	0.018	0.020	**-0.193**	-0.109	-0.128	-0.039	0.015	0.031	0.034	**0.150**	-0.122	**0.474**	**0.409**	**-0.260**	**0.9999**						
FIBI	0.086	-0.095	0.076	-0.061	-0.043	0.023	0.125	-0.064	0.021	0.018	0.084	-0.032	0.004	0.028	-0.009	-0.027	-0.063	**0.267**	**0.477**	**-0.255**	**-0.304**	**0.471**	**-0.364**	**1**					
Conductivity (In Situ)	**0.558**	-0.068	**0.151**	-0.041	**0.149**	0.100	**0.139**	**0.128**	-0.008	-0.013	**0.450**	**0.445**	**0.496**	**0.134**	0.001	0.048	0.042	-0.011	-0.015	-0.116	-0.064	0.123	**-0.164**	0.095	**1**				
Dissolved Oxygen (In Situ)	-0.055	**0.144**	**0.234**	0.116	-0.056	0.086	**0.349**	-0.125	**-0.196**	**-0.206**	-0.068	0.048	0.038	**-0.211**	-0.009	**-0.171**	-0.010	**-0.155**	**0.243**	0.027	-0.086	-0.013	-0.069	0.062	0.016	**1**			
pH (In Situ)	**0.216**	0.060	**0.172**	0.038	0.008	**0.158**	**0.192**	0.108	-0.049	-0.062	**0.164**	**0.404**	**0.368**	0.014	**-0.127**	-0.061	0.070	-0.103	0.046	-0.069	-0.010	0.105	-0.106	0.067	**0.268**	**0.260**	**1**		
Turbidity (In Situ)	-0.098	0.081	-0.027	0.064	0.071	0.071	-0.067	0.030	0.069	0.055	-0.136	-0.019	-0.046	0.028	-0.028	0.070	0.048	-0.004	-0.138	0.114	0.083	0.022	0.069	-0.082	-0.004	-0.015	0.063	**1**	
Water Temperature	0.046	0.059	0.015	0.058	0.018	**0.146**	-0.015	0.119	0.117	0.100	0.079	0.135	**0.137**	0.087	-0.085	0.026	0.050	0.095	-0.043	-0.070	-0.023	0.125	-0.033	0.106	**0.175**	**-0.135**	**0.205**	**0.182**	**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: Benthic Macroinvertebrates Versus Land Use Variables (Large Sites)

Variables	Drainage area	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI	% Impervious	Impervious acres	Airport %	Commercial %	Forested wetland %	Industrial %	Open space	Wetland %	Pasture %	Residential 1/8-ac. %	Residential 1/2-ac. %	Residential 1/4-ac. %	Residential 1-ac. %	Residential 2-ac. %	Residential woods %	Right-of-Way %	Transportation %	Utility %	Water %	Woods %	Woods coniferous %	Woods deciduous %	Woods mixed %	%Developed	%Agriculture	%Forested	%Open
Drainage area	**1**																																		
No. Taxa	**0.191**	**1**																																	
No. EPT Taxa	**0.295**	**0.397**	**1**																																
% Ephem	**0.296**	**0.166**	**0.450**	**1**																															
No. Ephem Taxa	**0.298**	**0.176**	**0.489**	**0.921**	**1**																														
% Intolerant	0.051	**0.159**	**0.264**	**0.184**	**0.182**	**1**																													
No. Scraper Taxa	**0.243**	**0.357**	**0.275**	**0.165**	**0.164**	0.038	**1**																												
% climbers	0.087	**0.244**	**0.170**	**0.169**	**0.184**	**-0.117**	**0.200**	**1**																											
BIBI	**0.306**	**0.521**	**0.628**	**0.547**	**0.571**	**0.318**	**0.505**	**0.307**	**1**																										
% Impervious	**0.095**	0.028	**-0.185**	**-0.302**	**-0.318**	**-0.299**	**0.164**	-0.031	**-0.161**	**1**																									
Impervious acres	**0.568**	**0.135**	0.082	0.046	0.040	**-0.165**	**0.307**	0.063	**0.131**	**0.491**	**1**																								
Airport %	**0.173**	-0.008	0.077	0.115	0.094	**-0.137**	0.083	**-0.128**	0.037	**0.175**	**0.224**	**1**																							
Commercial %	**0.193**	**0.107**	-0.056	**-0.126**	**-0.123**	**-0.245**	**0.162**	0.049	-0.018	**0.537**	**0.486**	**0.174**	**1**																						
Forested wetland %	**0.251**	**0.197**	**0.230**	**0.185**	**0.222**	**0.142**	0.077	0.097	**0.261**	**-0.145**	0.085	-0.017	-0.041	**1**																					
Industrial %	**0.347**	**0.148**	**0.125**	0.041	0.033	-0.084	**0.289**	0.023	**0.146**	**0.344**	**0.485**	**0.315**	**0.383**	0.025	**1**																				
Open space	**0.102**	-0.028	0.023	-0.098	-0.111	-0.084	0.071	-0.033	-0.052	**0.252**	**0.220**	**0.239**	**0.234**	**-0.128**	**0.262**	**1**																			
Wetland %	**0.428**	**0.148**	**0.189**	**0.133**	**0.129**	0.016	**0.296**	0.003	**0.231**	**0.189**	**0.433**	**0.142**	**0.233**	**0.269**	**0.409**	**0.122**	**1**																		
Pasture %	0.079	**0.107**	**0.157**	**0.291**	**0.313**	**0.166**	0.010	**0.180**	**0.237**	**-0.369**	**-0.165**	**-0.155**	**-0.198**	**0.249**	**-0.214**	**-0.209**	-0.046	**1**																	
Residential 1/8-ac. %	**0.187**	0.047	-0.060	**-0.129**	**-0.155**	**-0.205**	**0.298**	-0.005	0.001	**0.484**	**0.428**	0.108	**0.375**	-0.095	**0.264**	**0.191**	**0.307**	**-0.357**	**1**																
Residential 1/2-ac. %	**0.227**	0.094	-0.020	-0.089	-0.093	-0.080	**0.210**	-0.022	0.050	**0.303**	**0.373**	0.103	**0.279**	0.008	**0.281**	0.050	**0.298**	**-0.260**	**0.348**	**1**															
Residential 1/4-ac. %	**0.185**	0.048	**-0.116**	**-0.140**	**-0.166**	**-0.223**	**0.214**	0.009	-0.058	**0.544**	**0.465**	0.091	**0.434**	**-0.198**	**0.331**	**0.184**	**0.275**	**-0.401**	**0.625**	**0.390**	**1**														
Residential 1-ac. %	**0.226**	**0.127**	0.037	-0.080	-0.079	-0.047	**0.163**	0.079	0.083	**0.285**	**0.370**	-0.025	**0.238**	**0.109**	**0.238**	0.043	**0.242**	**-0.133**	**0.171**	**0.460**	**0.241**	**1**													
Residential 2-ac. %	-0.008	0.075	**0.121**	**0.189**	**0.215**	0.090	-0.052	**0.108**	**0.140**	**-0.378**	**-0.235**	**-0.173**	**-0.312**	**0.248**	**-0.237**	**-0.234**	-0.088	**0.476**	**-0.461**	**-0.217**	**-0.469**	-0.043	**1**												
Residential woods %	**-0.008**	**0.075**	**0.121**	**0.189**	**0.215**	**0.090**	**-0.052**	**0.108**	**0.140**	**-0.378**	**-0.235**	**-0.173**	**-0.312**	**0.248**	**-0.237**	**-0.234**	**-0.088**	**0.476**	**-0.461**	**-0.217**	**-0.469**	**-0.043**	**1.000**	**1**											
Right-of-Way %	0.036	0.094	**0.203**	**0.357**	**0.385**	**0.135**	-0.076	**0.116**	**0.230**	**-0.570**	**-0.270**	-0.109	**-0.342**	**0.171**	**-0.267**	**-0.252**	**-0.114**	**0.434**	**-0.400**	**-0.208**	**-0.435**	**-0.154**	**0.443**	**0.000**	**1**										
Transportation %	0.089	0.035	-0.069	**-0.138**	**-0.153**	**-0.286**	**0.182**	0.029	-0.066	**0.428**	**0.343**	**0.185**	**0.411**	**-0.122**	**0.371**	**0.216**	**0.176**	**-0.246**	**0.336**	**0.277**	**0.324**	**0.254**	**-0.157**	**0.000**	**-0.336**	**1**									
Utility %	0.070	0.015	**0.130**	0.054	0.061	**0.146**	0.088	-0.092	0.078	-0.063	0.020	0.043	-0.101	**0.132**	0.048	0.107	0.052	-0.059	-0.022	-0.058	-0.070	-0.043	-0.024	**0.000**	-0.090	-0.010	**1**								
Water %	**0.236**	0.064	**0.112**	0.064	0.072	-0.027	**0.153**	0.010	**0.122**	0.087	**0.254**	0.035	**0.162**	**0.182**	**0.246**	**0.113**	**0.330**	-0.009	**0.168**	**0.185**	0.094	**0.205**	-0.023	**0.000**	0.015	**0.148**	0.013	**1**							
Woods %	0.100	0.057	0.008	**-0.148**	**-0.153**	**0.136**	-0.027	0.027	-0.011	**0.118**	**0.112**	-0.093	-0.059	**0.149**	-0.040	**-0.128**	0.077	-0.026	-0.015	**0.185**	-0.048	**0.297**	0.050	**0.000**	-0.085	-0.073	-0.012	0.037	**1**						
Woods coniferous %	**0.210**	**0.151**	**0.210**	0.013	0.010	**0.150**	0.067	-0.078	**0.112**	0.063	**0.135**	**0.188**	-0.008	0.070	**0.139**	**0.261**	**0.214**	-0.089	0.098	**0.159**	0.010	**0.120**	**-0.171**	**0.000**	**-0.109**	0.072	**0.133**	0.030	0.107	**1**					
Woods deciduous %	**0.187**	-0.075	0.068	0.057	0.053	0.042	0.036	-0.068	-0.007	0.030	**0.158**	-0.075	-0.010	-0.053	0.010	-0.067	0.069	0.005	0.083	0.052	0.074	0.013	-0.067	**0.000**	-0.037	0.095	**0.245**	-0.065	0.100	0.091	**1**				
Woods mixed %	0.062	0.094	**0.181**	**0.132**	**0.129**	**0.288**	-0.055	0.026	**0.137**	**-0.374**	**-0.209**	**-0.127**	**-0.321**	0.077	-0.076	-0.088	-0.082	**0.112**	**-0.252**	**-0.190**	**-0.327**	**-0.133**	**0.138**	**0.000**	**0.154**	**-0.288**	**0.113**	-0.081	0.065	**0.158**	0.097	**1**			
%Developed	0.021	-0.028	**-0.206**	**-0.250**	**-0.259**	**-0.316**	**0.155**	-0.029	**-0.156**	**0.592**	**0.385**	0.042	**0.394**	**-0.128**	**0.231**	**0.102**	**0.172**	**-0.319**	**0.412**	**0.347**	**0.518**	**0.332**	**-0.108**	**0.000**	**-0.431**	**0.410**	-0.085	**0.111**	0.105	**-0.134**	-0.043	**-0.524**	**1**		
%Agriculture	-0.019	0.098	0.101	**0.279**	**0.298**	0.082	-0.066	**0.211**	**0.177**	**-0.476**	**-0.263**	**-0.163**	**-0.216**	**0.182**	**-0.310**	**-0.240**	**-0.178**	**0.600**	**-0.396**	**-0.245**	**-0.368**	**-0.168**	**0.402**	**0.000**	**0.712**	**-0.332**	**-0.170**	-0.054	**-0.115**	**-0.180**	-0.092	0.085	**-0.381**	**1**	
%Forested	0.028	0.055	**0.196**	**0.146**	**0.149**	**0.343**	**-0.107**	-0.027	**0.128**	**-0.404**	**-0.256**	-0.090	**-0.369**	**0.171**	**-0.138**	**-0.119**	-0.077	**0.114**	**-0.266**	**-0.224**	**-0.382**	**-0.149**	**0.125**	**0.000**	**0.170**	**-0.336**	**0.187**	-0.097	**0.136**	**0.212**	**0.128**	**0.782**	**-0.577**	0.051	**1**
%Open	**0.115**	-0.019	0.042	-0.087	-0.101	-0.048	0.105	-0.063	-0.018	**0.244**	**0.229**	**0.248**	**0.241**	-0.064	**0.305**	**0.885**	**0.222**	**-0.197**	**0.228**	0.081	**0.162**	0.073	**-0.236**	**0.000**	**-0.256**	**0.225**	0.098	**0.201**	-0.074	**0.250**	-0.080	**-0.112**	**0.102**	**-0.241**	**-0.131**	**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: Benthic Macroinvertebrates Versus Geomorphic Variables (Large Sites

Variables	**No. Taxa**	**No. EPT Taxa**	**% Ephem**	**No. Ephem Taxa**	**% Intolerant**	**No. Scraper Taxa**	**% climbers**	**BIBI**	**Entrenchment Ratio**	**Bankfull Width**	**Mean Depth**	**Width:Depth Ratio**	**Bankfull Area**	**Water Surface Slope (%)**	**Water Surface Slope (ft)**	**Bankfull Discharge**	**Sinuosity**	**Flood-Prone Width**	**D50**
No. Taxa	**1**																		
No. EPT Taxa	**0.40**	**1**																	
% Ephem	**0.17**	**0.45**	**1**																
No. Ephem Taxa	**0.18**	**0.49**	**0.92**	**1**															
% Intolerant	**0.16**	**0.26**	**0.18**	**0.18**	**1**														
No. Scraper Taxa	**0.36**	**0.28**	**0.17**	**0.16**	0.04	**1**													
% climbers	**0.24**	**0.17**	**0.17**	**0.18**	**-0.12**	**0.20**	**1**												
BIBI	**0.52**	**0.63**	**0.55**	**0.57**	**0.32**	**0.51**	**0.31**	**1**											
Entrenchment Ratio	0.09	0.03	0.01	0.00	**0.13**	0.07	-0.04	0.09	**1**										
Bankfull Width	**0.12**	**0.27**	**0.23**	**0.24**	-0.05	**0.26**	**0.18**	**0.27**	-0.08	**1**									
Bankfull Area	**0.19**	**0.28**	**0.29**	**0.29**	0.00	**0.30**	**0.19**	**0.34**	0.06	**0.66**	**1**								
Mean Depth	**0.18**	**0.22**	**0.25**	**0.25**	0.07	**0.21**	**0.14**	**0.31**	**0.22**	**0.30**	**0.63**	**1**							
Width:Depth Ratio	-0.05	0.08	0.03	0.03	**-0.12**	0.05	0.05	-0.01	**-0.25**	**0.43**	0.09	**-0.27**	**1**						
Water Surface Slope (%)	-0.09	-0.06	**-0.16**	**-0.17**	-0.06	-0.07	0.00	**-0.12**	-0.05	**-0.16**	**-0.23**	**-0.20**	0.05	**1**					
Water Surface Slope (ft)	-0.08	-0.06	**-0.15**	**-0.17**	-0.07	-0.06	0.04	**-0.11**	-0.06	**-0.17**	**-0.24**	**-0.21**	0.04	**0.89**	**1**				
Bankfull Discharge	**0.17**	**0.31**	**0.21**	**0.22**	-0.02	**0.20**	**0.21**	**0.28**	0.01	**0.44**	**0.63**	**0.58**	0.02	0.10	0.06	**1**			
Sinuosity	-0.04	0.04	0.08	0.06	0.02	-0.02	-0.01	0.00	-0.03	0.05	0.04	0.04	0.04	**0.10**	0.10	0.06	**1**		
Flood-Prone Width	**0.14**	**0.17**	**0.11**	0.11	**0.11**	**0.20**	0.02	**0.21**	**0.61**	**0.31**	**0.36**	**0.33**	0.00	**-0.16**	**-0.16**	**0.17**	-0.01	**1**	
D50	**0.12**	**0.17**	0.10	0.10	**-0.10**	**0.12**	0.06	**0.12**	**-0.23**	**0.25**	**0.20**	**0.10**	**0.15**	**0.11**	0.09	**0.23**	**0.16**	**-0.10**	**1**

Values in bold are different from 0 with a significance level alpha=0.0

Highlighted values are different from 0 with a significance level alpha=0.00

Kendall Correlation Matrix: Spring Physical Habitat Versus Benthic Macroinvertebrate Variables (Large Sites)

Variables	**No. Taxa**	**No. EPT Taxa**	**% Ephem**	**No. Ephem Taxa**	**% Intolerant**	**No. Scraper Taxa**	**% climbers**	**BIBI**	**Instream Habitat**	**Bank Stability**	**Epifaunal Substrate**	**Remoteness**	**Percent Shading**	**# Woody Debris/Rootwads**	**Remoteness Score**	**Epifaunal Substrate Score**	**Shading Score**	**Instream Habitat Score**	**Bank Stability Score**	**Woody Debris Score**	**PHI Score**	**Bank Stability (LB)**	**Bank Stability (RB)**	**Bank Stability (combined)**	**Channel Flow**	**Vegetative Protection (LB)**	**Vegetative Protection (RB)**	**Vegetative Protection (combined)**	**Channel Alteration**	**Channel Sinuosity**	**Pool Substrate**	**Pool Variability**	**Riparian Zone Width (LB)**	**Riparian Zone Width (RB)**	**Riparian Zone Width (combined)**	**Epi. Substrate/Avail. Cover**	**Sediment Deposition**	**RBP Score**	**RBP %**
No. Taxa	**1**																																						
No. EPT Taxa	**0.40**	**1**																																					
% Ephem	**0.17**	**0.45**	**1**																																				
No. Ephem Taxa	**0.18**	**0.49**	**0.92**	**1**																																			
% Intolerant	**0.16**	**0.26**	**0.18**	**0.18**	**1**																																		
No. Scraper Taxa	**0.36**	**0.28**	**0.17**	0.16	0.04	**1**																																	
% climbers	**0.24**	**0.17**	**0.17**	**0.18**	-0.12	**0.20**	**1**																																
BIBI	**0.52**	**0.63**	**0.55**	**0.57**	**0.32**	**0.51**	**0.31**	**1**																															
Instream Habitat	0.11	**0.23**	0.12	0.12	0.09	**0.17**	0.06	**0.19**	**1**																														
Bank Stability	0.04	-0.01	-0.12	-0.12	0.04	0.06	-0.10	-0.04	0.11	**1**																													
Epifaunal Substrate	0.13	**0.31**	0.15	0.15	**0.21**	0.13	0.04	**0.24**	**0.71**	**0.13**	**1**																												
Remoteness	-0.01	0.08	0.07	0.07	**0.18**	-0.10	-0.02	0.05	0.03	-0.05	0.08	**1**																											
Percent Shading	-0.01	-0.01	-0.05	-0.05	0.09	**-0.19**	0.00	-0.06	-0.11	0.07	-0.03	**0.18**	**1**																										
# Woody Debris/Rootwads	-0.02	0.06	0.06	0.08	0.06	0.03	-0.02	0.07	**0.28**	0.05	**0.26**	**0.14**	0.11	**1**																									
Remoteness Score	-0.01	0.08	0.07	0.07	**0.18**	-0.10	-0.02	0.05	0.03	-0.05	0.08	**1.00**	**0.18**	**0.14**	**1**																								
Epifaunal Substrate Score	0.08	**0.22**	0.06	0.07	**0.17**	0.04	0.02	**0.14**	**0.57**	**0.15**	**0.82**	0.11	0.05	**0.23**	0.11	**1**																							
Shading Score	0.00	-0.01	-0.06	-0.06	0.09	**-0.18**	0.00	-0.05	-0.10	0.09	-0.02	**0.17**	**0.97**	0.11	**0.17**	0.06	**1**																						
Instream Habitat Score	0.01	0.06	-0.05	-0.05	0.04	0.04	0.02	0.02	**0.67**	**0.16**	**0.56**	0.09	0.02	**0.25**	0.09	**0.62**	0.03	**1**																					
Bank Stability Score	0.04	-0.01	-0.12	-0.12	0.03	0.06	-0.10	-0.03	0.11	**1.00**	**0.13**	-0.05	0.07	0.05	-0.05	**0.15**	0.09	**0.16**	**1**																				
Woody Debris Score	-0.13	-0.12	-0.10	-0.09	0.00	-0.10	-0.05	-0.10	0.04	0.08	0.08	**0.18**	**0.25**	**0.59**	**0.18**	**0.18**	**0.24**	**0.22**	0.08	**1**																			
PHI Score	0.00	0.07	-0.07	-0.06	**0.16**	-0.05	-0.03	0.01	**0.35**	**0.33**	**0.43**	**0.33**	**0.35**	**0.35**	**0.33**	**0.52**	**0.36**	**0.52**	**0.33**	**0.42**	**1**																		
Bank Stability (LB)	0.05	0.01	-0.12	-0.12	0.01	0.05	0.00	-0.02	0.09	**0.70**	0.13	-0.01	0.09	0.00	-0.01	**0.16**	0.11	**0.16**	**0.70**	0.06	**0.31**	**1**																	
Bank Stability (RB)	0.05	0.01	-0.12	-0.11	0.02	0.07	-0.04	-0.02	0.11	**0.70**	**0.14**	-0.04	0.10	0.07	-0.04	**0.17**	0.12	**0.18**	**0.70**	0.13	**0.33**	**0.77**	**1**																
Bank Stability (combined)	0.05	0.01	-0.12	-0.12	0.01	0.06	-0.02	-0.02	0.11	**0.73**	**0.15**	-0.02	0.10	0.05	-0.02	**0.17**	0.12	**0.18**	**0.73**	0.10	**0.33**	**0.90**	**0.91**	**1**															
Channel Flow	0.12	0.09	0.01	0.02	**0.22**	0.10	-0.08	0.14	**0.18**	**0.26**	**0.19**	-0.02	-0.04	0.05	-0.03	**0.14**	-0.02	**0.13**	**0.26**	-0.03	0.12	**0.26**	**0.26**	**0.26**	**1**														
Vegetative Protection (LB)	0.07	-0.06	**-0.26**	**-0.26**	0.05	-0.01	-0.03	-0.06	**0.17**	**0.38**	**0.22**	0.02	**0.21**	0.10	0.02	**0.25**	**0.22**	**0.23**	**0.38**	0.12	**0.36**	**0.41**	**0.37**	**0.39**	**0.20**	**1**													
Vegetative Protection (RB)	0.08	-0.05	**-0.19**	**-0.19**	0.08	0.00	-0.07	-0.04	**0.16**	**0.33**	**0.22**	0.03	**0.19**	0.11	0.03	**0.25**	**0.20**	**0.22**	**0.33**	0.13	**0.34**	**0.35**	**0.33**	**0.35**	**0.20**	**0.79**	**1**												
Vegetative Protection (combined)	0.07	-0.06	**-0.22**	**-0.23**	0.07	-0.01	-0.05	-0.05	**0.16**	**0.36**	**0.22**	0.03	**0.20**	0.11	0.03	**0.25**	**0.21**	**0.23**	**0.36**	0.13	**0.36**	**0.39**	**0.35**	**0.38**	**0.21**	**0.92**	**0.91**	**1**											
Channel Alteration	0.02	0.05	0.09	0.09	0.12	-0.03	0.00	0.07	0.07	-0.05	0.13	**0.29**	0.12	0.13	**0.30**	**0.14**	0.12	0.09	-0.05	0.12	**0.21**	-0.04	-0.03	-0.03	0.00	0.04	0.04	0.04	**1**										
Channel Sinuosity	0.02	0.04	0.09	0.06	0.06	0.00	0.03	0.05	0.13	-0.01	0.09	0.11	-0.04	0.06	0.11	0.07	-0.04	0.12	-0.01	0.01	0.08	-0.08	-0.02	-0.05	-0.11	0.06	0.14	0.10	0.07	**1**									
Pool Substrate	**0.14**	**0.27**	0.14	0.14	0.10	**0.21**	0.01	**0.23**	**0.49**	0.10	**0.48**	-0.01	**-0.14**	**0.20**	-0.01	**0.38**	-0.13	**0.34**	0.10	0.00	**0.20**	0.04	0.05	0.05	**0.15**	0.08	0.09	0.09	-0.02	0.10	**1**								
Pool Variability	**0.14**	**0.20**	**0.26**	**0.26**	0.00	**0.22**	**0.15**	**0.26**	**0.46**	-0.04	**0.36**	0.00	-0.13	**0.23**	0.00	**0.25**	-0.12	**0.29**	-0.04	0.02	0.11	-0.01	-0.02	-0.01	0.13	-0.02	-0.03	-0.03	0.05	0.00	**0.37**	**1**							
Riparian Zone Width (LB)	**0.15**	**0.17**	0.11	0.10	**0.18**	0.11	0.04	**0.17**	**0.19**	0.04	**0.22**	**0.26**	0.12	0.03	**0.26**	**0.21**	0.12	**0.16**	0.04	-0.04	**0.23**	0.04	-0.01	0.01	0.12	**0.20**	**0.20**	**0.20**	**0.42**	**0.19**	0.11	0.04	**1**						
Riparian Zone Width (RB)	0.06	0.11	0.09	0.10	0.13	0.00	0.06	0.11	**0.16**	0.03	**0.17**	**0.30**	**0.15**	0.07	**0.30**	0.14	**0.15**	0.12	0.03	0.00	**0.20**	0.04	0.07	0.06	0.09	0.15	**0.19**	**0.17**	**0.35**	**0.17**	0.13	0.05	**0.37**	**1**					
Riparian Zone Width (combined)	0.11	**0.16**	0.10	0.10	**0.20**	0.06	0.02	**0.15**	**0.19**	0.04	**0.21**	**0.31**	**0.15**	0.02	**0.31**	**0.18**	**0.15**	**0.15**	0.04	-0.08	**0.22**	0.05	0.03	0.04	0.14	**0.17**	**0.21**	**0.20**	**0.39**	**0.20**	**0.14**	0.04	**0.75**	**0.73**	**1**				
Epi. Substrate/Avail. Cover	**0.15**	**0.29**	0.15	0.15	**0.16**	**0.15**	0.08	**0.24**	**0.84**	0.13	**0.86**	0.06	-0.06	**0.28**	0.06	**0.71**	-0.04	**0.62**	0.13	0.07	**0.41**	0.14	**0.15**	**0.15**	**0.19**	**0.21**	**0.21**	**0.22**	0.11	0.11	**0.50**	**0.43**	**0.22**	**0.17**	**0.21**	**1**			
Sediment Deposition	0.05	0.05	-0.09	-0.08	**0.17**	0.08	-0.08	0.05	0.10	**0.19**	**0.16**	-0.04	-0.12	0.01	-0.04	**0.16**	-0.10	0.12	**0.19**	0.01	0.10	**0.19**	**0.18**	**0.18**	**0.38**	**0.22**	**0.24**	**0.24**	-0.02	0.05	**0.15**	0.02	0.09	0.03	0.07	**0.15**	**1**		
RBP Score	**0.16**	**0.16**	0.02	0.02	**0.18**	**0.15**	0.00	**0.16**	**0.48**	**0.39**	**0.50**	0.09	0.03	**0.21**	0.09	**0.45**	0.04	**0.41**	**0.39**	0.08	**0.42**	**0.42**	**0.40**	**0.42**	**0.44**	**0.46**	**0.46**	**0.48**	**0.19**	**0.16**	**0.41**	**0.30**	**0.33**	**0.32**	**0.36**	**0.53**	**0.38**	**1**	
RBP %	**0.16**	**0.16**	0.02	0.02	**0.18**	**0.15**	0.00	**0.16**	**0.47**	**0.39**	**0.50**	0.08	0.02	**0.20**	0.09	**0.45**	0.04	**0.41**	**0.39**	0.08	**0.42**	**0.42**	**0.40**	**0.42**	**0.43**	**0.46**	**0.46**	**0.47**	**0.19**	**0.16**	**0.41**	**0.30**	**0.33**	**0.32**	**0.36**	**0.52**	**0.38**	**1.00**	**1**

Kendall Correlation Matrix: Benthic Macroinvertebrate Variables (Large Sites) Versus Water Quality (Spring In Situ & Grab Samples)

Variables	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI	Conductivity (In Situ)	Dissolved Oxygen (In Situ)	pH (In Situ)	Turbidity (In Situ)	Water Temperature	Chloride	Total Phosphorus	Total Nitrogen	Orthophosphate	Ammonia N	Nitrite-N	Nitrate-N	TKN	TOC	DOC	Magnesium	Calcium	Hardness	Copper	Zinc	Lead	Turbidity (Lab)
No. Taxa	**1**																													
No. EPT Taxa	**0.397**	**1**																												
% Ephem	**0.166**	**0.450**	**1**																											
No. Ephem Taxa	**0.176**	**0.489**	**0.921**	**1**																										
% Intolerant	**0.159**	**0.264**	**0.184**	**0.182**	**1**																									
No. Scraper Taxa	**0.357**	**0.275**	**0.165**	**0.164**	0.038	**1**																								
% climbers	**0.244**	**0.170**	**0.169**	**0.184**	**-0.117**	**0.200**	**1**																							
BIBI	**0.521**	**0.628**	**0.547**	**0.571**	**0.318**	**0.505**	**0.307**	**1**																						
Conductivity (In Situ)	0.006	-0.092	**-0.145**	**-0.161**	**-0.268**	**0.189**	0.038	-0.047	**1**																					
Dissolved Oxygen (In Situ)	0.053	**0.106**	**0.177**	**0.182**	**-0.109**	0.021	**0.134**	0.098	-0.019	**1**																				
pH (In Situ)	0.019	0.011	0.087	0.093	**-0.160**	**0.209**	0.019	0.074	**0.249**	**0.103**	**1**																			
Turbidity (In Situ)	0.037	-0.037	0.018	0.026	0.020	**0.206**	0.019	**0.110**	0.044	-0.032	**0.112**	**1**																		
Water Temperature	-0.006	-0.060	-0.039	-0.040	0.085	-0.017	0.008	-0.014	-0.053	**-0.423**	**-0.107**	0.065	**1**																	
Chloride	0.081	-0.079	**-0.214**	**-0.232**	**-0.256**	**0.190**	0.075	-0.047	**0.715**	-0.051	**0.203**	0.016	-0.052	**1**																
Total Phosphorus	-0.028	0.041	**0.215**	**0.229**	0.074	0.011	0.075	**0.101**	**-0.114**	**0.103**	0.018	**0.191**	0.081	**-0.181**	**1**															
Total Nitrogen	0.067	-0.023	0.069	0.057	**-0.141**	**0.126**	0.058	0.053	**0.144**	**0.140**	**0.096**	0.029	-0.045	0.070	**0.168**	**1**														
Orthophosphate	-0.064	0.008	**0.192**	**0.187**	0.095	0.046	-0.031	0.086	-0.098	0.076	0.022	**0.124**	**0.102**	**-0.202**	**0.579**	**0.307**	**1**													
Ammonia N	0.028	**-0.115**	-0.103	-0.095	-0.045	0.012	0.011	-0.053	**0.112**	**-0.189**	0.019	0.050	**0.115**	**0.172**	**0.101**	**0.182**	0.090	**1**												
Nitrite-N	-0.061	**-0.112**	-0.026	-0.034	**-0.105**	0.106	-0.048	-0.037	0.080	0.034	**0.163**	**0.128**	0.015	0.016	**0.214**	**0.380**	**0.361**	**0.281**	**1**											
Nitrate-N	**0.134**	0.055	**0.123**	**0.122**	**-0.156**	**0.134**	**0.173**	**0.131**	**0.125**	**0.261**	0.071	-0.008	-0.080	0.070	0.091	**0.619**	**0.124**	-0.027	**0.152**	**1**										
TKN	0.001	**-0.116**	**-0.135**	**-0.139**	-0.030	**0.117**	-0.060	-0.041	**0.151**	**-0.186**	**0.134**	**0.134**	**0.106**	**0.149**	**0.181**	**0.220**	**0.260**	**0.406**	**0.363**	**-0.124**	**1**									
TOC	-0.067	-0.061	-0.003	-0.003	0.072	**0.144**	**-0.167**	0.013	-0.049	**-0.152**	**0.131**	**0.239**	**0.119**	**-0.114**	**0.110**	0.060	**0.272**	0.069	**0.208**	**-0.127**	**0.343**	**1**								
DOC	-0.057	-0.062	-0.021	-0.019	0.072	**0.136**	**-0.165**	0.011	-0.053	**-0.173**	**0.117**	**0.233**	**0.129**	**-0.106**	0.088	0.045	**0.246**	0.079	**0.210**	**-0.140**	**0.345**	**0.937**	**1**							
Magnesium	0.023	**-0.192**	**-0.228**	**-0.252**	**-0.282**	0.103	0.080	**-0.133**	**0.536**	-0.040	**0.216**	-0.097	-0.051	**0.599**	**-0.172**	**0.133**	**-0.264**	**0.209**	**0.112**	0.078	**0.184**	**-0.192**	**-0.186**	**1**						
Calcium	-0.059	**-0.162**	**-0.151**	**-0.143**	**-0.311**	**0.163**	0.091	-0.100	**0.523**	**0.129**	**0.352**	0.093	**-0.128**	**0.421**	**0.137**	**0.209**	0.062	0.072	**0.224**	**0.141**	**0.264**	-0.023	-0.036	**0.391**	**1**					
Hardness	-0.019	**-0.175**	**-0.179**	**-0.187**	**-0.311**	**0.186**	0.073	-0.096	**0.589**	0.085	**0.328**	0.052	-0.095	**0.516**	0.051	**0.169**	0.027	**0.134**	**0.200**	**0.137**	**0.218**	-0.024	-0.031	**0.522**	**0.869**	**1**				
Copper	-0.002	-0.090	**-0.200**	**-0.214**	-0.069	**0.132**	**-0.180**	-0.075	**0.199**	**-0.223**	0.091	**0.158**	0.014	**0.168**	**-0.119**	**0.116**	0.034	0.074	**0.169**	-0.062	**0.328**	**0.445**	**0.462**	0.070	0.086	**0.101**	**1**			
Zinc	0.007	-0.071	**-0.141**	**-0.159**	0.028	-0.035	-0.019	-0.071	0.075	-0.053	**-0.204**	**-0.105**	**-0.126**	**0.143**	**-0.192**	0.050	**-0.197**	**0.132**	-0.025	0.039	-0.055	**-0.107**	-0.094	**0.169**	**-0.112**	-0.036	0.078	**1**		
Lead	0.013	-0.052	-0.087	-0.091	0.048	**0.132**	**-0.171**	0.008	0.009	**-0.251**	0.008	**0.312**	**0.102**	-0.015	0.039	0.073	**0.136**	**0.133**	**0.147**	-0.074	**0.275**	**0.504**	**0.509**	**-0.164**	-0.057	-0.042	**0.512**	0.069	**1**	
Turbidity (Lab)	0.054	-0.061	0.018	0.041	-0.069	0.056	**0.107**	0.037	-0.006	0.000	0.039	**0.444**	0.054	0.011	**0.230**	-0.063	0.005	**0.215**	0.068	-0.044	**0.097**	0.076	0.083	-0.017	**0.107**	0.069	-0.045	-0.032	**0.162**	**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: Land Use Variables Versus Water Quality (Spring In Situ & Grab Samples

