Monitoring Data Collected under Maryland's Municipal Separate Storm Sewer System (MS4) Permits: Database Design and Preliminary Analysis of Benthic and Stream Habitat Data

Prepared for:

Maryland Department of the Environment

Prepared by:

Interstate Commission on the Potomac River Basin

March 5, 2019

Revised August 5, 2019

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LIST OF ABBREVIATIONS

BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practices
DNR	Maryland Department of Natural Resources
EPA	Environmental Protection Agency
ICPRB	Interstate Commission on the Potomac River Basin
MBSS	Maryland Biological Stream Survey
MDE	Maryland Department of the Environment
MEP	Maximum Extent Practicable
MS4	Municipal Separate Strom Sewer System
NPDES	National Pollutant Discharge Elimination System

PHI	Physical Habitat Index
QAPP	Quality Assurance Project Plan
RBP	Rapid Bioassessment Protocol
SHA	State Highway Administration
WRM	MS4 Watershed Restoration Monitoring

EXECUTIVE SUMMARY

The Maryland Department of the Environment (MDE) has issued Phase I Municipal Separate Strom Sewer System (MS4) permits to Baltimore City, nine counties, and the State Highway Administration (SHA) since the early 1990's. As part of the permit requirements, permittees are required to submit water chemistry, physical habitat, aquatic biology, and stream geomorphic monitoring data. The Interstate Commission on the Potomac River Basin (ICPRB) worked with MDE to design an MS Access database to store MS4 monitoring data and related information. The benthic and habitat database consists of biological and habitat metrics and indices calculated by Phase I MS4 jurisdictions as well as benthic taxa count data provided by MDE. A total of 1,743 benthic and habitat monitoring results were added to the database, of which 539 are associated with MS4 Watershed Restoration Monitoring (WRM) sampling. Very little data are available prior to 2006, and Baltimore County data could not be extracted from an older version EDAS database and therefore was not included in the database.

The updated database and a user manual describing the tables and their relationships to each other are provided in **Appendix A.** Basic descriptive statistics (minimum, maximum, mean, median, standard deviation, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles) were calculated for all available benthic and habitat metrics (**Appendix B**) and indices (**Table 9** and **Table 11**). Boxplots were produced to display the range of variability and the median values of the benthic and habitat indices (**Appendix C**). Linear regressions were conducted for stations with more than five years of data. Scatter plots of the fitted values for each station as well as the regression statistics can be found in **Appendix D**.

Although there were not enough metrics with significant trends at a given station to ascertain substantial changes in either the benthic community or the physical habitat, some metrics displayed linear trends such as nept (number of Ephemeroptera, Plecoptera, and Trichoptera taxa) at the Air Business Center, Carroll County and nephem (number of Ephemeroptera taxa) in the Bear Branch watershed, Prince George's County. Only three sites showed linear trends for the benthic and habitat indices likely due to limited record length. Only 29 of the 60 WRM sites with Benthic Index of Biotic Integrity (BIBI) data had more than five years of data. Among the 29 sites, only one station in the Moores Run Tributary, Baltimore County displayed a significant worsening trend in its BIBI score, which decreased from 1.8 to 1.0 from 2002 to 2007. Twelve of the seventeen WRM sites with Physical Habitat Index (PHI) scores had more than five years of data. Of these, only two sites in the Picture Spring Branch watershed in Anne Arundel County displayed significant trends that showed some degradation overtime.

INTRODUCTION

In 1990, the Environmental Protection Agency (EPA) published the National Pollutant Discharge Elimination System (NPDES) stormwater regulations. As part of these regulations, EPA requires that Phase I urban jurisdictions control stormwater pollutant discharges to the maximum extent practicable (MEP). In response to these regulations, the Maryland Department of the Environment (MDE) started issuing NPDES Municipal Separate Stormwater Sewer System (MS4) permits to Anne Arundel, Baltimore, Carroll, Charles, Frederick, Harford, Howard, Montgomery, and Prince George's Counties, Baltimore City, and the State Highway Administration in 1993. The MS4 permits are reissued every five years.

To stay in compliance with their MS4 permits, jurisdictions must conduct stormwater discharge characterization at approved long-term monitoring sites. The goals of these monitoring efforts have changed over the years. Initially, the intent was to characterize stormwater discharges draining a specific land use in select watersheds. Permittees were required to collect water quality samples at up to five outfalls and at instream stations above the outfalls. Around 2000, the monitoring requirements were modified so that permittees only needed to collect water quality samples at one storm sewer outfall and one associated instream station, but additionally were also required to conduct biological and physical stream assessments. The goal still was stormwater runoff characterization but shifted to assessing variations in land use types on a state-wide basis rather than on a jurisdictional scale. Starting around 2004, with the third generation of permits, permittees were required to monitor watersheds where restoration projects were expected to be built so that pre- and post- implementation conditions could be assessed and determine if and how these efforts affect water quality, instream habitat, and the benthic community. At present, the overall goal of the chemical, biological, and physical monitoring is to evaluate watershed restoration efforts, assess the effectiveness of Best Management Practices (BMPs), and document progress toward reducing in-stream pollutant loads.

MDE is interested in using the available MS4 monitoring data that has been collected for over 20 years to determine whether the data can be used in statistical analyses to answer questions such:

- Are there any trends across watersheds that are reflective of variable watershed characteristics such as land use;
- Are there temporal trends in the chemical, biological or physical data within watersheds;
- Are there any state-wide temporal trends in the water quality data, instream habitat, or biotic integrity;
- Are there indications that restoration efforts and/or BMPs are effective;
- Do stormwater management regulations prevent pollutant loads from increasing, biotic integrity from decreasing, or channel morphology from changing due to new development in the watersheds?

The permittees have stored and submitted MS4 monitoring data to the Maryland Department of the Environment (MDE) in various formats, including MS Access databases, MS Excel spreadsheets, MS Word documents, pdf files, and MDE MS4 geodatabases. To facilitate data analyses, MDE has tasked the Interstate Commission on the Potomac River Basin (ICPRB) to migrate these data into an MS Access Database.

In an initial project, ICPRB worked closely with MDE to design an MS Access 2010 database to house the chemical, biological, and physical monitoring data and associated information. The database was populated with all available water quality data collected for MS4 permits. Basic descriptive statistics were calculated, and preliminary tests for linear trends in the chemical data were also performed. The results of these analyses are described in Nagel and Mandel, 2018.

The current project is a continuation of that work and involves modifying the existing MS4 database design to house biological and habitat metrics and indices calculated by the Phase I MS4 jurisdictions as well as raw benthic taxa data provided to MDE by the permittees. Other goals are to calculate basic summary statistics for the benthic and habitat data and to use the raw data, if feasible, for temporal trend analyses in two watersheds. This report describes the steps taken to populate the database with available benthic and habitat data and summarizes basic descriptive statistics and trends.

The final phase of this project will focus on using raw benthic data from two watersheds for statistical analyses. The Maryland Department of Natural Resources (DNR) MBSStools R package will be used to calculate benthic metrics and indices. This analysis will attempt to find trends in the biological monitoring data, and if trends exist, attempt to relate them to restoration efforts in the watersheds. During a meeting on January 10, 2019 between MDE and ICPRB, the Air Business Center watershed in Carroll County and the Bear Branch watershed in Prince George's County were selected as the demonstration watersheds.