Variables	Drainage area (acres)	% Impervious	Airport %	Commercial %	Forested wetland %	Industrial %	Open space	Wetland %	Pasture %	Residential 1/8-ac. %	Residential 1/2-ac. %	Residential 1/4-ac. %	Residential 1-ac. %	Residential 2-ac. %	Right-of-Way %	Transportation %	Utility %	Water %	Woods %	Woods coniferous %	Woods deciduous %	Woods mixed %	%Developed	%Agriculture	%Forested	%Open	Conductivity (In Situ)	Dissolved Oxygen (In Situ)	pH (In Situ)	Turbidity (In Situ)	Water Temperature	Chloride	Total Phosphorus	Total Nitrogen	Orthophosphate	Ammonia N	Nitrite-N	Nitrate-N	TKN	TOC	DOC	Magnesium	Calcium	Hardness	Copper	Zinc	Lead	Turbidity (Lab)
Drainage area (acres)	**1**																																														
% Impervious	**0.112**	**1**																																													
Airport %	**0.133**	**0.153**	**1**																																											
Commercial %	**0.281**	**0.450**	**0.135**	**1**																																									
Forested wetland %	**0.281**	**-0.079**	-0.006	0.020	**1**																																							
Industrial %	**0.281**	**0.300**	**0.194**	**0.312**	0.046	**1**																																						
Open space	**0.243**	**0.218**	**0.181**	**0.279**	0.003	**0.258**	**1**																																					
Wetland %	**0.243**	**0.153**	**0.095**	**0.227**	**0.242**	**0.372**	**0.244**	**1**																																			
Pasture %	**0.243**	**-0.270**	**-0.094**	-0.018	**0.174**	**-0.114**	-0.037	0.049	**1**																																		
Residential 1/8-ac. %	**0.243**	**0.433**	0.073	**0.316**	-0.022	**0.246**	**0.155**	**0.313**	**-0.191**	**1**																																						
Residential 1/2-ac. %	**0.243**	**0.320**	0.072	**0.275**	0.032	**0.225**	0.071	**0.292**	**-0.137**	**0.339**	**1**																																					
Residential 1/4-ac. %	**0.243**	**0.454**	0.054	**0.329**	-0.081	**0.301**	**0.106**	**0.207**	**-0.237**	**0.503**	**0.362**	**1**																																				
Residential 1-ac. %	**0.243**	**0.186**	-0.003	**0.222**	**0.106**	**0.178**	**0.091**	**0.254**	0.006	**0.129**	**0.351**	**0.156**	**1**																																			
Residential 2-ac. %	0.030	**-0.304**	**-0.121**	**-0.195**	0.058	**-0.191**	**-0.134**	**-0.088**	**0.373**	**-0.320**	**-0.158**	**-0.311**	0.023	**1**																																		
Right-of-Way %	**0.030**	**-0.437**	-0.049	**-0.113**	**0.096**	**-0.198**	**-0.126**	0.019	**0.420**	**-0.245**	**-0.133**	**-0.296**	-0.013	**0.359**	**1**																																	
Transportation %	0.053	**0.382**	**0.138**	**0.312**	**-0.096**	**0.270**	**0.131**	**0.085**	**-0.142**	**0.221**	**0.198**	**0.235**	**0.219**	**-0.163**	**-0.221**	**1**																																
Utility %	**0.203**	-0.003	0.055	-0.010	**0.141**	**0.100**	**0.093**	**0.097**	0.038	0.012	0.009	0.020	0.033	-0.057	-0.016	0.032	**1**																															
Water %	**0.203**	**0.136**	0.042	**0.244**	**0.201**	**0.295**	**0.208**	**0.409**	**0.098**	**0.204**	**0.243**	**0.148**	**0.261**	-0.018	0.053	**0.123**	**0.138**	**1**																														
Woods %	0.040	**0.139**	-0.074	0.002	**0.131**	-0.043	-0.063	0.055	0.005	-0.026	**0.109**	-0.037	**0.200**	0.053	-0.071	0.006	-0.015	0.025	**1**																													
Woods coniferous %	**0.040**	-0.012	**0.113**	-0.008	**0.146**	**0.147**	**0.224**	**0.257**	0.064	0.032	**0.089**	-0.012	**0.098**	**-0.090**	0.032	-0.019	**0.153**	**0.146**	0.048	**1**																												
Woods deciduous %	**0.201**	0.049	-0.049	0.043	0.041	0.076	0.006	**0.120**	0.028	**0.102**	0.052	**0.121**	0.019	-0.066	-0.015	0.060	**0.255**	**0.090**	0.040	**0.114**	**1**																											
Woods mixed %	0.002	**-0.361**	-0.053	**-0.250**	**0.100**	-0.066	-0.036	-0.074	**0.103**	**-0.272**	**-0.233**	**-0.286**	**-0.075**	0.057	0.056	**-0.223**	**0.080**	-0.058	0.002	**0.096**	0.037	**1**																										
%Developed	0.014	**0.527**	0.026	**0.285**	**-0.137**	**0.144**	0.017	**0.088**	**-0.246**	**0.373**	**0.337**	**0.439**	**0.222**	-0.011	**-0.316**	**0.309**	-0.063	**0.076**	**0.086**	**-0.197**	-0.011	**-0.552**	**1**																									
%Agriculture	**0.141**	**-0.370**	**-0.090**	-0.061	**0.091**	**-0.216**	**-0.131**	-0.042	**0.612**	**-0.226**	**-0.130**	**-0.242**	-0.027	**0.337**	**0.740**	**-0.203**	-0.067	0.015	**-0.084**	0.018	-0.041	0.024	**-0.297**	**1**																								
%Forested	-0.028	**-0.387**	-0.040	**-0.292**	**0.167**	-0.074	-0.063	-0.054	**0.090**	**-0.284**	**-0.266**	**-0.322**	**-0.117**	0.032	0.068	**-0.268**	**0.127**	-0.066	0.065	**0.170**	0.051	**0.798**	**-0.605**	-0.022	**1**																							
%Open	**0.246**	**0.211**	**0.181**	**0.274**	0.048	**0.279**	**0.916**	**0.321**	-0.038	**0.171**	**0.088**	**0.091**	**0.102**	**-0.147**	**-0.129**	**0.127**	**0.088**	**0.273**	-0.044	**0.218**	0.010	-0.047	0.006	**-0.136**	-0.056	**1**																						
Conductivity (In Situ)	-0.013	**0.396**	**0.149**	**0.321**	**-0.094**	**0.225**	**0.105**	**0.109**	**-0.170**	**0.248**	**0.148**	**0.201**	**0.158**	**-0.118**	**-0.214**	**0.413**	-0.065	**0.104**	0.018	**-0.103**	**-0.091**	**-0.278**	**0.364**	**-0.206**	**-0.306**	**0.123**	**1**																					
Dissolved Oxygen (In Situ)	**0.218**	**-0.134**	-0.024	0.030	0.037	0.007	0.054	0.061	**0.208**	0.011	**-0.079**	-0.017	0.000	**0.167**	**0.270**	-0.031	0.070	**0.109**	**-0.299**	0.011	**0.080**	0.051	**-0.105**	**0.254**	0.003	0.035	-0.047	**1**																				
pH (In Situ)	**0.179**	**0.179**	**0.112**	**0.239**	0.008	**0.223**	**0.072**	**0.175**	0.024	**0.183**	**0.100**	**0.140**	**0.165**	-0.024	-0.022	**0.208**	**0.094**	**0.239**	**-0.078**	-0.059	0.021	**-0.084**	**0.146**	-0.040	**-0.102**	**0.092**	**0.256**	**0.141**	**1**																			
Turbidity (In Situ)	-0.020	**-0.133**	-0.024	-0.053	0.058	0.022	0.021	**0.075**	-0.007	**-0.079**	**-0.076**	-0.053	0.010	0.028	0.040	0.027	**0.156**	**0.086**	-0.072	0.072	-0.042	0.050	**-0.078**	-0.026	**0.096**	0.041	0.000	-0.050	**0.108**	**1**																		
Water Temperature	-0.073	**-0.079**	0.013	**-0.080**	-0.022	-0.061	-0.046	-0.015	0.008	**-0.086**	-0.010	**-0.082**	-0.035	0.036	0.023	-0.039	-0.070	**-0.079**	**0.234**	0.009	**-0.107**	0.003	-0.022	-0.009	0.058	-0.037	-0.045	**-0.368**	**-0.090**	**0.142**	**1**																	
Chloride	0.020	**0.453**	**0.135**	**0.325**	-0.055	**0.231**	**0.117**	**0.125**	**-0.159**	**0.250**	**0.173**	**0.200**	**0.202**	**-0.076**	**-0.241**	**0.456**	-0.043	**0.116**	**0.124**	**-0.079**	-0.072	**-0.271**	**0.380**	**-0.227**	**-0.288**	**0.135**	**0.762**	-0.061	**0.216**	-0.017	-0.048	**1**																
Total Phosphorus	**-0.112**	**-0.315**	-0.045	**-0.145**	0.053	**-0.214**	**-0.173**	**-0.080**	**0.230**	**-0.237**	**-0.211**	**-0.234**	**-0.137**	**0.262**	**0.320**	**-0.142**	-0.049	-0.065	**-0.122**	-0.066	**-0.146**	0.020	**-0.127**	**0.272**	0.061	**-0.163**	-0.029	0.025	0.018	**0.250**	**0.100**	**-0.075**	**1**															
Total Nitrogen	0.012	**0.122**	**0.086**	**0.161**	**-0.172**	0.028	-0.039	0.067	0.018	**0.175**	**0.193**	**0.182**	0.045	0.004	**0.117**	**0.107**	**-0.087**	0.006	**-0.137**	**-0.087**	**-0.133**	**-0.298**	**0.221**	**0.088**	**-0.310**	-0.041	**0.171**	0.031	**0.092**	0.007	0.035	**0.137**	**0.119**	**1**														
Orthophosphate	-0.057	**-0.254**	0.078	**-0.127**	-0.024	**-0.156**	**-0.122**	-0.020	**0.172**	**-0.131**	**-0.113**	**-0.113**	**-0.170**	**0.162**	**0.242**	**-0.132**	-0.039	-0.047	**-0.284**	-0.055	**-0.147**	-0.021	**-0.073**	**0.188**	0.007	**-0.122**	-0.048	0.053	0.002	**0.155**	**0.099**	**-0.114**	**0.569**	**0.248**	**1**													
Ammonia N	0.044	**0.138**	**0.095**	**0.159**	0.059	0.057	-0.010	0.053	0.026	0.042	**0.132**	**0.127**	**0.106**	0.004	0.001	**0.160**	-0.005	0.035	**0.082**	0.029	-0.080	**-0.138**	**0.144**	0.024	**-0.129**	0.003	**0.153**	**-0.160**	0.049	**0.092**	**0.109**	**0.193**	**0.193**	**0.205**	**0.147**	**1**												
Nitrite-N	**0.105**	**0.107**	**0.136**	**0.116**	-0.006	0.074	**0.083**	**0.123**	0.006	0.076	0.067	**0.125**	-0.026	**-0.099**	0.018	**0.078**	0.061	0.053	**-0.335**	**0.090**	0.000	**-0.157**	**0.074**	-0.014	**-0.134**	**0.086**	0.061	0.056	**0.116**	**0.107**	0.045	0.028	**0.189**	**0.329**	**0.366**	**0.298**	**1**											
Nitrate-N	0.057	0.062	-0.005	**0.136**	**-0.152**	-0.007	-0.050	0.037	**0.113**	**0.126**	**0.122**	**0.123**	**0.081**	**0.137**	**0.223**	0.064	**-0.096**	0.003	**-0.106**	**-0.104**	-0.069	**-0.299**	**0.190**	**0.208**	**-0.322**	**-0.068**	**0.139**	**0.192**	**0.094**	-0.057	-0.029	**0.122**	0.014	**0.625**	0.055	0.006	**0.121**	**1**										
TKN	0.024	**0.160**	0.072	**0.135**	0.017	**0.104**	0.055	**0.076**	-0.033	**0.099**	**0.120**	**0.164**	0.030	**-0.111**	**-0.122**	**0.108**	0.033	**0.098**	0.027	0.067	-0.052	-0.048	**0.114**	**-0.102**	-0.042	**0.070**	**0.111**	**-0.183**	**0.068**	**0.135**	**0.090**	**0.115**	**0.205**	**0.190**	**0.284**	**0.370**	**0.325**	**-0.153**	**1**									
TOC	0.026	0.012	**0.099**	-0.025	0.042	0.025	**0.099**	**0.113**	**-0.118**	**0.088**	**0.101**	**0.103**	0.002	**-0.163**	**-0.152**	-0.057	**0.110**	**0.075**	-0.077	**0.144**	0.044	**0.072**	-0.037	**-0.198**	**0.114**	**0.119**	**-0.130**	**-0.127**	0.053	**0.225**	**0.071**	**-0.174**	**0.078**	-0.004	**0.233**	0.043	**0.215**	**-0.216**	**0.375**	**1**								
DOC	0.026	0.037	**0.101**	-0.018	0.045	0.026	**0.099**	**0.110**	**-0.120**	**0.088**	**0.113**	**0.113**	0.012	**-0.176**	**-0.170**	-0.051	**0.117**	**0.077**	-0.053	**0.164**	0.047	**0.070**	-0.035	**-0.207**	**0.118**	**0.119**	**-0.130**	**-0.151**	0.039	**0.209**	**0.070**	**-0.162**	0.066	-0.014	**0.208**	0.060	**0.210**	**-0.231**	**0.391**	**0.925**	**1**							
Magnesium	-0.021	**0.414**	0.062	**0.318**	-0.079	**0.193**	0.023	0.076	**-0.111**	**0.239**	**0.143**	**0.213**	**0.158**	**-0.098**	**-0.246**	**0.334**	**-0.139**	**0.080**	**0.134**	**-0.148**	-0.065	**-0.248**	**0.359**	**-0.168**	**-0.277**	0.033	**0.590**	-0.066	**0.212**	**-0.104**	-0.028	**0.625**	**-0.090**	**0.209**	**-0.188**	**0.220**	0.050	**0.170**	**0.120**	**-0.246**	**-0.233**	**1**						
Calcium	-0.036	**0.257**	0.068	**0.311**	-0.070	**0.133**	0.028	0.038	-0.057	**0.150**	0.035	**0.094**	**0.085**	-0.030	-0.044	**0.308**	-0.035	**0.081**	-0.058	**-0.152**	**-0.112**	**-0.281**	**0.281**	-0.037	**-0.296**	0.031	**0.579**	0.056	**0.350**	0.061	**-0.095**	**0.489**	**0.197**	**0.205**	**0.094**	**0.159**	**0.132**	**0.150**	**0.193**	**-0.112**	**-0.124**	**0.451**	**1**					
Hardness	-0.031	**0.305**	**0.107**	**0.308**	-0.050	**0.141**	0.049	0.060	-0.072	**0.170**	0.074	**0.124**	**0.098**	-0.069	**-0.112**	**0.337**	-0.048	**0.080**	-0.023	**-0.112**	**-0.098**	**-0.282**	**0.292**	**-0.086**	**-0.290**	0.060	**0.631**	0.003	**0.308**	0.019	-0.062	**0.552**	**0.123**	**0.191**	0.058	**0.183**	**0.135**	**0.148**	**0.168**	**-0.113**	**-0.117**	**0.574**	**0.876**	**1**				
Copper	-0.001	**0.278**	**0.122**	**0.141**	**-0.119**	**0.204**	**0.167**	**0.088**	**-0.273**	**0.226**	**0.166**	**0.230**	0.040	**-0.294**	**-0.327**	**0.183**	0.075	0.072	**-0.090**	**0.097**	0.031	-0.045	**0.142**	**-0.358**	-0.054	**0.174**	**0.133**	**-0.183**	**0.090**	**0.129**	0.005	**0.113**	**-0.118**	**0.119**	0.045	0.057	**0.199**	**-0.079**	**0.333**	**0.438**	**0.440**	0.038	0.041	0.059	**1**			
Zinc	**-0.115**	**0.135**	0.068	-0.023	-0.063	**-0.081**	-0.041	**-0.141**	**-0.097**	**0.100**	0.049	0.060	-0.016	**-0.114**	**-0.139**	0.063	-0.048	**-0.155**	0.045	-0.034	-0.039	-0.054	0.064	-0.069	-0.065	-0.055	0.061	**-0.103**	**-0.230**	**-0.099**	**-0.089**	**0.133**	**-0.107**	**0.070**	**-0.121**	**0.101**	-0.040	0.047	-0.026	**-0.078**	-0.062	**0.142**	**-0.101**	-0.045	**0.088**	**1**		
Lead	**-0.137**	0.011	**0.117**	-0.041	-0.045	0.060	0.019	0.009	**-0.195**	0.046	0.048	0.005	**-0.078**	**-0.165**	**-0.147**	0.018	0.071	-0.035	-0.059	**0.103**	-0.028	0.014	-0.029	**-0.204**	0.057	0.043	-0.045	**-0.240**	-0.042	**0.284**	**0.110**	-0.051	**0.076**	**0.080**	**0.148**	**0.106**	**0.149**	**-0.102**	**0.280**	**0.425**	**0.424**	**-0.143**	**-0.082**	**-0.072**	**0.476**	**0.074**	**1**	
Turbidity (Lab)	-0.072	**-0.103**	-0.014	-0.037	**0.080**	-0.037	-0.062	-0.044	0.036	**-0.156**	**-0.118**	**-0.095**	-0.014	**0.088**	**0.076**	0.025	0.067	-0.028	-0.002	0.022	-0.027	0.038	-0.064	**0.074**	**0.068**	-0.055	0.012	-0.066	**0.074**	**0.482**	**0.095**	0.031	**0.346**	**-0.073**	**0.086**	**0.236**	0.055	**-0.109**	**0.112**	0.065	**0.072**	0.008	**0.129**	**0.085**	-0.045	-0.038	**0.178**	**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 Land Use Variables (Large Sites)

Variables	**Instream Habitat**	**Bank Stability**	**Epifaunal Substrate**	**Remoteness**	**Percent Shading**	**# Woody Debris/Rootwads**	**Remoteness Score**	**Epifaunal Substrate Score**	**Shading Score**	**Instream Habitat Score**	**Bank Stability Score**	**Woody Debris Score**	**PHI Score**	**Bank Stability**	**Channel Flow**	**Vegetative Protection**	**Channel Alteration**	**Channel Sinuosity**	**Pool Substrate**	**Pool Variability**	**Riparian Zone Width**	**Epi. Substrate/Avail. Cover**	**Sediment Deposition**	**RBP Score**	**Drainage area**	**% Impervious**	**%Developed**	**%Agriculture**	**%Forested**	**%Open**
Instream Habitat	**1**																													
Bank Stability	**0.11**	**1.00**																												
Epifaunal Substrate	**0.71**	**0.13**	**1.00**																											
Remoteness	0.03	-0.05	0.08	**1.00**																										
Percent Shading	**-0.11**	0.07	-0.03	**0.18**	**1.00**																									
# Woody Debris/Rootwads	**0.28**	0.05	**0.26**	**0.14**	**0.11**	**1.00**																								
Remoteness Score	0.03	-0.05	0.08	**1.00**	**0.18**	**0.14**	**1.00**																							
Epifaunal Substrate Score	**0.57**	**0.15**	**0.82**	**0.11**	0.05	**0.23**	**0.11**	**1.00**																						
Shading Score	**-0.10**	0.09	-0.02	**0.17**	**0.97**	**0.11**	**0.17**	0.06	**0.94**																					
Instream Habitat Score	**0.67**	**0.16**	**0.56**	0.09	0.02	**0.25**	0.09	**0.62**	0.03	**1.00**																				
Bank Stability Score	**0.11**	**1.00**	**0.13**	-0.05	0.07	0.05	-0.05	**0.15**	0.09	**0.16**	**1.00**																			
Woody Debris Score	0.04	0.08	0.08	**0.18**	**0.25**	**0.59**	**0.18**	**0.18**	**0.24**	**0.22**	0.08	**1.00**																		
PHI Score	**0.35**	**0.33**	**0.43**	**0.33**	**0.35**	**0.35**	**0.33**	**0.52**	**0.36**	**0.52**	**0.33**	**0.42**	**1.00**																	
Bank Stability	**0.11**	**0.73**	**0.15**	-0.02	0.10	0.05	-0.02	**0.17**	**0.12**	**0.18**	**0.73**	**0.10**	**0.33**	**1.00**																
Channel Flow	**0.18**	**0.26**	**0.19**	-0.02	-0.04	0.05	-0.03	**0.14**	-0.02	**0.13**	**0.26**	-0.03	**0.12**	**0.26**	**1.00**															
Vegetative Protection	**0.16**	**0.36**	**0.22**	0.03	**0.20**	**0.11**	0.03	**0.25**	**0.21**	**0.23**	**0.36**	**0.13**	**0.36**	**0.38**	**0.21**	**1.00**														
Channel Alteration	0.07	-0.05	**0.13**	**0.29**	**0.12**	**0.13**	**0.30**	**0.14**	**0.12**	0.09	-0.05	**0.12**	**0.21**	-0.03	0.00	0.04	**1.00**													
Channel Sinuosity	**0.13**	-0.01	0.09	**0.11**	-0.04	0.06	**0.11**	0.07	-0.04	**0.12**	-0.01	0.01	0.08	-0.05	**-0.11**	0.10	0.07	**1.00**												
Pool Substrate	**0.49**	**0.10**	**0.48**	-0.01	**-0.14**	**0.20**	-0.01	**0.38**	**-0.13**	**0.34**	**0.10**	0.00	**0.20**	0.05	**0.15**	0.09	-0.02	0.10	**1.00**											
Pool Variability	**0.46**	-0.04	**0.36**	0.00	**-0.13**	**0.23**	0.00	**0.25**	**-0.12**	**0.29**	-0.04	0.02	**0.11**	-0.01	**0.13**	-0.03	0.05	0.00	**0.37**	**1.00**										
Riparian Zone Width	**0.19**	0.04	**0.21**	**0.31**	**0.15**	0.02	**0.31**	**0.18**	**0.15**	**0.15**	0.04	-0.08	**0.22**	0.04	**0.14**	**0.20**	**0.39**	**0.20**	**0.14**	0.04	**1.00**									
Epi. Substrate/Avail. Cover	**0.84**	**0.13**	**0.86**	0.06	-0.06	**0.28**	0.06	**0.71**	-0.04	**0.62**	**0.13**	0.07	**0.41**	**0.15**	**0.19**	**0.22**	0.11	**0.11**	**0.50**	**0.43**	**0.21**	**1.00**								
Sediment Deposition	**0.10**	**0.19**	**0.16**	-0.04	**-0.12**	0.01	-0.04	**0.16**	**-0.10**	**0.12**	**0.19**	0.01	0.10	**0.18**	**0.38**	**0.24**	-0.02	0.05	**0.15**	0.02	0.07	**0.15**	**1.00**							
RBP Score	**0.48**	**0.39**	**0.50**	0.09	0.03	**0.21**	0.09	**0.45**	0.04	**0.41**	**0.39**	0.08	**0.42**	**0.42**	**0.44**	**0.48**	**0.19**	**0.16**	**0.41**	**0.30**	**0.36**	**0.53**	**0.38**	**1.00**						
RBP_PERCNT	**0.47**	**0.39**	**0.50**	0.08	0.02	**0.20**	0.09	**0.45**	0.04	**0.41**	**0.39**	0.08	**0.42**	**0.42**	**0.43**	**0.47**	**0.19**	**0.16**	**0.41**	**0.30**	**0.36**	**0.52**	**0.38**	**1.00**						
Drainage area	**0.37**	-0.06	**0.28**	-0.05	**-0.21**	**0.13**	-0.05	0.06	**-0.20**	0.01	-0.06	**-0.27**	**-0.11**	-0.07	**0.12**	-0.05	0.01	0.09	**0.29**	**0.36**	**0.14**	**0.32**	-0.03	**0.18**	**1.00**					
% Impervious	0.06	**0.21**	-0.03	**-0.26**	**-0.15**	-0.02	**-0.26**	-0.06	**-0.12**	0.02	**0.21**	-0.09	-0.08	**0.17**	0.01	**0.23**	**-0.23**	0.10	0.08	-0.04	-0.08	0.01	0.04	**0.10**	**0.10**	**1.00**				
%Developed	-0.08	**0.10**	**-0.16**	**-0.27**	**-0.13**	-0.06	**-0.27**	**-0.17**	**-0.12**	**-0.11**	**0.10**	-0.07	**-0.18**	0.09	-0.06	**0.10**	**-0.13**	0.00	-0.01	**-0.12**	**-0.13**	**-0.12**	0.00	-0.03	0.02	**0.59**	**1.00**			
%Agriculture	-0.05	**-0.15**	0.01	**0.18**	**0.14**	0.01	**0.18**	0.02	**0.14**	-0.04	**-0.15**	0.06	0.03	-0.07	-0.04	**-0.11**	**0.16**	**-0.11**	**-0.11**	**0.11**	0.02	-0.01	**-0.12**	-0.07	-0.02	**-0.48**	**-0.38**	**1.00**		
%Forested	0.08	-0.04	**0.16**	**0.21**	**0.10**	0.01	**0.21**	**0.16**	0.09	0.08	-0.04	-0.02	**0.14**	-0.04	**0.12**	-0.03	**0.14**	-0.01	0.06	0.07	**0.21**	**0.12**	0.04	0.09	0.03	**-0.40**	**-0.58**	0.05	**1.00**	
%Open	**0.17**	0.06	0.10	**-0.12**	-0.10	0.10	**-0.12**	0.05	-0.09	**0.10**	0.06	-0.02	0.02	0.05	0.03	0.09	**-0.22**	0.06	**0.13**	0.07	-0.06	**0.12**	**0.13**	0.08	**0.12**	**0.24**	**0.10**	**-0.24**	**-0.13**	**1.00**

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

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

Kendall Correlation Matrix: Physical Habitat Versus Geomorphic Variables (Large Sites)

Variables	Drainage area	Instream Habitat	Bank Stability	Epifaunal Substrate	Remoteness	Percent Shading	# Woody Debris/Rootwads	Remoteness Score	Epifaunal Substrate Score	Shading Score	Instream Habitat Score	Bank Stability Score	Woody Debris Score	PHI Score	Bank Stability	Channel Flow	Vegetative Protection	Channel Alteration	Channel Sinuosity	Pool Substrate	Pool Variability	Riparian Zone Width	Epi. Substrate/Avail. Cover	Sediment Deposition	RBP Score	Entrenchment Ratio	Bankfull Width	Bankfull Area	Mean Depth	Width:Depth Ratio	Water Surface Slope	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50
Drainage area	**1**																																		
Instream Habitat	**0.37**	**1**																																	
Bank Stability	-0.06	**0.11**	**1**																																
Epifaunal Substrate	**0.28**	**0.71**	**0.13**	**1**																															
Remoteness	-0.05	0.03	-0.05	0.08	**1**																														
Percent Shading	**-0.21**	**-0.11**	0.07	-0.03	**0.18**	**1**																													
# Woody Debris/Rootwads	**0.13**	**0.28**	0.05	**0.26**	**0.14**	**0.11**	**1**																												
Remoteness Score	-0.05	0.03	-0.05	0.08	**1.00**	**0.18**	**0.14**	**1**																											
Epifaunal Substrate Score	0.06	**0.57**	**0.15**	**0.82**	**0.11**	0.05	**0.23**	**0.11**	**1**																										
Shading Score	**-0.20**	**-0.10**	0.09	-0.02	**0.17**	**0.97**	**0.11**	**0.17**	0.06	**1**																									
Instream Habitat Score	0.01	**0.67**	**0.16**	**0.56**	0.09	0.02	**0.25**	0.09	**0.62**	0.03	**1**																								
Bank Stability Score	-0.06	**0.11**	**1.00**	**0.13**	-0.05	0.07	0.05	-0.05	**0.15**	0.09	**0.16**	**1**																							
Woody Debris Score	**-0.27**	0.04	0.08	0.08	**0.18**	**0.25**	**0.59**	**0.18**	**0.18**	**0.24**	**0.22**	0.08	**1**																						
PHI Score	**-0.11**	**0.35**	**0.33**	**0.43**	**0.33**	**0.35**	**0.35**	**0.33**	**0.52**	**0.36**	**0.52**	**0.33**	**0.42**	**1**																					
Bank Stability	-0.07	**0.11**	**0.73**	**0.15**	-0.02	0.10	0.05	-0.02	**0.17**	**0.12**	**0.18**	**0.73**	**0.10**	**0.33**	**1**																				
Channel Flow	**0.12**	**0.18**	**0.26**	**0.19**	-0.02	-0.04	0.05	-0.03	**0.14**	-0.02	**0.13**	**0.26**	-0.03	**0.12**	**0.26**	**1**																			
Vegetative Protection	-0.05	**0.16**	**0.36**	**0.22**	0.03	**0.20**	**0.11**	0.03	**0.25**	**0.21**	**0.23**	**0.36**	**0.13**	**0.36**	**0.38**	**0.21**	**1**																		
Channel Alteration	0.01	0.07	-0.05	**0.13**	**0.29**	**0.12**	**0.13**	**0.30**	**0.14**	**0.12**	0.09	-0.05	**0.12**	**0.21**	-0.03	0.00	0.04	**1**																	
Channel Sinuosity	0.09	**0.13**	-0.01	0.09	**0.11**	-0.04	0.06	**0.11**	0.07	-0.04	**0.12**	-0.01	0.01	0.08	-0.05	**-0.11**	0.10	0.07	**1**																
Pool Substrate	**0.29**	**0.49**	**0.10**	**0.48**	-0.01	**-0.14**	**0.20**	-0.01	**0.38**	**-0.13**	**0.34**	**0.10**	0.00	**0.20**	0.05	**0.15**	0.09	-0.02	0.10	**1**															
Pool Variability	**0.36**	**0.46**	-0.04	**0.36**	0.00	**-0.13**	**0.23**	0.00	**0.25**	**-0.12**	**0.29**	-0.04	0.02	**0.11**	-0.01	**0.13**	-0.03	0.05	0.00	**0.37**	**1**														
Riparian Zone Width	**0.14**	**0.19**	0.04	**0.21**	**0.31**	**0.15**	0.02	**0.31**	**0.18**	**0.15**	**0.15**	0.04	-0.08	**0.22**	0.04	**0.14**	**0.20**	**0.39**	**0.20**	**0.14**	0.04	**1**													
Epi. Substrate/Avail. Cover	**0.32**	**0.84**	**0.13**	**0.86**	0.06	-0.06	**0.28**	0.06	**0.71**	-0.04	**0.62**	**0.13**	0.07	**0.41**	**0.15**	**0.19**	**0.22**	0.11	**0.11**	**0.50**	**0.43**	**0.21**	**1**												
Sediment Deposition	-0.03	**0.10**	**0.19**	**0.16**	-0.04	**-0.12**	0.01	-0.04	**0.16**	**-0.10**	**0.12**	**0.19**	0.01	0.10	**0.18**	**0.38**	**0.24**	-0.02	0.05	**0.15**	0.02	0.07	**0.15**	**1**											
RBP Score	**0.18**	**0.48**	**0.39**	**0.50**	0.09	0.03	**0.21**	0.09	**0.45**	0.04	**0.41**	**0.39**	0.08	**0.42**	**0.42**	**0.44**	**0.48**	**0.19**	**0.16**	**0.41**	**0.30**	**0.36**	**0.53**	**0.38**	**1**										
Entrenchment Ratio	0.07	0.01	**0.21**	0.03	-0.03	**-0.13**	0.04	-0.03	0.00	**-0.11**	-0.03	**0.21**	0.01	0.00	**0.23**	**0.30**	**0.15**	0.00	0.00	0.07	0.01	0.00	0.05	**0.22**	**0.24**	**1**									
Bankfull Width	**0.47**	**0.29**	-0.04	**0.25**	-0.09	**-0.13**	**0.11**	-0.09	**0.11**	**-0.13**	0.04	-0.04	**-0.15**	-0.06	-0.04	-0.07	**-0.10**	-0.04	0.04	**0.27**	**0.27**	0.08	**0.26**	**-0.13**	0.08	-0.08	**1**								
Bankfull Area	**0.63**	**0.32**	**-0.10**	**0.24**	-0.08	**-0.16**	**0.14**	-0.08	0.07	**-0.15**	0.03	**-0.10**	**-0.18**	**-0.10**	**-0.10**	0.03	**-0.11**	-0.04	0.02	**0.30**	**0.35**	0.07	**0.28**	-0.09	**0.10**	0.06	**0.66**	**1**							
Mean Depth	**0.47**	**0.23**	**-0.14**	**0.16**	-0.04	**-0.14**	**0.12**	-0.04	0.02	**-0.13**	-0.02	**-0.14**	**-0.17**	**-0.13**	**-0.14**	**0.11**	-0.08	-0.03	0.01	**0.21**	**0.28**	0.03	**0.21**	0.00	0.08	**0.22**	**0.30**	**0.63**	**1**						
Width:Depth Ratio	0.00	0.02	0.04	0.04	-0.06	0.02	-0.03	-0.06	0.04	0.01	0.01	0.04	0.00	0.01	0.04	**-0.24**	-0.06	0.00	0.04	0.05	-0.02	0.06	0.02	**-0.17**	-0.05	**-0.25**	**0.43**	0.09	**-0.27**	**1**					
Water Surface Slope	**-0.34**	**-0.14**	-0.06	-0.04	0.03	0.03	-0.07	0.03	0.07	0.02	0.02	-0.06	**0.13**	0.04	-0.04	**-0.16**	-0.03	**-0.12**	0.07	-0.04	**-0.15**	-0.08	-0.07	0.08	**-0.11**	-0.05	**-0.16**	**-0.23**	**-0.20**	0.05	**1**				
Bankfull Discharge	**0.36**	**0.24**	**-0.17**	**0.23**	-0.08	-0.04	**0.12**	-0.08	**0.14**	-0.04	0.07	**-0.17**	-0.09	-0.04	**-0.13**	-0.03	-0.09	-0.10	-0.03	**0.22**	**0.27**	-0.02	**0.25**	-0.07	0.04	0.01	**0.44**	**0.63**	**0.58**	0.02	0.10	**1**			
Sinuosity	0.03	**0.17**	-0.05	**0.13**	0.09	-0.05	**0.12**	0.09	**0.12**	-0.05	**0.16**	-0.05	0.06	0.09	-0.09	-0.05	0.02	0.02	**0.60**	**0.11**	0.02	**0.16**	**0.15**	0.01	**0.10**	-0.03	0.05	0.04	0.04	0.04	**0.10**	0.06	**1**		
Flood-Prone Width	**0.36**	**0.20**	**0.20**	**0.18**	-0.07	**-0.18**	0.09	-0.07	0.07	**-0.17**	0.01	**0.20**	**-0.11**	-0.01	**0.23**	**0.27**	**0.13**	0.01	0.04	**0.25**	**0.15**	0.10	**0.21**	**0.14**	**0.32**	**0.61**	**0.31**	**0.36**	**0.33**	0.00	**-0.16**	**0.17**	-0.01	**1**	
D50	**0.13**	**0.20**	**-0.14**	**0.17**	-0.06	-0.05	0.08	-0.06	**0.14**	-0.05	**0.12**	**-0.14**	-0.02	0.02	**-0.22**	**-0.25**	**-0.11**	-0.06	**0.15**	**0.19**	0.09	-0.03	**0.18**	**-0.14**	-0.08	**-0.23**	**0.25**	**0.20**	0.10	**0.15**	**0.11**	**0.23**	**0.16**	**-0.10**	**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: Geomorphic Variables Versus Land Use Variables (Large Sites)

Variables	Entrenchment Ratio	Bankfull Width	Bankfull Area	Mean Depth	Width:Depth Ratio	Water Surface Slope (%)	Water Surface Slope (ft)	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50	Drainage area	% Impervious	Airport %	Commercial %	Forested wetland %	Industrial %	Open space	Wetland %	Pasture %	Residential 1/8-ac. %	Residential 1/2-ac. %	Residential 1/4-ac. %	Residential 1-ac. %	Residential 2-ac. %	Right-of-Way %	Transportation %	Utility %	Water %	Woods %	Woods coniferous %	Woods deciduous %	Woods mixed %	%Developed	%Agriculture	%Forested	%Open
Entrenchment Ratio	**1**																																				
Bankfull Width	-0.079	**1**																																			
Bankfull Area	0.057	**0.661**	**1**																																		
Mean Depth	**0.216**	**0.295**	**0.635**	**1**																																	
Width:Depth Ratio	**-0.245**	**0.430**	0.091	**-0.275**	**1**																																
Water Surface Slope (%)	-0.053	**-0.164**	**-0.231**	**-0.198**	0.052	**1**																															
Water Surface Slope (ft)	-0.058	**-0.172**	**-0.238**	**-0.206**	0.043	**0.887**	**1**																														
Bankfull Discharge	0.006	**0.443**	**0.630**	**0.581**	0.022	0.104	0.063	**1**																													
Sinuosity	-0.025	0.050	0.041	0.043	0.044	**0.100**	0.096	0.064	**1**																												
Flood-Prone Width	**0.612**	**0.310**	**0.360**	**0.326**	0.004	**-0.159**	**-0.159**	**0.171**	-0.009	**1**																											
D50	**-0.228**	**0.247**	**0.200**	**0.102**	**0.150**	**0.110**	0.087	**0.234**	**0.163**	**-0.101**	**1**																										
Drainage area	0.071	**0.469**	**0.632**	**0.471**	-0.001	**-0.339**	**-0.338**	**0.356**	0.030	**0.355**	**0.132**	**1**																									
% Impervious	0.068	0.086	0.078	0.042	0.031	0.004	0.004	0.030	0.052	**0.119**	**0.103**	**0.095**	**1**																								
Airport %	-0.013	**0.202**	**0.169**	0.071	0.078	-0.097	-0.076	0.107	0.046	0.091	**0.129**	**0.173**	**0.175**	**1**																							
Commercial %	0.049	**0.166**	**0.186**	**0.148**	0.009	-0.057	-0.066	0.080	-0.037	**0.144**	**0.107**	**0.193**	**0.537**	**0.174**	**1**																						
Forested wetland %	0.070	0.087	**0.198**	**0.224**	**-0.134**	**-0.206**	**-0.195**	**0.185**	**-0.105**	**0.133**	-0.060	**0.251**	**-0.145**	-0.017	-0.041	**1**																					
Industrial %	0.087	**0.276**	**0.309**	**0.253**	-0.006	-0.082	-0.099	**0.215**	0.001	**0.219**	**0.214**	**0.347**	**0.344**	**0.315**	**0.383**	0.025	**1**																				
Open space	0.007	**0.126**	**0.128**	0.095	0.025	0.015	-0.004	0.092	**0.113**	0.092	**0.122**	**0.102**	**0.252**	**0.239**	**0.234**	**-0.128**	**0.262**	**1**																			
Wetland %	0.088	**0.249**	**0.332**	**0.284**	-0.061	**-0.106**	**-0.127**	**0.218**	-0.024	**0.225**	**0.138**	**0.428**	**0.189**	**0.142**	**0.233**	**0.269**	**0.409**	**0.122**	**1**																		
Pasture %	**-0.116**	0.018	0.045	0.059	-0.047	-0.083	-0.074	0.059	**-0.139**	**-0.115**	-0.096	0.079	**-0.369**	**-0.155**	**-0.198**	**0.249**	**-0.214**	**-0.209**	-0.046	**1**																	
Residential 1/8-ac. %	0.016	**0.180**	**0.203**	**0.146**	0.044	-0.076	-0.076	0.102	0.069	**0.129**	**0.160**	**0.187**	**0.484**	0.108	**0.375**	-0.095	**0.264**	**0.191**	**0.307**	**-0.357**	**1**																
Residential 1/2-ac. %	**0.144**	**0.104**	**0.138**	**0.146**	-0.029	-0.095	**-0.125**	0.082	0.040	**0.233**	0.062	**0.227**	**0.303**	0.103	**0.279**	0.008	**0.281**	0.050	**0.298**	**-0.260**	**0.348**	**1**															
Residential 1/4-ac. %	0.079	**0.136**	**0.181**	**0.162**	-0.018	-0.020	-0.031	0.108	0.014	**0.155**	**0.136**	**0.185**	**0.544**	0.091	**0.434**	**-0.198**	**0.331**	**0.184**	**0.275**	**-0.401**	**0.625**	**0.390**	**1**														
Residential 1-ac. %	**0.154**	0.094	**0.149**	**0.151**	-0.041	**-0.114**	**-0.128**	0.029	0.024	**0.214**	-0.001	**0.226**	**0.285**	-0.025	**0.238**	**0.109**	**0.238**	0.043	**0.242**	**-0.133**	**0.171**	**0.460**	**0.241**	**1**													
Residential 2-ac. %	-0.076	-0.083	-0.067	-0.043	-0.024	**-0.099**	-0.088	-0.024	**-0.140**	**-0.130**	**-0.116**	-0.008	**-0.378**	**-0.173**	**-0.312**	**0.248**	**-0.237**	**-0.234**	-0.088	**0.476**	**-0.461**	**-0.217**	**-0.469**	-0.043	**1**												
Right-of-Way %	-0.073	0.005	0.031	0.052	-0.011	-0.019	-0.021	**0.116**	-0.077	-0.098	-0.035	0.036	**-0.570**	-0.109	**-0.342**	**0.171**	**-0.267**	**-0.252**	**-0.114**	**0.434**	**-0.400**	**-0.208**	**-0.435**	**-0.154**	**0.443**	**1**											
Transportation %	0.024	**0.114**	**0.104**	0.053	0.059	-0.009	-0.025	0.027	-0.013	0.084	**0.169**	0.089	**0.428**	**0.185**	**0.411**	**-0.122**	**0.371**	**0.216**	**0.176**	**-0.246**	**0.336**	**0.277**	**0.324**	**0.254**	**-0.157**	**-0.336**	**1**										
Utility %	0.097	0.023	0.051	0.098	-0.079	**-0.143**	**-0.137**	-0.033	0.036	0.067	0.012	0.070	-0.063	0.043	-0.101	**0.132**	0.048	0.107	0.052	-0.059	-0.022	-0.058	-0.070	-0.043	-0.024	-0.090	-0.010	**1**									
Water %	0.044	**0.165**	**0.198**	**0.164**	-0.013	-0.088	**-0.112**	**0.156**	-0.052	**0.126**	0.088	**0.236**	0.087	0.035	**0.162**	**0.182**	**0.246**	**0.113**	**0.330**	-0.009	**0.168**	**0.185**	0.094	**0.205**	-0.023	0.015	**0.148**	0.013	**1**								
Woods %	**0.189**	-0.060	-0.055	0.001	-0.088	**-0.125**	-0.097	-0.093	-0.050	**0.202**	**-0.191**	0.100	**0.118**	-0.093	-0.059	**0.149**	-0.040	**-0.128**	0.077	-0.026	-0.015	**0.185**	-0.048	**0.297**	0.050	-0.085	-0.073	-0.012	0.037	**1**							
Woods coniferous %	0.073	**0.141**	**0.144**	**0.126**	0.007	-0.059	-0.084	0.085	**0.118**	**0.178**	**0.114**	**0.210**	0.063	**0.188**	-0.008	0.070	**0.139**	**0.261**	**0.214**	-0.089	0.098	**0.159**	0.010	**0.120**	**-0.171**	**-0.109**	0.072	**0.133**	0.030	0.107	**1**						
Woods deciduous %	0.089	**0.127**	**0.128**	**0.116**	0.007	-0.073	-0.069	0.011	0.080	**0.163**	0.057	**0.187**	0.030	-0.075	-0.010	-0.053	0.010	-0.067	0.069	0.005	0.083	0.052	0.074	0.013	-0.067	-0.037	0.095	**0.245**	-0.065	0.100	0.091	**1**					
Woods mixed %	0.017	0.029	0.033	0.040	0.002	**-0.064**	-0.052	0.007	0.003	**0.061**	-0.044	**0.062**	**-0.374**	**-0.127**	**-0.321**	**0.077**	**-0.076**	**-0.088**	**-0.082**	**0.112**	**-0.252**	**-0.190**	**-0.327**	**-0.133**	**0.138**	**0.154**	**-0.288**	**0.113**	**-0.081**	0.065	**0.158**	0.097	**1**				
%Developed	**0.058**	0.009	0.001	0.005	0.017	-0.024	-0.030	-0.033	-0.025	0.053	0.012	0.021	**0.592**	0.042	**0.394**	**-0.128**	**0.231**	**0.102**	**0.172**	**-0.319**	**0.412**	**0.347**	**0.518**	**0.332**	**-0.108**	**-0.431**	**0.410**	**-0.085**	**0.111**	**0.105**	**-0.134**	-0.043	**-0.524**	**1**			
%Agriculture	-0.064	-0.061	-0.017	0.029	-0.060	0.010	0.017	0.069	**-0.106**	**-0.111**	**-0.124**	-0.019	**-0.476**	**-0.163**	**-0.216**	**0.182**	**-0.310**	**-0.240**	**-0.178**	**0.600**	**-0.396**	**-0.245**	**-0.368**	**-0.168**	**0.402**	**0.712**	**-0.332**	**-0.170**	-0.054	**-0.115**	**-0.180**	-0.092	0.085	**-0.381**	**1**		
%Forested	0.008	0.008	-0.002	0.001	-0.013	-0.051	-0.038	-0.023	0.024	0.042	-0.046	0.028	**-0.404**	-0.090	**-0.369**	**0.171**	**-0.138**	**-0.119**	-0.077	**0.114**	**-0.266**	**-0.224**	**-0.382**	**-0.149**	**0.125**	**0.170**	**-0.336**	**0.187**	-0.097	**0.136**	**0.212**	**0.128**	**0.782**	**-0.577**	0.051	**1**	
%Open	0.042	**0.125**	**0.138**	**0.110**	0.001	0.016	-0.009	0.103	**0.124**	**0.126**	**0.109**	**0.115**	**0.244**	**0.248**	**0.241**	-0.064	**0.305**	**0.885**	**0.222**	**-0.197**	**0.228**	0.081	**0.162**	0.073	**-0.236**	**-0.256**	**0.225**	0.098	**0.201**	-0.074	**0.250**	-0.080	**-0.112**	**0.102**	**-0.241**	**-0.131**	**1**

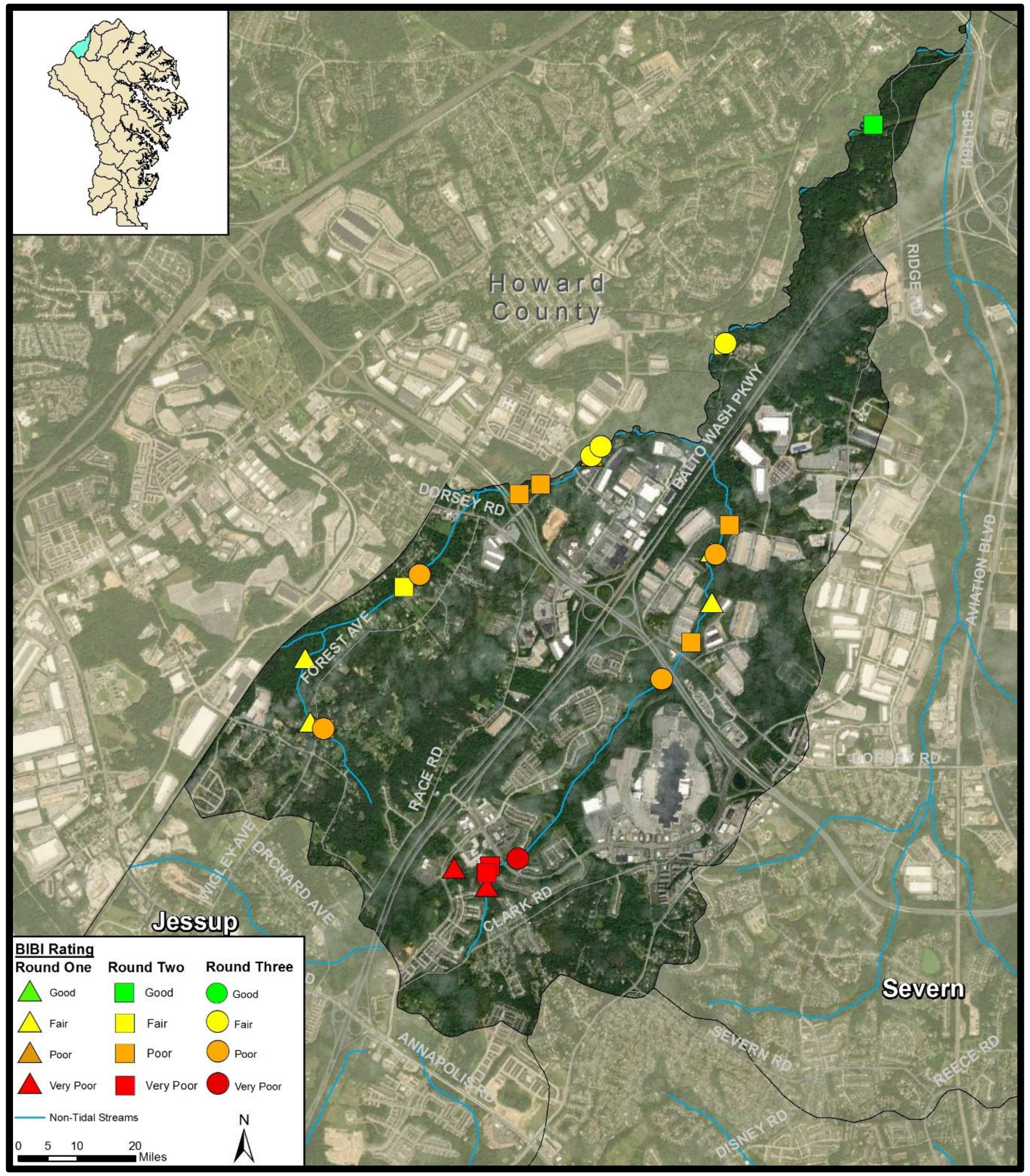
Values in bold are different from 0 with a significance level alpha=0.05

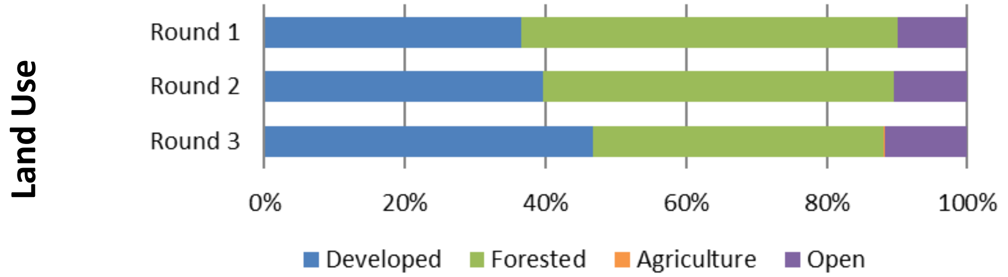
Highlighted values are different from 0 with a significance level alpha=0.001

Appendix C: PSU Summaries

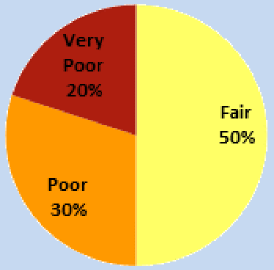
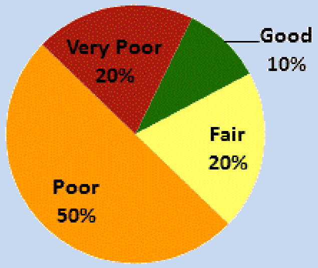
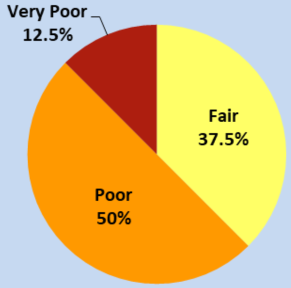
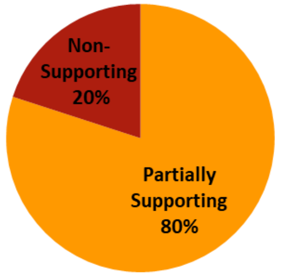
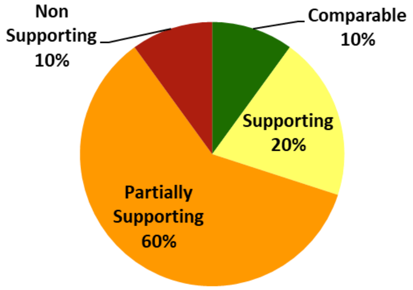
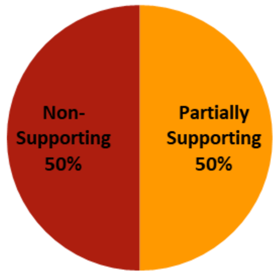
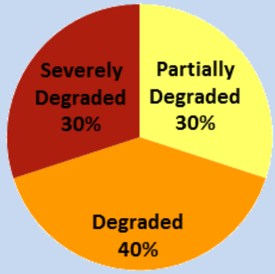
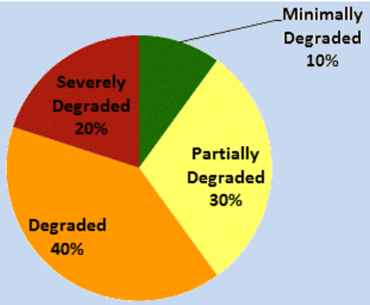
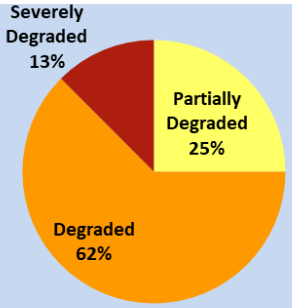
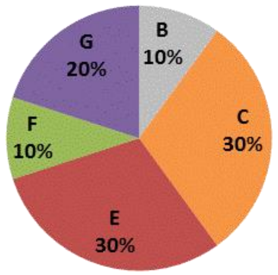
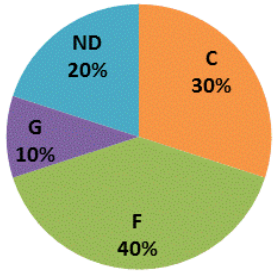
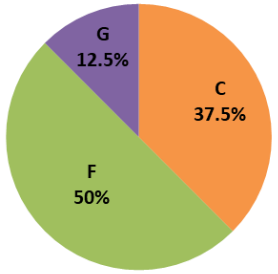
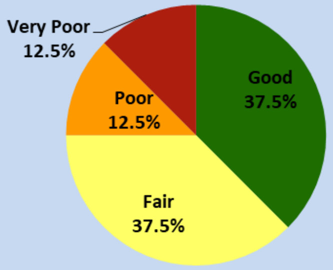
PSU 1: Piney Run

The Piney Run sampling unit is in the northwestern portion of the County, along the border with Howard County, and has a total drainage area of 4,868 acres. In 2018, impervious surfaces comprised 23.5 % of the overall sampling unit, with individual sites ranging from 7.0 % to 29.8 %.



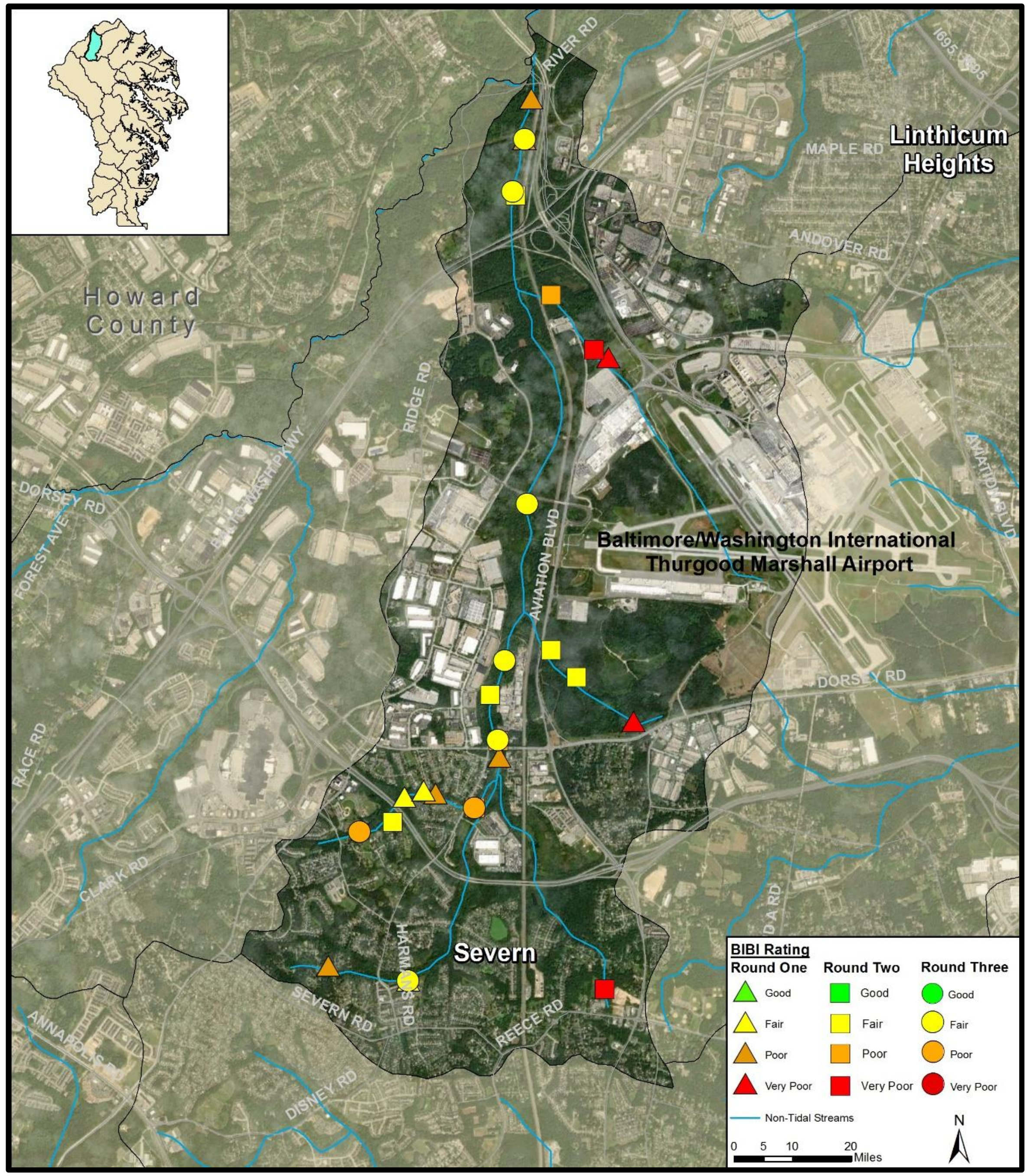


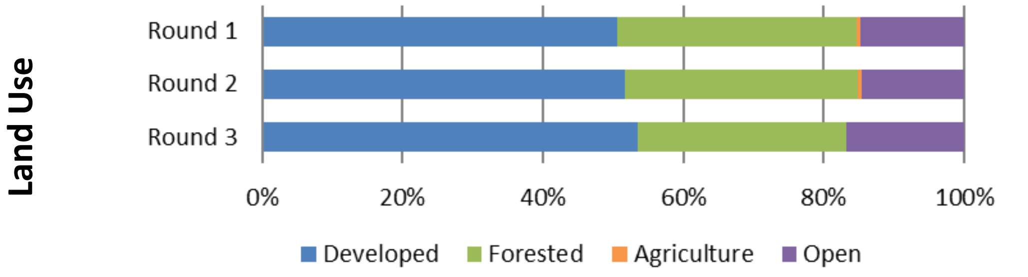
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2014

	Round 1 (2007)	Round 2 (2012)	Round 3 (2018)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	Yes ↓
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

PSU 2: Stony Run

The Stony Run sampling unit is in the northern part of the County, near the town of Severn, and has a drainage area of 6,203 acres. This sampling unit also contains a large portion of BWI Airport and drains north to the Patapsco River. In 2020, 18.3 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 14.7 % to 20.2 %.



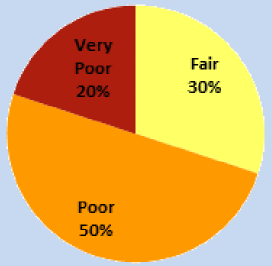


*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

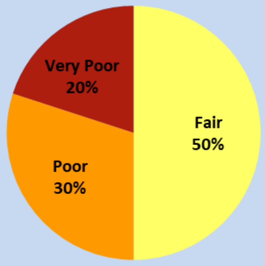
	Round 1 (2007)	Round 2 (2010)	Round 3 (2020)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				Yes ↑	No
RBP Score				Yes ↑	No
PHI Score				Yes ↑	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

BIBI Score

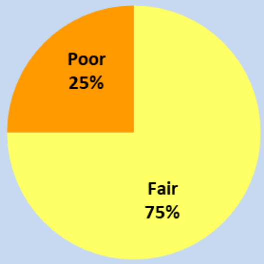
Round 1 (2007)



Round 2 (2010)

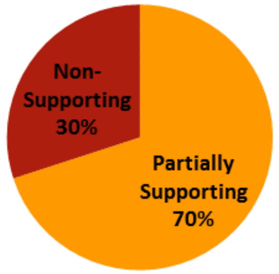


Round 3 (2020)

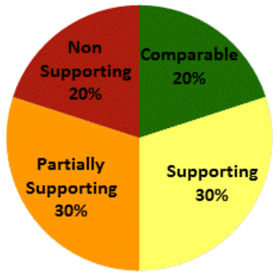


RBP Score

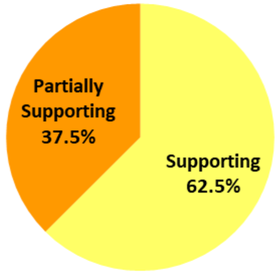
Round 1 (2007)



Round 2 (2010)

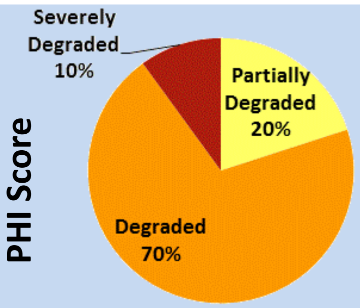


Round 3 (2020)

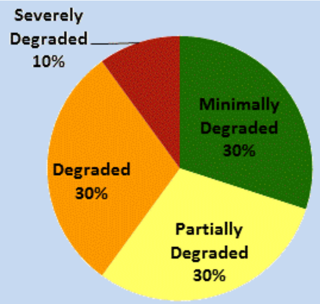


PHI Score

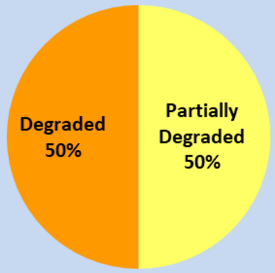
Round 1 (2007)



Round 2 (2010)

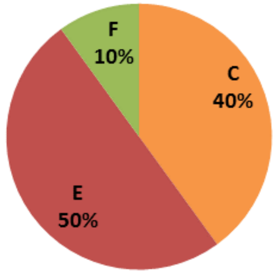


Round 3 (2020)

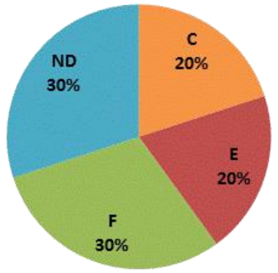


Rosgen Type

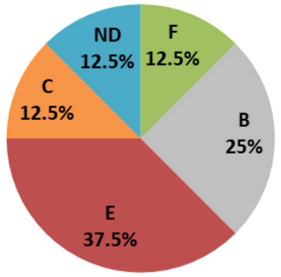
Round 1 (2007)



Round 2 (2010)

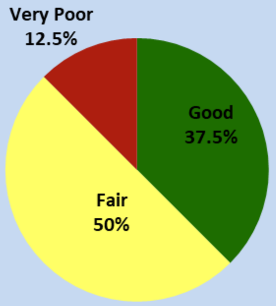


Round 3 (2020)



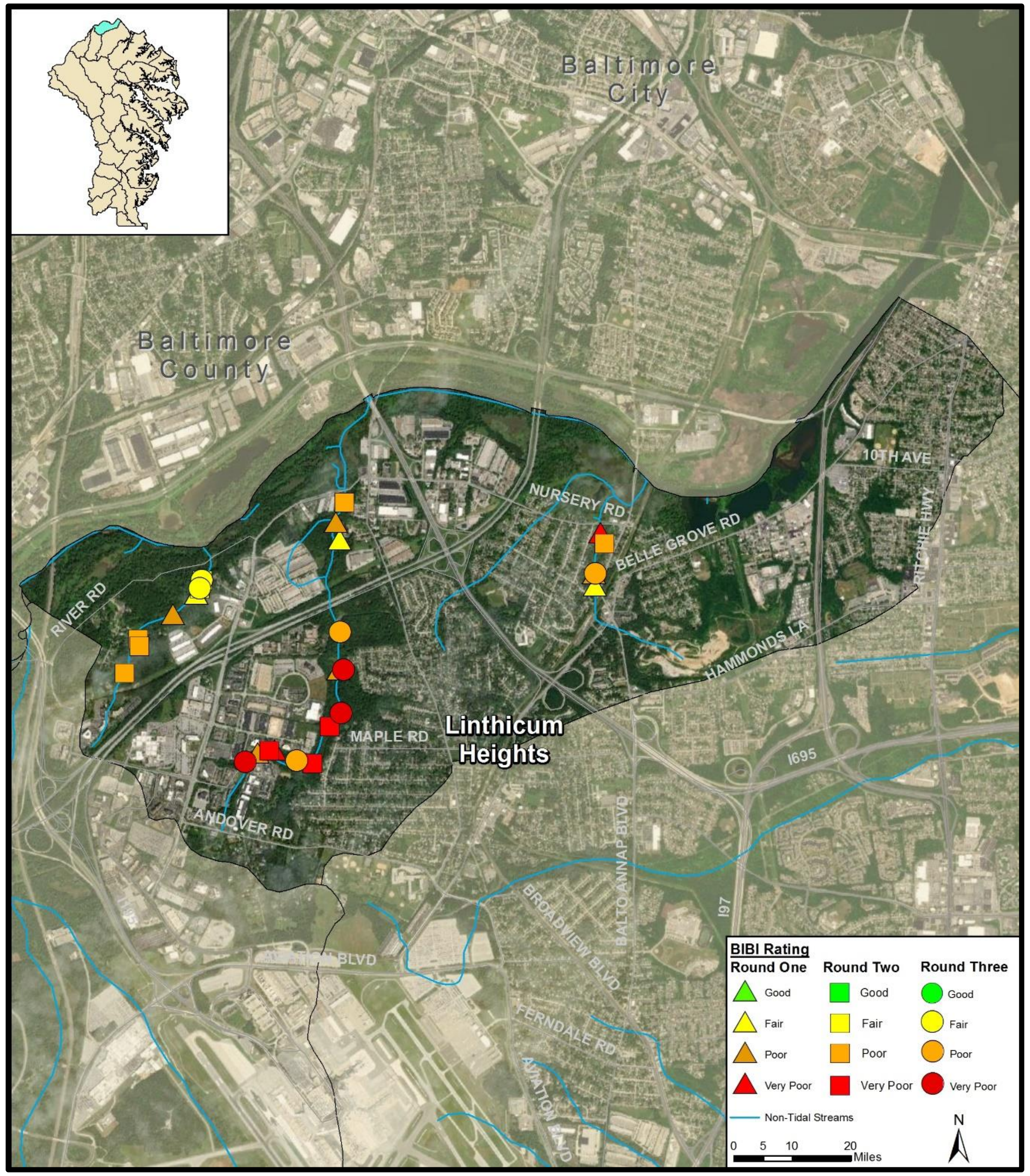
FIBI Score

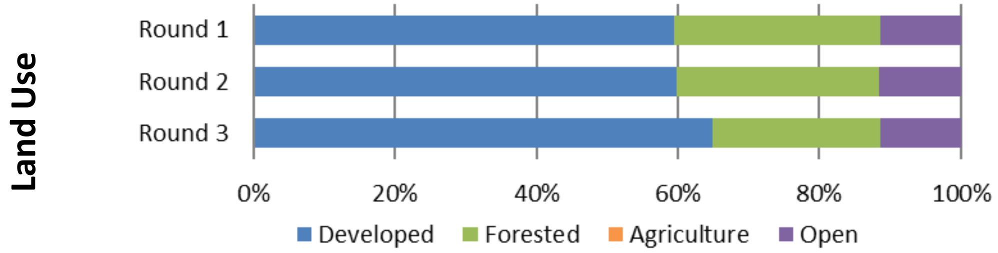
Round 3 (2020)



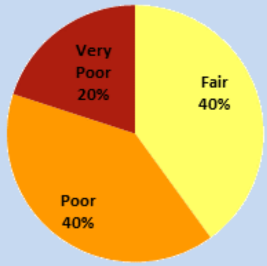
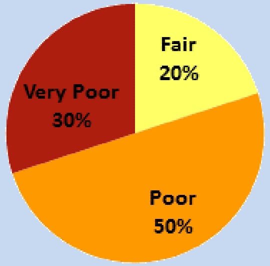
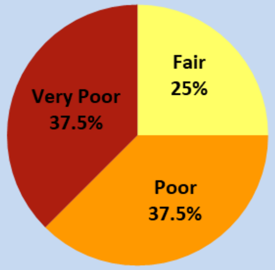
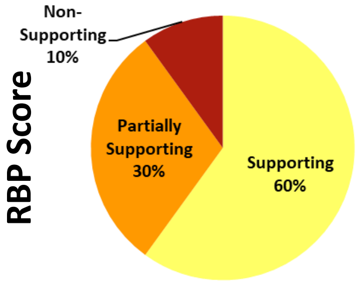
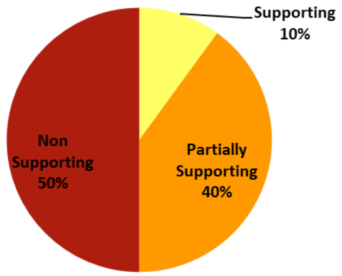
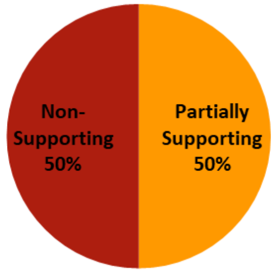
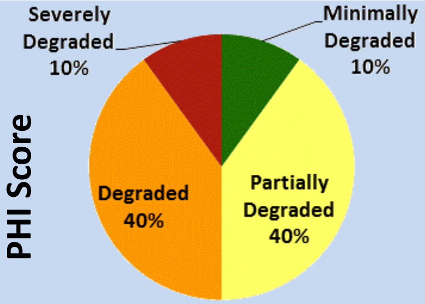
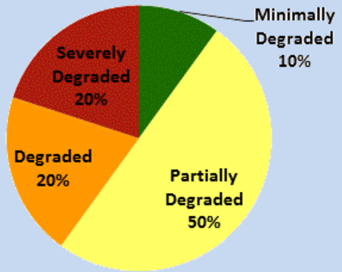
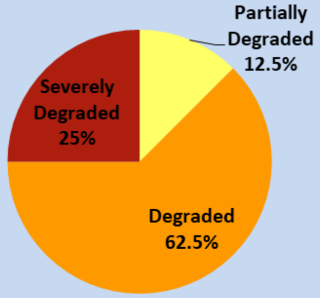
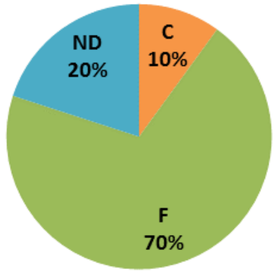
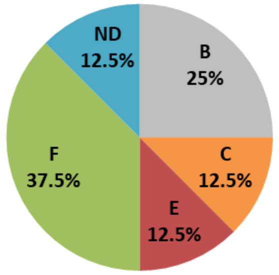
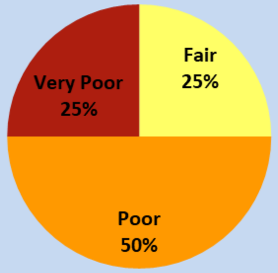
PSU 3: Lower Patapsco

The Lower Patapsco sampling unit is located on the northern edge of the County, due north of BWI Airport, and has a drainage area of 4,040 acres. In 2018, impervious surfaces comprised 31.5 % of the overall sampling unit, with individual sites ranging from 26.7 % to 44.7 %.



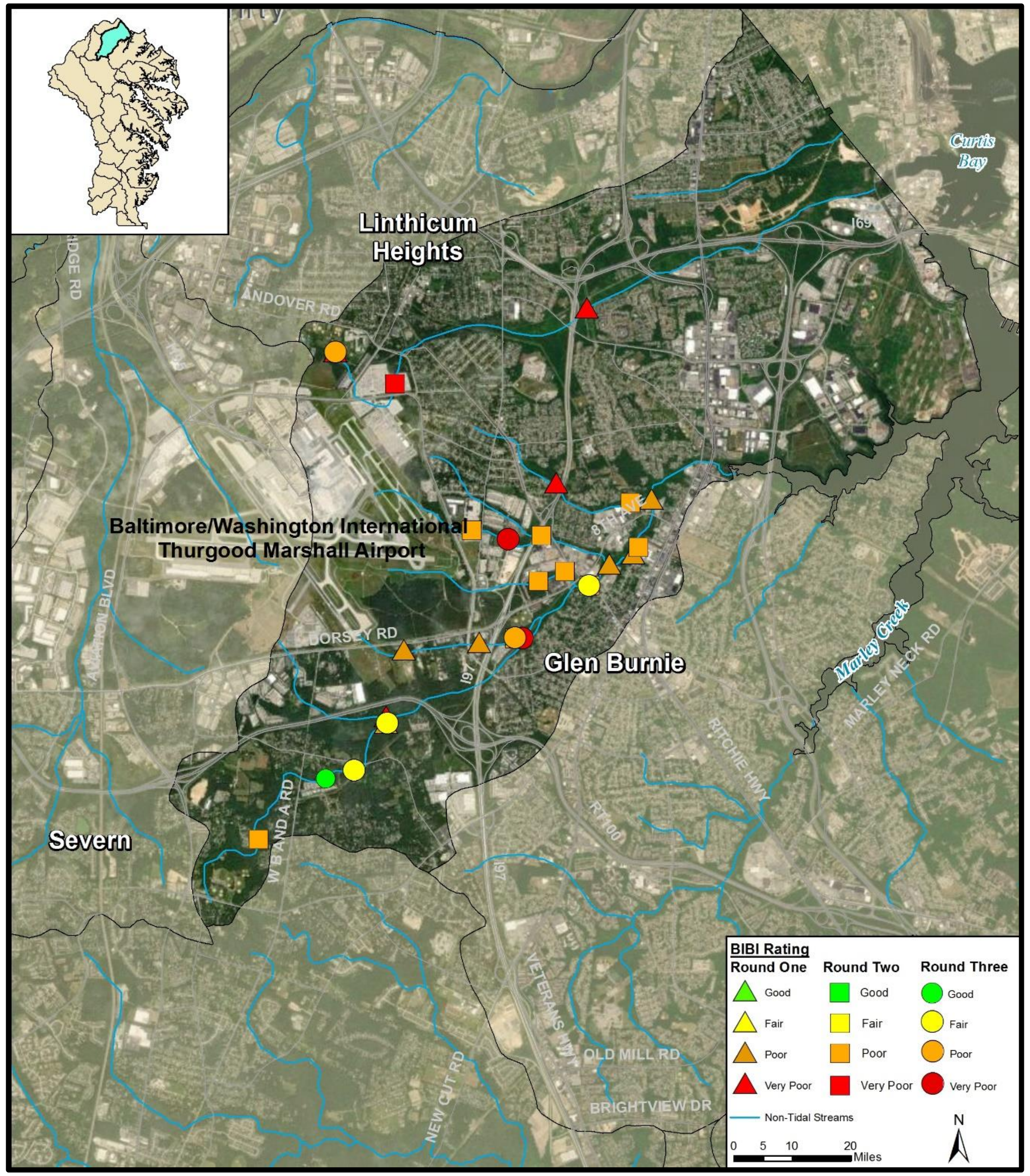


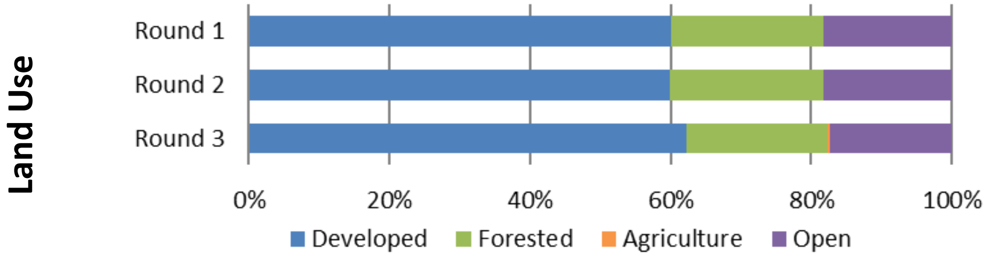
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

	Round 1 (2004)	Round 2 (2012)	Round 3 (2018)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				Yes ↓	No
PHI Score				Yes ↓	No
Rosgen Type	N/A			N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

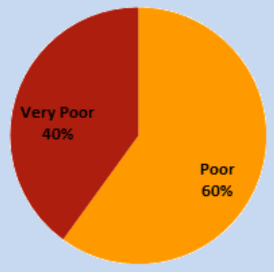
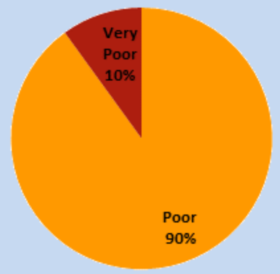
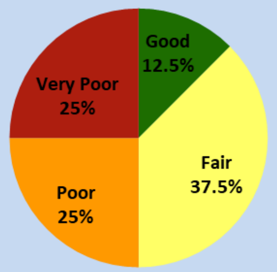
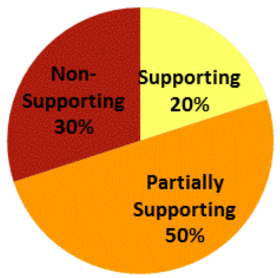
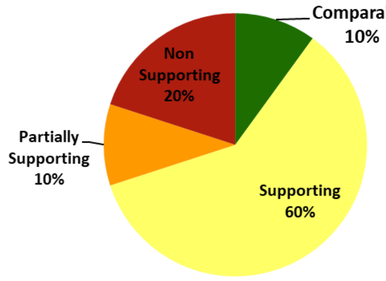
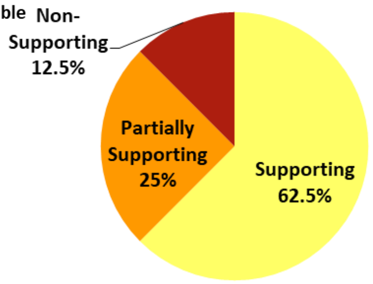
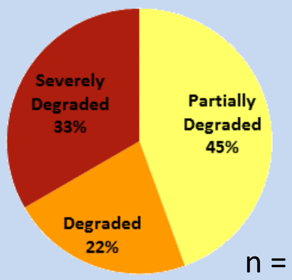
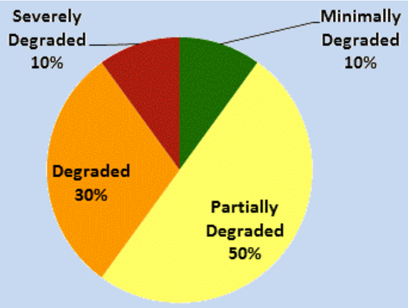
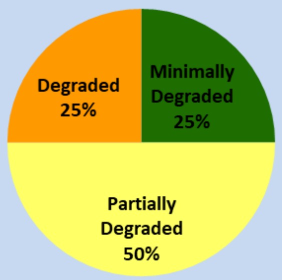
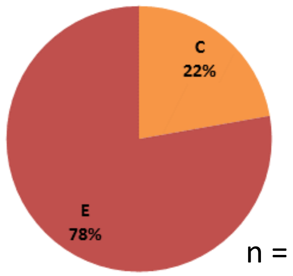
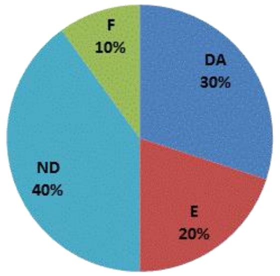
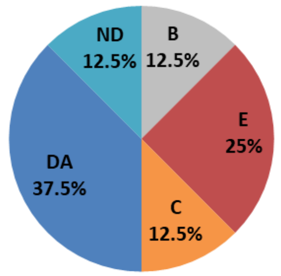
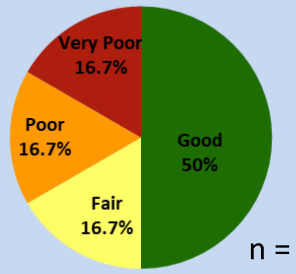
PSU 4: Sawmill Creek

The Sawmill Creek sampling unit is in the northern portion of the County, in the vicinity of Ferndale and Glen Burnie, and has a total drainage area of 11,044 acres. This sampling unit also contains a large portion of BWI Airport. In 2019, impervious surfaces comprised 32.7 % of the overall sampling unit, with individual sites ranging from 11.1 % to 56.2 %.



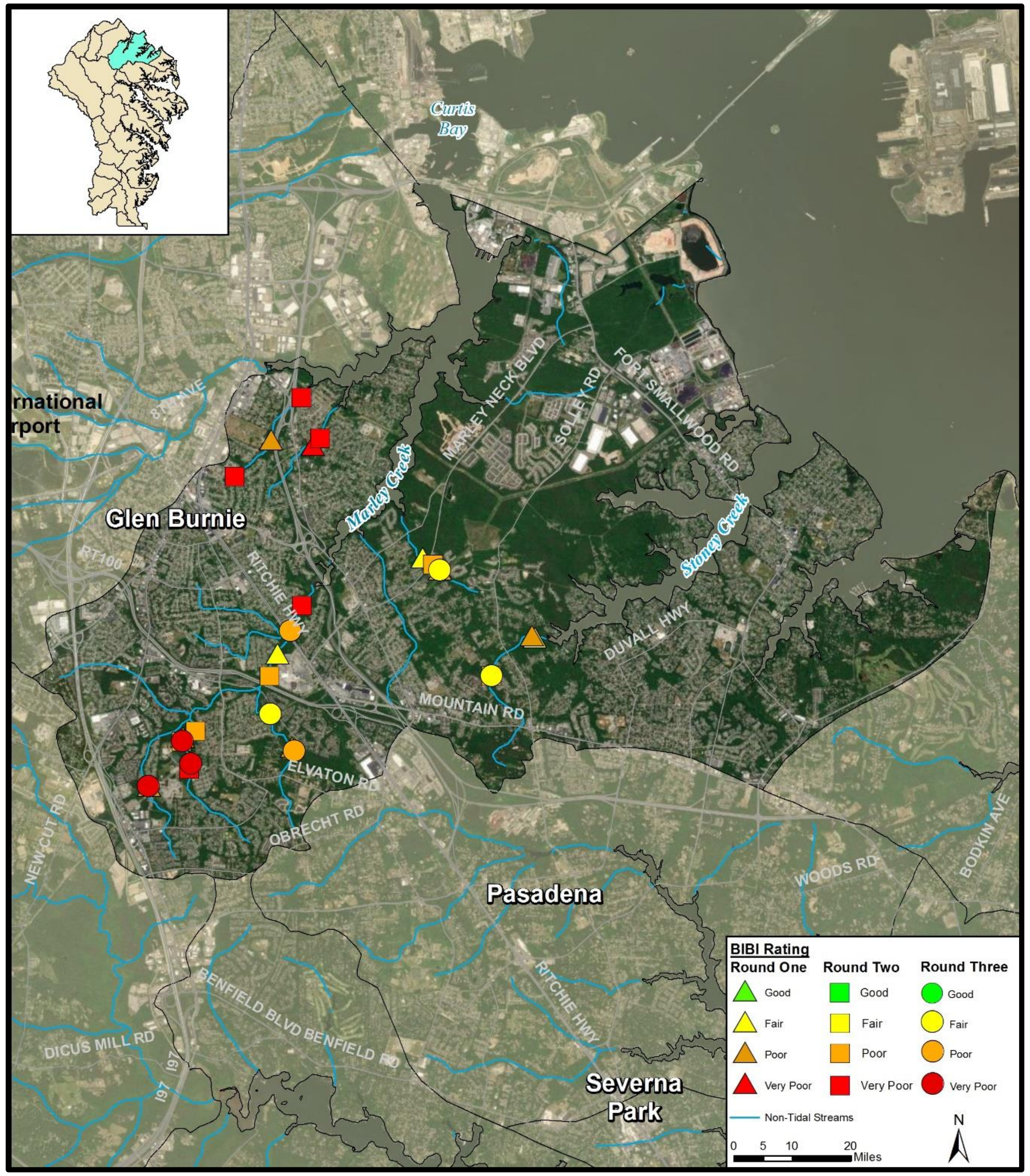


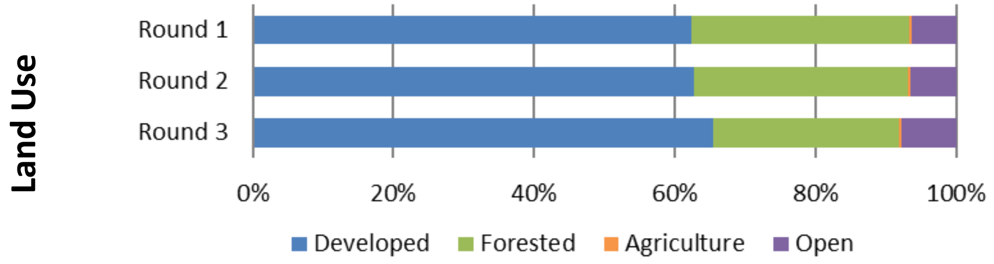
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007; R3 = 2017

	Round 1 (2008)	Round 2 (2010)	Round 3 (2019)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				Yes ↑	No
RBP Score				No	No
PHI Score	 n = 9			Yes ↑	No
Rosgen Type	 n = 9			N/A	N/A
FIBI Score	N/A	N/A	 n = 6	N/A	N/A

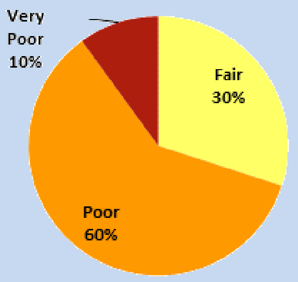
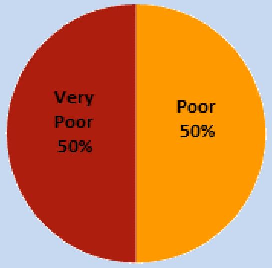
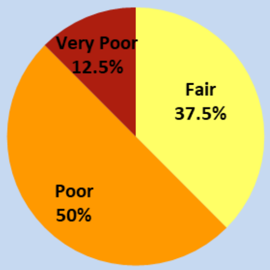
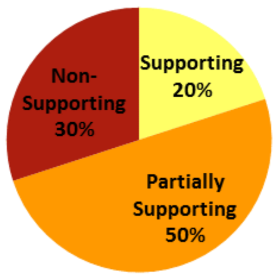
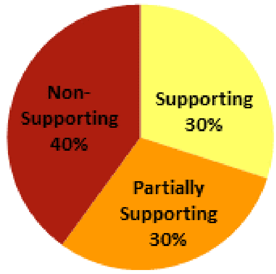
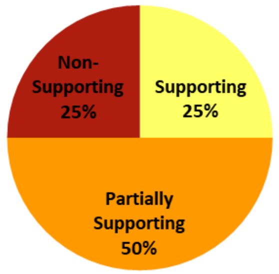
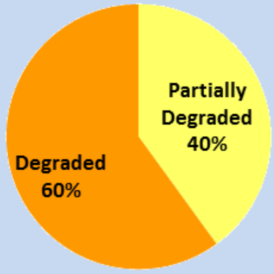
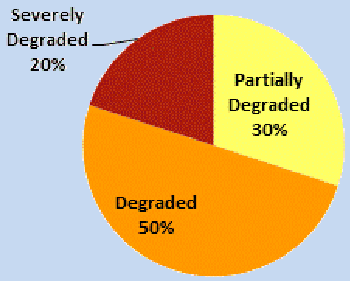
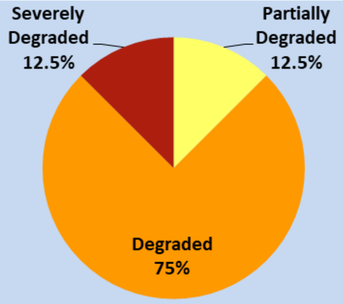
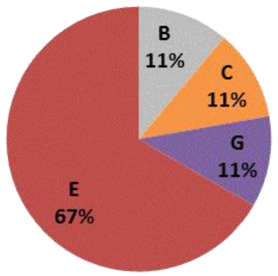
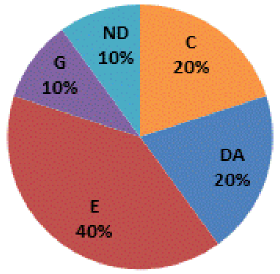
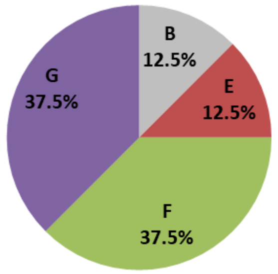
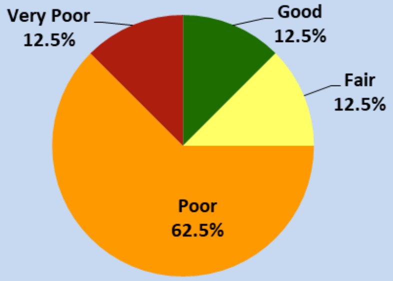
PSU 5: Marley Creek

The Marley Creek sampling unit is in the northern part of the County, with a total drainage area of 19,425 acres. In 2018, 28.4 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 14.8 % to 41.5 %.



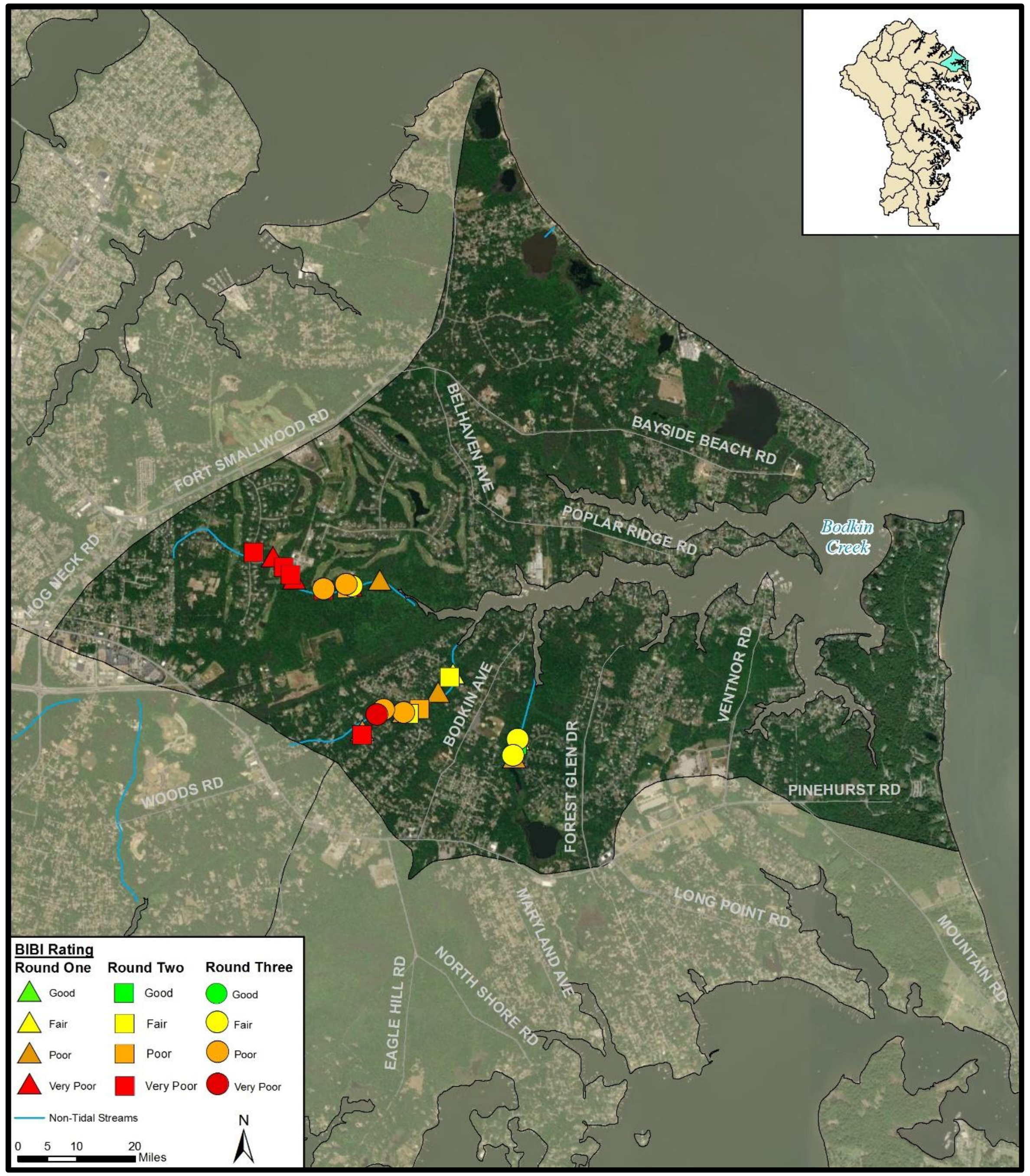


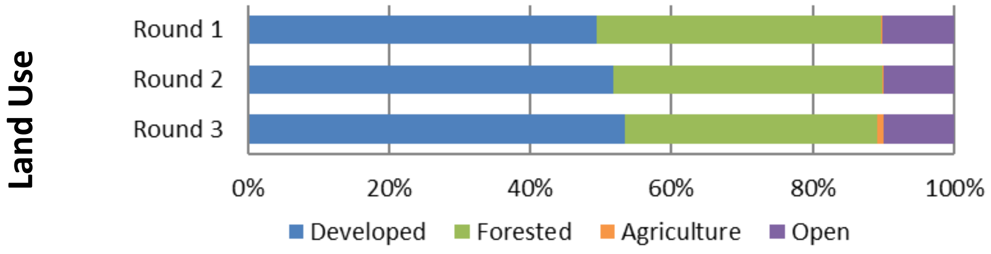
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2014

	Round 1 (2006)	Round 2 (2009)	Round 3 (2018)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	Yes ↑
RBP Score				No	No
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

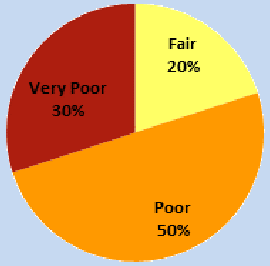
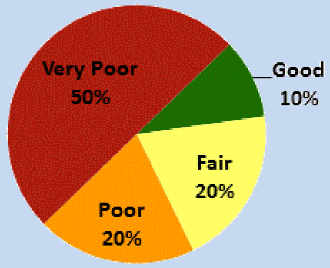
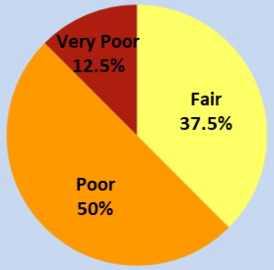
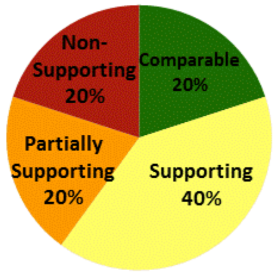
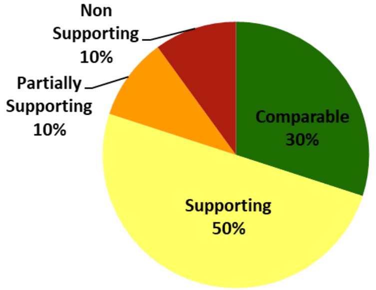
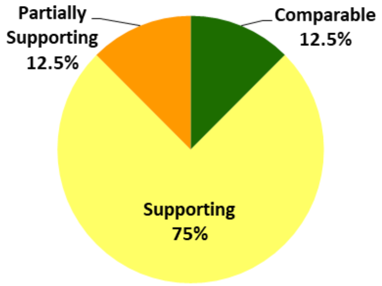
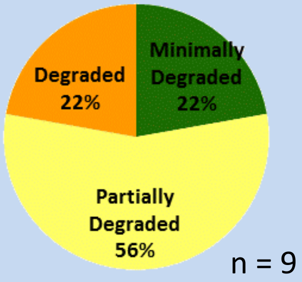
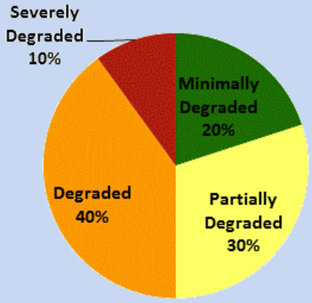
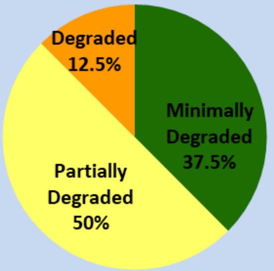
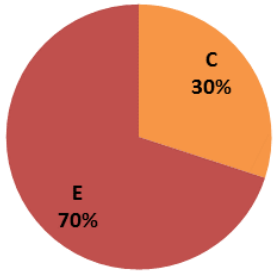
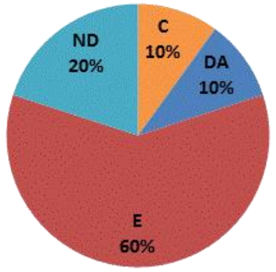
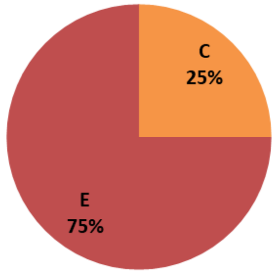
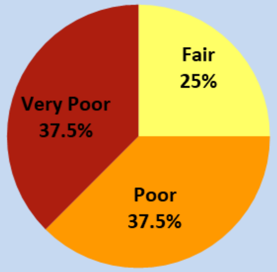
PSU 6: Bodkin Creek

The Bodkin Creek sampling unit, located in the northeastern portion of the County, has a total drainage area of 5,872 acres. In 2017, impervious surfaces comprised 13.6 % of the overall sampling unit, with individual sites ranging from 10.6 % to 14.1 %.