DATABASE

For the current project, ICPRB worked with MDE to revise some of the MS4 database tables created for the MS4 water quality database to better accommodate benthic and habitat metrics and indices calculated by Phase I MS4 permittees. Tables that house raw benthic counts and in-situ water chemistry data provided by the MS4 jurisdictions were also added.

Database Design

The MS4 database was designed based on the principle of normalization. This entails creating tables and establishing relationships between the tables in such a manner that data redundancy and inconsistent dependencies are avoided. Separate tables are created for sets of related data, which are linked to each other by common key fields. Most of the tables relate to each other via one-to-many relationships. In other words, the one record in the "parent" table is related to many records in the "child" table. Using the key fields to create relationships between the tables allows for the enforcement of referential integrity, which prevents entry of duplicate records in the parent table or adding records to a child table for which there is no record in the

parent table. Tables are divided into primary data tables and associated domain tables, whose names are prefixed with a "d". The domain tables essentially function as lookup tables and define in detail the codes contained in the primary tables.

Table 1 shows all tables housed in the MDE MS4 database and provides a description of their function. The database and a user manual that describes the tables, fields in the tables, and the relationships between the tables in more detail are provided in **Appendix A.**

Table 1. Primary and domain tables in the MDE MS4 database.

Table Name	Function
Primary Tables	
ACTIVITY	Records the location, date and time, and type of sampling activities.
ACTIVITY_COMMENT	Tracks activity comments provided by collecting agencies or data manipulations performed by ICPRB.
ACTIVITY_EMC	Stores information about EMC data that may be censored.
ASSESSMENT_CHEMICAL	Includes information about chemical monitoring and event mean concentrations of stormwater discharges from MS4 outfall and instream monitoring locations.
ASSESSMENT_INSITU	Stores in-situ chemical data that was taken in conjunction with biological and habitat assessments.
ASSESSMENT_PHYSICAL	Stores information related to geomorphologic stream assessments.
INDEX_BENTHIC	Contains Benthic Index of Biotic Integrity (BIBI) scores calculated by the MS4 permittees to assess stream health.
INDEX_HABITAT	Contains habitat assessment index scores based on the Physical Habitat Index (PHI) and EPA's Rapid Bioassessment Protocols (RBP). The scores were provided by the MS4 permittees.
MASTER_TAXA_LIST	Provides taxonomic information for all collected macroinvertebrates.
METRIC_BENTHIC	Stores benthic metrics calculated by the MS4 permittees to assess stream health.
METRIC_HABITAT	Stores habitat metrics calculated MS4 permittees to assess overall stream health.
MONITORING_SITES	Provides sampling location names and associated geographic attributes.
OUTFALLS	Provides information about outfalls associated with MS4 permit monitoring.
PROJECT	Provides ad description of the project purpose and/or a summary.
TAXA_COUNT	Contains raw benthic counts submitted by the MS4 permittees.
Domain Tables	
dAgency	Lists sampling agencies.
dActivity_Type	Provides information about the type of sample collected.
dFFGroup	Describes the functional feeding group designation of a benthic organism.
dHabit	Provides a description of the habit/behavior assignment of benthic organisms based on their locomotion or behavior in relation to their habitat.
dIndex_Biohab	Defines benthic and habitat indices
dLandUse	Provides Maryland Department of Planning (MDP) land use descriptions.
dLifeStage	Lists life stages of benthic organisms.
dMetrics_Benthic	Provides descriptions of benthic metrics calculated by the MS4 jurisdictions.
dMonitoringRequirement	Defines the specific monitoring requirement for an activity.
dOutfallMaterial	Provides information about the outfall material at monitoring locations.
dOutfallType	Provides information about the outfall type at monitoring locations.
dParameter_Chemical	Provides descriptions of chemical assessment parameters.
dParameter_Habitat	Clarifies the habitat assessment parameters.
dParameter_Physical	Describes the characteristics of the physical assessment.
dSiteCriteria	Defines the site selection criteria

Table Name	Function
dStatisticalBase	Describes methods used to calculate the values for the chemical assessment.
dStrata	Defines the physiographic stratum in which a site is located. The three strata used by MBSS for BIBI calculations are Coastal, Piedmont, and Highland.
dQuality	Provides qualitative description of the benthic or habitat sample

Data Entry

With certain exceptions as described below, all benthic, habitat, and in-situ water quality monitoring data made available by MDE or extracted by ICPRB from annual NPDES MS4 reports were entered into the database. Therefore, the database includes data collected for both MS4 permit requirements and for other monitoring purposes. Per MDE's instructions, the monitoring type was indicated in the database as: WRM (MS4 Watershed Restoration Monitoring), ORM (Other Restoration Monitoring), OBM (Other Biological Monitoring, likely not related to the MS4 permits), or UNK (unknown).

In total, the database contains 1,743 sampling events related to benthic and habitat monitoring of which 539 are associated WRM sampling. **Table 2** provides a summary of the date ranges and counts of reported data for WRM by jurisdiction and location.

Table 2. Counts of MS4 related benthic and habitat sampling events by jurisdiction and location.

Jurisdiction	Location	Site	Period of Record	Counts of Reported Data[1]				
				Benthic		Habitat		In situ
				Index	Metric	Index	Metric	
Anne Arundel County	Church Creek	AA06MSI000001	2007 - 2016	12	5	9	5	3
		AA06MSI000002		12	5	9	5	3
		AA06MSI000003		12	5	9	5	3
		AA07MSI000004		12	5	8	5	3
	Picture Spring Branch	AA04MSI000005	2007 - 2016	12	5	11	5	5
		AA04MSI000006		12	5	11	5	5
		AA04MSI000007		12	5	11	5	5
Baltimore City	Moores Run	BC16MSI24	2002 - 2015	8	6		2	
		BC16MSI25		8	6		2	
	Moores Run Tributary	BACI02IMR02	2002 - 2007	6	6			
		BACI02IMR04		5	5			
Carroll County	Air Business Center	CR15MSI000001	2004 - 2018	6	6		15	
		CR15MSI000002		6	6		15	
Charles County	Acton/Hamilton	CC14MSI000023	2006 - 2017	11		11	12	11
Frederick County	Peter Pan Run	FR99MSI000042	1999 - 2016	16	16	15	18	18
		FR99MSI000043		16	16	16	18	18
		FR99MSI000044		16	16	16	18	18
		FR99MSI000045		16	16	16	18	18
Harford County	Wheel Creek	HA09MSI004006	2009 - 2015	7			7	
		HA09MSI004007		7			7	
		HA09MSI004008		7			7	
		HA09MSI004009		6			6	