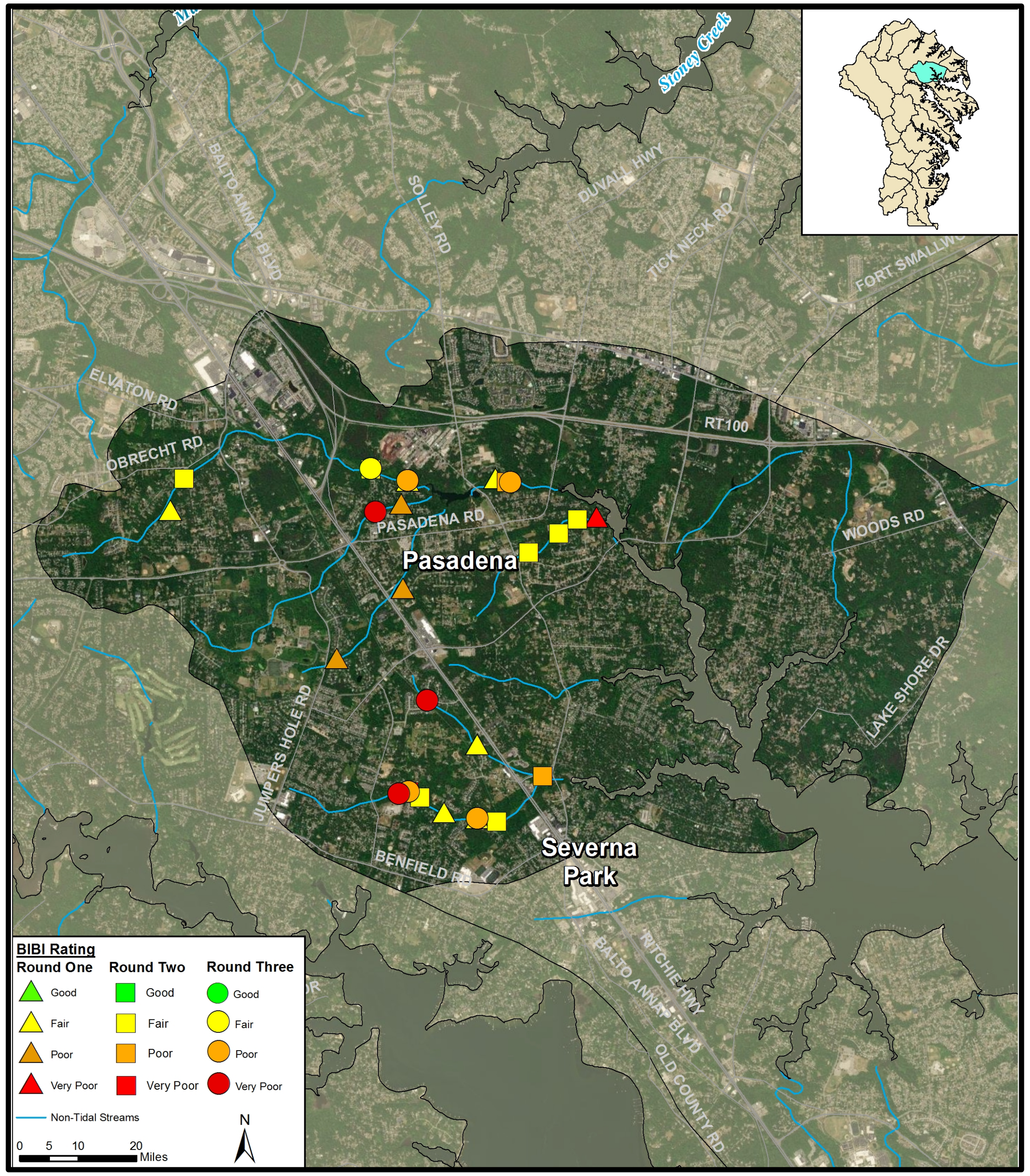


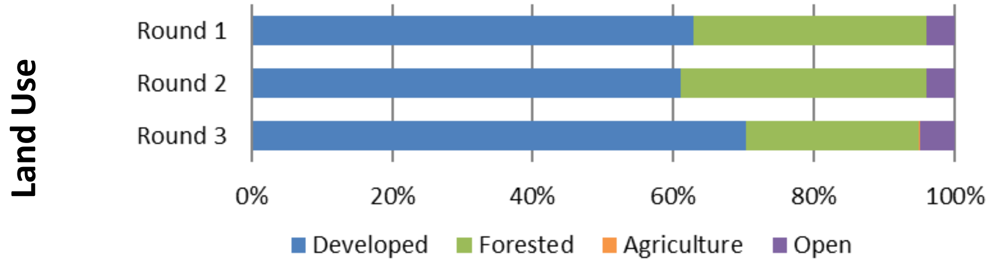
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2014

	Round 1 (2006)	Round 2 (2011)	Round 3 (2017)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	No
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

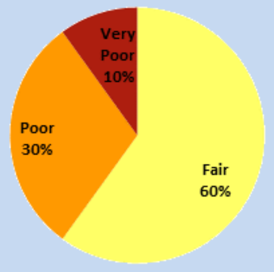
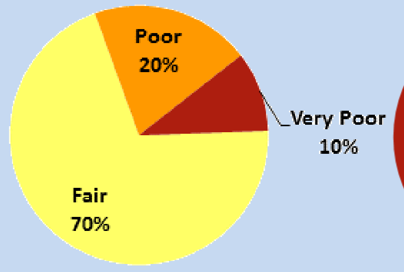
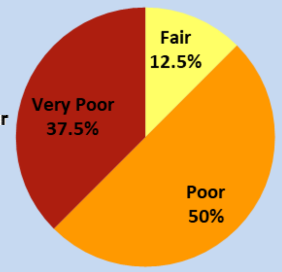
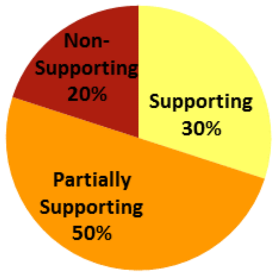
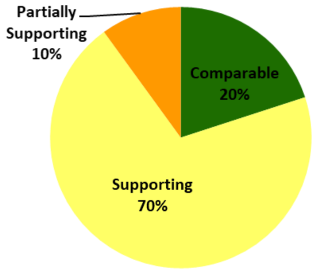
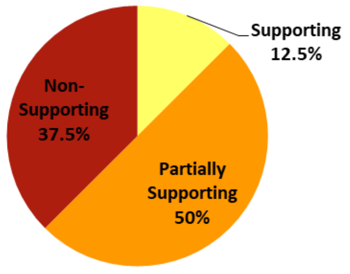
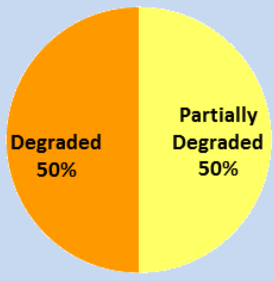
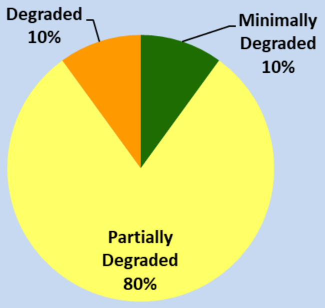
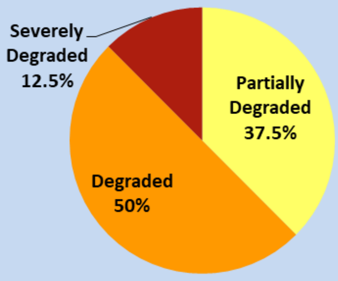
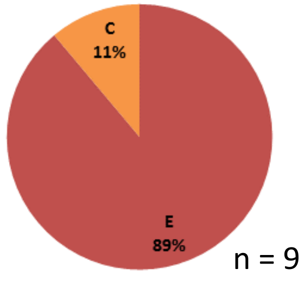
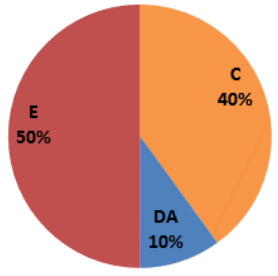
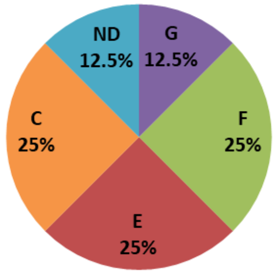
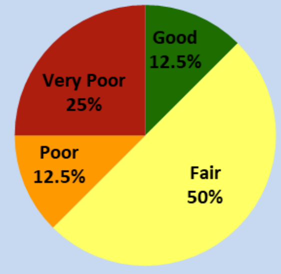
PSU 7: Upper Magothy

The Upper Magothy sampling unit is in the eastern central portion of the County in the vicinity of Pasadena, with a total drainage area of 10,031 acres. In 2020, impervious surfaces comprised 13.9 % of the overall sampling unit, with individual sites ranging from 9.3 % to 20.9 %.



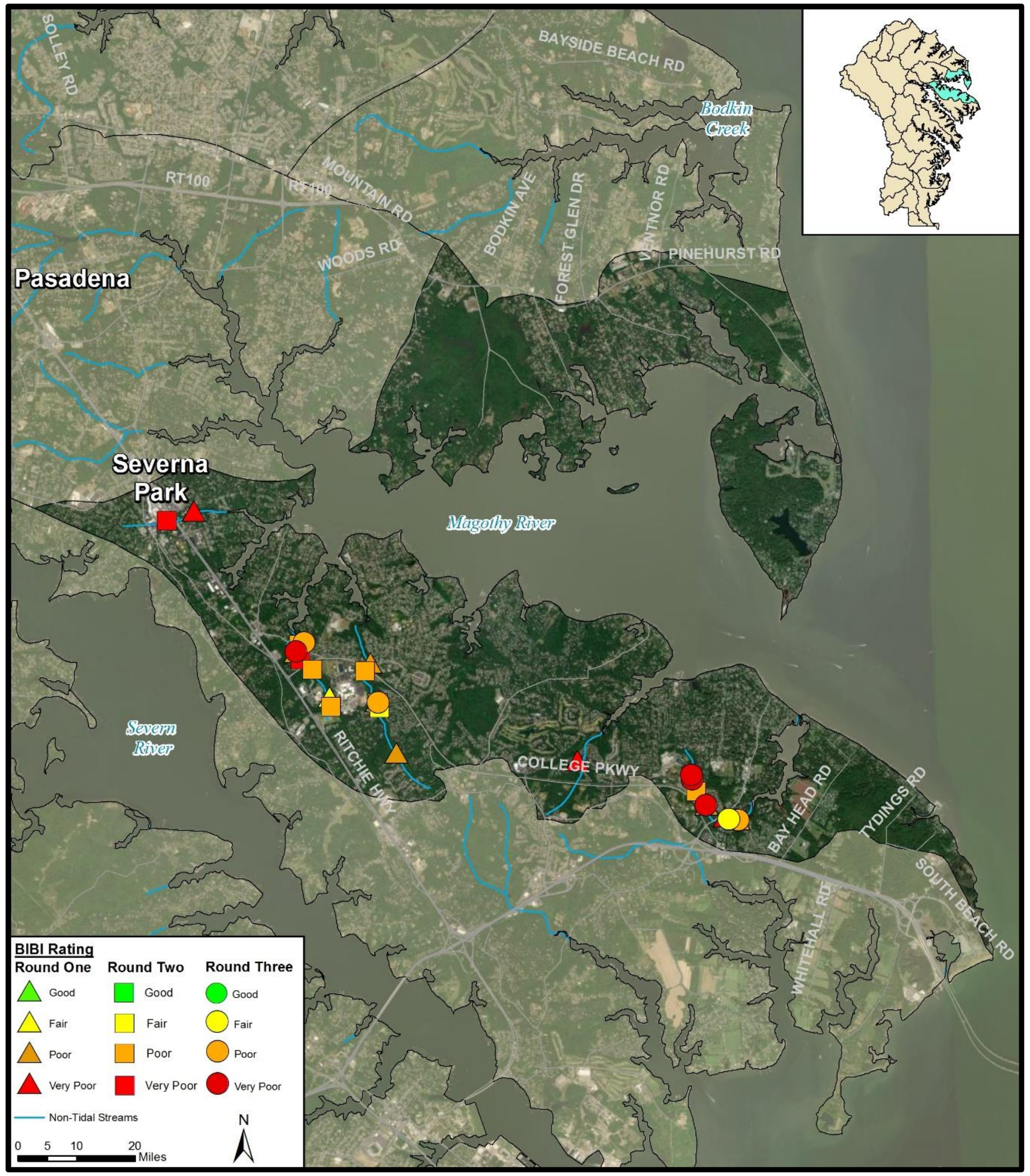


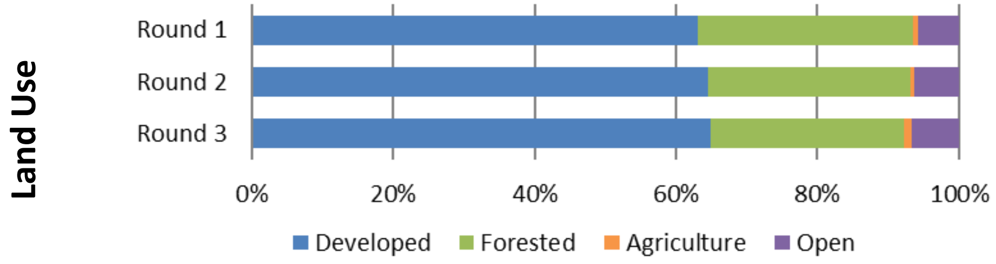
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

	Round 1 (2006)	Round 2 (2011)	Round 3 (2020)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				Yes ↓	Yes ↓
RBP Score				No	Yes ↓
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

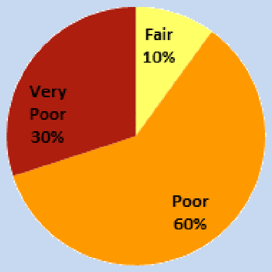
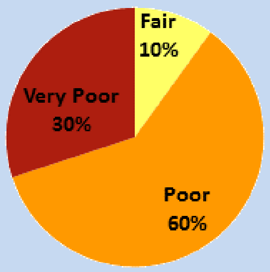
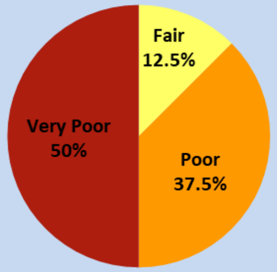
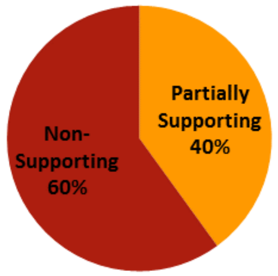
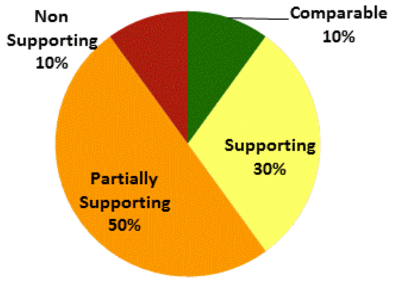
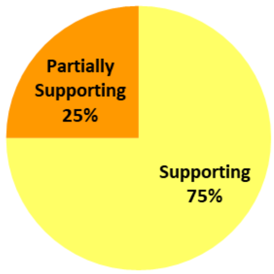
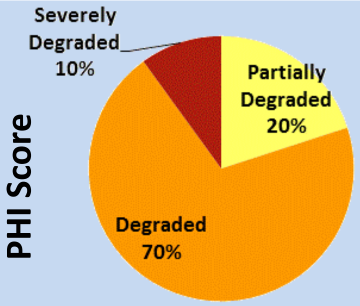
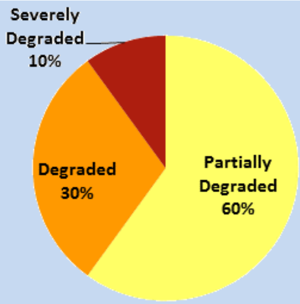
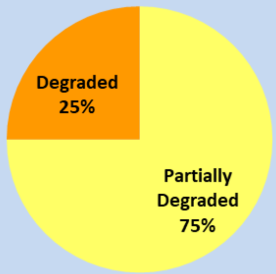
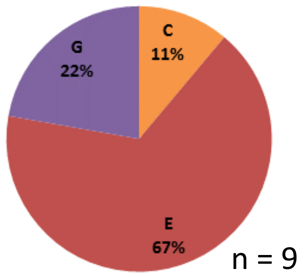
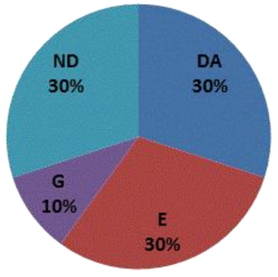
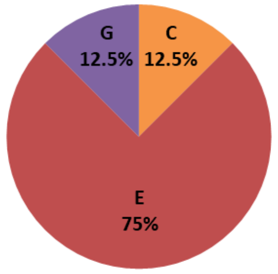
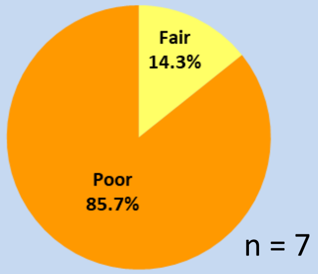
PSU 8: Lower Magothy

The Lower Magothy sampling unit has a drainage area of 12,697 acres and drains directly into the Magothy River, which empties into the Chesapeake Bay. In 2018, impervious surfaces comprised 19.9 % of the overall sampling unit, with individual sites ranging from 19.7 % to 29.3 %.



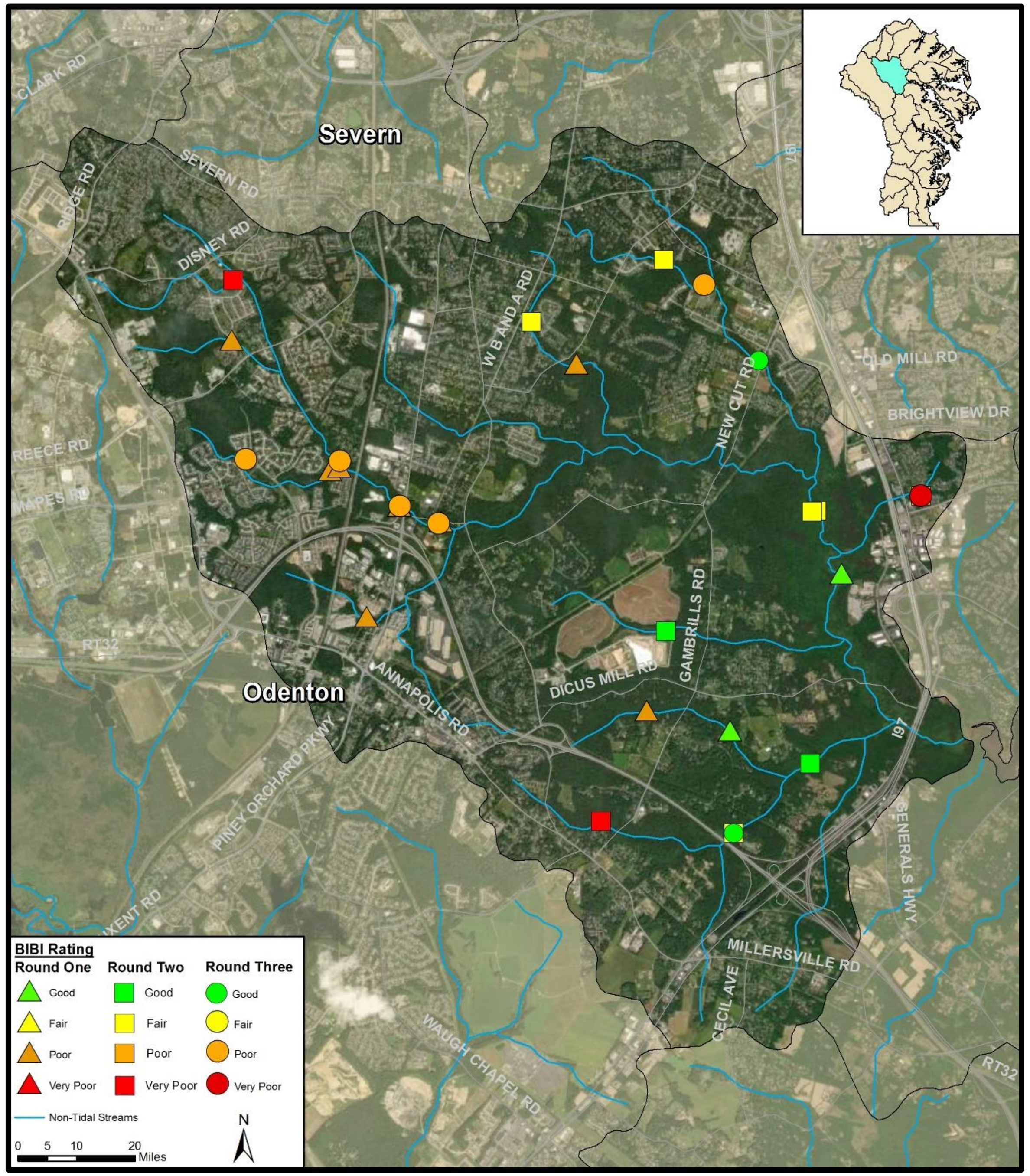


*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011; R3 = 2014

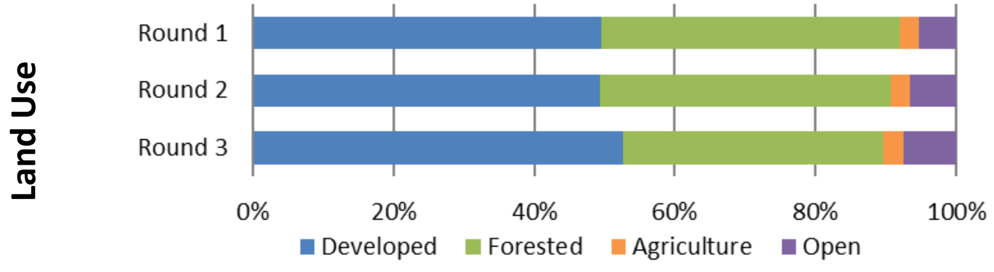
	Round 1 (2007)	Round 2 (2013)	Round 3 (2018)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				Yes ↑	No
PHI Score				Yes ↑	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

PSU 9: Severn Run

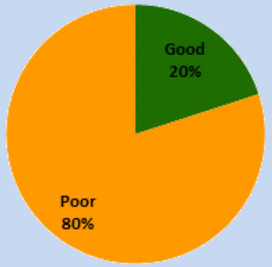
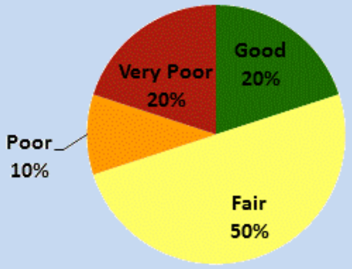
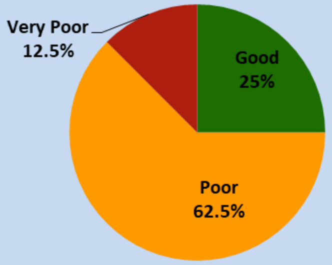
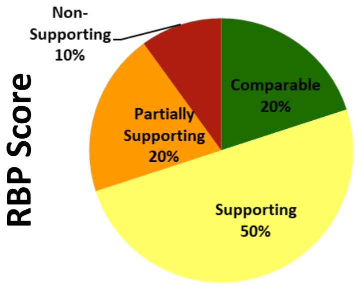
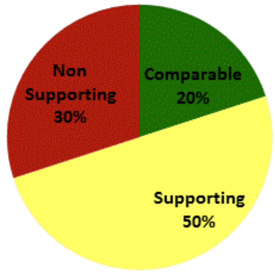
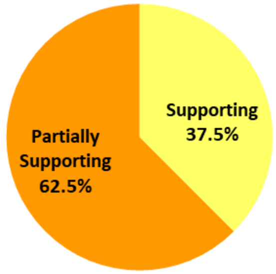
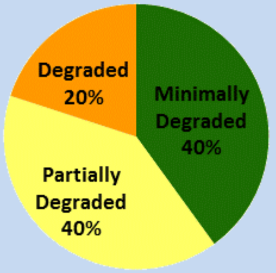
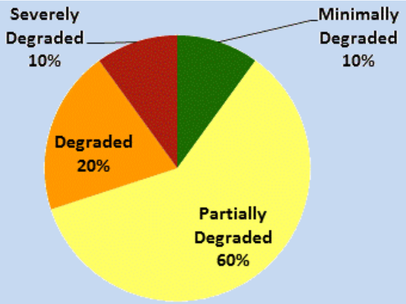
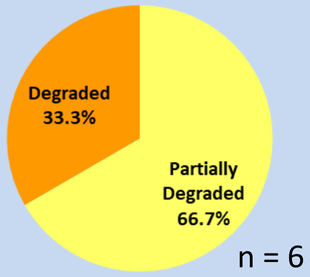
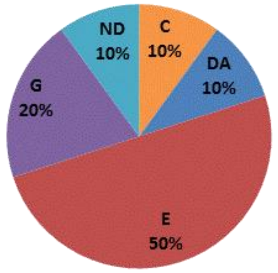
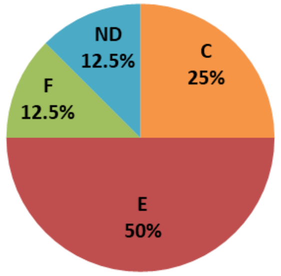
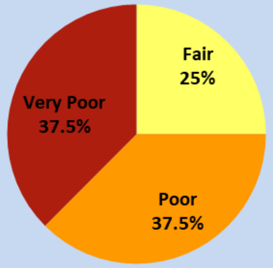
The Severn Run sampling unit is in the central part of the County to the east of the Fort George G. Meade Military Reservation, with a drainage area of 15,424 acres. In 2017, impervious surfaces comprised 19.6 % of the overall sampling unit, with individual sites ranging from 13.3 % to 27.8 %.



Land Use

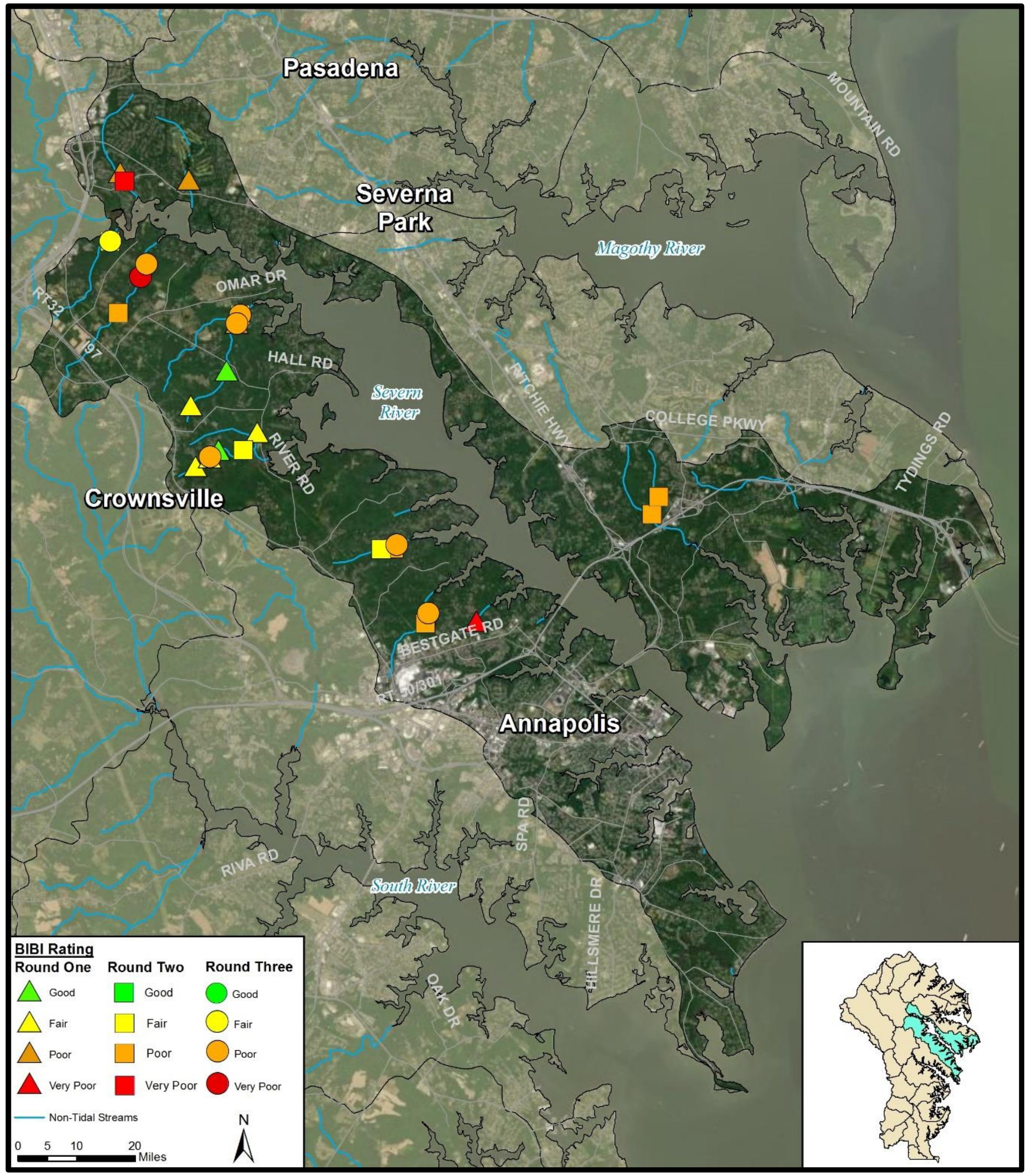


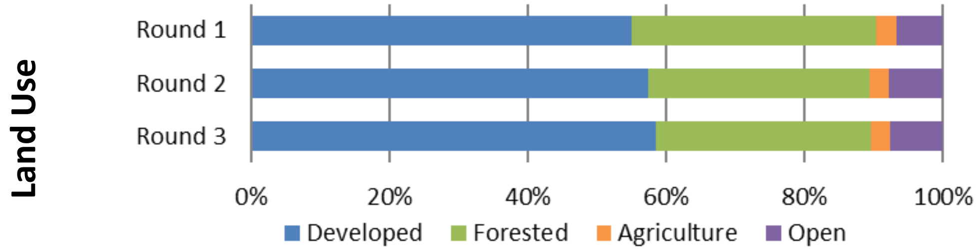
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2014

	Round 1 (2004)	Round 2 (2011)	Round 3 (2017)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	No
PHI Score				Yes ↓	No
Rosgen Type	N/A			N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

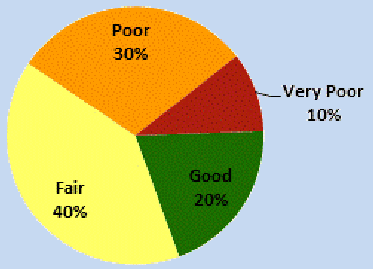
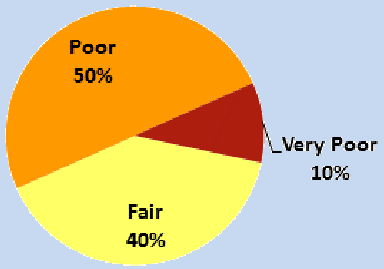
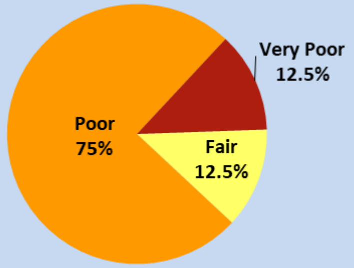
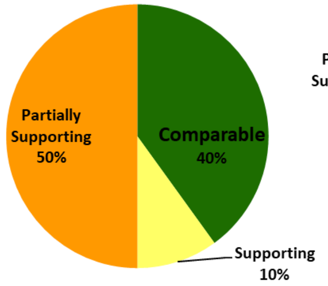
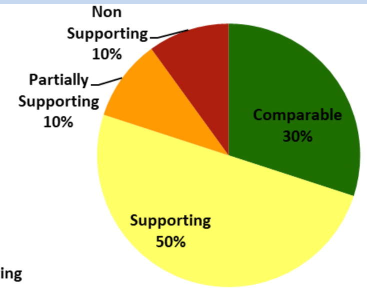
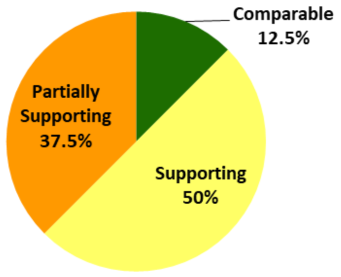
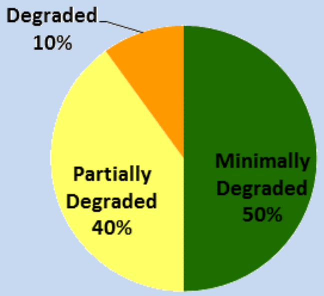
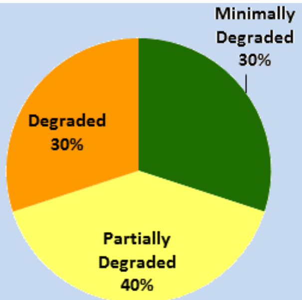
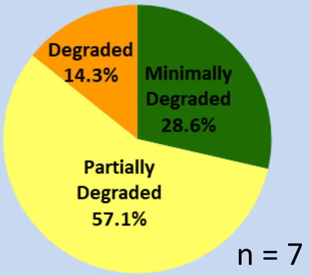
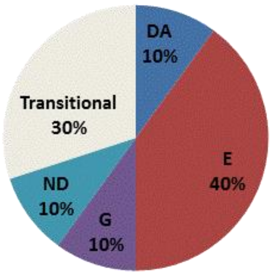
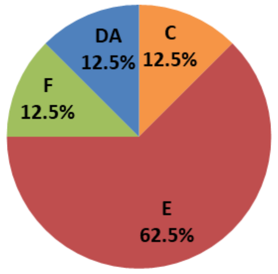
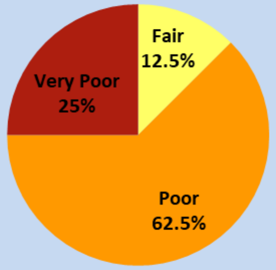
PSU 10: Severn River

The Severn River sampling unit, which consists of direct tributaries to the Severn River, is in the vicinity of Annapolis and Crownsville and has a drainage area of 28,920 acres. In 2017, impervious surfaces comprised 19.9 % of the overall sampling unit, with individual sites ranging from 7.0 % to 24.2 %.



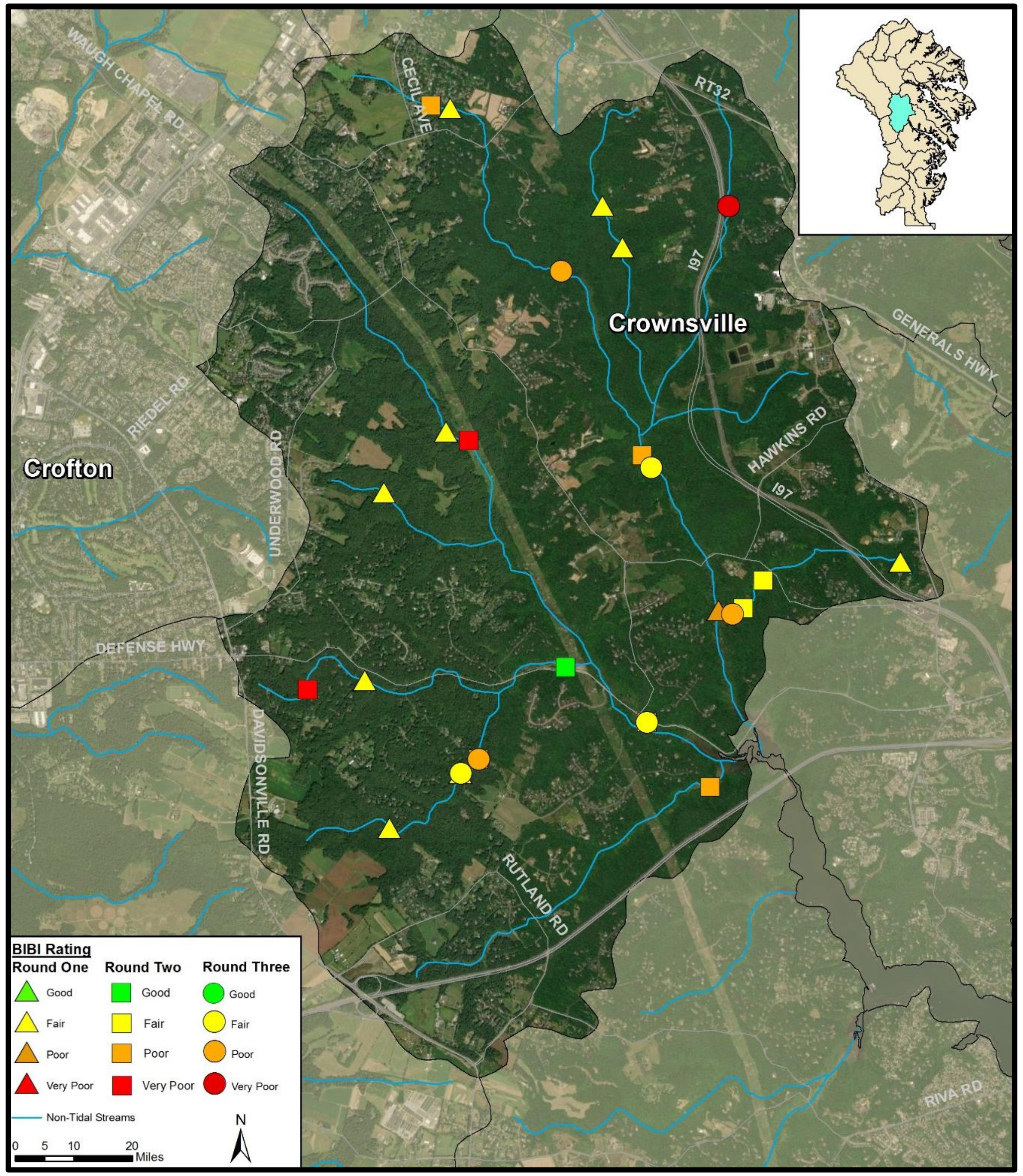


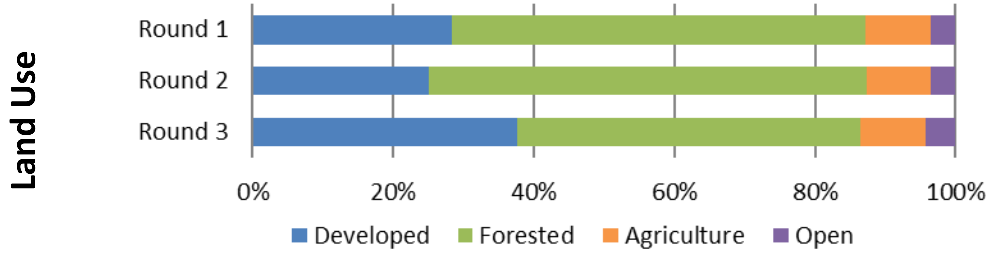
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011; R3 = 2014

	Round 1 (2004)	Round 2 (2013)	Round 3 (2017)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	No
PHI Score				No	No
Rosgen Type	N/A			N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

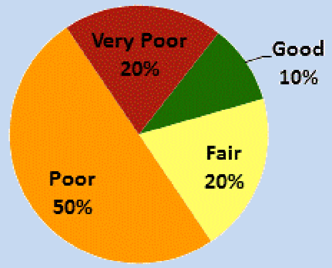
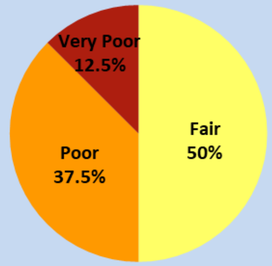
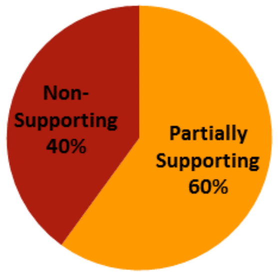
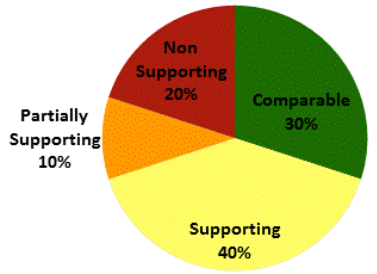
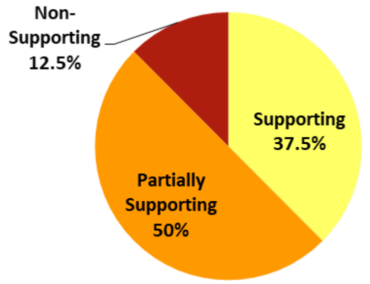
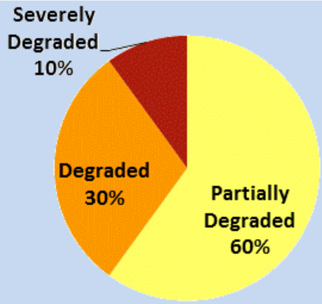
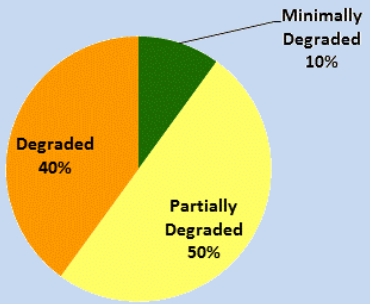
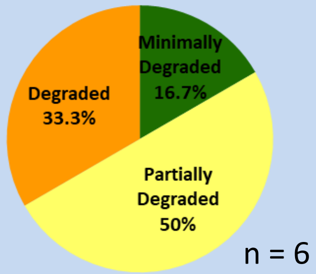
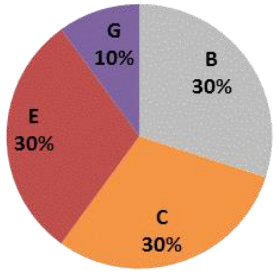
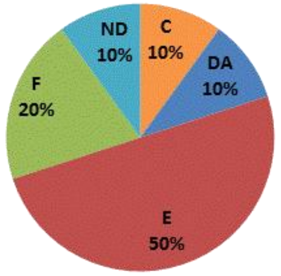
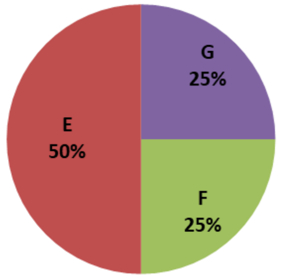
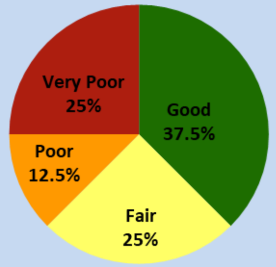
PSU 11: Upper North River

The Upper North River sampling unit is in the central part of the County, between Crofton and Crownsville, and has a drainage area of 12,797 acres. In 2017, impervious surfaces comprised 7.0 % of the overall sampling unit, with individual sites ranging from 3.1 % to 9.7 %.



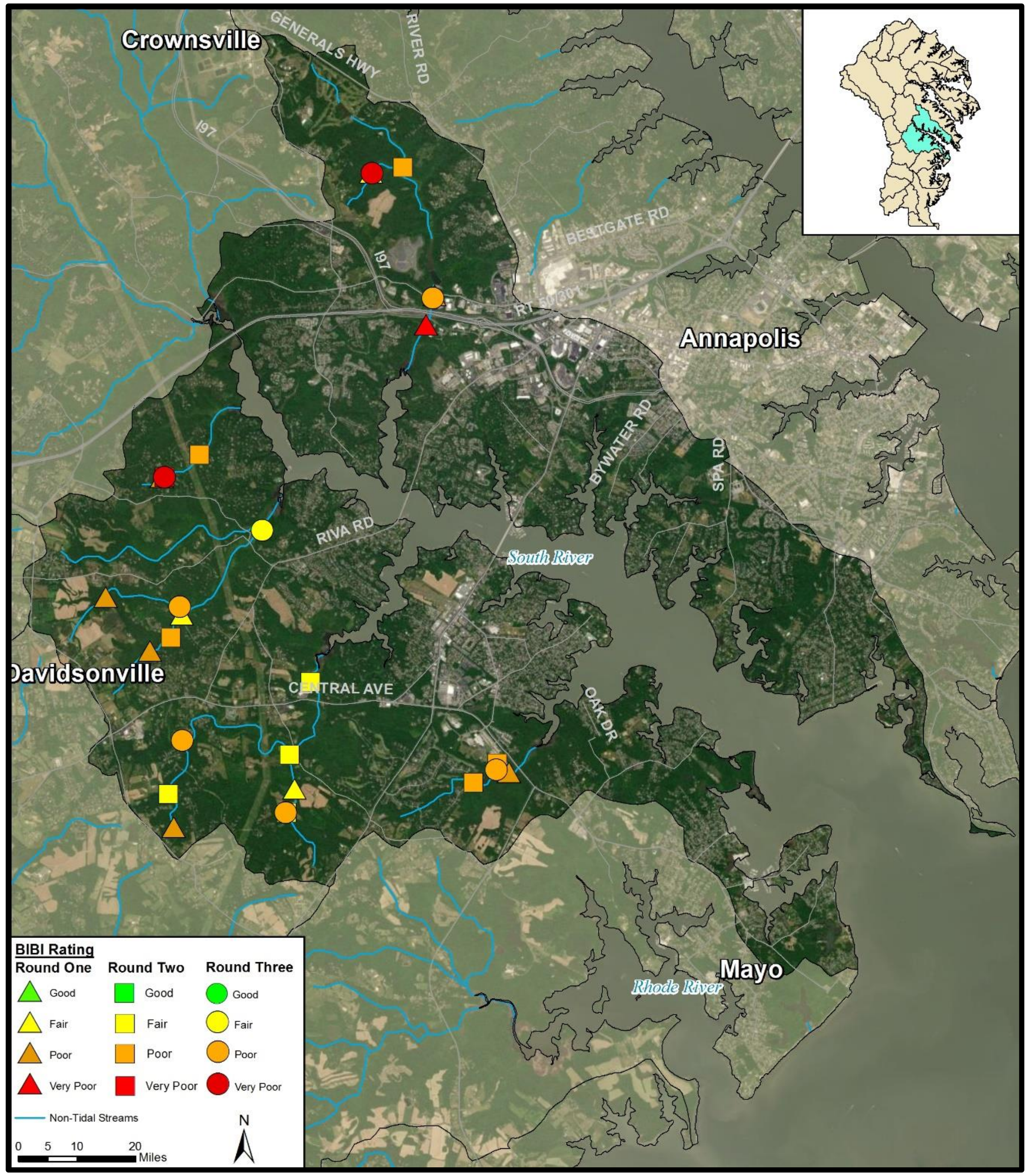


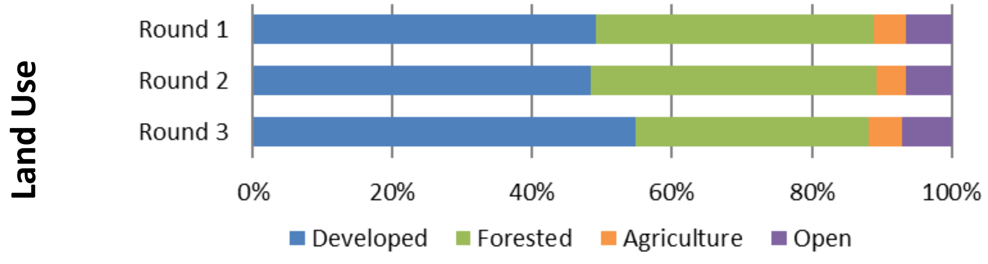
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2014

	Round 1 (2005)	Round 2 (2011)	Round 3 (2017)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				Yes ↓	No
RBP Score				No	No
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

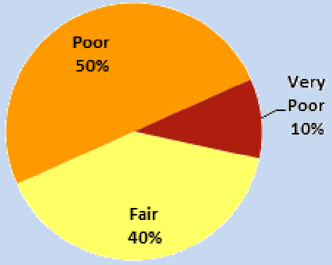
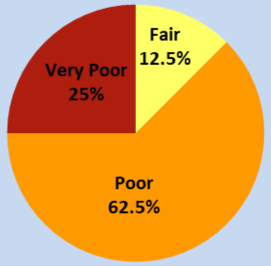
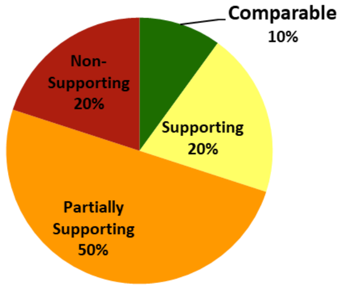
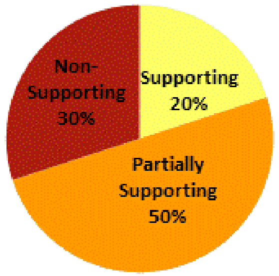
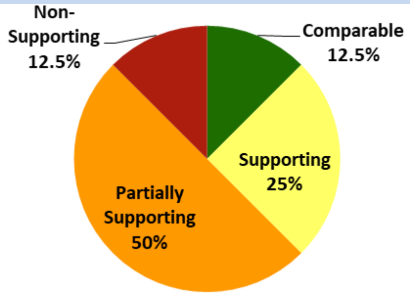
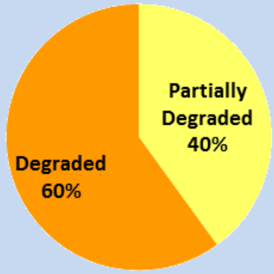
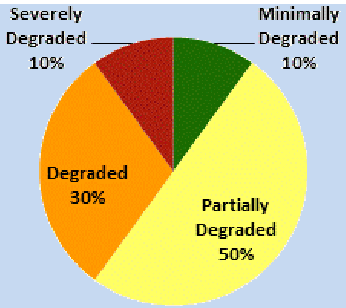
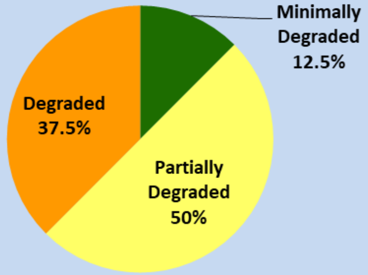
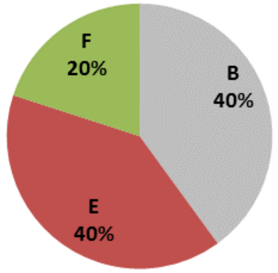
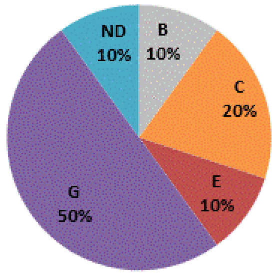
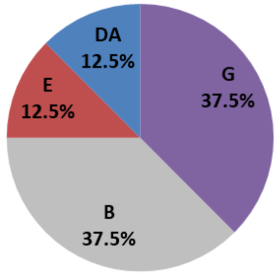
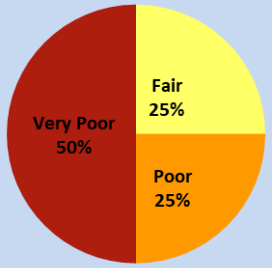
PSU 12: Lower North River

The Lower North River sampling unit, located between Annapolis and Davidsonville, has a drainage area of 23,681 acres and drains directly into the South River, which empties into the Chesapeake Bay. In 2019, impervious surfaces comprised 16.4 % of the overall sampling unit, with individual sites ranging from 2.9 % to 11.3 %.



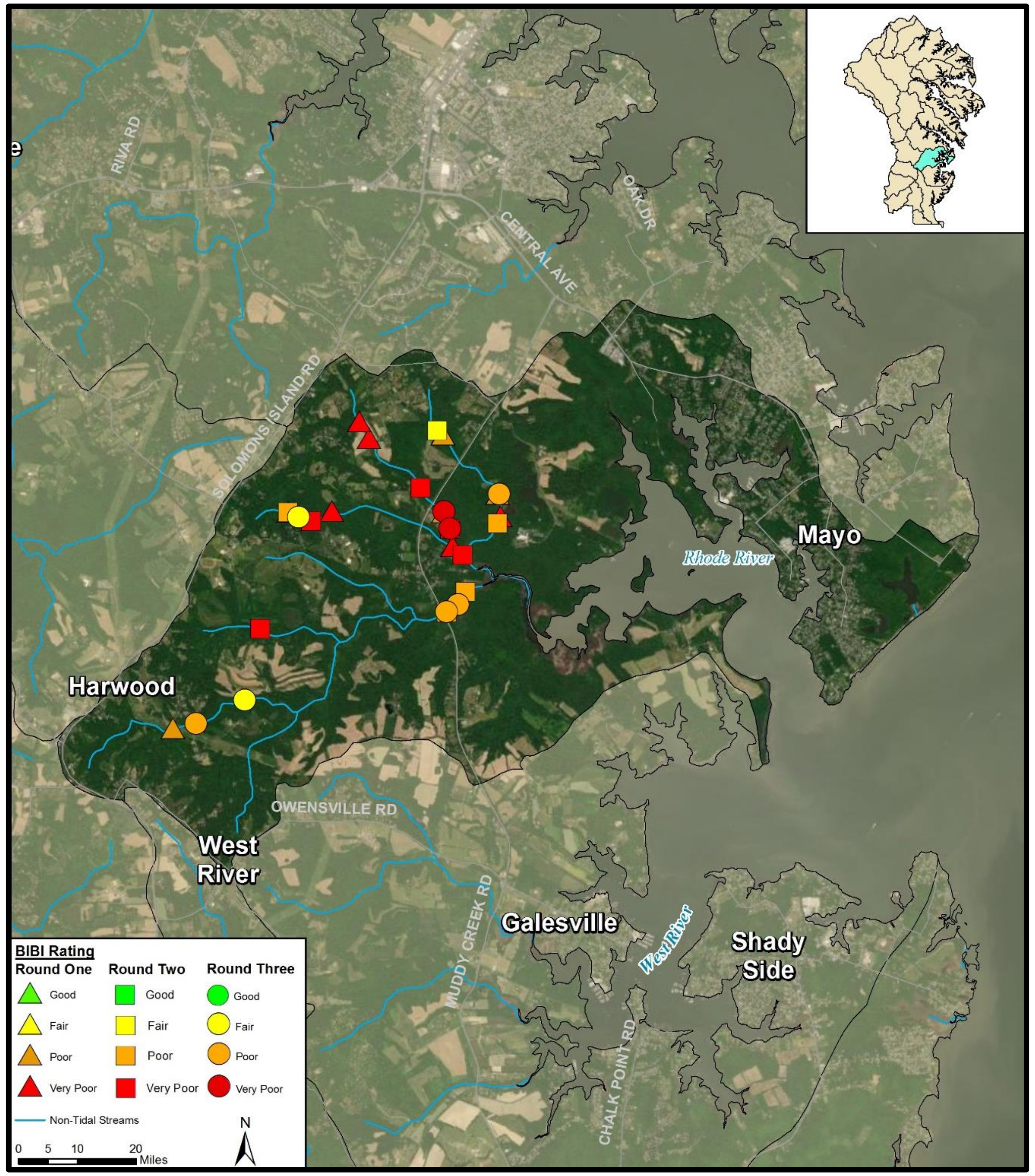


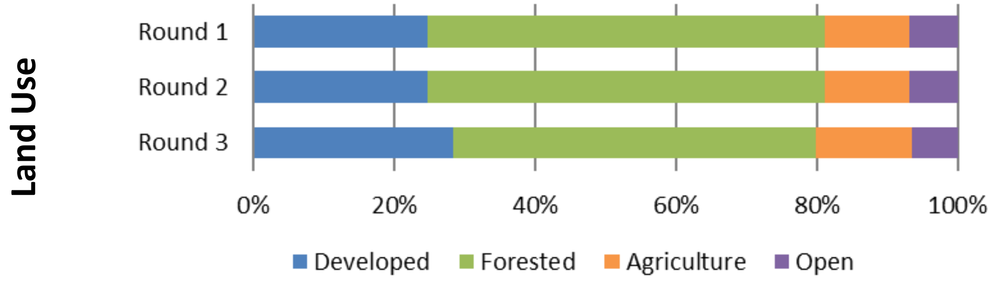
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

	Round 1 (2005)	Round 2 (2009)	Round 3 (2019)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	No
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

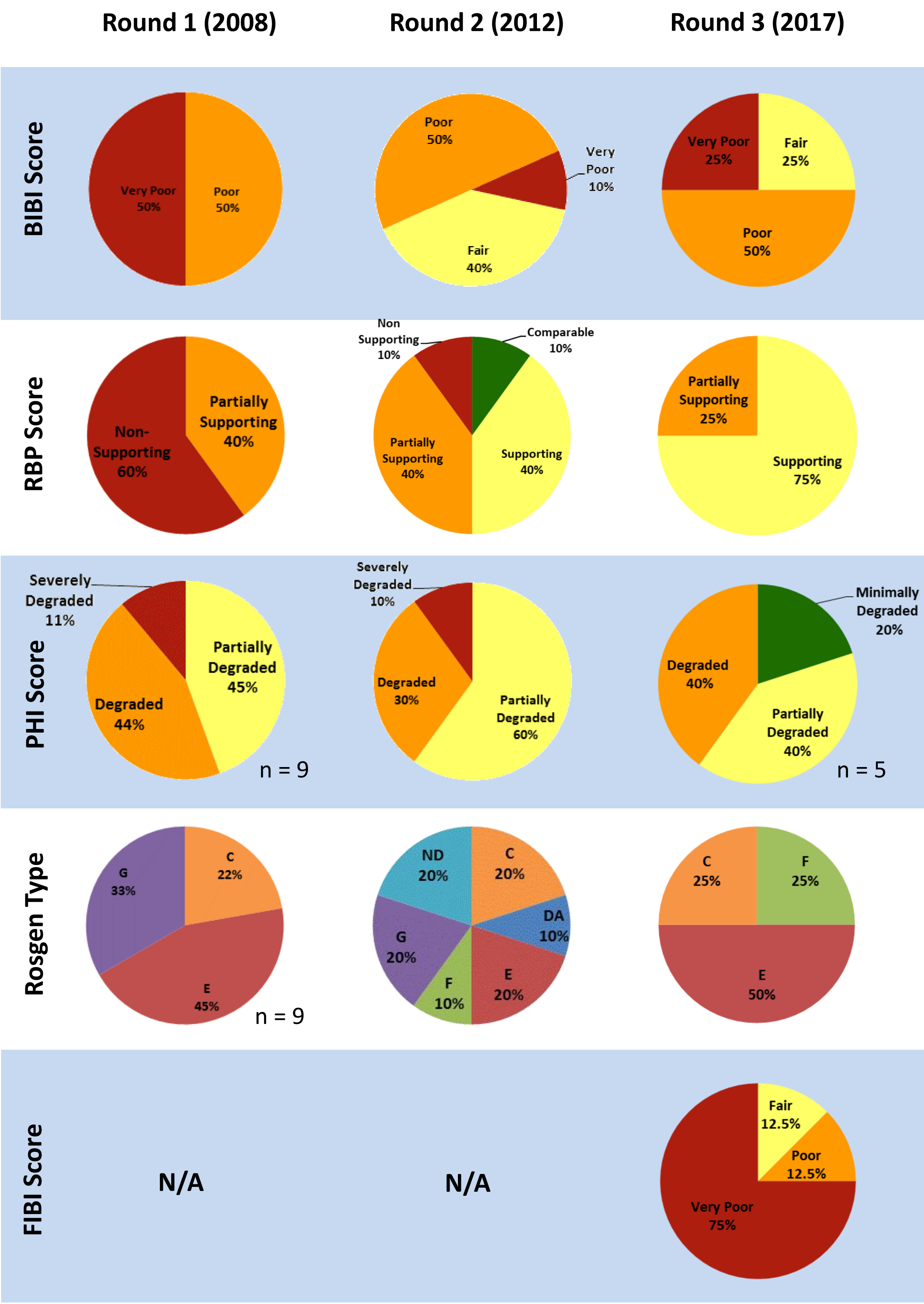
PSU 13: Rhode River

The Rhode River sampling unit is in the southeastern part of the County, south of Edgewater, and has a drainage area of 8,737 acres. In 2017, impervious surfaces comprised 6.1 % of the overall sampling unit, with individual sites ranging from 3.4 % to 6.7 %.





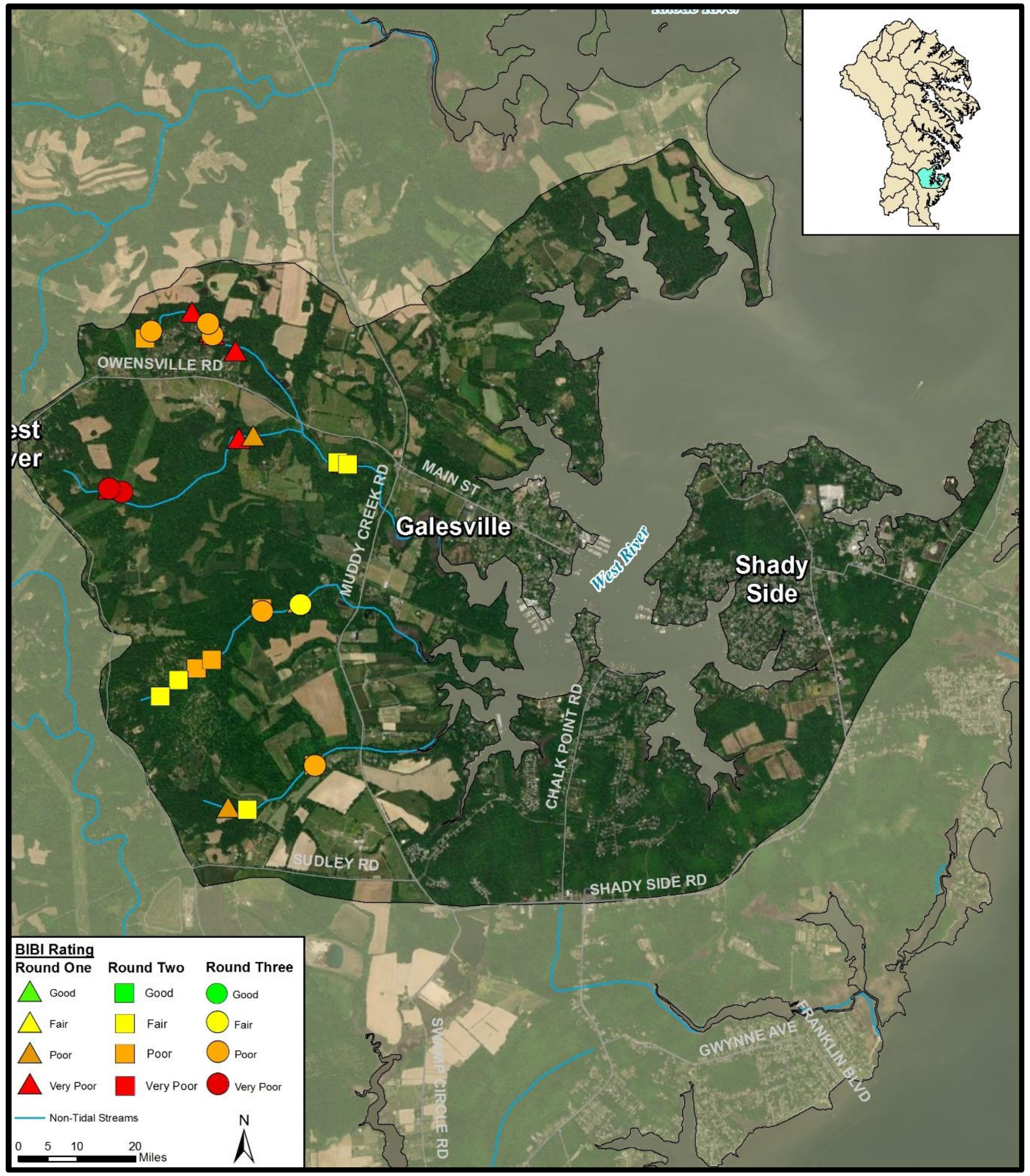
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007; R3 = 2014

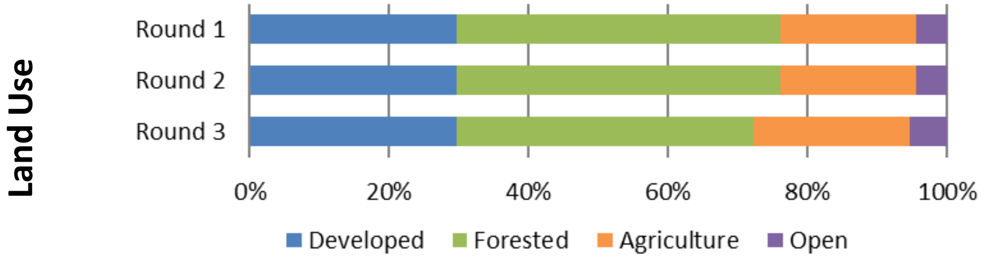


	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score	No	No
RBP Score	Yes ↑	No
PHI Score	Yes ↑	Yes ↑
Rosgen Type	N/A	N/A
FIBI Score	N/A	N/A

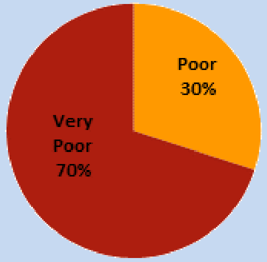
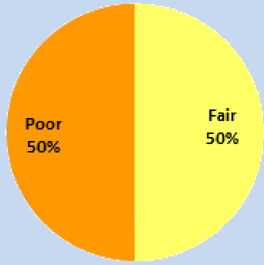
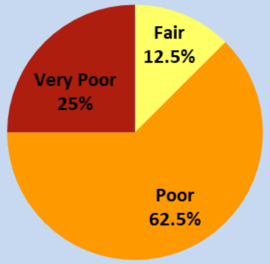
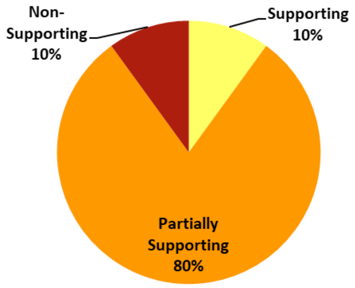
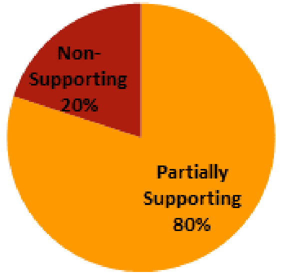
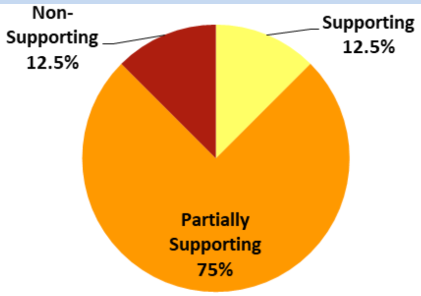
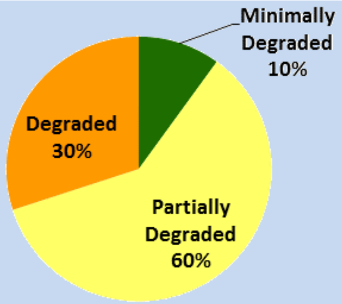
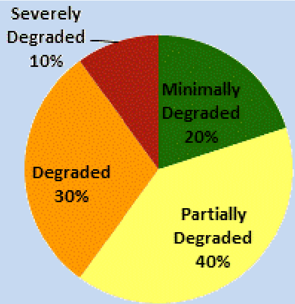
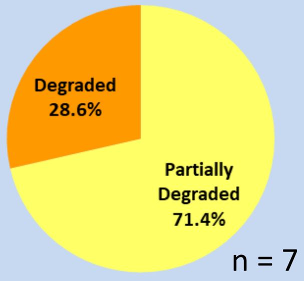
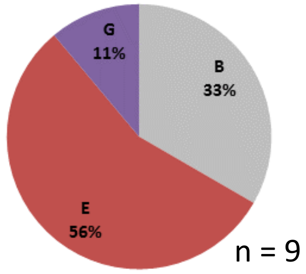
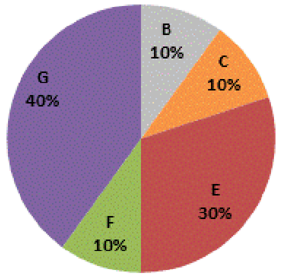
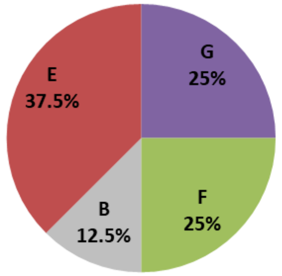
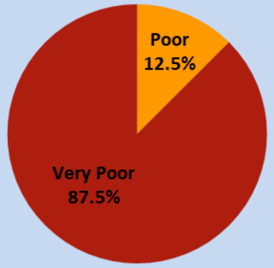
PSU 14: West River

The West River sampling unit is in the southeastern part of the County in the vicinity of Galesville, with a drainage area of 7,558 acres. In 2020, 4.9 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 1.0 % to 4.5 %.



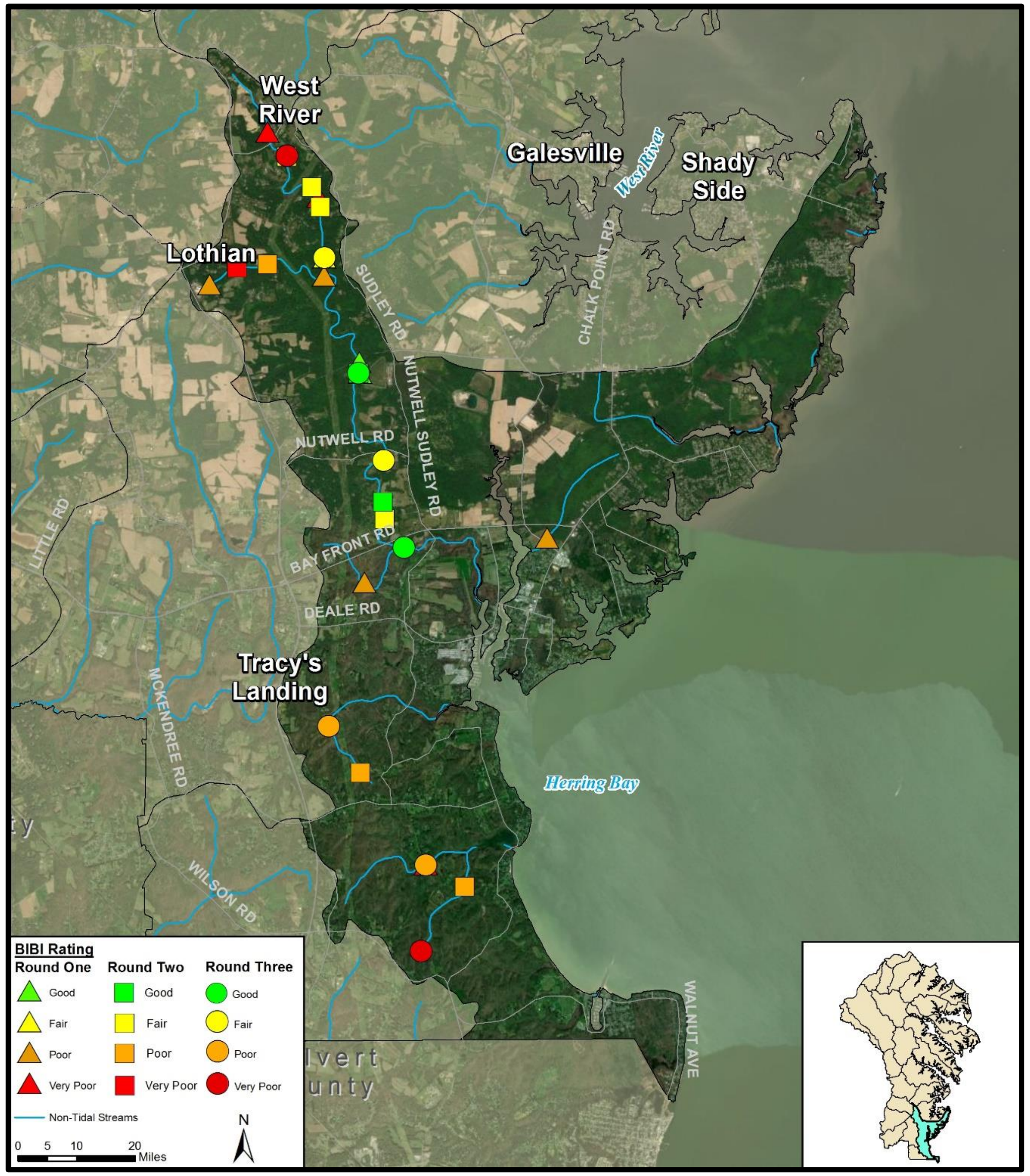


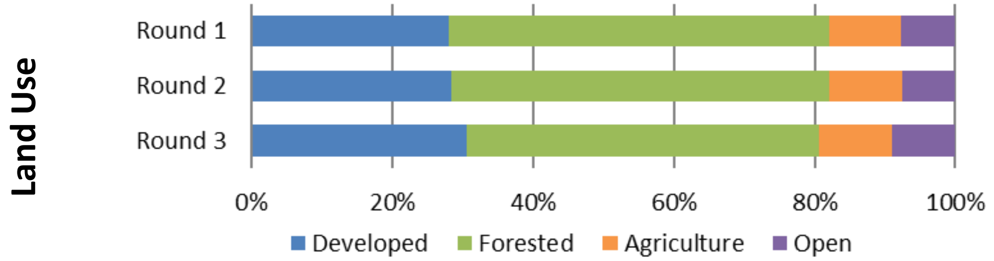
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007; R3 = 2017

	Round 1 (2008)	Round 2 (2009)	Round 3 (2020)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	No
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

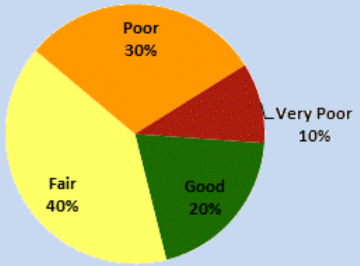
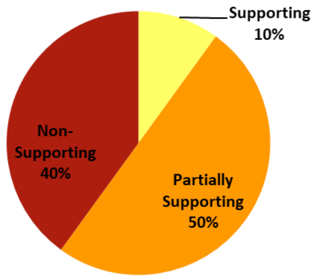
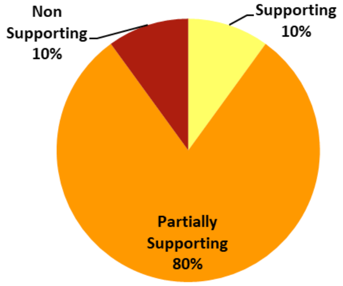
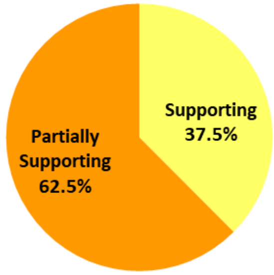
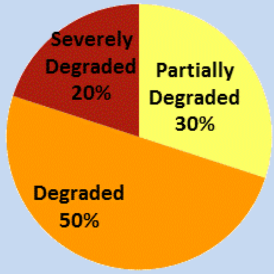
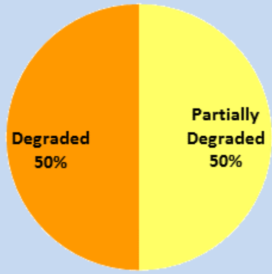
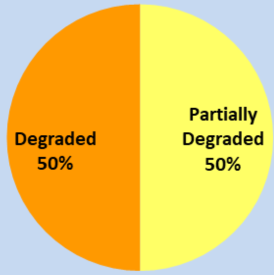
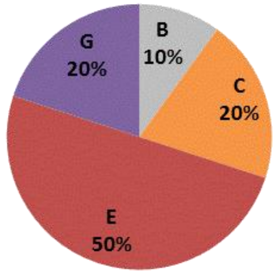
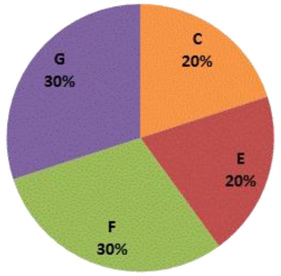
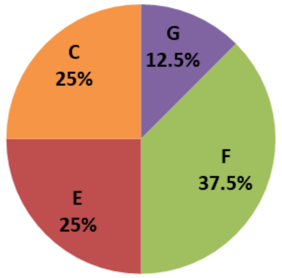
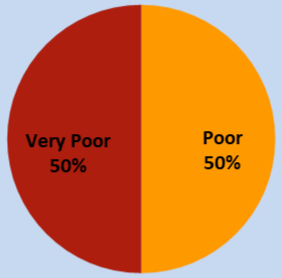
PSU 15: Herring Bay

The Herring Bay sampling unit has a drainage area of 14,595 acres and is in the southeastern portion of the County, bordering the Chesapeake Bay. In 2021, impervious surfaces comprised 4.7 % of the overall sampling unit, with individual sites ranging from 1.2 % to 5.0 %.



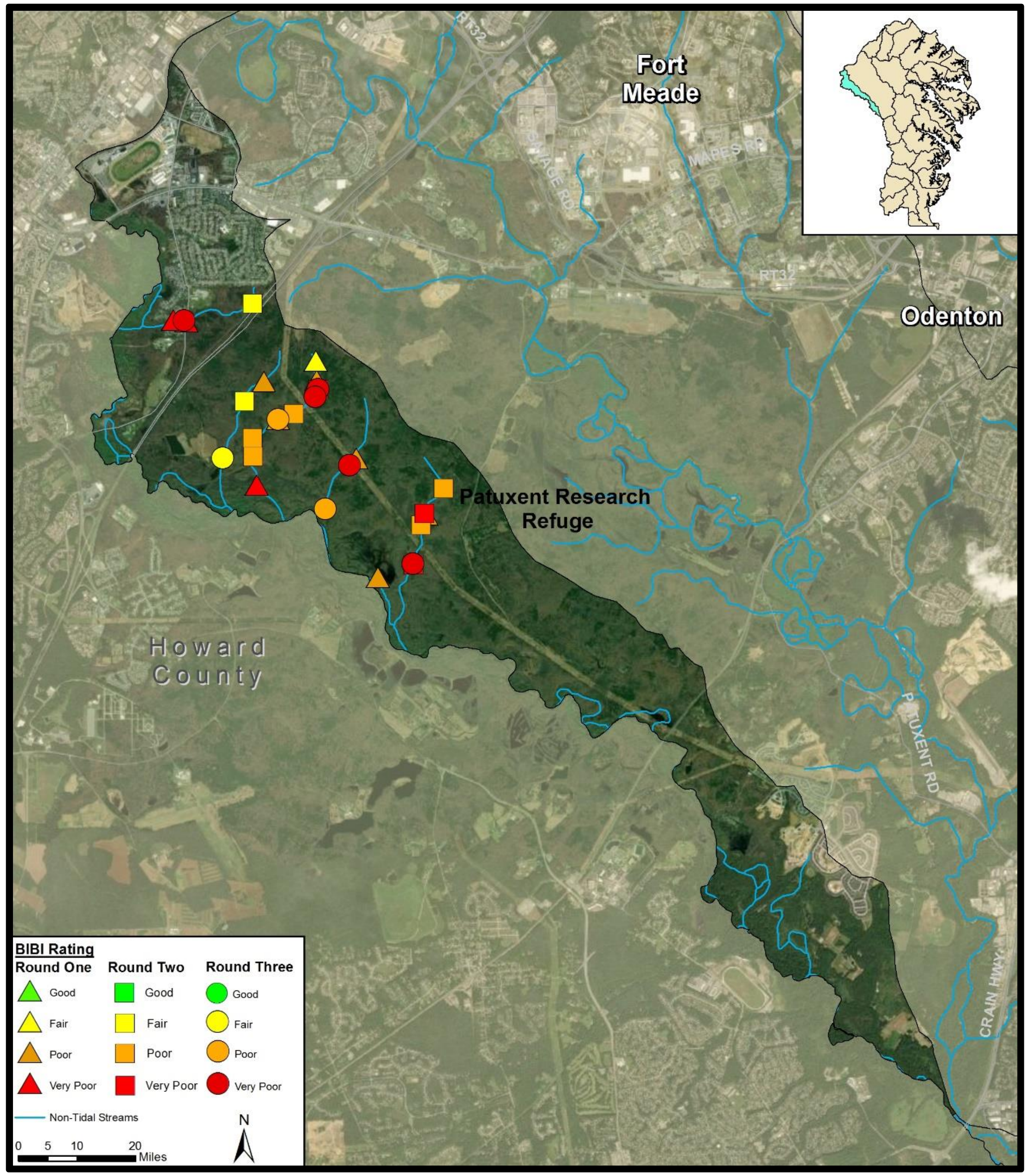


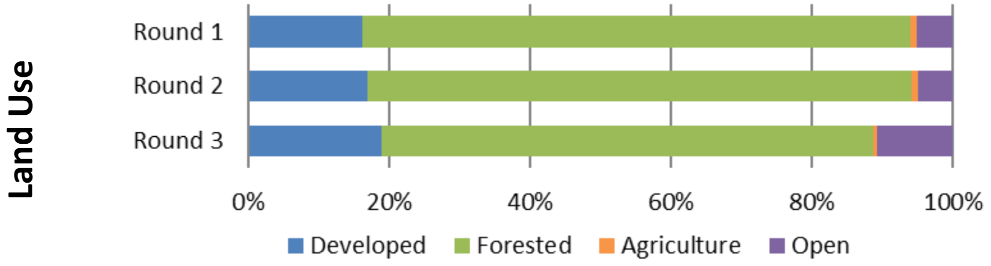
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

	Round 1 (2005)	Round 2 (2010)	Round 3 (2021)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				Yes ↑	No
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

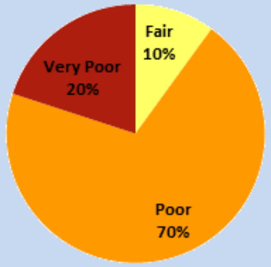
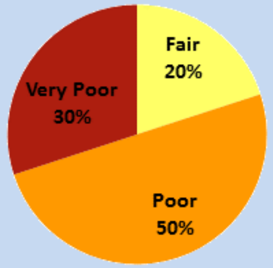
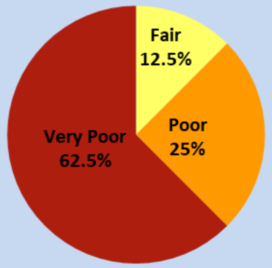
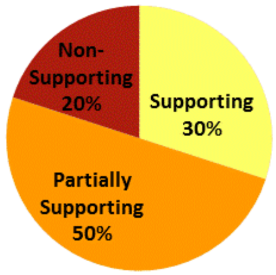
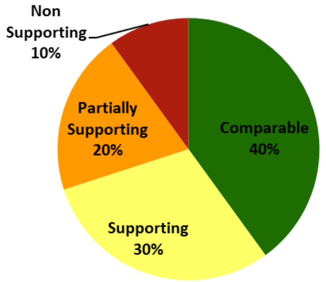
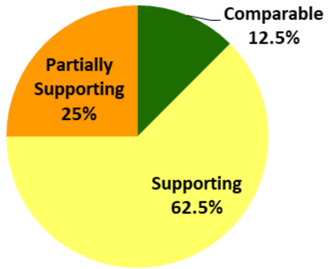
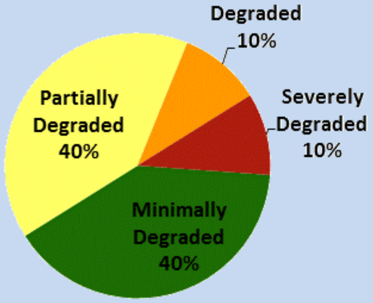
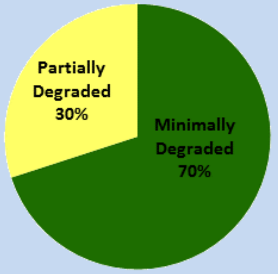
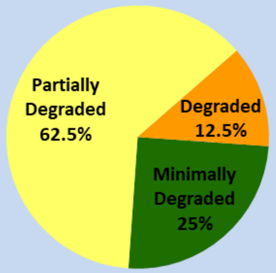
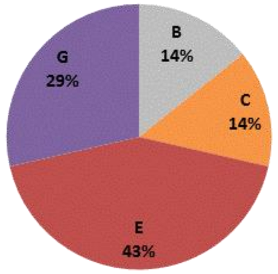
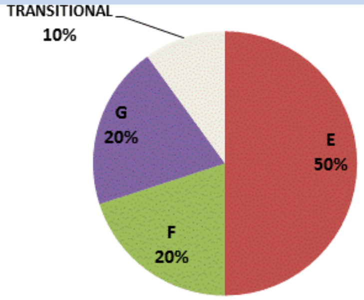
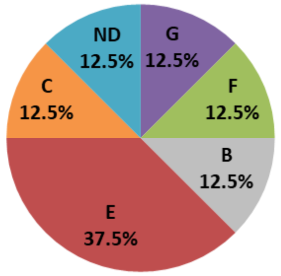
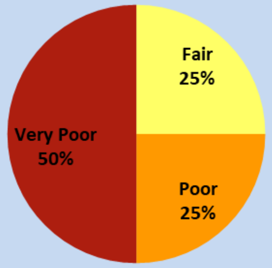
PSU 16: Upper Patuxent

The Upper Patuxent sampling unit has a drainage area of 6,957 acres, is located along the northwestern border of the County, and drains directly to the Patuxent River. In 2019, impervious surfaces comprised 6.9 % of the overall sampling unit, with individual sites ranging from 0.7 % to 12.9 %.