Jurisdiction	Location	Site	Period of Record	Counts of Reported Data[1]				
				Benthic		Habitat		In situ
				Index	Metric	Index	Metric	
		HA09MSI004010		7			7	
		HA09MSI004011		7			7	
		HA09MSI004012		7			7	
		HA09MSI004013		7			7	
	Winters Run	HA98MSI000001	2006 - 2008			4	3	
		HA98MSI000003				4	3	
		HA98MSO000002				4	3	
Howard County	Red Hill Branch	HO10MSI000004	2010 - 2016	7			7	
		HO10MSI000005		7			7	
		HO10MSI000006		7			7	
		HO10MSI000007		7			7	
	Turf Valley	HO14MSI000001	2014 - 2016	3			3	
		HO14MSI000002		3			3	
		HO14MSI000003	2015 - 2016	2			2	
	Wilde Lake	HO06MSI000013	2006 - 2016	3			3	
		HO06MSI000019		3			3	
		HO06MSI000025		3			3	
		HO06MSI000031		3			3	
		HO06MSI000032		3			3	
		HO07MSI000017	2007 - 2012	2			2	
		HO07MSI000022		2			2	
		HO07MSI000026		2			2	
		HO07MSI000028		2			2	
		HO07MSI000029		2			2	
		HO08MSI000016	2008 - 2013	2			2	
		HO08MSI000021		2			2	
		HO08MSI000023		2			2	
		HO08MSI000024		2			2	
		HO08MSI000033		2			2	
		HO09MSI000014	2009 - 2015	4			4	
		HO09MSI000018	2009 - 2014	2			2	
		HO09MSI000027		2			2	
		HO09MSI000030		2			2	
		HO09MSI000034		2			2	
		HO10MSI000010	2010 - 2015	2			2	
		HO10MSI000011		2			2	
		HO10MSI000012		2			2	
		HO10MSI000020		2			2	
Montgomery County	Breewood	MO10BSI000101	2010 - 2014	5			5	5
	Good Hope Trib	MO02MSI000308	2010 - 2013					4
	Lower Paint Branch	MO02MSI000309	2003 - 2008				2	1
		MO02MSI000310	2003 - 2008				2	1
	Stewart-April Lane	MO02MSI000104	2003 - 2008				2	1
Prince George's	Bear Branch	PG15MSI000001	2007 - 2017	2	11	1	11	11

Jurisdiction	Location	Site	Period of Record	Counts of Reported Data[1]				
				Benthic		Habitat		In situ
				Index	Metric	Index	Metric	
County		PG15MSI000002	2008 - 2017	1	10	1	10	10

[1]These counts include replicate samples and samples taken outside of the spring sampling season.

Table 3 shows a summary of the years of permit related benthic, habitat and in-situ water chemistry data stored in the MS4 database by jurisdiction and location. The record for Frederick County appears to be the most complete with 18 years of data from the Peter Pan tributary. Other jurisdictions with ten or more years of monitoring data include Carroll, Charles, Prince George's, and Anne Arundel Counties. Although eleven years of data were provided for Wilde Lake in Howard County, it appears that the monitoring locations were relocated several times and very little data (two to four years) are available for any given site (see **Table 2**). Benthic and habitat data prior to 2006 were not provided for Anne Arundel, Charles, Harford, Howard, and Prince George's Counties. Overall, very little data were made available to the project from Baltimore City and Montgomery County.

Table 3. Collection years of MS4 permit related biological, habitat, and in-situ water quality samples.

Jurisdiction	Location	Count (Years)	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Anne Arundel County	Church Creek	10									Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
	Picture Spring Branch	10									Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Baltimore City	Moores Run	8				Y	Y	Y	Y	Y	Y							Y	Y			
	Moores Run Trib.	6				Y	Y	Y	Y	Y	Y											
Carroll County	Air Business Center	15						Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Charles County	Acton/Hamilton	12								Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Frederick County	Peter Pan Run	18	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Harford County	Wheel Creek	7											Y	Y	Y	Y	Y	Y	Y			
	Winters Run	3								Y	Y	Y										
Howard County	Red Hill Branch	7												Y	Y	Y	Y	Y	Y	Y		
	Turf Valley	3																Y	Y	Y		
	Wilde Lake	11								Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Montgomery County	Breewood	5												Y	Y	Y	Y	Y				
	Good Hope Trib	4												Y	Y	Y	Y					
	Lower Paint Branch	3					Y				Y	Y										
	Stewart-April Lane	3					Y				Y	Y										
Prince George's County	Bear Branch	11									Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	

Data Quality

Several common problems were encountered while working with both MS4 permit required and other benthic and habitat monitoring data as described below. Site specific problems are addressed in the next section.

- Some station names and/or sampling locations have changed over time, which hampers trend and statistical analyses. To lessen this problem, any stations with coordinates (in decimal degrees) that were equal when rounded to six decimals were assumed to be the same station and given the same MDE_MONITORING_LOCATION_ID in the database. The original station name(s) were recorded as ALTERNATE_MONITORING_LOCATION_IDs.
- The site selection criteria (e.g., random, fixed) was often not provided. Although all WRM stations are fixed, it was frequently unknown how other stations were selected.
- Other important site information such as physiographic strata (i.e., Coastal, Piedmont, Highland) as well as sampling design and methods were often not provided. This information, however, is needed when calculating biotic and habitat indices.
- Much of the missing site information may be stated in the jurisdictions' quality assurance project plans (QAPPs) or site-specific annual reports. These documents, however, were often not available or difficult to find online.
- At times, only sampling years but not the sampling dates were available. In these cases, ICPRB either used sampling dates stated in MS4 annual reports or substituted March 30 plus the sampling year. The later action was noted as an ACTIVITY_COMMENT.
- As specified in the MS4 permit requirements, benthic sampling should occur during the spring month, however, some stations were also sampled during the summer or fall possibly for jurisdiction specific purposes. Therefore, the assumed dates should to be verified in the future because the sampling season can affect benthic analyses.
- Some benthic and habitat metric and index scores were suspiciously high and need to be verified. It is possible that a different method was used to calculate the values, which needs to be verified.

County-specific problems were also identified as described below:

Anne Arundel County (AACO): Benthic and habitat data prior to 2007 were not provided, and much of the habitat and in-situ data included in the database were extracted from MS4 annual reports. These data lacked date information, and ICPRB assumed that sampling took place in mid-March.

Baltimore City (BACI): Baltimore City includes detailed monitoring results in the Appendices to their annual MS4 reports, however, the Appendices were neither provided nor accessible online. Therefore, only data provided in the EXCEL workbook titled *Macroinvertebrate Sample Results 2002 through 2007* could be included in the MS4 database. Most data appear to be associated with randomly selected stations (i.e., only one sample was collected between 2002 –

2007). There were, however, 20 stations for which more than one sample was collected, and these may represent fixed stations. In addition, station coordinates were provided either as "MID_LAT "and MID_LON" or START_LAT, START_LON, END_LAT, END_LON from which ICPRB calculated the "mid coordinates" by averaging.

Data from the Excel workbook titled *Moores Run Habitat Assessments 2005 through 2014* were also not included in the MS4 database because metrics were reported for segments rather than stations (see example below) and therefore the data could not be associated with a specific station.

	Moores Run above Radecke Ave. Segments											
	1	2	3	4	5	6	7	8	9	10	11	Tributary
Parameter Instream Habitat												
2005-05-18	16	16	16	4	16	16	16	16	13	16	1	13
2006-05-01	15	16	15	4	15	15	15	14	13	14	1	13

Baltimore County (BACO): Most of the Baltimore County data could not be entered into the MS4 database because it is stored in an older version EDAS databases. While these are Access databases, these older versions are incompatible with ICPRB's MS Access edition, and ICPRB could not find an efficient way to extract the data by other means.

Although ICPRB obtained some benthic and habitat data from available annual MS4 reports, they were ultimately not included in the database because they lacked dates and station information and represented mostly probabilistic sampling.

Physical habitat index (PHI) values as well as some other habitat metrics for the years 2004 - 2014 were provided in an Excel workbook titled *PHI Worksheet_WORK_2014*. Sampling dates and in some instances even years were not included. The names of 14 of 82 stations located within the Piedmont region begin with "SL" indicating Scotts Level Branch monitoring, the watershed sampled for the Phase I MS4 permit. It was unclear, however, if all stations were associated with MS4 monitoring. The remaining stations represent either random, reference, or other restoration sites located throughout Baltimore County. Because of these uncertainties, the data were not added to the MS4 database. Likewise, benthic data from the *Compiled _ BIBI Data_2015* Excel workbook, which contains some benthic metrics and Benthic Index of Biotic Integrity (BIBI) values, were also not included because they lacked the same information as the PHI data.