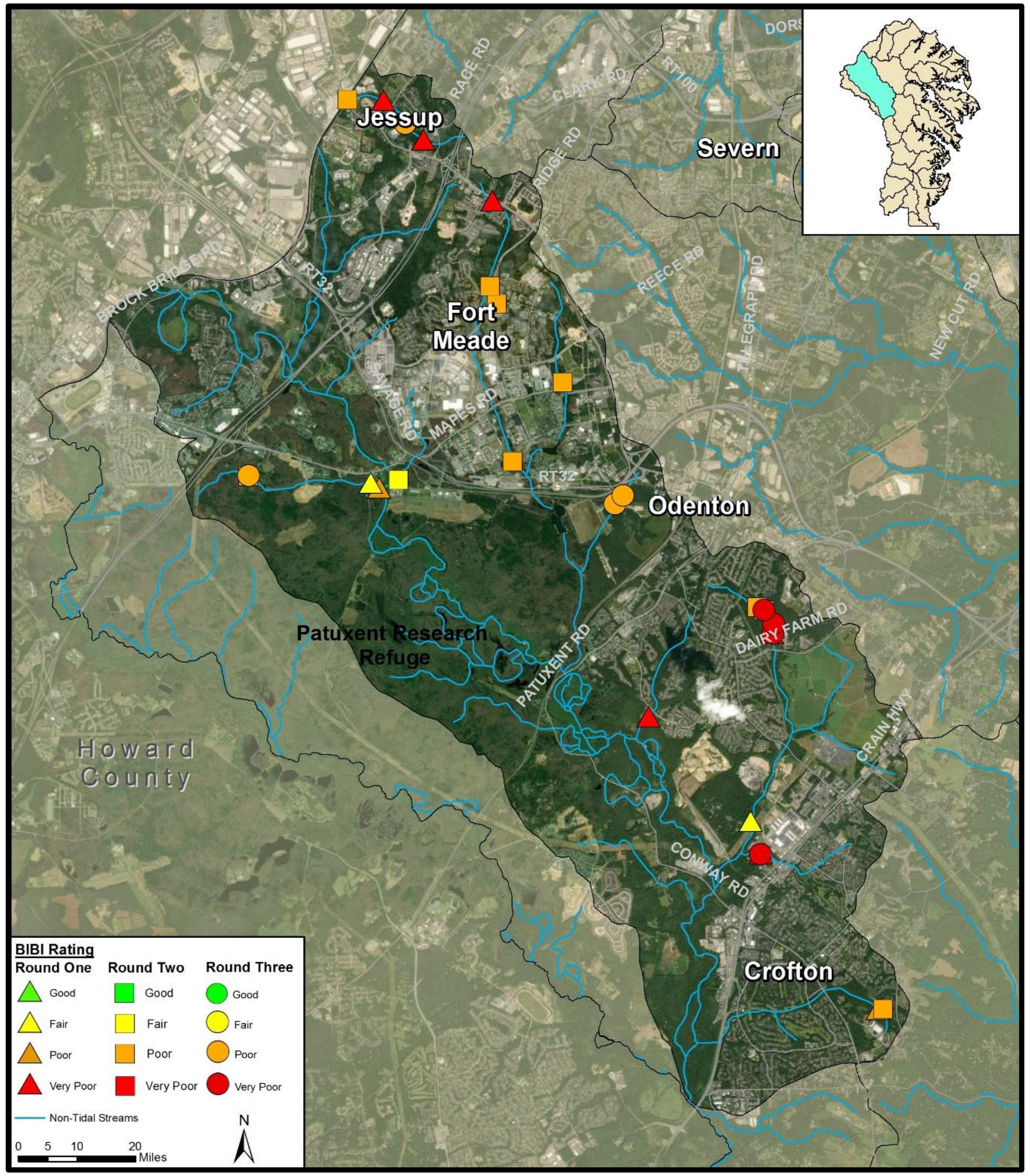


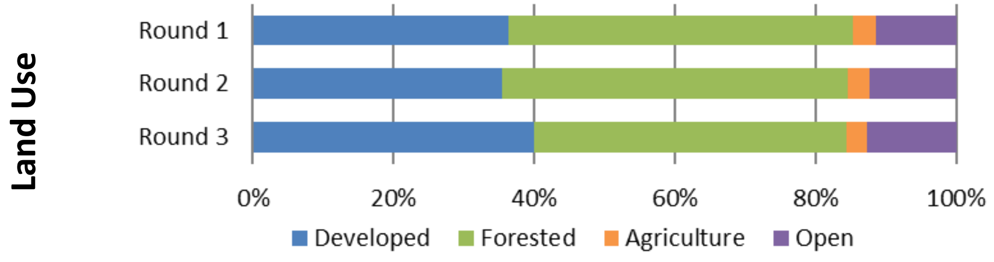
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

	Round 1 (2007)	Round 2 (2011)	Round 3 (2019)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	No
PHI Score				No	Yes ↓
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

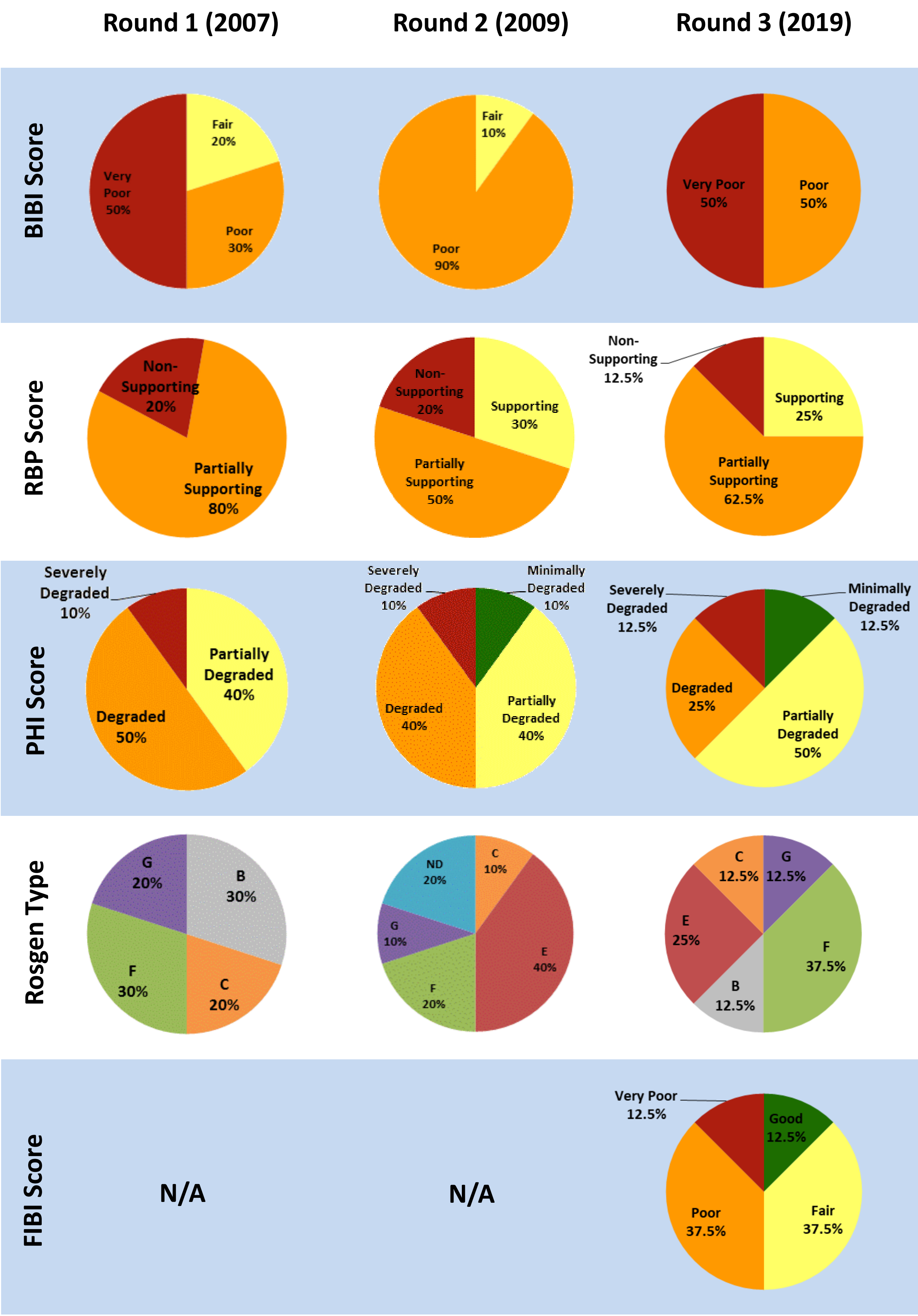
PSU 17: Little Patuxent

The Little Patuxent sampling unit is in the northwestern part of the County, in the vicinity of Fort Meade and Crofton, and has a drainage area of 28,196 acres. In 2019, 18.0 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 6.0 % to 37.4 %.





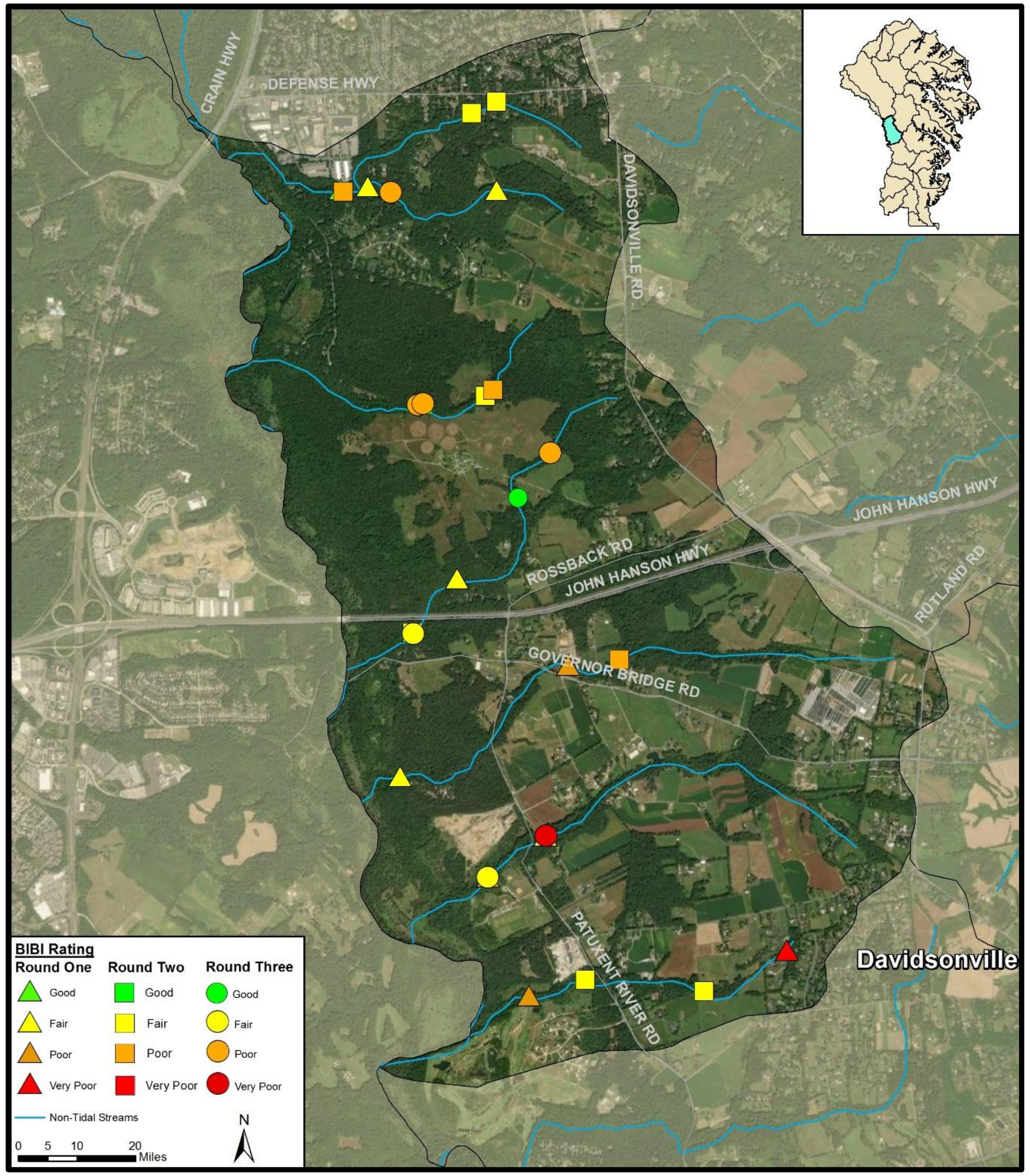
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

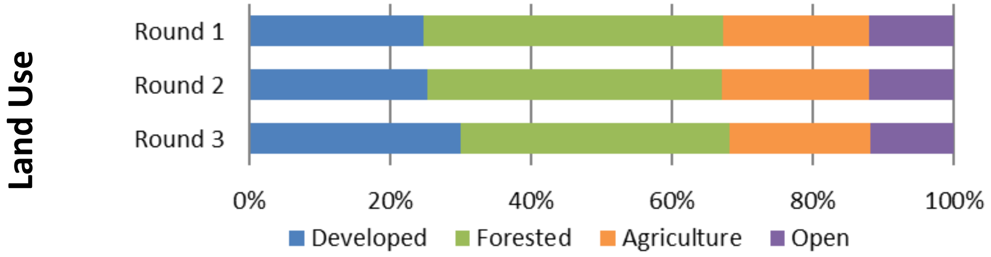


	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score	No	No
RBP Score	No	No
PHI Score	No	No
Rosgen Type	N/A	N/A
FIBI Score	N/A	N/A

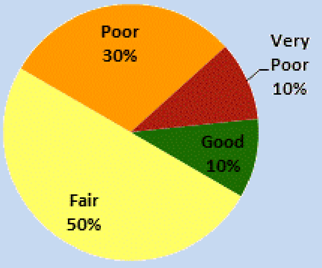
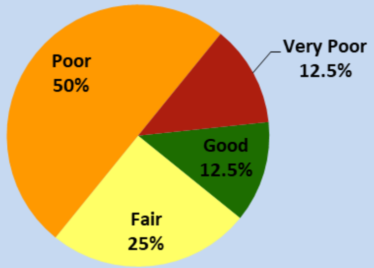
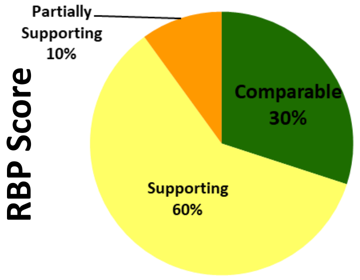
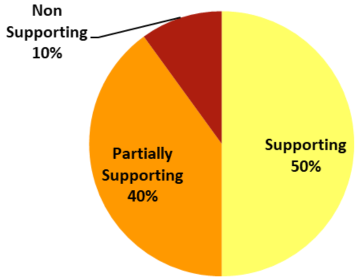
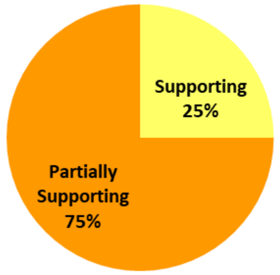
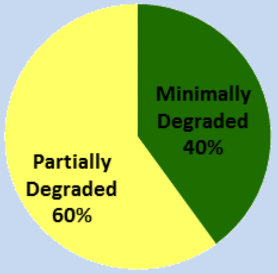
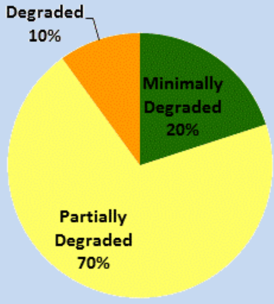
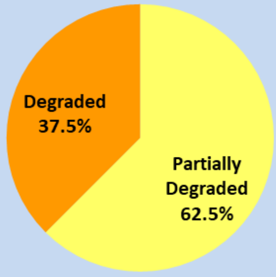
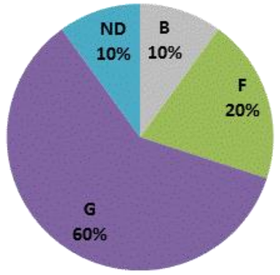
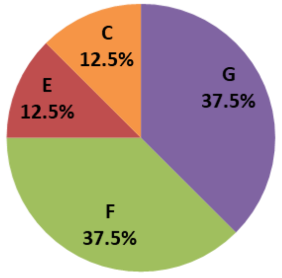
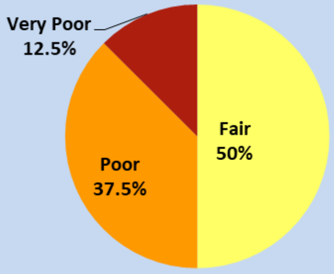
PSU 18: Middle Patuxent

The Middle Patuxent sampling unit is in the west-central part of the County, between Crofton and Davidsonville, and has a drainage area of 6,332 acres. In 2019, impervious surfaces comprised 6.3 % of the overall sampling unit, with individual sites ranging from 1.2 % to 5.7 %.



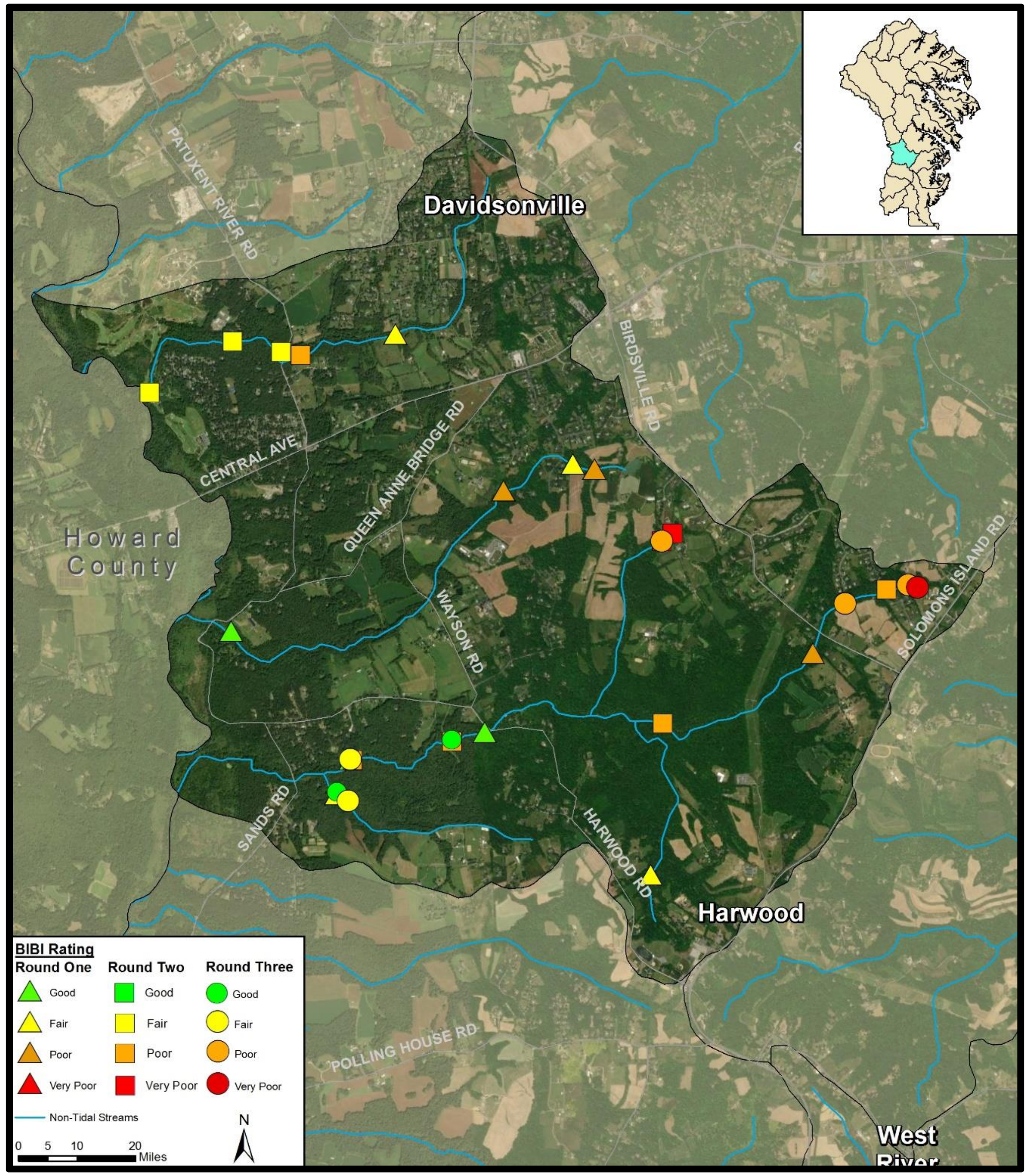


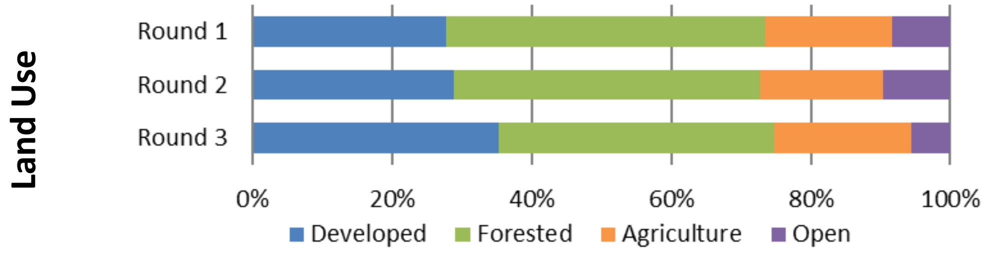
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

	Round 1 (2004)	Round 2 (2010)	Round 3 (2019)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				Yes ↓	No
PHI Score				Yes ↓	No
Rosgen Type	N/A			N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

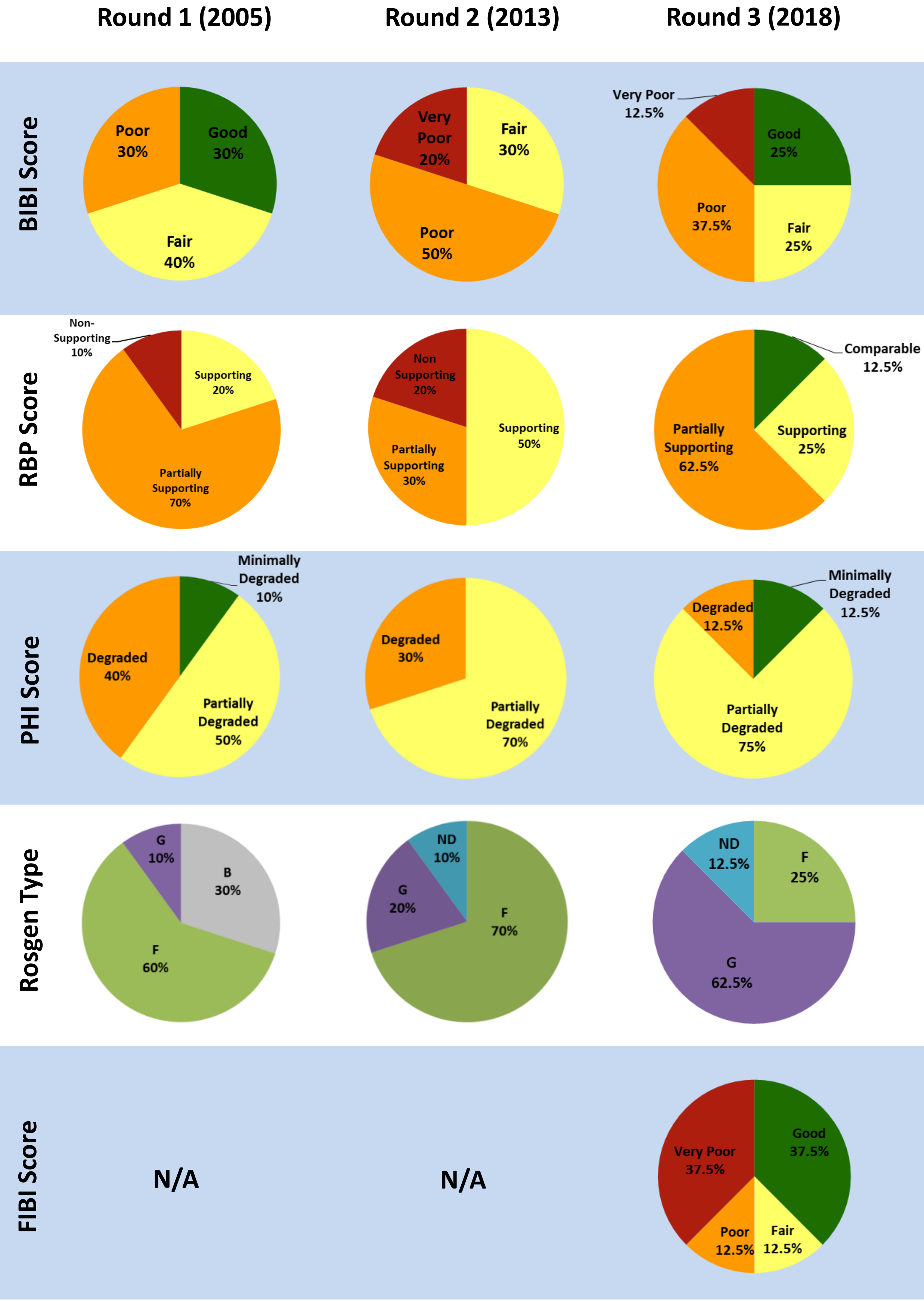
PSU 19: Stocketts Run

The Stocketts Run sampling unit, which drains to the Patuxent River and has a drainage area of 8,714 acres, is in the south-central portion of the County between Davidsonville and Harwood. In 2018, impervious surfaces comprised 5.8 % of the overall sampling unit, with individual sites ranging from 3.9 % to 15.1 %.





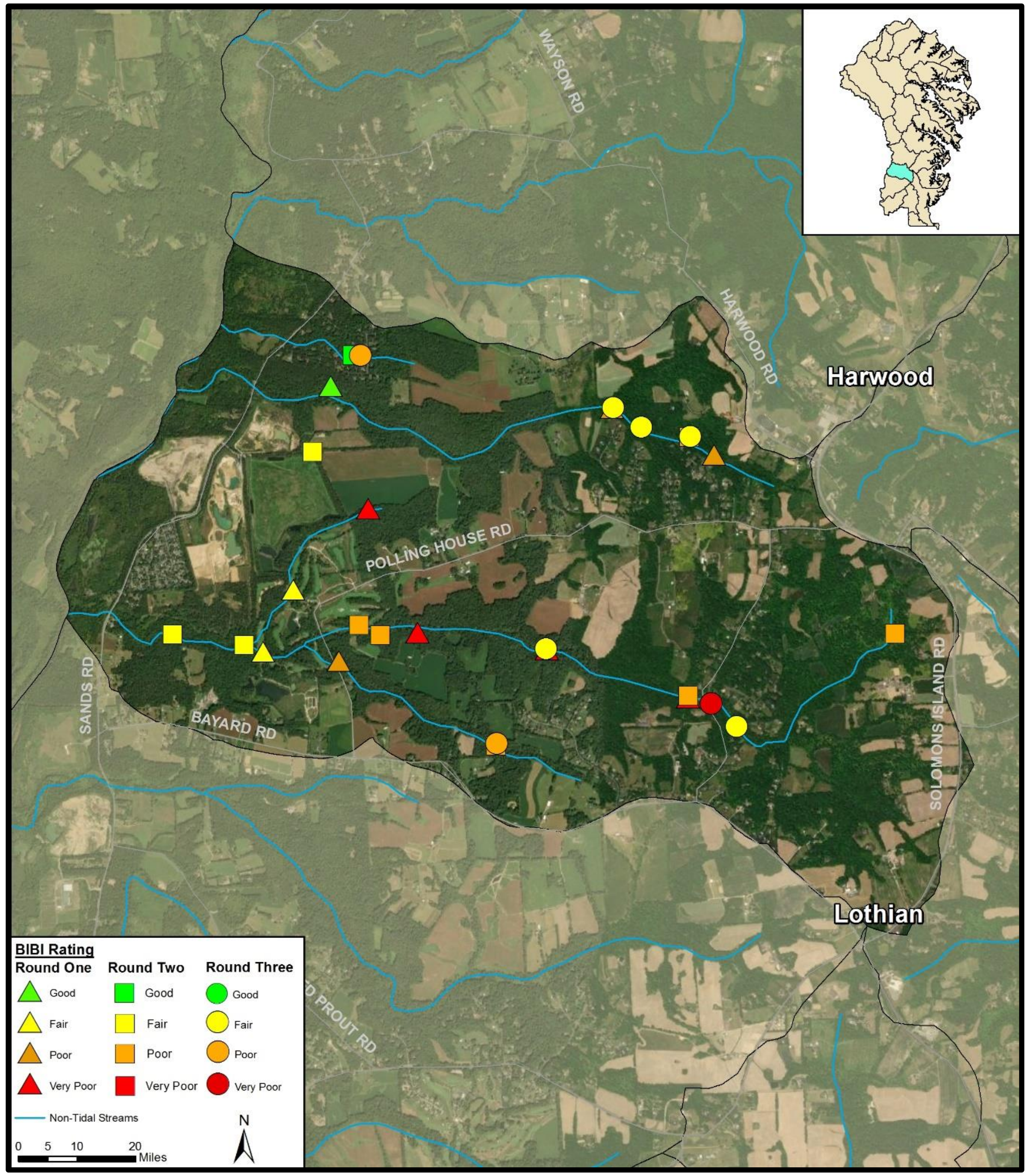
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011; R3 = 2014

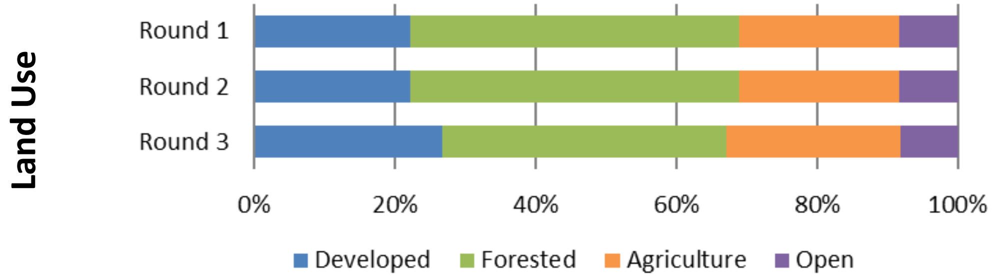


	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score	No	No
RBP Score	No	No
PHI Score	No	Yes ↑
Rosgen Type	N/A	N/A
FIBI Score	N/A	N/A

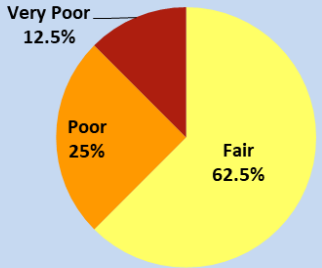
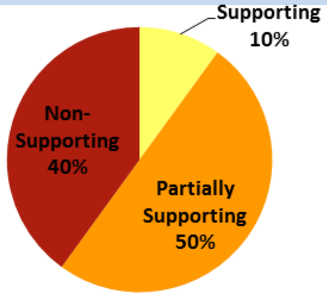
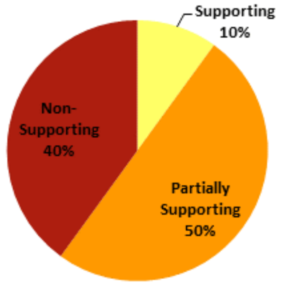
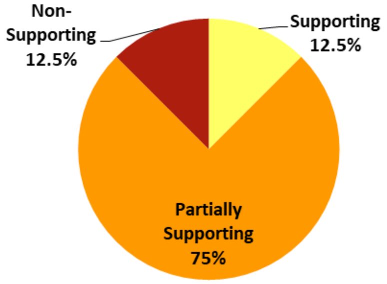
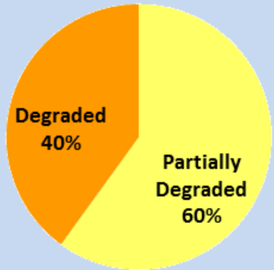
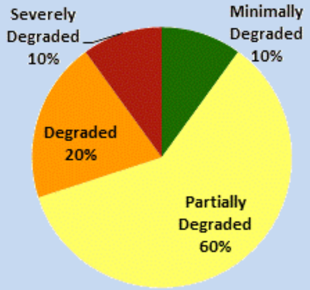
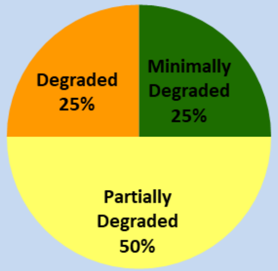
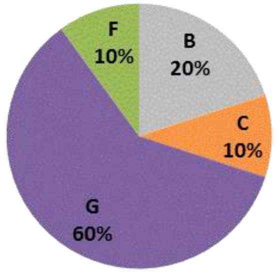
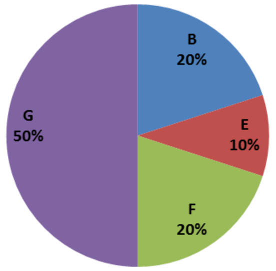
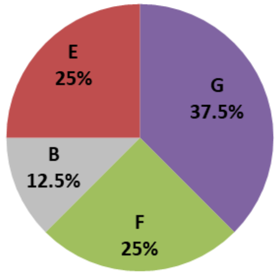
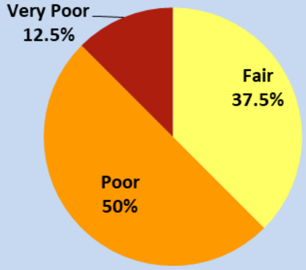
PSU 20: Rock Branch

The Rock Branch sampling unit has a drainage area of 6,131 acres and is in the south-central portion of the County, between Harwood and Lothian. In 2020, 3.8 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 0.9 % to 5.8 %.



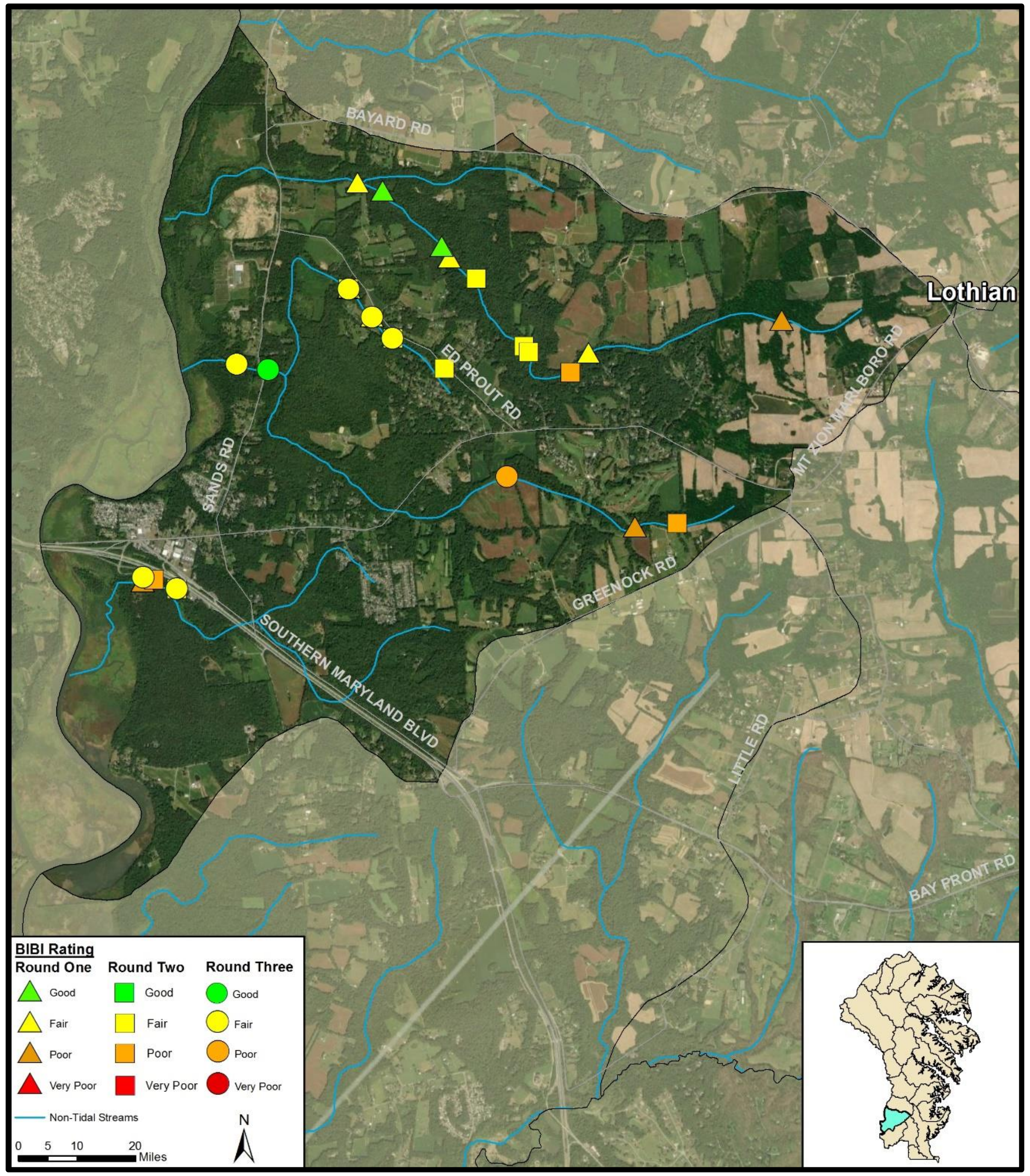


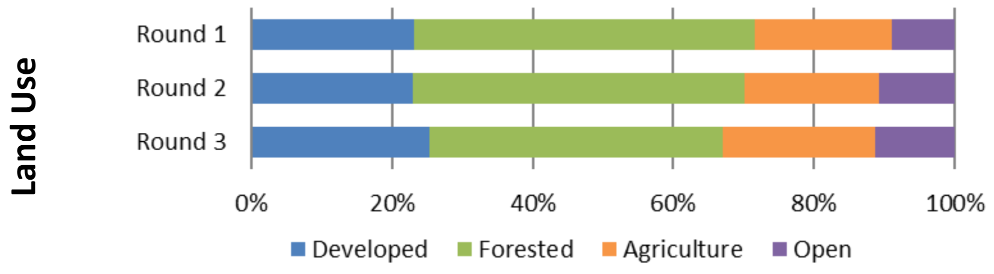
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007; R3 = 2017

	Round 1 (2008)	Round 2 (2009)	Round 3 (2020)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score	 Good 10% Fair 20% Poor 30% Very Poor 40%	 Fair 30% Good 10% Poor 60%	 Very Poor 12.5% Poor 25% Fair 62.5%	No	No
RBP Score	 Supporting 10% Non-Supporting 40% Partially Supporting 50%	 Supporting 10% Non-Supporting 40% Partially Supporting 50%	 Non-Supporting 12.5% Supporting 12.5% Partially Supporting 75%	No	No
PHI Score	 Degraded 40% Partially Degraded 60%	 Severely Degraded 10% Minimally Degraded 10% Degraded 20% Partially Degraded 60%	 Degraded 25% Minimally Degraded 25% Partially Degraded 50%	No	No
Rosgen Type	 F 10% B 20% C 10% G 60%	 B 20% E 10% F 20% G 50%	 E 25% G 37.5% B 12.5% F 25%	N/A	N/A
FIBI Score	N/A	N/A	 Very Poor 12.5% Fair 37.5% Poor 50%	N/A	N/A

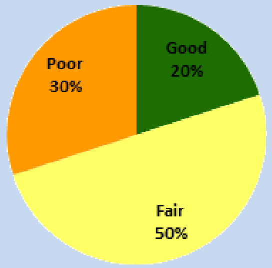
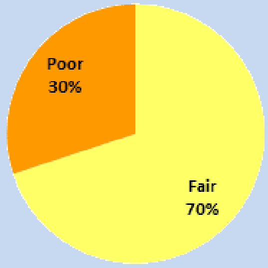
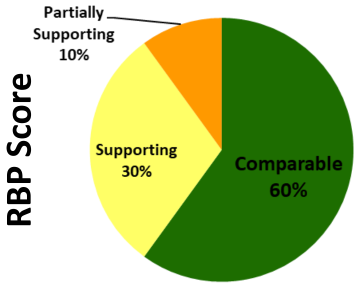
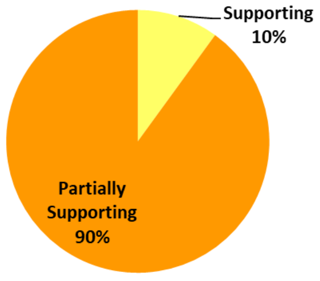
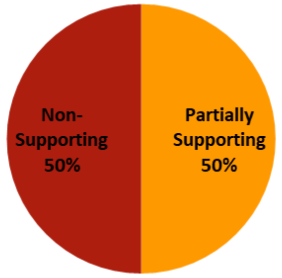
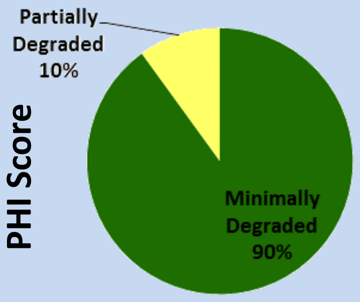
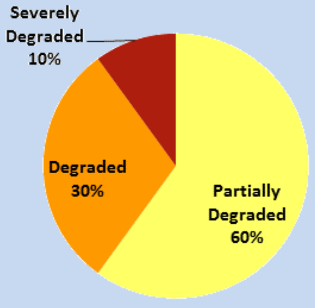
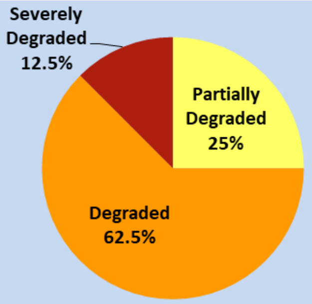
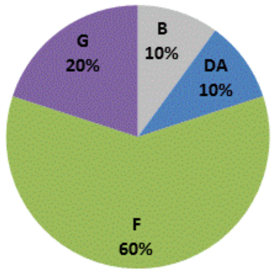
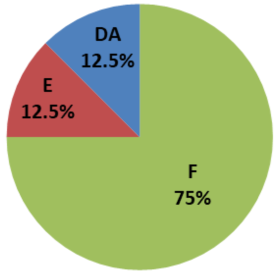
PSU 21: Ferry Branch

The Ferry Branch sampling unit, located in the southwestern portion of the County and west of Lothian, has a total drainage area of 8,038 acres. In 2021, impervious surfaces comprised 3.8 % of the overall sampling unit, with individual sites ranging from 3.2 % to 6.1 %.



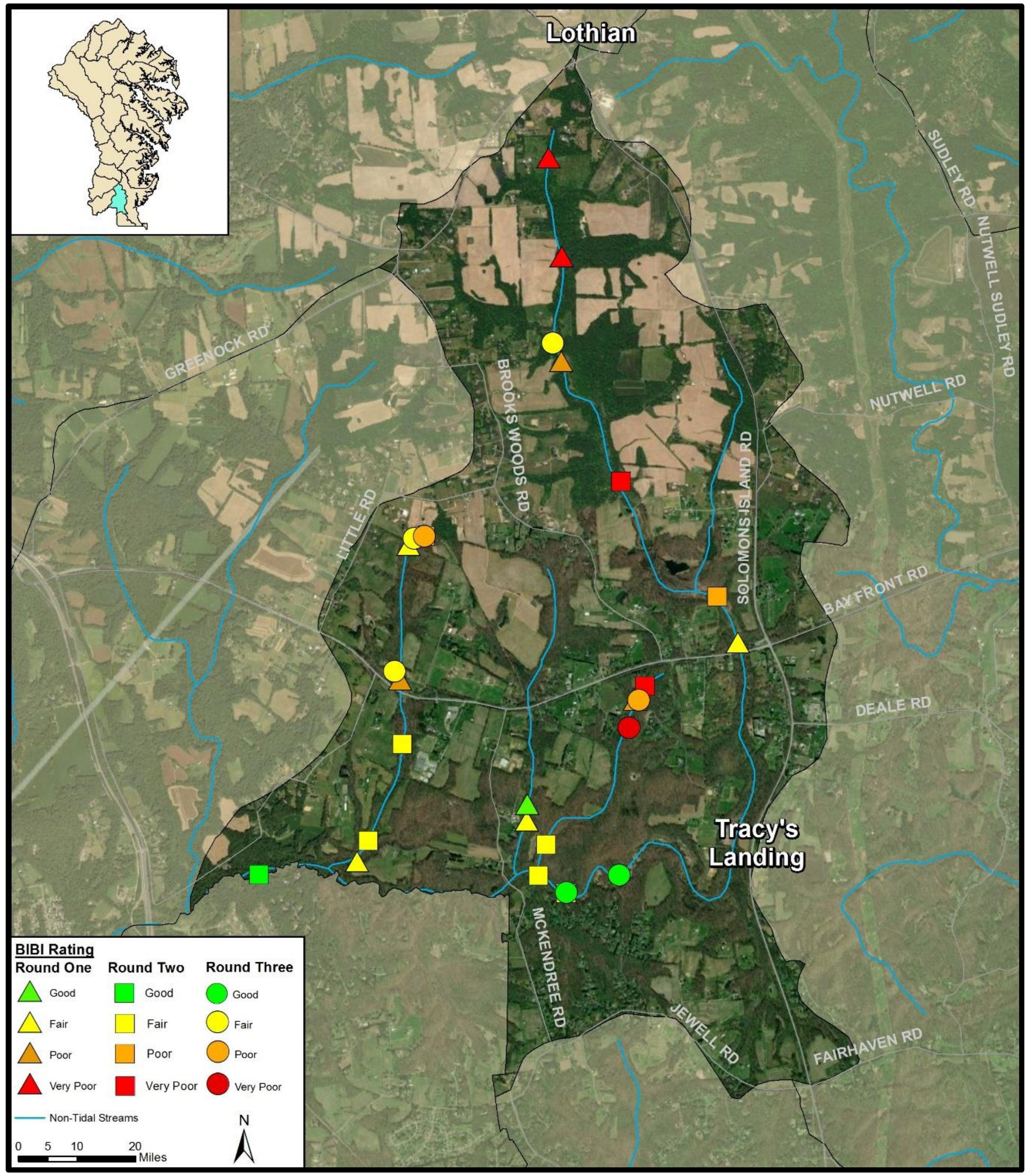


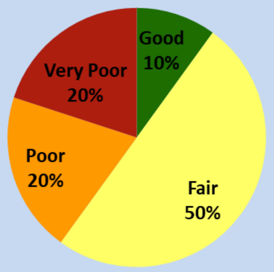
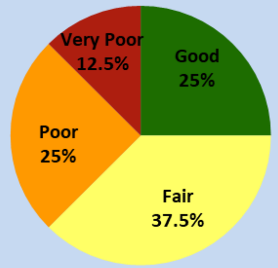
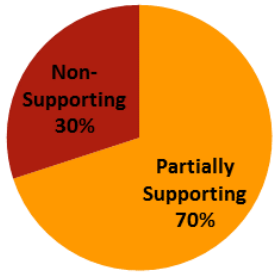
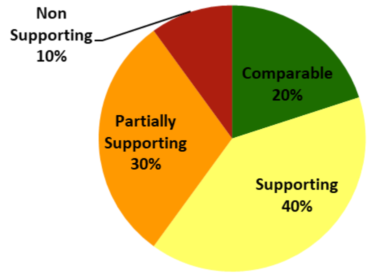
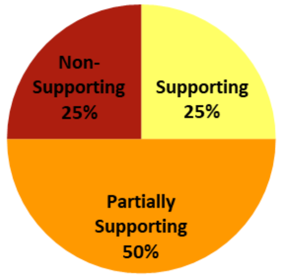
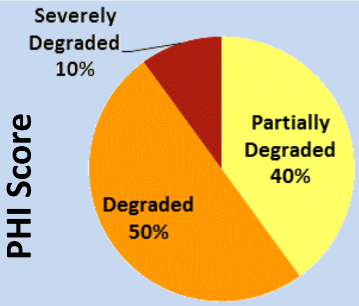
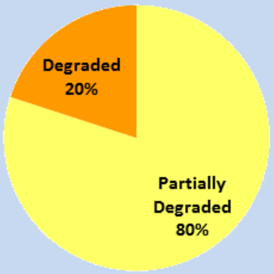
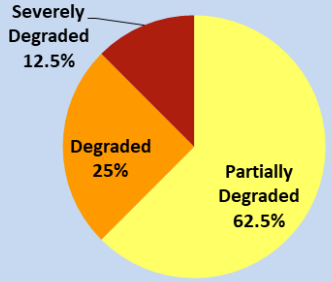
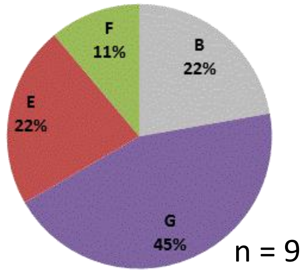
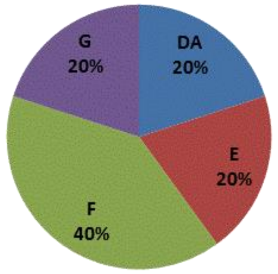
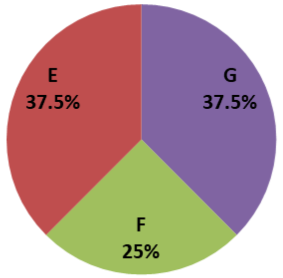
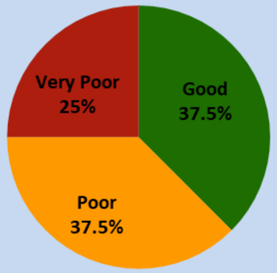
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

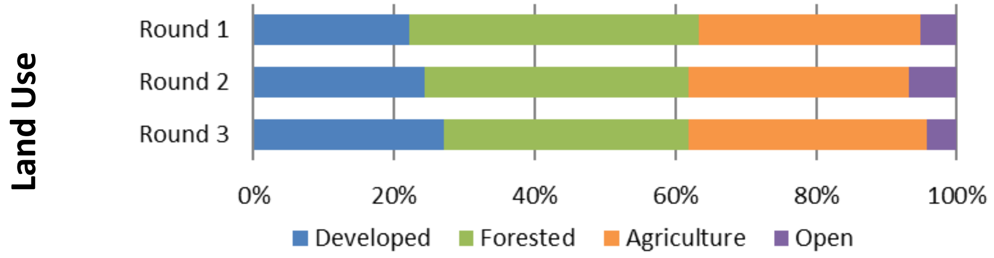
	Round 1 (2004)	Round 2 (2010)	Round 3 (2021)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				Yes ↓	Yes ↓
PHI Score				Yes ↓	No
Rosgen Type	N/A			N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

PSU 22: Lyons Creek

The Lyons Creek sampling unit is in the southern portion of the County, along the border with Calvert County, and has a total drainage area of 6,154 acres. In 2021, impervious surfaces comprised 3.2 % of the overall sampling unit, with individual sites ranging from 1.8 % to 3.7 %.



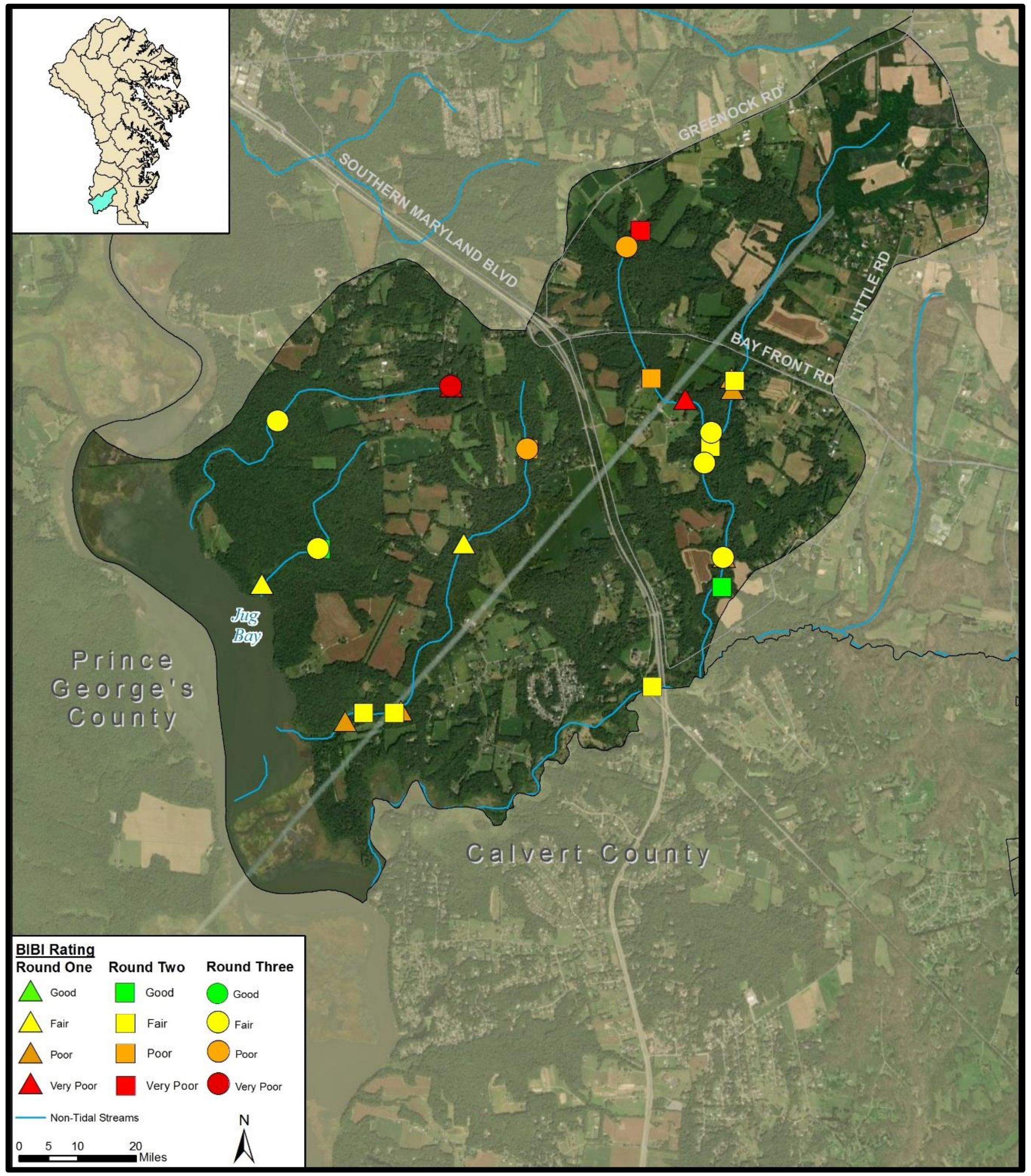
	Round 1 (2005)	Round 2 (2013)	Round 3 (2021)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	No
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

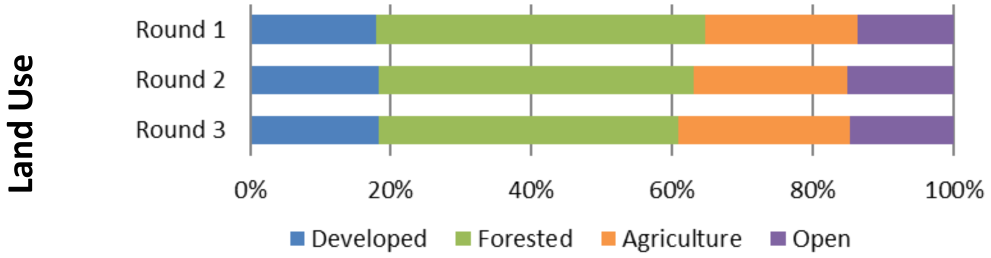


*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011; R3 = 2017

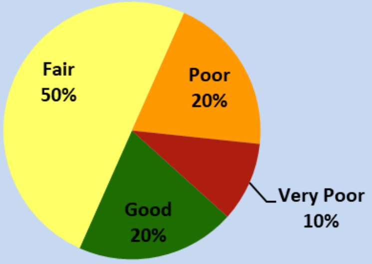
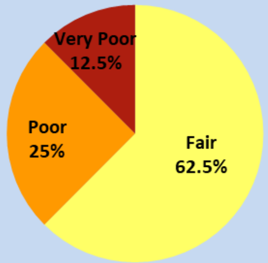
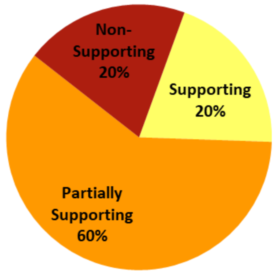
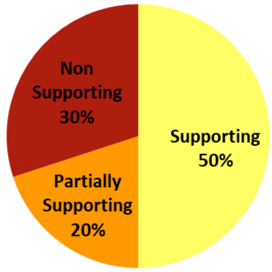
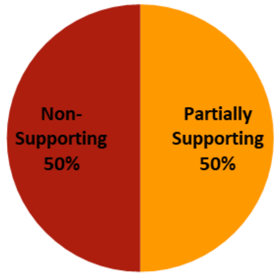
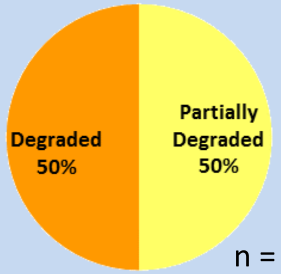
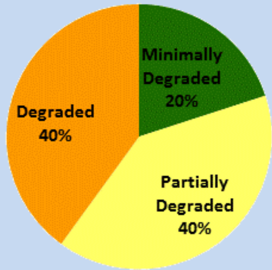
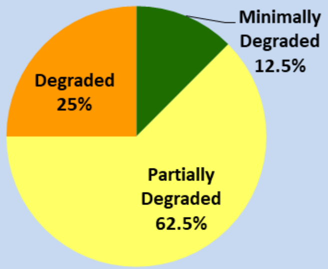
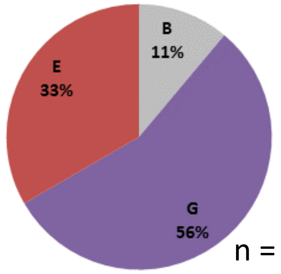
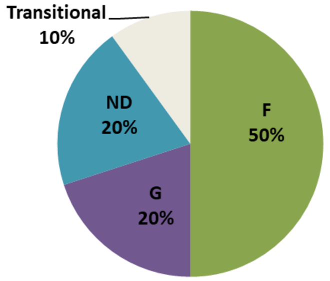
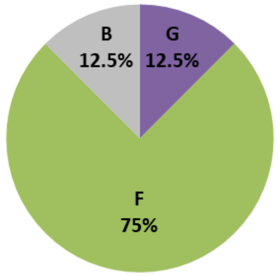
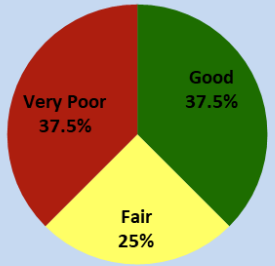
PSU 23: Cabin Branch

The Cabin Branch sampling unit is in the southwestern-most tip of the County, adjacent to Jug Bay, and has a total drainage area of 6,443 acres. In 2021, impervious surfaces comprised 2.0 % of the overall sampling unit, with individual sites ranging from 0.6 % to 2.7 %.



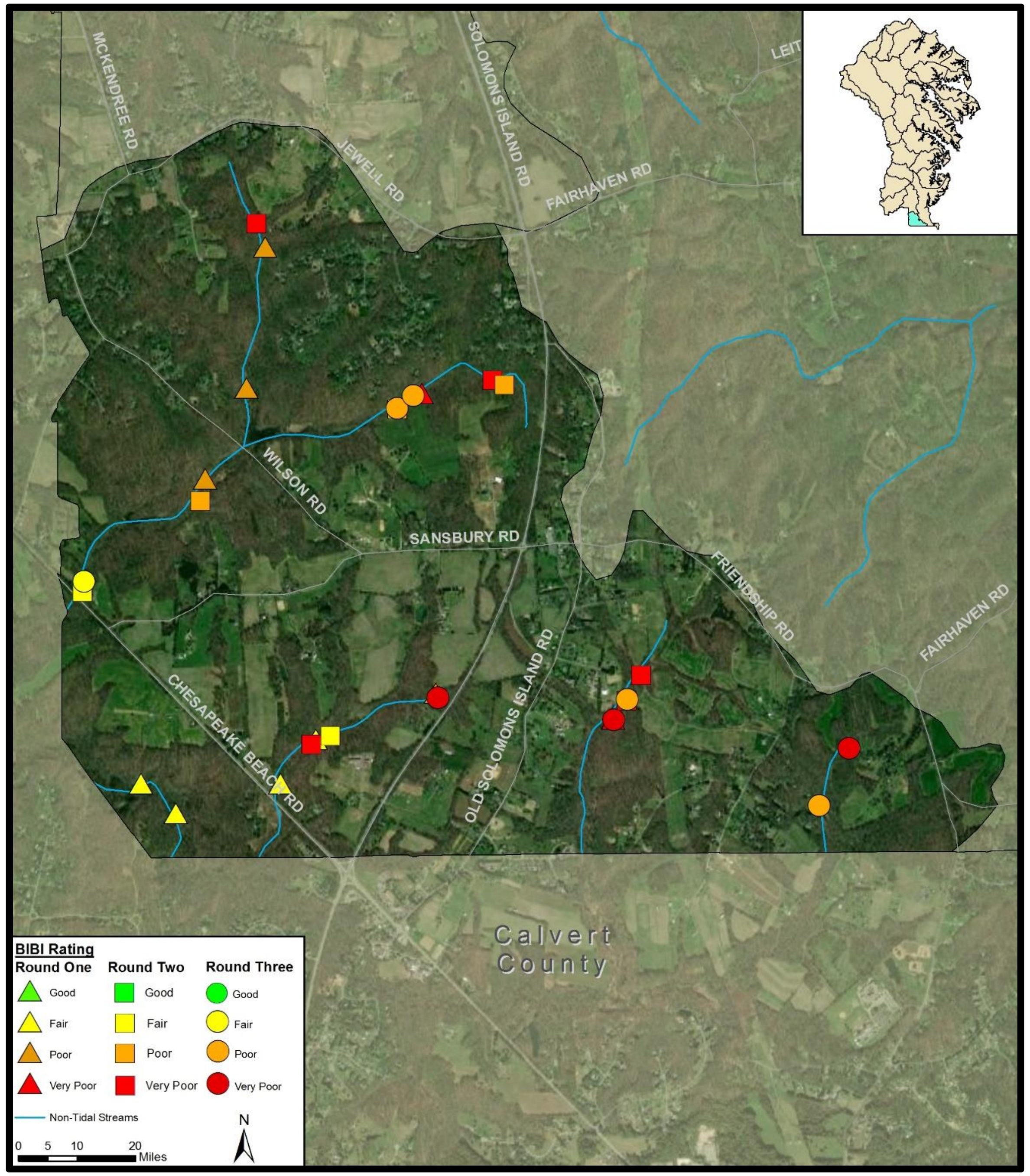


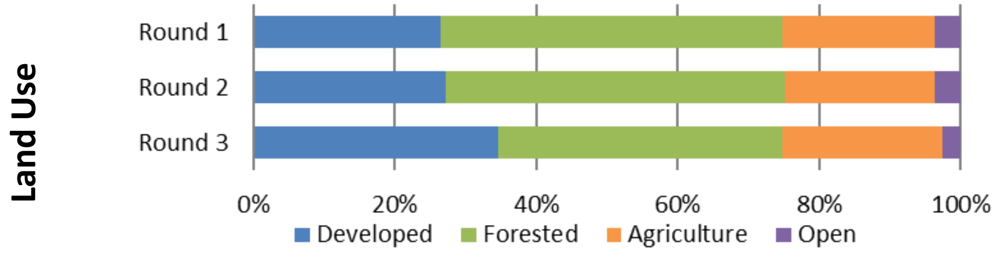
*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2011; R3 = 2017

	Round 1 (2008)	Round 2 (2013)	Round 3 (2021)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				Yes ↓	Yes ↓
PHI Score	 n = 8			No	No
Rosgen Type	 n = 9			N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

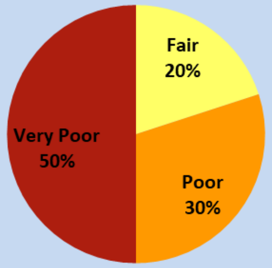
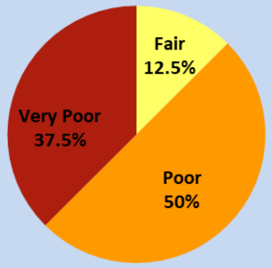
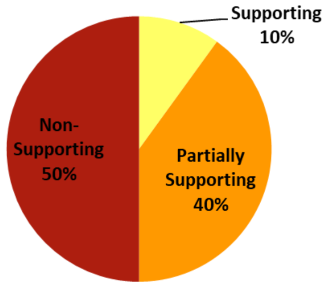
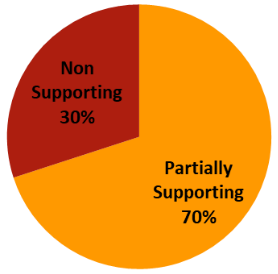
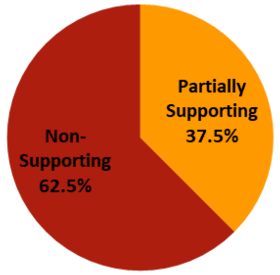
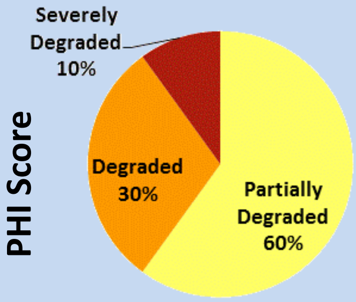
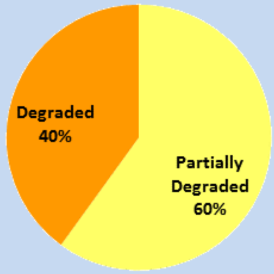
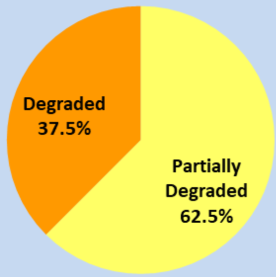
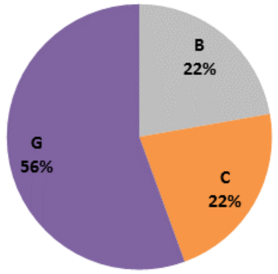
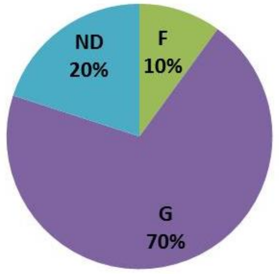
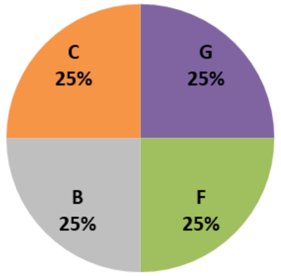
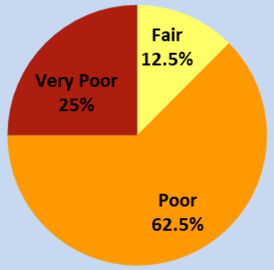
PSU 24: Hall Creek

The Hall Creek sampling unit, located in the southern tip of the County along the Calvert County border, has a total drainage area of 3,168 acres. In 2021, impervious surfaces comprised 3.0 % of the overall sampling unit, with individual sites ranging from 1.6 % to 5.2 %.





*Land use for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007; R3 = 2017

	Round 1 (2006)	Round 2 (2012)	Round 3 (2021)	Significant Difference from R1 to R3?	Significant Difference from R2 to R3?
BIBI Score				No	No
RBP Score				No	Yes ↓
PHI Score				No	No
Rosgen Type				N/A	N/A
FIBI Score	N/A	N/A		N/A	N/A

Appendix D: Revisit Site Comparisons

2017 Revisit Site Comparison

Site Name	Year First Sampled	Cross-Sectional Area (ft^2)			D_{50} Substrate Classification (Size in mm)		Rosgen Classification		BIBI Narrative Ranking (Score)	
		R1/R2	R3	%Δ	R1/R2	R3	R1/R2	R3	R1/R2	R3
06-L1M-02-17	2006	5.2	7.4	42.3	fine sand (0.16)	medium sand (0.28)	E5	E5	Fair (3.00)	Fair (3.00)
06-L1M-03-17	2006	8.2	10.5	28	medium sand (0.25)	medium sand (0.27)	E5	E5	Very Poor (1.86)	Fair (3.29)
06-L1M-04-17	2006	2.3	3.4	47.8	fine sand (0.13)	fine sand (0.16)	C5	E5	Poor (2.71)	Poor (2.14)
06-L2M-01-17	2011	5.9	7.9	33.9	medium sand (0.40)	medium sand (0.30)	E5	E5	Very Poor (1.29)	Poor (2.43)
06-L2M-03-17	2011	22*	10.2**	**	coarse sand (0.50)	fine sand (0.22)	DA5	E5	Poor (2.71)	Poor (2.43)
Bodkin Creek Average		5.4	7.9	38	medium sand (0.29)	fine sand (0.25)	--	--	Poor (2.31)	Poor (2.66)
09-L1M-01-17	2004	ND	32.1	ND	ND	medium gravel (9.40)	ND	E4/5	Poor (2.43)	Poor (2.71)
09-L1M-02-17	2004	ND	31.1	ND	ND	medium sand (0.28)	ND	F5	Poor (2.71)	Poor (2.14)
09-L2M-02-17	2011	0.1	2.7	4	fine sand (0.17)	fine sand (0.18)	DA5	E5	Poor (2.71)	Very Poor (1.29)
09-L2M-03-17	2011	6.7	15	123.9	medium sand (0.29)	coarse sand (0.58)	C5	E5	Fair (3.86)	Good (4.71)
Severn Run Average		3.4	20.2	1361.9	1	medium sand (0.35)	--	--	Poor (2.93)	Poor (2.71)
10-L1M-05-17	2004	ND	4.4	ND	1	fine sand (0.21)	ND	E5	Poor (2.71)	Poor (2.71)
10-L1M-06-17	2004	ND	5.2	ND	ND	coarse sand (0.53)	ND	F5	Fair (3.00)	Poor (2.14)
10-L2M-01-17	2013	2.7	3.3	22.2	very fine sand (0.09)	coarse sand (0.55)	DA5	DA5	Fair (3.57)	Fair (3.57)
10-L2M-04-17	2013	4.9	6.8	38.8	very fine sand (0.06)	medium sand (0.29)	E6	E5	Fair (3.57)	Poor (2.43)
Severn River Average		3.8	4.9	30.5	very fine sand (0.08)	medium sand (0.40)	--	--	Fair (3.21)	Poor (2.71)
11-L1M-03-17	2005	8.2	14.2	73.2	medium sand (0.30)	fine sand (0.23)	B5c	G5	Good (4.14)	Fair (3.86)
11-L1M-04-17	2005	8.53*	**	3	fine sand (0.19)	fine sand (0.22)	C5	E5	Fair (3.86)	Poor (2.43)
11-L2M-01-17	2011	11.9	15	26.1	medium sand (0.32)	fine sand (0.18)	F5	G5	Poor (2.43)	Fair (3.00)
11-L2M-02-17	2011	61.4	66.6	8.5	fine gravel (4.10)	coarse gravel (18.00)	ND	E4	Poor (2.14)	Fair (3.29)
Upper North River Avg***		27.2	31.9	35.9	very coarse sand (1.23)	fine gravel (4.66)	--	--	Fair (3.14)	Fair (3.15)
13-L1M-03-17	2008	11.4	10.5	-7.9	fine sand (0.16)	medium sand (0.27)	C5	C5	Poor (2.43)	Very Poor (1.57)
13-L1M-04-17	2008	8.9	4.3	-51.7	medium sand (0.25)****	fine sand (0.13)	C5	E5	Poor (2.14)	Poor (2.14)
13-L2M-03-17	2012	6.3	6.8	7.9	fine sand (0.22)	very fine sand (0.06)	C6	C6	Very Poor (1.86)	Very Poor (1.86)
13-L2M-04-17	2012	25.8	26	0.8	fine sand (0.13)	very fine sand (0.06)	ND	E6	Poor (2.43)	Poor (2.43)
Rhode River Average		13.1	11.9	-12.7	fine sand (0.19)	fine sand (0.13)	--	--	Poor (2.22)	Poor (2.00)

ND - no data collected; -- = did not calculate; * - Round One or Two cross-sectional area not adjusted to match the bankfull elevation from 2017 due to lack of 2017 data; ** - overlay not completed due to change in placement of one or more end pins; *** - Cross-sectional averages do not include sites where cross-section overlays could not be completed; **** - value estimated in Round One; R1 - Round One; R2 - Round Two; R3 - Round Three; %Δ = ((R3 cross-sectional area - R1 or R2 cross-sectional area)/ R1 or R2 cross-sectional area) * 100

2018 Revisit Site Comparison

Site Name	Year First Sampled	Cross-Sectional Area (ft^2)			D_{50} Substrate Classification (Size in mm)		Rosgen Classification		BIBI Narrative Ranking (Score)	
		R1/R2	R3	%Δ	R1/R2	R3	R1/R2	R3	R1/R2	R3
08-L1M-01-18	2007	5.3	6.4	20.7	medium sand (0.25)	very fine sand (0.12)	C5	E5	Poor (2.14)	Very Poor (1.86)
08-L1M-02-18	2007	81	6.7	-15.7	fine sand (0.13)	very fine sand (0.062)	E5	E6	Poor (2.14)	Poor (2.14)
08-L2M-01-18	2013	9.71	10.4	6.7	fine sand (0.15)	medium sand (0.41)	E5	E5	Poor (2.71)	Poor (2.71)
08-L2M-02-18	2013	2.8	2.1	-25.5	very fine sand (0.062)	very fine sand (0.062)	ND	E6	Very Poor (1.57)	Very Poor (1.86)
Lower Magothy Average		6.5	6.4	-3.5	fine sand (0.15)	fine sand (0.16)	--	--	Poor (2.14)	Poor (2.14)
03-L1M-02-18	2004	2	7.7	[2]	2	medium gravel (10)	2	B4c	Poor (2.71)	Very Poor (1.57)
03-L1M-03-18	2004	2	8.5	[2]	2	medium gravel (8.3)	2	F4/5	Poor (2.71)	Poor (2.43)
03-L2M-01-18	2012	11.7	9.9	-15.3	fine gravel (5.5)	coarse gravel (18)	C4/5	C4	Fair (3.57)	Fair (3.00)
03-L2M-03-18	2012	8.4	4.7	4	medium gravel (15)	coarse gravel (24)	F4/5	F4	Fair (3.86)	Fair (3.86)
Lower Patapsco Average		10.1	7.7	-29.5	medium gravel (10.3)	medium gravel (15.1)	--	--	Fair (3.21)	Poor (2.72)
05-L1M-03-18	2006	4.4	6.2	41.43	[1]	medium sand (0.25)	[5]	F5	Poor (2.43)	Poor (2.43)
05-L1M-04-18	2006	13.41	11.4	-14.6	[1]	fine sand (0.14)	C6	G5c	Poor (2.43)	Fair (3.29)
05-L2M-02-18	2009	6.41	8.8	37	very fine sand (0.067)	coarse sand (0.54)	E6	E5	Poor (2.14)	Fair (3.00)
05-L2M-03-18	2009	9.8	14.3	45.9	fine sand (0.21)	medium sand (0.34)	E5	G5	Poor (2.14)	Very Poor (1.86)
Marley Creek Average		8.5	10.2	27.4	very fine sand (0.11)	medium sand (0.32)	--	--	Poor (2.29)	Poor (2.65)
01-L1M-01-18	2007	8.91	32.1	6	very coarse sand (1)	coarse gravel (22)	E5	F4	Fair (3.00)	Poor (2.14)
01-L1M-02-18	2007	35.11	50.5	43.8	fine gravel (6)	medium gravel (9.9)	C4	C4	Poor (2.71)	Fair (3.00)
01-L2M-01-18	2012	3.7	3.7	[3]	very fine sand (0.062)	very fine sand (0.088)	F6	G5c	Poor (2.14)	Poor (2.43)
01-L2M-02-18	2012	89.1	97.1	9	medium sand (0.45)	medium sand (0.43)	ND	F5	Fair (3.86)	Fair (3.00)
Piney Run Average		34.2	45.9	17.5	fine gravel 7.5	medium gravel 8.1	--	--	Poor (2.93)	Poor (2.64)
19-L1M-01-18	2005	36.41	33.5	-7.9	5	fine gravel (7.1)	5	G4c	Good (4.71)	Fair 3.86
19-L1M-03-18	2005	26.6	10.9	6	5	very fine gravel (2)	5	F4/5	Fair (3.00)	Good 4.71
19-L2M-01-18	2013	36.1	86.6	139.9	very coarse sand (1.3)	medium sand (0.34)	F4/5	ND	Poor (2.43)	Good 4.43
19-L2M-07-18	2013	3.2	2.7	-15.3	very fine sand (0.062)	coarse sand (0.73)	G6c	G5c	Very Poor (1.57)	Poor 2.14
Stocketts Run Average		25.6	33.4	116.7	coarse sand (0.7)	very fine gravel (2.5)	--	--	Poor (2.93)	Fair (3.79)

*[1] Bankfull elevation adjusted to match 2018 bankfull discharge for comparison, [2] Geomorph survey not performed in 2004, [3] Only one existing XS pin was found in R3 but cross sections were determined to be consistent enough for comparison, [4] Only one existing XS pin was found in R3 and cross sections were not determined to be consistent enough for comparison , [5] Not reported in R1/R2, [6] R1/R2 XS pins were not found in R3, re-established XS, comparison could not be made between the rounds, R1 - Round One; R2 - Round Two; R3 - Round Three; %Δ = ((R3 cross-sectional area - R1 or R2 cross-sectional area)/ R1 or R2 cross-sectional area) * 100*

2019 Revisit Site Comparison

2019 Site Name	Year First Sampled	Cross-Sectional Area (ft^2)			D_{50} Substrate Classification (Size in mm)		Rosgen Classification		BIBI Narrative Ranking (Score)	
		R1/R2	R3	%Δ	R1/R2	R3	R1/R2	R3	R1/R2	R3
17-L1M-01-19	2007	10.7	8.82	-2	fine sand (0.23)	very coarse sand (1.4)	Transitional	B5c	Very Poor (1.57)	Very Poor (1.57)
17-L1M-02-19	2007	29.8	10.3	-65.3	medium sand (0.44)	coarse sand (0.74)	G5c	F5	Very Poor (1.57)	Very Poor (1.57)
17-L2M-01-19	2009	9.1	8.3	-9	medium sand (0.47)	coarse sand (0.84)	E5	E5	Poor (2.43)	Poor (2.71)
17-L2M-02-19	2009	16.1	9.2	-42.7	very fine gravel (2.6)	medium gravel (8)	E4	G4c	Poor (2.43)	Very Poor (1.57)
Little Patuxent Average		16.4	9.2	-58.5	coarse sand (0.94)	very fine gravel (2.75)	---	---	Poor (2.00)	Very Poor (1.86)
12-L1M-02-19	2005	5.9	4.6	-21.6	medium sand (0.38)	fine sand (0.17)	F5	B5c	Fair (3.00)	Very Poor (1.86)
12-L1M-03-19	2005	41.8	25.9	8.7	medium sand (0.38)	medium gravel (8)	B5c	G4c	Poor (2.14)	Poor (2.43)
12-L2M-01-19	2009	4.9	2.82	-2	fine sand (0.14)	fine sand (0.16)	B5c	B5c	Very Poor (1.29)	Very Poor (1.00)
12-L2M-02-19	2009	10	8	4	very fine sand (0.081)	medium sand (0.3)	E6	G5c	Fair (3.00)	Poor (2.71)
Lower North River Average		11.2	10.3	-26.6	medium sand (0.25)	very fine gravel (2.16)	---	---	Poor (2.36)	Poor (2.00)
18-L1M-02-19	2004	-1	10.8	---	[1]	medium gravel (12)	-1	C4	Poor (2.43)	Fair (3.00)
18-L1M-03-19	2004	-1	10.5	---	[1]	fine gravel (7.7)	-1	F4	Fair (3.00)	Very Poor (1.57)
18-L2M-01-19	2010	6.5	7.4	13.5	very coarse sand (1.8)	coarse sand (0.5)	G4/5c	G5/4c	Good (4.43)	Poor (2.14)
18-L2M-02-19	2010	17.6	12.5	-29	very fine sand (0.12)	very coarse sand (1.8)	F5	F4/5	Fair (3.86)	Fair (3.57)
Middle Patuxent Average		12.1	10.3	-7.8	coarse sand (0.96)	fine gravel (5.5)	---	---	Fair (3.43)	Poor (2.57)
04-L1M-01-19	2008	15.8	12.5	-20.6	medium sand (0.26)	silt/clay (0.06)	E5	C5/6	Very Poor (1.29)	Poor (2.71)
04-L1M-02-19	2008	17.4	14.9	-14.1	medium sand (0.25)	medium sand (0.48)	E5	E5	Poor (2.14)	Fair (3.86)
04-L2M-02-19	2010	26.6	32.8	[3]	medium gravel (14)	medium sand (0.33)	ND	ND	Poor (2.71)	Fair (3.86)
04-L2M-03-19	2010	10.7	8.9	-17.1	medium sand (0.31)	medium sand (0.43)	Da5	Da5	Poor (2.43)	Poor (2.14)
Sawmill Creek Average		17.6	17.3	-7.1	very fine gravel (3.71)	medium sand (0.32)	---	---	Poor (2.14)	Fair (3.14)
16-L1M-01-19	2007	7.6	5.42	-2	medium sand (0.42)	medium gravel (13)	ND	ND	Very Poor (1.86)	Very Poor (1.86)
16-L1M-02-19	2007	14.2	6.32	-2	medium sand (0.47)	very coarse sand (1)	E5	F5	Poor (2.14)	Poor (2.14)
16-L2M-01-19	2011	14.3	8.1	-43.5	very fine sand (0.09)	very fine sand (0.09)	E5	E5	Very Poor (1.57)	Very Poor (1.86)
16-L2M-02-19	2011	4	4.3	8.2	very fine gravel (3.2)	medium gravel (13)	G4/5c	G4c	Very Poor (1.86)	Very Poor (1.57)
Upper Patuxent Average		10	6	-17.7	very coarse sand (1.0)	fine gravel 6.77)	---	---	Very Poor (1.86)	Very Poor (1.86)

*Table 28: [1] Geomorph survey not performed in 2004, [2] R1/R2 XS pins were not found in R3, re-established XS, comparison could not be made between the rounds, [3] No monuments established at request of landowner, Estimated value, R1 - Round One; R2 - Round Two; R3 - Round Three; %Δ = ((R3 cross-sectional area - R1 or R2 cross-sectional area)/ R1 or R2 cross-sectional area) * 100*

2020 Revisit Site Comparison

Site Name	Year First Sampled	Bankfull Cross-Sectional Area (ft2)			D50 Substrate Classification (Size in mm)		Rosgen Classification		BIBI Narrative Ranking (Score)	
		R1/R2	R3	%Δ	R1/R2	R3	R1/R2	R3	R1/R2	R3
20-L1M-04-20	2008	22.8	20.5	-[2]	fine sand (0.17)	fine gravel (4.30)	G5c	F4/5	Very Poor (1.86)	Fair (3.86)
20-L1M-08-20	2008	8.9	9	0.6	medium sand (0.25)	medium gravel (13)	G5c	G4c	Poor (2.14)	Fair (3.57)
20-L2M-01-20	2009	12.7	4.6	-63.7	very fine sand (0.06)	very fine sand (0.09)	B6c	F5	Poor (2.14)	Poor (2.43)
20-L2M-03-20	2009	8.4	4.7	-43.6	fine sand (0.16)	very coarse sand (1.40)	E5	G4/5c	Poor (2.43)	Fair (3.00)
Rock Branch Average		13.2	9.7	-35.6	fine sand (0.16)	fine gravel (4.70)	---	---	Poor (2.14)	Fair (3.22)
02-L1M-01-20	2007	4.8	6.6	-[2]	medium sand (0.32)	fine sand (0.22)	C5	B5c	Fair (3.00)	Fair (3.00)
02-L1M-03-20	2007	41.9	60	-[2]	coarse gravel (22)	coarse gravel (22)	C4	C4	Poor (2.71)	Fair (3.86)
02-L2M-01-20	2010	28.2	28.8	2.3	fine gravel (6.90)	medium gravel (11)	ND	ND	Poor (2.71)	Fair (3.00)
02-L2M-04-20	2010	8.8	7.1	4	very fine sand 0.06	very fine sand (0.09)	E6	E5	Poor (2.43)	Poor (2.14)
Stony Run Average		20.9	25.6	2.3	fine gravel (7.32)	medium gravel (8.33)	---	---	Poor (2.71)	Fair (3.00)
07-L1M-02-20	2006	14.9	13.6	-8.6	[1]	medium sand (0.39)	---	ND	Fair (3.00)	Poor (2.43)
07-L1M-03-20	2006	18.2	18.6	-[2]	[1]	medium sand (0.28)	E5	E5	Fair (3.86)	Poor (2.71)
07-L2M-02-20	2011	13.6	19.2	41	medium sand (0.35)	medium sand (0.35)	C5	C5	Fair (3.00)	Fair (3.00)
07-L2M-03-20	2011	6.9	11.9	73.2	medium sand (0.38)	medium sand (0.39)	E5/4	F5	Very Poor (1.86)	Poor (2.14)
Upper Magothy Average		13.4	15.8	35.2	medium sand (0.29)	medium sand (0.35)	---	---	Poor (2.93)	Poor (2.57)
14-L1M-01-20	2008	4.2	4.2	0.3	medium sand (0.25)	fine sand (0.16)	B5c	G5c	Very Poor (1.86)	Very Poor (1.86)
14-L1M-02-20	2008	-1	4.2	---	---	fine sand (0.17)	---	F5	Very Poor (1.57)	Poor (2.71)
14-L2M-02-20	2009	5.9	6.2	[3]	fine sand (0.17)	fine sand (0.23)	F5	F5	Poor (2.71)	Poor (2.71)
14-L2M-03-20	2009	5.2	5.3	2	very fine sand (0.10)	fine sand (0.13)	E5	E5	Poor (2.71)	Poor (2.71)
West River Average		5.1	5	2.7	fine sand (0.17)	fine sand (0.17)	---	---	Poor (2.21)	Poor (2.50)