Benthic metric and index data from the *BC_Random_Benthic_20082014_BIBI* Excel workbook were also omitted from the MS4 database because it only contained data from randomly selected sites. Furthermore, site information and dates (except sampling year) were missing. In summary, it appears that most of the available benthic and habitat data were associated with random sites, some reference sites, and six restoration sites.

Carroll County (CACO): MS4 permit related data prior to 2004 were not available. Other than that, there were few issues except occasionally missing sampling dates. These were either extracted from annual MS4 annual reports or March 30 plus the sampling year was used as a surrogate date as described above.

Charles County (CHCO): No MS4 permit related data prior to 2006 were available. The only other issue encountered was that only sampling years but not dates were provided. Therefore, sampling dates extracted from MS4 annual reports were substituted.

Frederick County (FRCO): Most data included in the MS4 database were extracted from the appendices of the 2016 annual MS4 report. No other major problems were found.

Data from the Excel workbook *FD_BIBI* were not included in the MS4 database because all appeared to be associated with randomly selected sites.

Harford County (HACO): MS4 monitoring data prior to 2006 were not available. It is unclear if all eight sampling sites in the Wheel Creek watershed were used for Phase I MS4 permit monitoring.

Harford County only provided raw benthic counts for 2015; other years were reported as relative abundance and therefore were not added to the MS4 database. Dates were also not given, and March 30 plus the sampling year was used as a surrogate.

Howard County (HOCO): MS4 permit related data prior to data prior to 2006 were not available. It is unclear if all 24 sampling sites in the Wilde Lake watershed are or were used for Phase I MS4 permit monitoring. Based on the sampling dates, the stations appear to be divided into eight groups with overlapping date ranges (see **Table 2**). Each group was only sampled two to four times, which makes it impossible to perform trend analyses. No other major problems were not found.

Montgomery County (MOCO): Overall, very little MS4 monitoring data were available for Montgomery County except for some BIBI scores and a few habitat metrics. In addition, sampling dates were not provided and therefore, March 30 plus the sampling year was used as the surrogate date.

Prince Georges County (PGCO): MS4 permit related data prior to 2005 were not available. No major problems were encountered with the rest of the data. Probabilistic sampling data from *PG Co ALL Data (Probability Sites) (DataRequest_20180713c_MDE)* were not included in the MS4 database.

State Highway Administration (SHA): Data submitted by SHA contained very little information related to long-term benthic and habitat monitoring and therefore, were not included in the MS4 database as per MDE's instructions.

DESCRIPTIVE STATISTICS

Only biological and habitat data related to WRM sites were used when calculating descriptive statistics, which include:

- Minimum and Maximum

- Standard deviation
- Median and Mean
- 10th, 25th, 75th, and 90th percentiles

As stated in the Assessment of Controls section of the Phase I MS4 permit requirements "*Benthic macroinvertebrate samples shall be gathered each Spring*." Therefore, only benthic data related to the spring sampling period (i.e., March through May) were included. Because the sampling season for the habitat monitoring is not explicitly specified in the permit requirements, habitat values were averaged when more than one value was provided for a given year. The results are discussed in the following sections.

Benthic Metrics and the Benthic Index of Biotic Integrity

Benthic Metrics

As specified in the Phase I MS4 permits, permittees "*shall use EPA Rapid Bioassessment Protocols (RBP), Maryland Biological Stream Survey (MBSS), or other similar method approved by MDE*" for biological monitoring. Therefore, all discussion below related to benthic monitoring assume that MBSS protocols were followed.

Scores for the twenty benthic metrics shown in **Table 4** were available from Anne Arundel, Carroll, Frederick, and Prince George's Counties and Baltimore City and were added to the MDE MS4 database. The data were either provided by MDE or extracted from annual MS4 reports. **Table 4** also describes the expected response of the metrics to anthropogenic stressors (Southerland et al. 2005). Descriptive statistics for all available benthic metrics are provided in **Table B1** in **Appendix B**.

The total individual (totind) values are consistently very high for Baltimore City. This may indicate that the City used a method other than MBSS for calculating its benthic metrics or that the data need to be rarified. To ensure that benthic metrics can be compared between sites or over time, all need to be calculated using the same standard. For example, it is important that approximately the same number of macroinvertebrates (e.g., about 100 individuals) are identified and enumerated because a deviation from this number may influence richness and diversity metrics, which in turn would alter the BIBI scores.

Table 4. Definition of benthic metrics in the MDE MS4 database and expected response to stressors.

Benthic Metric	Description	Expected Response	Metric Class
ndipt	Number of Diptera taxa	Decrease	**Taxonomic richness/diversity:** These metrics tally the total counts of distinct taxa identified in the sample and provide information about the overall taxonomic diversity. Common richness metrics include ntaxa, nept, and nephrem.
nephem	Number of Ephemeroptera taxa	Decrease	
nept	Number of EPT taxa (Ephemeroptera, Plecoptera, Trichoptera)	Decrease	
ntaxa	Total number of taxa	Decrease	
pchiron	Percent of Chironomidae	Increase	**Taxanomic composition**: The purpose of these metrics is to provide the proportions of a taxa in
pephem	Percent of Ephemeroptera	Decrease	

Benthic Metric	Description	Expected Response	Metric Class
pdipt	Percent of Diptera	Increase	relation to all individual organisms. Frequently used metrics are pephem, pchiron, pdipt, ptany.
ptany	Percent of Tanytarsini	Decrease	
pclimb	Percent of climber taxa	Decrease	**Habit**: Benthic macroinvertebrates receive habit assignments based on their locomotion or behavior in relation to their habitat. Commonly used habit metrics are pclimb, pcling, and pswim.
pcling	Percent of clinger taxa	Decrease	
pswim	Percent of swimmer taxa	Decrease	
pcoll	Percent of collector taxa	Decrease	**Trophic feeding habit**: The functional feeding group designation refers to the type of food resource a benthic macroinvertebrate utilizes in a stream. Two frequently used metrics are nscrap and pscrap.
nscrape	Number of scraper taxa	Decrease	
pscrape	Percent of scraper taxa	Decrease	
totscrape	Total number of individual scrapers		
Beck	Beck's Biotic Index	Decrease	**Tolerance**: These metrics describe the tolerances of benthic organisms to stressors (e.g., chemical pollution, hydrologic alterations, and habitat degradation). pintol_urb is a frequently used metric.
nint	Number of intolerant taxa	Decrease	
pintol_urb	Percent of intolerant urban taxa	Decrease	
ptol	Percent of tolerant taxa	Increase	
totind	Total number of individual organisms	Varies	**Abundance**: The sum of all individuals excluding those identified as "exclusion taxa." Note: laboratory counting protocols require organisms in raw samples to be randomly "picked" to achieve a specific sample count (e.g., 100, 200).

Benthic Index of Biotic Integrity

The Benthic Index of Biotic Integrity (BIBI) is a multi-metric index useful for assessing the health of stream macroinvertebrate communities. Multi-metric BIBIs were first introduced by Karr et al. in 1986. The first BIBI specific to Maryland was developed by Stribling et al. in 1998 for the Maryland Biological Stream Survey (MBSS) and was subsequently refined by Southerland et al. in 2005.

The selection of the metrics used to calculate BIBI scores varies, depending on the physiographic stratum (Highlands, Piedmont, Coastal Plain) in which a sampling site is located. The MBSS Coastal Plain index is based on number of taxa, number of EPT taxa, number of Ephemeroptera taxa, percent intolerant to urban taxa, percent Ephemeroptera, number of scraper taxa, and percent climber taxa. The Piedmont index is based on number of taxa, number of EPT taxa, number of Ephemeroptera taxa, percent intolerant to urban taxa, percent Chironomidae taxa, and percent clinger taxa. The Highlands index uses on number of taxa, number of EPT taxa, number of Ephemeroptera taxa, percent intolerant to urban taxa, percent Tanytarsini taxa, percent scraper taxa, percent swimmer taxa, percent Diptera taxa (Southerland et al. 2005). Metrics are scored on a scale of 1 (very poor) to 5 (excellent) using region-specific scoring thresholds derived from "reference" or least-disturbed populations in that region.

BIBI scores are divided into four categories as shown in **Table 5**. A site with a higher score is closer to reference conditions and is considered to be minimally impacted, while a lower score indicates some degree of impairment.

Table 5. Maryland Biological Stream Survey (MBSS) BIBI scoring scale.

BIBI Score	Narrative	Index Description (Roth et al. 1999)
4.0 – 5.0	Good	Comparable to reference streams considered to be minimally impacted. Fall within the upper 50% of reference site conditions.
3.0 - 3.9	Fair	Comparable to reference conditions, but some aspects of biological integrity may not resemble the qualities of these minimally impacted streams. Fall within the lower portion of the range of reference sites (10th to 50th percentile).
2.0 - 2.9	Poor	Significant deviation from reference conditions, with many aspects of biological integrity not resembling the qualities of these minimally impacted streams, indicating some degradation.
1.0 - 1.9	Very Poor	Strong deviation from reference conditions, with most aspects of biological integrity not resembling the qualities of these minimally impacted streams, indicating severe degradation.

Generally, benthic macroinvertebrate samples collected during the spring index period are assumed to be good indicators of environmental stress (Plafkin et al. 1989). Therefore, only BIBI scores associated with the spring index period (March through May) were used to calculate descriptive statistics for sites with at least five years of data. **Table 6** shows these by location and station. When possible, the stations were arranged from upstream to downstream to explore whether there are differences based on location.

As can be seen in **Table 6**, the minimum BIBI scores for most stations are in the very poor category, while the maximum scores tend to be in the poor to fair range. It is unclear what the BIBI scores for Montgomery County at the Breewood location represent, as all values are outside the range of the BIBI scoring scale, with a minimum score of 8 and a maximum score of 18.

At the Church Creek locations in Anne Arundel County, the median BIBI score decreases from poor to very poor from upstream to downstream, and the tributary has the lowest median score. In the Picture Spring Branch, the median BIBI score for the two mainstem locations hover just around the fair mark, while the median score for the tributary is in the poor range.

In Carroll County's Air Business Center location, the median BIBI scores are in the fair range, with the score for the site located nearest the outfall having the lower score.

The median BIBI scores for the Peter Pan Run sites in Frederick Count are in the poor range for both mainstem and tributary locations.

At the Wheel Creek location in Harford County, the control site has the highest median BIBI score and the mainstem location increase from upstream (very poor) to downstream (poor).

The range of variability and the median values of the BIBI scores for each site can also explored via the boxplots provided in **Appendix C**.

Table 6. Descriptive statistics for BIBI scores by location and station.

The rating of median BIBI scores is indicated by the color of the shading: very poor (< 2) in red, poor (2.0 - 2.9) in orange, and fair (3.0 -3.9) in yellow. Values for Montgomery County are outside the rating scale and are therefore not color coded.

Jurisdiction	LOCATION	SITE	Count	Min	Median	Mean	Max	Std Dev.	Percentile			
									10th	25th	75th	90th
Anne Arundel	Picture Spring Branch	AA04MSI000005	12	2.43	3.00	3.03	3.86	0.41	2.46	2.71	3.29	3.29
		AA04MSI000006	12	2.43	3.00	2.95	3.29	0.24	2.71	2.93	3.00	3.26
		AA04MSI000007	12	1.57	2.86	2.73	3.57	0.55	2.04	2.43	3.00	3.26
	Church Creek	AA06MSI000001	12	1.00	1.57	1.66	2.43	0.43	1.03	1.50	1.90	2.13
		AA06MSI000002	12	1.57	1.86	2.00	2.71	0.35	1.60	1.86	2.11	2.43
		AA06MSI000003	12	1.29	2.00	1.95	2.71	0.40	1.57	1.57	2.14	2.40
		AA07MSI000004	12	1.29	2.14	2.12	2.71	0.42	1.60	1.97	2.43	2.68
Baltimore City	Moores Run	BACI02IMR02	6	1.00	1.15	1.29	1.86	0.36	1.00	1.00	1.50	1.72
		BACI02IMR04	5	1.00	1.33	1.33	1.67	0.24	1.13	1.33	1.33	1.53
		BC16MSI24	8	1.00	1.33	1.37	1.67	0.22	1.23	1.33	1.42	1.67
		BC16MSI25	8	1.00	1.33	1.33	1.67	0.25	1.00	1.25	1.42	1.67
Carroll	Air Business Center	CR15MSI000001	6	1.33	2.00	1.94	2.67	0.54	1.33	1.50	2.25	2.50
		CR15MSI000002	6	1.67	2.67	2.61	3.33	0.61	2.00	2.33	3.00	3.17
Charles	Acton/Hamilton	CC14MSI000023	11	1.90	2.70	2.74	3.60	0.49	2.10	2.55	3.00	3.30
Frederick	Peter Pan Run	FR99MSI000042	16	1.75	2.75	2.69	3.75	0.60	1.88	2.25	3.06	3.38
		FR99MSI000043	16	1.50	2.00	2.00	2.50	0.30	1.63	1.75	2.25	2.38
		FR99MSI000044	16	1.50	2.25	2.33	3.25	0.52	1.75	2.00	2.50	3.13
		FR99MSI000045	16	2.00	2.25	2.59	3.50	0.56	2.00	2.25	2.88	3.50
Harford	Wheel Creek	HA09MSI004006	7	1.00	2.33	2.14	3.00	0.74	1.20	1.67	2.67	2.80
		HA09MSI004007	7	1.33	1.67	1.76	2.00	0.25	1.53	1.67	2.00	2.00
		HA09MSI004008	7	1.33	1.67	1.81	2.67	0.47	1.33	1.50	2.00	2.27
		HA09MSI004009	6	1.33	1.50	1.67	2.33	0.42	1.33	1.33	1.92	2.17
		HA09MSI004010	7	1.33	2.00	1.90	2.67	0.50	1.33	1.50	2.17	2.47
		HA09MSI004011	7	1.00	2.00	1.86	2.33	0.54	1.20	1.50	2.33	2.33
		HA09MSI004012	7	1.33	1.67	1.62	2.00	0.23	1.33	1.50	1.68	1.81
		HA09MSI004013	7	1.33	2.67	2.38	3.00	0.65	1.53	2.00	2.84	3.00
	Red Hill Branch	HO10MSI000004	7	1.67	1.67	1.81	2.00	0.18	1.67	1.67	2.00	2.00
		HO10MSI000005	7	1.67	2.00	2.14	2.67	0.42	1.67	1.84	2.50	2.67
		HO10MSI000006	7	1.33	2.33	2.28	3.00	0.53	1.73	2.17	2.50	2.80
		HO10MSI000007	7	1.00	1.67	1.52	2.33	0.47	1.00	1.17	1.67	1.93
Montgomery	Breewood	MO10BSI000101	5	8.00	14.00	14.00	18.00	3.74	10.40	14.00	16.00	17.20

Habitat Metrics and the Physical Habitat Index

Habitat Metrics

Habitat metric data were available from Baltimore City and Anne Arundel, Carroll, Charles, Frederick, Harford, Howard, Montgomery, and Prince George's Counties and were included in the MS4 database. The data were either provided by MDE or extracted from annual MS4 reports.