[1] Geomorph survey not performed in 2008, [2] R1/R2 XS pins were not found in R3, re-established XS, comparison could not be made between the rounds, R1 - Round One; R2 - Round Two; R3 - Round Three; %Δ = ((R3 cross-sectional area - R1 or R2 cross-sectional area)/ R1 or R2 cross-sectional area)

2021 Revisit Site Comparison

Site Name	Year First Sampled	Cross-Sectional Area (ft2)			D50 Substrate Classification (Size in mm)		Rosgen Classification		BIBI Narrative Ranking (Score)	
		R1/R2	R3	%Δ	R1/R2	R3	R1/R2	R3	R1/R2	R3
23-L1M-01-21	2008	58.2	26.5	[-2]	medium sand (0.36)	medium sand (0.3)	E5	F5	Poor (2.43)	Fair (3.57)
23-L1M-02-21	2008	8.8	1	-88.6	---	fine sand (0.23)	---	F5	Very Poor (1.86)	Very Poor (1.86)
23-L2M-02-21	2013	6.4	8.1	26.5	medium sand (0.4)	fine gravel (6)	F4/5	F4	Good (4.43)	Fair (3.29)
23-L2M-03-21	2013	2.1	1.3	-38	very fine sand (0.08)	very fine sand (0.08)	Transitional	G5c	Poor (2.71)	Poor (2.14)
Cabin Branch Average		18.9	9.2	-38.6	medium sand (0.28)	very coarse sand (1.65)	---	---	Poor (2.86)	Poor (2.72)
21-L1M-01-21	2004	---	5.4	[-1]	---	coarse sand (0.67)	---	F5	Fair (3.00)	Fair (3.00)
21-L1M-05-21	2004	---	15.6	[-1]	---	fine sand (0.2)	---	E5/6	Poor (2.14)	Fair (3.86)
21-L2M-02-21	2010	7.5	14.8	96.8	very fine sand (0.06)	very fine sand (0.06)	DA5	DA6	Fair (3.00)	Fair (3.57)
21-L2M-05-21	2010	8.2	4.8	4	very fine gravel (2.1)	very coarse sand (1.4)	F4/6	F5/4	Fair (3.00)	Fair (3.00)
Ferry Branch Average		7.9	10.1	27.8	very coarse sand (1.08)	coarse sand (0.58)	---	---	Poor (2.79)	Fair (3.36)
24-L1M-03-21	2006	2.7	2.9	6.9	[1]	medium sand (0.35)	G5c	B5c	Poor (2.71)	Very Poor (1.86)
24-L1M-04-21	2006	5	8.4	[-2]	[1]	medium sand (0.42)	G5c	G5c	Very Poor (1.86)	Very Poor (1.57)
24-L2M-01-21	2012	5.8	12.8	120.8	fine sand (0.16)	medium sand (0.33)	G5c	C5	Poor (2.71)	Poor (2.43)
24-L2M-03-21	2012	7.6	6.5	-15	fine sand (0.15)	medium sand (0.47)	G5c	B5c	Very Poor (1.57)	Poor (2.14)
Hall Creek Average		5.3	7.6	37.5	very fine sand (0.11)	medium sand (0.39)	---	---	Poor (2.21)	Poor (2.00)
15-L1M-01-21	2005	9.9	10.5	-2	---	very fine sand (0.062)	---	C6	Very Poor (1.86)	Poor (2.43)
15-L1M-02-21	2005	81.2	11.8	-85.4	---	fine sand (0.18)	---	F5	Fair (3.86)	Fair (3.00)
15-L2M-02-21	2010	17	21.8	[3]	very fine sand (0.07)	medium sand (0.35)	C5/6c-	C5c-	Good (4.43)	Good (4.43)
15-L2M-07-21	2010	9.6	6.4	-33.3	very fine sand (0.09)	very fine sand (0.081)	G5c	F5/6	Fair (3.00)	Very Poor (1.86)
Herring Bay Average		29.4	12.7	-59.4	very fine sand (0.08)	fine sand (0.168)	---	---	Fair (3.29)	Poor (2.93)
22-L1M-01-21	2005	133.6	11.7	-91.2	---	medium sand (0.26)	---	G5c	Poor (2.43)	Poor (2.43)
22-L1M-02-21	2005	52.1	4.2	-92	---	fine sand (0.23)	---	F5/4	Poor (2.43)	Fair (3.00)
22-L2M-01-21	2013	3.6	8.7	141.5	fine sand (0.21)	very fine sand (0.11)	G4/5c	G5c	Poor (2.14)	Poor (2.71)
22-L2M-02-21	2013	33.4	38.8	16.3	very fine sand (0.12)	very fine gravel (2)	E5	E4	Fair (3.00)	Good (4.43)
Lyons Creek Average		55.7	15.9	21.9	fine sand (0.17)	coarse sand (0.65)	---	---	Poor (2.50)	Fair (3.14)

[1] Geomorph survey not performed in 2004, [2] R1/R2 XS pins were not found in R3, re-established XS, comparison could not be made between the rounds, R1 - Round One; R2 - Round Two; R3 - Round Three; %Δ = ((R3 cross-sectional area - R1 or R2 cross-sectional area)/ R1 or R2 cross-sectional area)

Appendix E: Master Taxa List

Order	Family	Genus	Final ID	Functional Feeding Group	Habit[1]	Tolerance Value[2]	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Diptera	Chironomidae	Orthocladius	Orthocladius	Collector	sp, bu	9.2	2300	11.20%	158	82.3%
Diptera	Chironomidae	Polypedilum	Polypedilum	Shredder	cb, cn	6.3	1983	9.70%	156	81.3%
Amphipoda	Gammaridae	Gammarus	Gammarus	Shredder	sp	6.7	1099	5.40%	71	37.0%
Haplotaxida	Naididae	not identified	Naididae	Collector	bu	8.5	1055	5.20%	128	66.7%
Diptera	Chironomidae	Hydrobaenus	Hydrobaenus	Scraper	sp	7.2	883	4.30%	53	27.6%
Diptera	Chironomidae	Parametriocnemus	Parametriocnemus	Collector	sp	4.6	883	4.30%	113	58.9%
Isopoda	Asellidae	Caecidotea	Caecidotea	Collector	sp	2.6	624	3.10%	66	34.4%
Chironomidae	Chironomidae	Rheocricotopus	Rheocricotopus	Collector	sp	6.2	558	2.70%	92	47.9%
Diptera	Simuliidae	Simulium	Simulium	Filterer	cn	5.7	536	2.60%	78	40.6%
Diptera	Simuliidae	Stegopterna	Stegopterna	Filterer	cn	2.4	510	2.50%	27	14.1%
Diptera	Chironomidae	Diplocladius	Diplocladius	Collector	sp	5.9	496	2.40%	91	47.4%
Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	Filterer	cn	7.2	403	2.00%	69	35.9%
Diptera	Chironomidae	Thienemannimyia group	Thienemannimyia group	Predator	sp	8.2	373	1.80%	110	57.3%
Hydropsychidae	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	Filterer	cn	6.5	354	1.70%	63	32.8%
Amphipoda	Crangonyctidae	Synurella	Synurella	0	0	0.4	334	1.60%	47	24.5%
Coleoptera	Elmidae	Stenelmis	Stenelmis	Scraper	cn	7.1	324	1.60%	46	24.0%
Diptera	Chironomidae	Chaetocladius	Chaetocladius	Collector	sp	7	286	1.40%	65	33.9%
Diptera	Chironomidae	Cricotopus/Orthocladius	Cricotopus/Orthocladius	Shredder	0	7.7	284	1.40%	31	16.1%
Diptera	Chironomidae	Tanytarsus	Tanytarsus	Filterer	cb, cn	4.9	262	1.30%	77	40.1%
Amphipoda	not identified	not identified	Amphipoda	0	sp	6	247	1.20%	49	25.5%
Chironomidae	Chironomidae	Eukiefferiella	Eukiefferiella	Collector	sp	6.1	245	1.20%	51	26.6%
Veneroida	Pisidiidae	Pisidium	Pisidium	Filterer	bu	5.7	243	1.20%	45	23.4%
Chironomidae	Chironomidae	Chironomus	Chironomus	Collector	bu	4.6	237	1.20%	15	7.8%
Veneroida	Pisidiidae	not identified	Sphaeriidae	Filterer	bu	6.5	191	0.90%	46	24.0%
Ephemeroptera	Baetidae	Acerpenna	Acerpenna	Collector	sw, cn	2.6	187	0.90%	36	18.8%
Diptera	Chironomidae	Cricotopus	Cricotopus	Shredder	cn, bu	9.6	182	0.90%	53	27.6%
Diptera	Ceratopogonidae	not identified	Ceratopogoninae	0	0	na	176	0.90%	46	24.0%
Diptera	Chironomidae	Zavrelimyia	Zavrelimyia	Predator	sp	5.3	172	0.80%	51	26.6%
Diptera	Chironomidae	Diamesa	Diamesa	Collector	sp	8.5	157	0.80%	34	17.7%
Diptera	Chironomidae	Tvetenia	Tvetenia	Collector	sp	5.1	155	0.80%	65	33.9%
Lumbriculida	Lumbriculidae	not identified	Lumbriculidae	Collector	bu	6.6	152	0.70%	36	18.8%
Plecoptera	Nemouridae	Amphinemura	Amphinemura	Shredder	sp, cn	3	149	0.70%	43	22.4%
Diptera	Chironomidae	Corynoneura	Corynoneura	Collector	sp	4.1	148	0.70%	58	30.2%
Diptera	Chironomidae	Thienemanniella	Thienemanniella	Collector	sp	5.1	148	0.70%	54	28.1%
0	0	not identified	Nematoda	0	0	na	138	0.70%	35	18.2%
Plecoptera	Leuctridae	Leuctra	Leuctra	Shredder	cn	0.4	117	0.60%	17	8.9%
Basommatophora	Physidae	Physa	Physa	Scraper	cb	7	114	0.60%	41	21.4%
Coleoptera	Ptilodactylidae	Anchytarsus	Anchytarsus	Shredder	cn	3.1	110	0.50%	11	5.7%

Order	Family	Genus	Final ID	Functional Feeding Group	Habit[1]	Tolerance Value[2]	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Trichoptera	Hydropsychidae	Hydropsyche	Hydropsyche	Filterer	cn	7.5	108	0.50%	38	19.8%
Diptera	Chironomidae	Micropsectra	Micropsectra	Collector	cb, sp	2.1	103	0.50%	21	10.9%
Diptera	Tipulidae	Tipula	Tipula	Shredder	bu	6.7	102	0.50%	51	26.6%
Trichoptera	Limnephilidae	Ironoquia	Ironoquia	Shredder	sp	4.9	101	0.50%	41	21.4%
Coleoptera	Elmidae	Oulimnius	Oulimnius	Scraper	cn	2.7	98	0.50%	12	6.3%
Ephemeroptera	Baetidae	Plauditus	Plauditus	0	0	na	94	0.50%	11	5.7%
Trichoptera	Hydropsychidae	Diplectrona	Diplectrona	Filterer	cn	2.7	89	0.40%	32	16.7%
Amphipoda	Crangonyctidae	Crangonyx	Crangonyx	Collector	sp	6.7	79	0.40%	12	6.3%
Diptera	Chironomidae	Ablabesmyia	Ablabesmyia	Predator	sp	8.1	75	0.40%	16	8.3%
Trichoptera	Philopotamidae	Chimarra	Chimarra	Filterer	cn	4.4	72	0.40%	18	9.4%
Crangonyctidae	Crangonyctidae	not identified	Crangonyctidae	Collector	sp	6.5	70	0.30%	17	8.9%
Diptera	Simuliidae	Prosimulium	Prosimulium	Filterer	cn	2.4	67	0.30%	8	4.2%
Veneroida	not identified	not identified	Veneroida	0	0	na	67	0.30%	9	4.7%
Odonata	Calopterygidae	Calopteryx	Calopteryx	Predator	cb	8.3	65	0.30%	38	19.8%
Diptera	Chironomidae	Parakiefferiella	Parakiefferiella	Collector	sp	2.1	64	0.30%	18	9.4%
Ephemeroptera	Heptageniidae	Maccaffertium	Maccaffertium	Scraper	cn	3	56	0.30%	10	5.2%
Diptera	Chironomidae	Microtendipes	Microtendipes	Filterer	cn	4.9	56	0.30%	15	7.8%
Trichoptera	Polycentropodidae	Polycentropus	Polycentropus	Filterer	cn	1.1	56	0.30%	17	8.9%
Diptera	Empididae	Hemerodromia	Hemerodromia	Predator	sp, bu	7.9	55	0.30%	31	16.1%
Chironomidae	Chironomidae	Brillia	Brillia	Shredder	bu, sp	7.4	53	0.30%	20	10.4%
Diptera	Chironomidae	Phaenopsectra	Phaenopsectra	Collector	cn	8.7	53	0.30%	26	13.5%
Hoplonemertea	Tetrastemmatidae	Prostoma	Prostoma	Predator	0	7.3	51	0.20%	23	12.0%
Amphipoda	Gammaridae	not identified	Gammaridae	0	0	6	50	0.20%	11	5.7%
not identified	not identified	not identified	Turbellaria	Predator	sp	4	49	0.20%	20	10.4%
Basommatophora	Planorbidae	Menetus	Menetus	Scraper	cb	7.6	48	0.20%	12	6.3%
Diptera	Chironomidae	Limnophyes	Limnophyes	Collector	sp	8.6	46	0.20%	17	8.9%
Chironomidae	Chironomidae	Apsectrotanypus	Apsectrotanypus	Predator	bu, sp	6.6	45	0.20%	9	4.7%
Chironomidae	Chironomidae	Cryptochironomus	Cryptochironomus	Predator	sp, bu	7.6	44	0.20%	28	14.6%
Trichoptera	Limnephilidae	not identified	Limnephilidae	Shredder	cb, sp, cn	3.4	44	0.20%	24	12.5%
Diptera	Chironomidae	Paratanytarsus	Paratanytarsus	Collector	sp	7.7	44	0.20%	19	9.9%
Enchytraeidae	Enchytraeidae	not identified	Enchytraeidae	Collector	bu	9.1	43	0.20%	32	16.7%
Plecoptera	Chloroperlidae	Haploperla	Haploperla	Predator	cn	1.6	42	0.20%	7	3.6%
Basommatophora	Lymnaeidae	not identified	Lymnaeidae	Scraper	cb	6.9	38	0.20%	11	5.7%
Coleoptera	Elmidae	Optioservus	Optioservus	Scraper	cn	5.4	38	0.20%	9	4.7%
Plecoptera	Nemouridae	not identified	Nemouridae	Shredder	sp, cn	2.9	37	0.20%	15	7.8%
Mesogastropoda	Hydrobiidae	not identified	Hydrobiidae	Scraper	cb	8	35	0.20%	1	0.5%
Diptera	Chironomidae	Thienemannimyia	Thienemannimyia	Predator	sp	6.7	35	0.20%	10	5.2%
Diptera	Chironomidae	Dicrotendipes	Dicrotendipes	Collector	bu	9	34	0.20%	16	8.3%

Order	Family	Genus	Final ID	Functional Feeding Group	Habit[1]	Tolerance Value[2]	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Coleoptera	Dytiscidae	not identified	Dytiscidae	Predator	sw, dv	5.4	33	0.20%	19	9.9%
Diptera	Chironomidae	Potthastia	Potthastia	Collector	sp	0.01	33	0.20%	20	10.4%
Plecoptera	Chloroperlidae	not identified	Chloroperlidae	Predator	cn	1.6	32	0.20%	5	2.6%
Diptera	Ceratopogonidae	not identified	Bezzia/Palpomyia	0	0	na	30	0.10%	13	6.8%
Diptera	Chironomidae	Tribelos	Tribelos	Collector	bu	7	29	0.001	15	0.078
Ceratopogonidae	Ceratopogonidae	not identified	Ceratopogonidae	Predator	sp, bu	3.6	28	0.10%	17	8.9%
Diptera	Chironomidae	Stenochironomus	Stenochironomus	Shredder	bu	7.9	28	0.10%	15	7.8%
Trichoptera	Uenoidae	Neophylax	Neophylax	Scraper	cn	2.7	26	0.10%	9	4.7%
Trichoptera	Polycentropodidae	not identified	Polycentropodidae	0	cn	0.2	26	0.10%	11	5.7%
Coleoptera	Elmidae	Macronychus	Macronychus	Scraper	cn	6.8	25	0.10%	16	8.3%
Diptera	Tipulidae	Dicranota	Dicranota	Predator	sp, bu	1.1	24	0.10%	12	6.3%
Diptera	Chironomidae	Odontomesa	Odontomesa	Collector	sp	6.6	24	0.10%	9	4.7%
Diptera	Chironomidae	Saetheria	Saetheria	Collector	bu	6.6	23	0.10%	9	4.7%
Diptera	Simuliidae	not identified	Simuliidae	Filterer	cn	3.2	23	0.10%	12	6.3%
Coleoptera	Elmidae	Dubiraphia	Dubiraphia	Scraper	cn, cb	5.7	22	0.10%	11	5.7%
not identified	not identified	not identified	Lumbricina	Collector	bu	na	22	0.10%	17	8.9%
Odonata	Coenagrionidae	Argia	Argia	Predator	cn, cb, sp	9.3	21	0.10%	7	3.6%
Plecoptera	Perlodidae	Isoperla	Isoperla	Predator	cn, sp	2.4	21	0.10%	9	4.7%
Megaloptera	Corydalidae	Nigronia	Nigronia	Predator	cn, cb	1.4	20	0.10%	15	7.8%
Diptera	Chironomidae	not identified	Orthocladiinae	Collector	0	7.6	20	0.10%	14	7.3%
Diptera	Chironomidae	Pseudorthocladius	Pseudorthocladius	Collector	sp	6	20	0.10%	13	6.8%
Diptera	Ceratopogonidae	Bezzia	Bezzia	Predator	bu	3.3	19	0.10%	5	2.6%
Ostracoda	not identified	not identified	Ostracoda	Collector	0	8	19	0.10%	5	2.6%
Coleoptera	Elmidae	Ancyronyx	Ancyronyx	Scraper	cn, sp	7.8	18	0.10%	16	8.3%
Basommatophora	Ancylidae	Ferrissia	Ferrissia	Scraper	cb	7	18	0.10%	11	5.7%
Diptera	Chironomidae	Paracladopelma	Paracladopelma	Collector	sp	6.6	18	0.10%	14	7.3%
Diptera	Chironomidae	Paratendipes	Paratendipes	Collector	bu	6.6	18	0.10%	14	7.3%
Ephemeroptera	Baetidae	not identified	Baetidae	Collector	sw, cn	2.3	17	0.10%	5	2.6%
Tipulidae	Tipulidae	Erioptera	Erioptera	Collector	bu	4.8	17	0.10%	10	5.2%
Isopoda	not identified	not identified	Isopoda	Collector	0	3.3	17	0.10%	6	3.1%
Diptera	Tabanidae	Chrysops	Chrysops	Predator	sp, bu	2.9	16	0.10%	12	6.3%
Chironomidae	Chironomidae	Natarsia	Natarsia	Predator	sp	6.6	16	0.10%	6	3.1%
Diptera	Ceratopogonidae	Dasyhelea	Dasyhelea	Collector	sp	3.6	14	0.10%	9	4.7%
Chironomidae	Chironomidae	Prodiamesa	Prodiamesa	Collector	bu, sp	6.6	14	0.10%	5	2.6%
Diptera	Chironomidae	not identified	Tanypodinae	Predator	0	7.5	13	0.10%	10	5.2%
Plecoptera	Capniidae	not identified	Capniidae	Shredder	sp, cn	3.7	12	0.10%	7	3.6%
Diptera	Empididae	Neoplasta	Neoplasta	Predator	0	na	12	0.10%	10	5.2%
Tipulidae	Tipulidae	not identified	Tipulidae	Predator	bu, sp	4.8	12	0.001	11	0.057

Order	Family	Genus	Final ID	Functional Feeding Group	Habit[1]	Tolerance Value[2]	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Odonata	Aeshnidae	Boyeria	Boyeria	Predator	cb, sp	6.3	11	0.10%	8	4.2%
not identified	not identified	not identified	Gastropoda	0	0	na	11	0.10%	5	2.6%
Diptera	Tipulidae	Hexatoma	Hexatoma	Predator	bu, sp	1.5	11	0.10%	9	4.7%
Diptera	Chironomidae	Nanocladius	Nanocladius	Collector	sp	7.6	11	0.10%	11	5.7%
Trichoptera	Limnephilidae	Pycnopsyche	Pycnopsyche	Shredder	sp, cb, cn	3.1	11	0.10%	7	3.6%
Diptera	Chironomidae	Stilocladius	Stilocladius	Collector	sp	6.6	11	0.10%	5	2.6%
Decapoda	Cambaridae	not identified	Cambaridae	Shredder	sp	2.8	10	0.00	5	0.026
Trichoptera	Psychomyiidae	Lype	Lype	Scraper	cn	4.7	10	0.00	8	0.042
Coleoptera	Elmidae	Microcylloepus	Microcylloepus	Collector	0	4.8	10	0.00	7	0.036
Trichoptera	Phryganeidae	Ptilostomis	Ptilostomis	Shredder	cb	4.3	10	0.00	10	0.052
Trichoptera	Hydropsychidae	not identified	Hydropsychidae	Filterer	cn	5.7	9	0.00	6	0.031
Coleoptera	Dytiscidae	Neoporus	Neoporus	Predator	0	na	9	0.00	6	0.031
Diptera	Tipulidae	Pilaria	Pilaria	Predator	bu	4.8	9	0.00	7	0.036
Tipulidae	Tipulidae	Pseudolimnophila	Pseudolimnophila	Predator	bu	2.8	9	0.00	6	0.031
Diptera	Chironomidae	Stictochironomus	Stictochironomus	Collector	bu	9.2	9	0.00	6	0.031
Diptera	Culicidae	Aedes	Aedes	Filterer	sw	8	8	0.00	1	0.005
Diptera	Tipulidae	Antocha	Antocha	Collector	cn	8	8	0.00	6	0.031
Odonata	Cordulegastridae	Cordulegaster	Cordulegaster	Predator	bu	2.4	8	0.00	8	0.042
Diptera	Chironomidae	Larsia	Larsia	Predator	sp	8.5	8	0.00	4	0.021
Ephemeroptera	Siphlonuridae	Siphlonurus	Siphlonurus	Collector	sw, cb	7	8	0.00	1	0.005
Basommatophora	Lymnaeidae	Stagnicola	Stagnicola	Scraper	cb	7.8	8	0.00	1	0.005
Plecoptera	Taeniopterygidae	Taeniopteryx	Taeniopteryx	Shredder	sp, cn	4.8	8	0.00	3	0.016
Diptera	Chironomidae	not identified	Tanytarsini	Collector	0	3.5	8	0.00	5	0.026
Trichoptera	Leptoceridae	Triaenodes	Triaenodes	Shredder	sw, cb	5	8	0.00	5	0.026
Odonata	0	not identified	Anisoptera	Predator	0	na	7	0.00	4	0.021
Veneroida	Corbiculidae	Corbicula	Corbicula	Filterer	bu	6	7	0.00	4	0.021
Diptera	Chironomidae	Glyptotendipes	Glyptotendipes	Filterer	bu, cn	6.6	7	0.00	2	0.01
Amphipoda	Hyalellidae	Hyalella	Hyalella	Shredder	sp	4.2	7	0.00	2	0.01
Ephemeroptera	Leptophlebiidae	not identified	Leptophlebiidae	Collector	sw, cn	1.7	7	0.00	4	0.021
Diptera	Chironomidae	Paralauterborniella	Paralauterborniella	Collector	cn	6.6	7	0.00	6	0.031
Diptera	Chironomidae	Paraphaenocladius	ParaphaenocladiuS	Collector	sp	4	7	0.00	7	0.036
Diptera	Chironomidae	Chironomini	Chironomini	0	0	5.9	6	0.00	5	0.026
Diptera	Chironomidae	Georthocladius	Georthocladius	0	sp	na	6	0.00	2	0.01
Coleoptera	Dryopidae	Helichus	Helichus	Scraper	cn	6.4	6	0.00	5	0.026
Ephemeroptera	Heptageniidae	not identified	Heptageniidae	Scraper	cn	2.6	6	0.00	3	0.016
Diptera	Chironomidae	Heterotrissocladius	Heterotrissocladius	Collector	sp, bu	2	6	0.00	5	0.026
Lepidoptera	not identified	not identified	Lepidoptera	0	0	6.7	6	0.00	4	0.021
Trichoptera	Leptoceridae	Oecetis	Oecetis	Predator	cn, sp, cb	4.7	6	0.00	4	0.021

Order	Family	Genus	Final ID	Functional Feeding Group	Habit[1]	Tolerance Value[2]	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Diptera	Chironomidae	Procladius	Procladius	Predator	sp	1.2	6	0.00	3	0.016
Coleoptera	Psephenidae	Psephenus	Psephenus	Scraper	cn	4.4	6	0.00	3	0.016
Amphipoda	Crangonyctidae	Stygobromus	Stygobromus	Collector	0	4	6	0.00	6	0.031
Plecoptera	Perlidae	Eccoptura	Eccoptura	Predator	cn	0.6	5	0.00	2	0.01
Trichoptera	Calamoceratidae	Heteroplectron	Heteroplectron	Shredder	sp	3	5	0.00	4	0.021
Trichoptera	Hydroptilidae	Hydroptila	Hydroptila	Scraper	cn	6	5	0.00	1	0.005
Trichoptera	Lepidostomatidae	Lepidostoma	Lepidostoma	Shredder	cb, sp, cn	0.01	5	0.00	5	0.026
Diptera	Chironomidae	Rheosmittia	Rheosmittia	0	0	6.6	5	0.00	4	0.021
Odonata	Corduliidae	Somatochlora	Somatochlora	Predator	sp	1	5	0.00	2	0.01
Diptera	Tabanidae	not identified	Tabanidae	Predator	0	2.8	5	0.00	6	0.031
Diptera	Chironomidae	Xylotopus	Xylotopus	Shredder	bu	6.6	5	0.00	4	0.021
Isopoda	Asellidae	not identified	Asellidae	0	0	3.3	4	0.00	3	0.016
Diptera	Chironomidae	Clinotanypus	Clinotanypus	Predator	bu	6.6	4	0.00	1	0.005
Plecoptera	Perlidae	Perlesta	Perlesta	Predator	cn	1.6	4	0.00	3	0.016
Basommatophora	Planorbidae	not identified	Planorbidae	Scraper	cb	7.6	4	0.00	3	0.016
Diptera	Chironomidae	Alotanypus	Alotanypus	0	0	6.6	3	0.00	2	0.01
Diptera	Chironomidae	Cladotanytarsus	Cladotanytarsus	Filterer	-	6.6	3	0.00	3	0.016
Odonata	Coenagrionidae	not identified	Coenagrionidae	Predator	cb	9	3	0.00	3	0.016
Coleoptera	Hydrophilidae	Cymbiodyta	Cymbiodyta	Collector	bu	4.1	3	0.00	2	0.01
Diptera	not identified	not identified	Diptera	0	0	6	3	0.00	1	0.005
Diptera	Dixidae	Dixa	Dixa	Predator	sw, cb	5.8	3	0.00	2	0.01
Ephemeroptera	Ephemerellidae	Eurylophella	Eurylophella	Scraper	cn, sp	4.5	3	0.00	1	0.005
Coleoptera	Hydrophilidae	Hydrobius	Hydrobius	Collector	cb, cn, sp	4.1	3	0.00	2	0.01
Plecoptera	Leuctridae	not identified	Leuctridae	Shredder	sp, cn	0.8	3	0.00	2	0.01
not identified	not identified	not identified	Nemata	0	0	na	3	0.00	3	0.016
Diptera	Psychodidae	not identified	Psychodidae	0	0	4	3	0.00	3	0.016
Diptera	Sciomyzidae	not identified	Sciomyzidae	Predator	bu	6	3	0.00	3	0.016
Trichoptera	not identified	not identified	Trichoptera	0	0	4.6	3	0.00	3	0.016
Diptera	Ptychopteridae	Bittacomorpha	Bittacomorpha	Collector	bu	4	2	0.00	2	0.01
Megaloptera	Corydalidae	not identified	Corydalidae	Predator	0	1.4	2	0.00	2	0.01
Plecoptera	Perlodidae	Diploperla	Diploperla	Predator	cn	2.2	2	0.00	2	0.01
Diptera	Dolichopodidae	not identified	Dolichopodidae	Predator	sp, bu	7.5	2	0.00	2	0.01
Trichoptera	Philopotamidae	Dolophilodes	Dolophilodes	Filterer	cn	1.7	2	0.00	2	0.01
Diptera	Empididae	not identified	Empididae	Predator	sp, bu	7.5	2	0.00	2	0.01
Odonata	Coenagrionidae	Enallagma	Enallagma	Predator	cb	9	2	0.00	2	0.01
Diptera	Ephydridae	not identified	Ephydridae	Collector	bu, sp	na	2	0.00	2	0.01
Hirudinida	Erpobdellidae	Erpobdella	Erpobdella	Predator	0	na	2	0.00	2	0.01
Odonata	Gomphidae	not identified	Gomphidae	Predator	bu	2.2	2	0.00	2	0.01

Order	Family	Genus	Final ID	Functional Feeding Group	Habit[1]	Tolerance Value[2]	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Coleoptera	Gyrinidae	Gyrinus	Gyrinus	Predator	sw, dv	4	2	0.00	1	0.005
Tubificida	Haplotaxidae	not identified	Haplotaxidae	0	0	na	2	0.00	2	0.01
Diptera	Chironomidae	Mesocricotopus	Mesocricotopus	0	0	6.6	2	0.00	1	0.005
Diptera	Chironomidae	Metriocnemus	Metriocnemus	0	0	na	2	0.00	2	0.01
Trichoptera	Molannidae	Molanna	Molanna	Scraper	sp, cn	6	2	0.00	1	0.005
Tipulidae	Tipulidae	Molophilus	Molophilus	0	bu	4.8	2	0.00	2	0.01
Veneroida	Pisidiidae	Musculium	Musculium	Filterer	0	5.5	2	0.00	2	0.01
Coleoptera	Haliplidae	Peltodytes	Peltodytes	Shredder	cb, cn	8.9	2	0.00	2	0.01
Plecoptera	Perlidae	not identified	Perlidae	Predator	cn	2.2	2	0.00	2	0.01
Trichoptera	Dipseudopsidae	Phylocentropus	Phylocentropus	Collector	bu	5	2	0.00	2	0.01
Basommatophora	Physidae	not identified	Physidae	Scraper	cb	7	2	0.00	1	0.005
Megaloptera	Sialidae	Sialis	Sialis	Predator	bu, cb, cn	1.9	2	0.00	2	0.01
Diptera	Chironomidae	Smittia	Smittia	Collector	lentic	6.6	2	0.00	2	0.01
Diptera	Chironomidae	Stempellinella	Stempellinella	Collector	cb, sp, cn	4.2	2	0.00	1	0.005
Plecoptera	Taeniopterygidae	Strophopteryx	Strophopteryx	Shredder	sp, cn	3.3	2	0.00	1	0.005
Diptera	Chironomidae	Trissopelopia	Trissopelopia	Predator	sp	4.1	2	0.00	1	0.005
Ephemeroptera	Baetidae	Acentrella	Acentrella	Collector	sw, cn	4.9	1	0.00	1	0.005
Plecoptera	Capniidae	Allocapnia	Allocapnia	Shredder	cn	4.2	1	0.00	1	0.005
Ephemeroptera	Ameletidae	Ameletus	Ameletus	Collector	sw, cb	2.6	1	0.00	1	0.005
Ephemeroptera	Baetidae	Baetis	Baetis	Collector	sw, cb, cn	3.9	1	0.00	1	0.005
Ephemeroptera	Caenidae	Caenis	Caenis	Collector	sp	2.1	1	0.00	1	0.005
Odonata	Calopterygidae	not identified	Calopterygidae	Predator	0	6	1	0.00	1	0.005
Decapoda	Cambaridae	Cambarus	Cambarus	Collector	sp	0.4	1	0.00	1	0.005
Diptera	Chironomidae	not identified	Chironominae	Collector	0	6.6	1	0.00	1	0.005
Odonata	Coenagrionidae	Coenagrion/Enallagma	Coenagrion/Enallagma	Predator	cb	na	1	0.00	1	0.005
Collembola	not identified	not identified	Collembola	0	0	6	1	0.00	1	0.005
Diptera	Chironomidae	Conchapelopia	Conchapelopia	Predator	sp	6.1	1	0.00	1	0.005
Odonata	Corduliidae	not identified	Corduliidae	Predator	sp, cb	2	1	0.00	1	0.005
Hemiptera	Corixidae	not identified	Corixidae	Predator	sw	5.6	1	0.00	1	0.005
Coleoptera	Gyrinidae	Dineutus	Dineutus	Predator	sw, dv	4	1	0.00	1	0.005
Ephemeroptera	Ephemerellidae	Ephemerella	Ephemerella	Collector	cn, sw	2.3	1	0.00	1	0.005
Diptera	Ceratopogonidae	Forcipomyia	Forcipomyia	Predator	0	na	1	0.00	1	0.005
Diptera	Chironomidae	Gymnometriocnemus	Gymnometriocnemus	0	0	na	1	0.00	1	0.005
Basommatophora	Planorbidae	Gyraulus	Gyraulus	Scraper	cb	7.6	1	0.00	1	0.005
Rhynchobdellida	Glossiphoniidae	Helobdella	Helobdella	Predator	sp	6	1	0.00	1	0.005
Coleoptera	Hydrophilidae	Helochares	Helochares	0	0	na	1	0.00	1	0.005
Trichoptera	Limnephilidae	Hydatophylax	Hydatophylax	Shredder	sp, cb	3.4	1	0.00	1	0.005
Trichoptera	Hydroptilidae	not identified	Hydroptilidae	0	0	4	1	0.00	1	0.005

Order	Family	Genus	Final ID	Functional Feeding Group	Habit[1]	Tolerance Value[2]	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Diptera	Chironomidae	Hydrosmittia	Hydrosmittia	0	0	na	1	0.00	1	0.005
Odonata	Coenagrionidae	Ischnura	Ischnura	Predator	cb	9	1	0.00	1	0.005
Diptera	Chironomidae	Krenosmittia	Krenosmittia	Collector	sp	na	1	0.00	1	0.005
Trichoptera	Leptoceridae	not identified	Leptoceridae	Collector	0	4.1	1	0.00	1	0.005
Ephemeroptera	Leptophlebiidae	Leptophlebia	Leptophlebia	Collector	sw, cn, sp	1.8	1	0.00	1	0.005
Odonata	Libellulidae	not identified	Libellulidae	Predator	0	9	1	0.00	1	0.005
Diptera	Muscidae	not identified	Muscidae	Predator	sp	7	1	0.00	1	0.005
Diptera	Chironomidae	Nilotanypus	Nilotanypus	Predator	sp	6.6	1	0.00	1	0.005
Odonata	not identified	not identified	Odonata	Predator	0	6.6	1	0.00	1	0.005
Decapoda	Cambaridae	Orconectes	Orconectes	Shredder	sp	2.8	1	0.00	1	0.005
Diptera	Tipulidae	Ormosia	Ormosia	Collector	bu	6.3	1	0.00	1	0.005
Diptera	Chironomidae	Parachaetocladius	Parachaetocladius	Collector	sp	3.3	1	0.00	1	0.005
Coleoptera	Hydrophilidae	Paracymus	Paracymus	0	bu	na	1	0.00	1	0.005
Diptera	Psychodidae	Pericoma	Pericoma	Collector	0	4	1	0.00	1	0.005
Plecoptera	Perlodidae	not identified	Perlodidae	Predator	cn	2.2	1	0.00	1	0.005
Trichoptera	Philopotamidae	not identified	Philopotamidae	Filterer	cn	2.6	1	0.00	1	0.005
Coleoptera	Dytiscidae	Platambus	Platambus	0	0	na	1	0.00	1	0.005
Plecoptera	not identified	not identified	Plecoptera	0	0	2.4	1	0.00	1	0.005
Diptera	Chironomidae	Radotanypus	Radotanypus	0	0	na	1	0.00	1	0.005
Trichoptera	Rhyacophilidae	Rhyacophila	Rhyacophila	Predator	cn	2.1	1	0.00	1	0.005
Diptera	Chironomidae	Robackia	Robackia	Collector	0	na	1	0.00	1	0.005
Diptera	Empididae	Roederiodes	Roederiodes	Predator	cn	na	1	0.00	1	0.005
Diptera	Stratiomyidae	not identified	Stratiomyidae	Collector	0	na	1	0.00	1	0.005
Diptera	Chironomidae	Sympotthastia	Sympotthastia	Collector	sp	8.2	1	0.00	1	0.005
Trichoptera	Philopotamidae	Wormaldia	Wormaldia	Filterer	cn	1.8	1	0.00	1	0.005

Common Name	Scientific Name	Tolerance	Trophic Status	Lithophilic Spawner	Composition	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Blacknose Dace	*Rhinichthys atratulus*	T	OM	N	NOTYPE	7933	28.4%	102	60.0%
Eastern Mudminnow	*Umbra pygmaea*	T	IV	N	NOTYPE	3548	12.7%	92	54.1%
Eastern Mosquitofish	*Gambusia holbrooki*	NOTYPE	IV	N	NOTYPE	2573	9.2%	63	37.1%
Green Sunfish	*Lepomis cyanellus*	T	GE	N	NOTYPE	1833	6.6%	70	41.2%
Tessellated Darter	*Etheostoma olmstedi*	T	IV	N	B	1621	5.8%	76	44.7%
American Eel	*Anguilla rostrata*	NOTYPE	GE	N	NOTYPE	1346	4.8%	111	65.3%
Creek Chub	*Semotilus atromaculatus*	T	GE	Y	NOTYPE	1199	4.3%	36	21.2%
Bluegill	*Lepomis macrochirus*	T	IV	N	NOTYPE	1102	3.9%	68	40.0%
Fallfish	*Semotilus corporalis*	I	GE	Y	NOTYPE	730	2.6%	35	20.6%
Least Brook Lamprey	*Lampetra aepyptera*	NOTYPE	FF	N	B	655	2.3%	45	26.5%
Rosyside Dace	*Clinostomus funduloides*	NOTYPE	IV	Y	NOTYPE	638	2.3%	27	15.9%
Swallowtail Shiner	*Notropis procne*	NOTYPE	IV	Y	NOTYPE	622	2.2%	23	13.5%
Pumpkinseed	*Lepomis gibbosus*	T	IV	N	NOTYPE	532	1.9%	43	25.3%
White Sucker	*Catostomus commersonii*	T	OM	Y	NOTYPE	405	1.4%	39	22.9%
Creek Chubsucker	*Erimyzon oblongus*	NOTYPE	IV	N	R	400	1.4%	31	18.2%
Golden Shiner	*Notemigonus crysoleucas*	T	OM	N	NOTYPE	386	1.4%	26	15.3%
Brown Bullhead	*Ameiurus nebulosus*	T	OM	N	NOTYPE	314	1.1%	27	15.9%
Fathead Minnow	*Pimephales promelas*	NOTYPE	OM	N	NOTYPE	308	1.1%	4	2.4%
Satinfin Shiner	*Cyprinella analostana*	I	IV	N	NOTYPE	305	1.1%	19	11.2%
Mummichog	*Fundulus heteroclitus*	NOTYPE	IV	N	NOTYPE	227	0.8%	11	6.5%
Redbreast sunfish	*Lepomis auritus*	NOTYPE	GE	N	NOTYPE	176	0.6%	13	7.6%
Central Stoneroller	*Campostoma anomalum*	I	AL	Y	NOTYPE	134	0.5%	10	5.9%
Longnose Dace	*Rhinichthys cataractae*	NOTYPE	OM	N	NOTYPE	132	0.5%	12	7.1%
Sea Lamprey	*Petromyzon marinus*	I	FF	N	NOTYPE	130	0.5%	11	6.5%
Yellow Bullhead	*Ameiurus natalis*	NOTYPE	OM	N	NOTYPE	107	0.4%	19	11.2%
Largemouth Bass	*Mictopterus salmoides*	T	TP	N	NOTYPE	104	0.4%	32	18.8%
Bluntnose Minnow	*Pimephales notatus*	T	OM	N	NOTYPE	97	0.3%	6	3.5%
Redfin Pickerel	*Esox americanus*	T	TP	N	NOTYPE	77	0.3%	12	7.1%
Banded Killifish	*Fundulus diaphanus*	NOTYPE	IV	N	NOTYPE	60	0.2%	14	8.2%
Bluespotted Sunfish	*Enneacanthus gloriosus*	NOTYPE	IV	N	NOTYPE	46	0.2%	6	3.5%
Blue Ridge Sculpin	*Cottus caeruleomentum*	I	IS	Y	B	29	0.1%	5	2.9%
Warmouth	*Lepomis gulosus*	NOTYPE	GE	N	NOTYPE	26	0.1%	8	4.7%
Spottail shiner	*Notropis hudsonius*	I	OM	Y	NOTYPE	22	0.1%	4	2.4%
Margined Madtom	*Noturus insignis*	I	IV	N	B	21	0.1%	2	1.2%
Northern Hogsucker	*Hypentelium nigricans*	I	IV	Y	R	18	0.1%	7	4.1%
Common Shiner	*Luxilus cornutus*	I	OM	Y	NOTYPE	17	0.1%	1	0.6%

Common Name	Scientific Name	Tolerance	Trophic Status	Lithophilic Spawner	Composition	Total Number of Organisms	% of Total Organisms	Total Number of Sites	% of Sites
Cutlip Minnow	*Exoglossum maxillingua*	NOTYPE	IV	Y	NOTYPE	11	0.0%	3	1.8%
Chain pickerel	*Esox niger*	NOTYPE	TP	N	NOTYPE	8	0.0%	3	1.8%
Black Crappie	*Pomoxis nigromaculatus*	NOTYPE	GE	N	NOTYPE	6	0.0%	3	1.8%
Lepomis hybrid	*Lepomis sp.*	NOTYPE	NOTYPE	NOTYPE	NOTYPE	6	0.0%	2	1.2%
River Chub	*Nocomis micropogon*	I	OM	Y	NOTYPE	6	0.0%	1	0.6%
Smallmouth Bass	*Micropterus dolomieu*	NOTYPE	TP	N	NOTYPE	6	0.0%	4	2.4%
Tadpole madtom	*Noturus gyrinus*	NOTYPE	IV	N	B	4	0.0%	2	1.2%
Goldfish	*Carassius auratus*	NOTYPE	OM	N	NOTYPE	3	0.0%	1	0.6%
Northern Snakehead	*Channa sp.*	0	0	0	0	3	0.0%	2	1.2%
Glassy darter	*Etheostoma vitreum*	NOTYPE	IS	Y	B	2	0.0%	1	0.6%
Yellow perch	*Perca flavescens*	NOTYPE	GE	N	B	2	0.0%	2	1.2%
Brook Trout	*Salvelinus fontinalis*	I	GE	Y	NOTYPE	1	0.0%	1	0.6%
Cyprinid Hybrid	*Cyprinid Hybrid*	NOTYPE	NOTYPE	NOTYPE	NOTYPE	1	0.0%	1	0.6%
Rock Bass	*Ambloplites rupestris*	NOTYPE	GE	Y	NOTYPE	1	0.0%	1	0.6%
White crappie	*Pomoxis annularis*	NOTYPE	GE	N	NOTYPE	1	0.0%	1	0.6%