Table 7 lists all available habitat metrics and provides permissible values. Most permittees reported at least four habitat measures: EMBED, EPIFAUN, HABITAT and HABITAT_DESCRIP as well as the PHI score.

Table 7. Habitat Metrics in the MDE MS4 database.

Habitat Metric	Stream Gradient	Description	Permissible Value
AESTHET		Aesthetics score	0 - 20
BANKS	Low and high	Bank stability score	0 - 20
BANKV	Low and high	Bank vegetative protection score	0 - 20
CHALT	Low and high	Channel alteration score	0 - 20
CHFLOW	Low and high	Channel flow status score	0 - 20
CHSIN	Low	Channel Sinuosity score	0 - 20
EMBED	High	Embeddedness score	0 - 20
EMBED_P		Embeddedness score as a percentage	0 - 100
EPIFAUN	Low and high	Epifaunal substrate score	0 - 20
HABITAT		Habitat score	0 - 200
HABITAT_DESCRIP		Qualitative description of habitat	1 - 4
INSTRHAB		Instream habitat structures score	0 - 20
MDEPTH		Maximum depth in sample reach (cm)	Measure
POOLQUAL		Pool/glide/eddy quality score	0 - 20
POOLSUB	Low	Pool Substrate Characterization	0 - 20
POOLVAR	Low	Pool Variability	0 - 20
REMOTE		Remoteness score	0 - 20
RIFF	High	Frequency of riffles score	0-20
RIFFQUAL		Riffle/run quality score	0 - 20
RIP_WID		Riparian buffer width (m)	Measure
RIPZW	Low and high	Riparian vegetative zone width score	0-20
SEDEP	Low and high	Sediment deposition score	0 - 20
SHAD_P		Shading scores as a percentage (%)	1 - 100
VEL_DPTH	High	Velocity/depth diversity score	0 - 20
WOOD		Number of instream woody debris score	0 - 20

Depending on the stream gradient (i.e., low or high), a different set of habitat parameters are used for EPA's Rapid Bioassessment Protocol (Barbour et al. 1999) as indicated in **Table 7**. When no stream gradient is given in **Table 7**, the metric represents an additional quantitative measure collected by the jurisdiction. Except for HABITAT and HABITAT_DESCRIP, permissible

values for the habitat metrics range from 0 to 20 and indicate their condition category as shown in **Table 8**.

Table 8. EPA Rapid Bioassessment Protocol (RBP) scoring scale.

Habitat Metric Score	Condition Category
16 - 20	Optimal
11 - 15	Suboptimal
6 - 10	Marginal
0 - 5	Poor

The metric HABITAT represents the sum of all measures and can have a value between 0 – 200. HABITAT_DESCRIP is a scaled qualitative description of the overall HABITAT score and ranges from 1 (excellent), 2 (good), 3 (fair), to 4 (poor) (Dewa et al 2017). Descriptive statistics for HABITAT_DESCRIP are presented in **Table 9** for stations with five or more years of data, while descriptive statistics for all habitat metrics are provided in **Table B2** in **Appendix B**.

As already mentioned, the highest score for HABITAT_DESCRIP should be 4, however both Anne Arundel and Howard Counties reported higher maximum scores. Howard County's highest score was reported as five, and Anne Arundel County's maximum score was consistently reported as fourteen. It is unknown how Anne Arundel's HABITAT_DESCRIP scores were calculated and scaled and are therefore are not shown in **Table 9**.

Only one HABITAT_DESCRIP score was available for each of Baltimore City's two stations in Moores Run; station BC16MSI24 was rated as excellent (1) and station BC16MSI25 as fair (3).

There were six measurements each for the two stations at the Air Business Center location in Carroll County, one had a median score rated as good (2) and the other as fair (3).

Sixteen HABITAT_DESCRIP scores were available for most of the Peter Pan Run stations in Frederick County. The two stations located on the mainstem below the outfall had median HABITAT_DESCRIP scores the good range. The other two stations (FR99MSI000042 and FR99MSI000043) are located on tributaries, and their median scores were in the fair category, possible reflecting the increasingly urban character in the watershed.

Two stations in Prince George's Bear Branch had HABITAT_DESCRIP scores from only two sampling events, which gave them a fair rating.

Table 9. Descriptive statistics for the scaled habitat measure, HABITAT_DESCRIP, by location and station.

The HABITAT_DESCRIP score rating is indicated by the color of the shading: good (2) in yellow, and fair (3) in orange. Howard County may have scaled their score differently, with a maximum score of five, and therefore, their median scores are not color-coded.

County	Location	Site	Count	Min	Median	Mean	Max	Std. Dev.	Percentiles 10th	25th	75th	90th
Carroll	Air Business Center	CR15MSI000001	6	3	3.0	3.0	3	0.0	3.0	3.0	3.0	3.0
		CR15MSI000002	6	2	2.0	2.0	2	0.0	2.0	2.0	2.0	2.0
Frederick	Peter Pan Run	FR99MSI000044	16	1	2.0	1.9	3	0.4	1.5	2.0	2.0	2.0
		FR99MSI000045	16	2	2.0	2.4	4	0.6	2.0	2.0	3.0	3.0

County	Location	Site	Count	Min	Median	Mean	Max	Std. Dev.	Percentiles			
									10th	25th	75th	90th
		FR99MSI000042	15	2	3.0	2.7	4	0.6	2.0	2.0	3.0	3.0
		FR99MSI000043	16	2	3.0	3.1	4	0.4	3.0	3.0	3.0	3.5
Howard	Red Hill Branch	HO10MSI000006	7	4	4.0	4.1	5	0.4	4.0	4.0	4.0	4.4
		HO10MSI000004	7	4	5.0	4.9	5	0.4	4.6	5.0	5.0	5.0
		HO10MSI000005	7	4	4.0	4.4	5	0.5	4.0	4.0	5.0	5.0
		HO10MSI000007	7	4	4.0	4.1	5	0.4	4.0	4.0	4.0	4.4

Physical Habitat Index

The composition of the stream communities is in part determined by the quality of the physical habitat. To assess the condition of the stream habitat, a variety of measures can be collected and combined into a multi-metric indicator of physical habitat quality such as MBSS' physical habitat index (PHI).

A provisional PHI was first developed for the MBSS by Hall et al. in 1999, which was subsequently revised by Paul et al. in 2002. The PHI is a quantitative rating of the stream habitat at a sampling site. It is calculated from several habitat characteristics including embeddedness, remoteness, shading, epifaunal substrate, instream habitat, bank stability, and others depending on the physiographic stratum (Paul et al. 2003). PHI values are adjusted to a centile scale and aggregated into four categories as shown in **Table 10**.

Table 10. Maryland Biological Stream Survey (MBSS) PHI scoring scale.

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

Table 11 shows the descriptive statistics for PHI scores of sites with five or more years of data. As can be seen, the median PHI scores for Church Creek in Anne Arundel County fall mostly into the degraded condition rating, while those from the Picture Spring Branch have a partial degraded rating. In Frederick County, the two stations on the mainstem of Peter Pan have median PHI scores in the partial degraded range, while the median PHI scores of both tributaries indicate degraded conditions. The one station in the Acton/Hamilton location in Charles County with enough data scored as partially degraded.

The relationship between the BIBI and PHI scores will be explored in the next section.

Table 11. Descriptive statistics for PHI scores for Phase I MS4 jurisdiction by location and station.

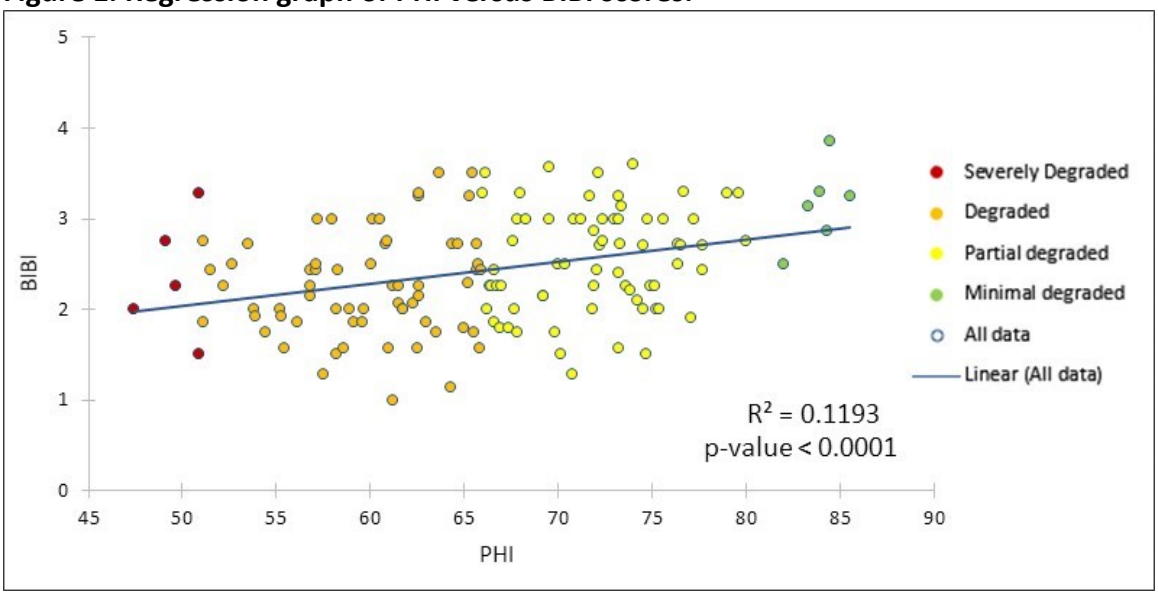
The rating of the median PHI score is indicated by color (orange = degraded and yellow = partially degraded).

County	Location	Site	Count	Min	Median	Mean	Max	Std. Dev.	Percentile			
									10th	25th	75th	90th
Anne Arundel	Church Creek	AA07MSI000004	8	57.5	61.26	61.15	65.2	2.44	58.06	60.18	62.38	63.38
		AA06MSI000003	9	56.8	66.6	65.57	70.79	4.05	61.36	65	66.9	69.52
		AA06MSI000002	9	51.5	55.4	55.7	59.6	2.6	53.1	53.9	56.8	59.2
		AA06MSI000001	9	51.1	64.3	63.59	73.2	6.6	55.9	61.2	67.4	70
	Picture Spring Branch	AA04MSI000005	11	66	79	78.55	84.5	5.72	72.1	76.8	83.6	84.3
		AA04MSI000006	11	60.1	67.8	68.05	74.8	4.92	62.6	64.55	72.7	73.4
		AA04MSI000007	11	50.9	68	65.69	73.8	7.79	57.2	59.55	72.55	73.3
Charles	Acton/ Hamilton	CC14MSI000023	11	71.2	74.5	74.81	77.7	2.1	72.2	73.6	76.6	77.1
Frederick	Peter Pan Run	FR99MSI000045	16	47.43	66.71	67.14	80.02	7.58	61.06	63.42	71.85	75.21
		FR99MSI000044	16	65.29	72.24	72.77	85.53	5.57	66.49	69.38	75.05	79.19
		FR99MSI000043	16	49.66	58.2	57.88	67.8	5.46	51.54	53.52	61.71	64.63
		FR99MSI000042	15	49.08	62.58	62.81	73.26	7.66	53.41	57.55	69.06	72.29

RELATIONSHIP BETWEEN BENTHIC AND HABITAT INDEX SCORES

The health of the benthic macroinvertebrate community depends in part on the condition of the physical habitat, but also on many other factors such as water quality, land use within the watershed, time elapsed since stream restoration efforts or BMP implementations. Regression graphs were examined to explore whether there was a relationship between stream habitats and the benthic communities of the MS4 sampling locations as reflected by their PHI and BIBI scores respectively without considering other stressors. Where available, the two indices were paired for a given year and plotted. **Figure 1** shows the relationship between the two indices for all stations.

Figure 1. Regression graph of PHI versus BIBI scores.



Looking all paired index scores (open blue circles, **Figure 1**), sites with higher PHI scores generally also had better BIBI scores, showing a weak positive correlation (Table 12). Next the paired indices were divided into four bins corresponding to the PHI rating categories (**Table 10**). Now, however, no significant correlations were found (**Table 12**). It is somewhat surprising that there are no statistically significant relationships between the two indices at either end of the scale, that is under severely degraded and minimal degraded conditions. But, perhaps, there were not enough data to show a tendency. The result for the paired indices in the middle of range may reflect that many factors other than the physical habitat, can affect the benthic community.

Table 12. Regression statistics for PHI versus BIBI scores.

PHI Category	Count	R2	P-value	Equation
Severely degraded	5	0.0306	0.7783	y = 0.0837x - 1.7938
Degraded	63	0.0155	0.3313	y = 0.0165x + 1.2559
Partial degraded	68	0.0290	0.1649	y = 0.0259x + 0.6824
Minimal degraded	6	0.3950	0.18141	y = 0.2389x - 16.9
All data	142	0.1193	<0.0001	y = 0.0244x + 0.8141

TREND ANALYSIS

Benthic and habitat information has been collected by the jurisdictions since the early 2000 (**Table 2**), resulting in up to 16 years of monitoring. Trend analyses using linear regression were completed for stations with five or more years of data. Time was used as the independent variable and benthic or habitat metrics or indices as the dependent variable. Scatter plots of the fitted values for each station can be found in **Appendix D**. The slope of the regression line and the p-value of the slope are shown in the figures. These statistics as well as the regression

coefficient of the determination (R^2), the estimated intercept of the line, and the p-value of the intercept are also provided in **Appendix D**.

Benthic Metrics and the Benthic Index of Biotic Integrity

Benthic Metrics

Some benthic metrics had statistically significant trends with slope p-values of less than 0.1 and high R^2 as shown in **Table 13**. However, there were not enough metrics with significant trends at any of the stations to ascertain whether there were substantial changes in the benthic communities over time.

Table 13. Linear regression statistics for benthic metrics with significant trend statistics.

Agency	Location	Station	Metric	Intercept		Slope		R^2
				Estimate	p-value	Estimate	p-value	
Baltimore City	Moores Run	BC16MSI25	pclimb	-391.0555	0.0212	12.0036	0.0171	0.7945
		BC16MSI24	pcling	-251.9561	0.0852	7.8061	0.0699	0.6014
		BACI02IMR02	pchiron	-491.9853	0.0787	16.0407	0.0560	0.6399
Carroll	Air Business Cnt	CR15MSI000001	nept	-25.3069	0.0899	0.5913	0.0801	0.5762
Prince Georges	Bear Branch	PG15MSI000001	nephem	-7.4656	0.0067	0.1915	0.0041	0.6177
			totscrape	-10.7042	0.0318	0.3067	0.0130	0.5139
			pephem	-20.0501	0.0790	0.5156	0.0590	0.3416

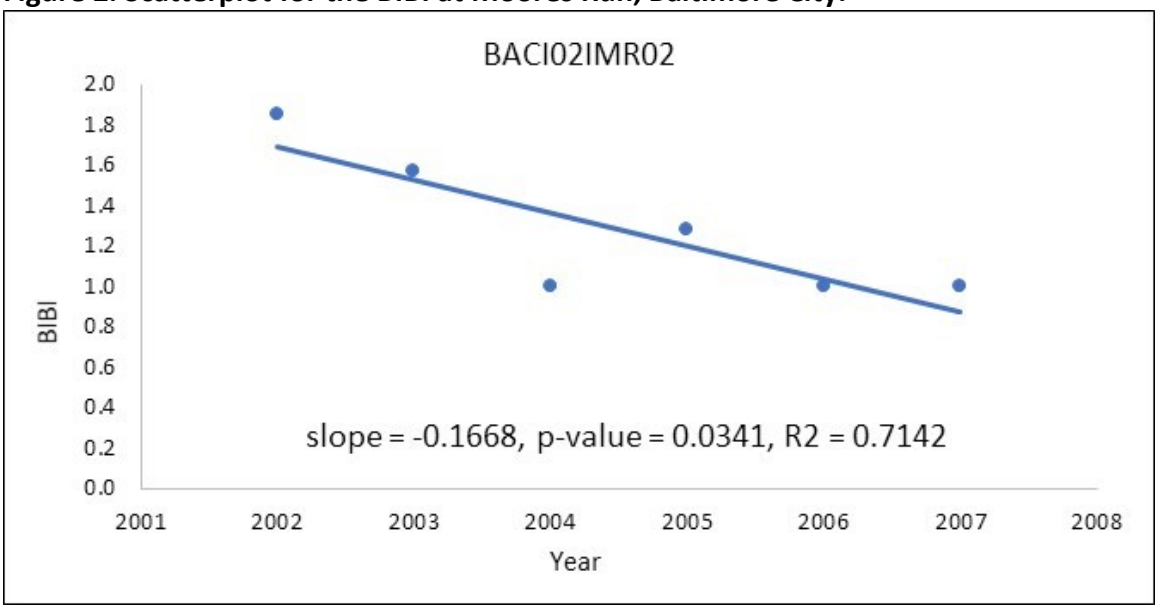
Benthic Index of Biotic Integrity

Of the 60 WRM sites with BIBI data, 29 had data for more than five years. Trend analyses using linear regression were completed for these stations, and the related scatterplots and slope statistics can be found in **Appendix D**. Of the 29 stations, only one station in Moores Run, Baltimore City displayed a significant trend for the BIBI scores that were available for the years 2002 – 2007. During this time the BIBI remained in the very poor category, decreasing from 1.8 to 1.0. The regression statistics are provided in **Table 14** and the scatter plot in **Figure 2**.

Table 14. Linear regression statistics for BIBI at Moores Run Tributary, Baltimore City.

Agency	Location	Station	Index	Intercept		Slope		R^2
				Estimate	p-value	Estimate	p-value	
Baltimore City	Moores Run	BACI02IMR02	BIBI	7.0915	0.0182	-0.1668	0.0341	0.7142

Figure 2. Scatterplot for the BIBI at Moores Run, Baltimore City.



As mentioned previously, the BIBI protocol was refined in 2005. To test whether the modification may have influenced the BIBI results, a two-sample t-Test was performed. Unfortunately, only data from Moores Run, Baltimore City (site BC16MSI24) and Peter Pan Run, Frederick County could be used because no other sites had BIBI data prior to 2006. The BIBI data for each site were divided into two bins: scores reported prior to 2006 and 2006 and later. Moores Run had four samples in each bin. BIBI scores from 2002 through 2005 were compared to scores from 2002, 2003, 2014, and 2015. For the four sites in the Peter Pan location, BIBI scores from 2002 through 2005 were tested against scores from 2006 through 2010. The test revealed no significant difference at alpha equal to 0.05 for any of the sites.

Habitat Metrics and the Physical Habitat Index

Habitat Metrics

A few habitat metrics showed significant trends with slope p-values of less than 0.1 and high R^2 values. These results are shown in **Table 15**. However, there are too few metrics with significant trends at a station to ascertain whether there were substantial changes in the physical habitat.

Table 15. Linear regression statistics for select habitat metrics with significant trend statistic.

Agency	Location	Station	Metric	Intercept		Slope		R2
				Estimate	p-value	Estimate	p-value	
Carroll	Air Business Center	CR15MSI000001	EMBED_P	-1.7736	0.9620	1.6412	0.0833	0.2291
			VEL_DPTH	-10.8728	0.0617	0.4540	0.0036	0.4913
		CR15MSI000002	EPIFAUN	-1.0747	0.8373	0.2748	0.0446	0.2754
			INSTRHAB	-19.7713	0.0806	0.6992	0.0152	0.5930
			POOLQUAL	-7.2994	0.3972	0.3942	0.0681	0.3988
			VEL_DPTH	-7.0054	0.0897	0.4136	0.0006	0.6083

Agency	Location	Station	Metric	Intercept		Slope		R2
				Estimate	p-value	Estimate	p-value	
Charles	Acton/Hamilton	CC14MSI000023	WOOD	-23.7315	0.0003	0.7672	0.0000	0.8410
Frederick	Peter Pan Run	FR99MSI000042	RIFFQUAL	-3.8853	0.4055	0.3682	0.0064	0.4468
			VEL_DPTH	12.4002	0.0000	-0.0962	0.0673	0.2347
		FR99MSI000043	POOLVAR	-0.7865	0.7892	0.1944	0.0190	0.3343
			SHAD_P	112.9631	0.0000	-0.6507	0.0075	0.3693
		FR99MSI000044	POOLVAR	-2.8542	0.4397	0.4039	0.0006	0.5837
			RIFFQUAL	4.5367	0.2408	0.2165	0.0373	0.2744
		FR99MSI000045	RIFFQUAL	1.2724	0.7486	0.2632	0.0186	0.3360
Howard	Red Hill Branch	HO10MSI000005	EMBED_P	324.2886	0.0032	-6.3110	0.0067	0.7987
		HO10MSI000007	EPIFAUN	37.9585	0.0238	-0.6467	0.0643	0.5282
Prince Georges	Bear Branch	PG15MSI000002	BANKS	46.1684	0.0180	-0.8681	0.0437	0.4172
			CHALT	46.3405	0.0019	-0.7320	0.0151	0.5425
			EPIFAUN	42.4953	0.0022	-0.7216	0.0121	0.5659

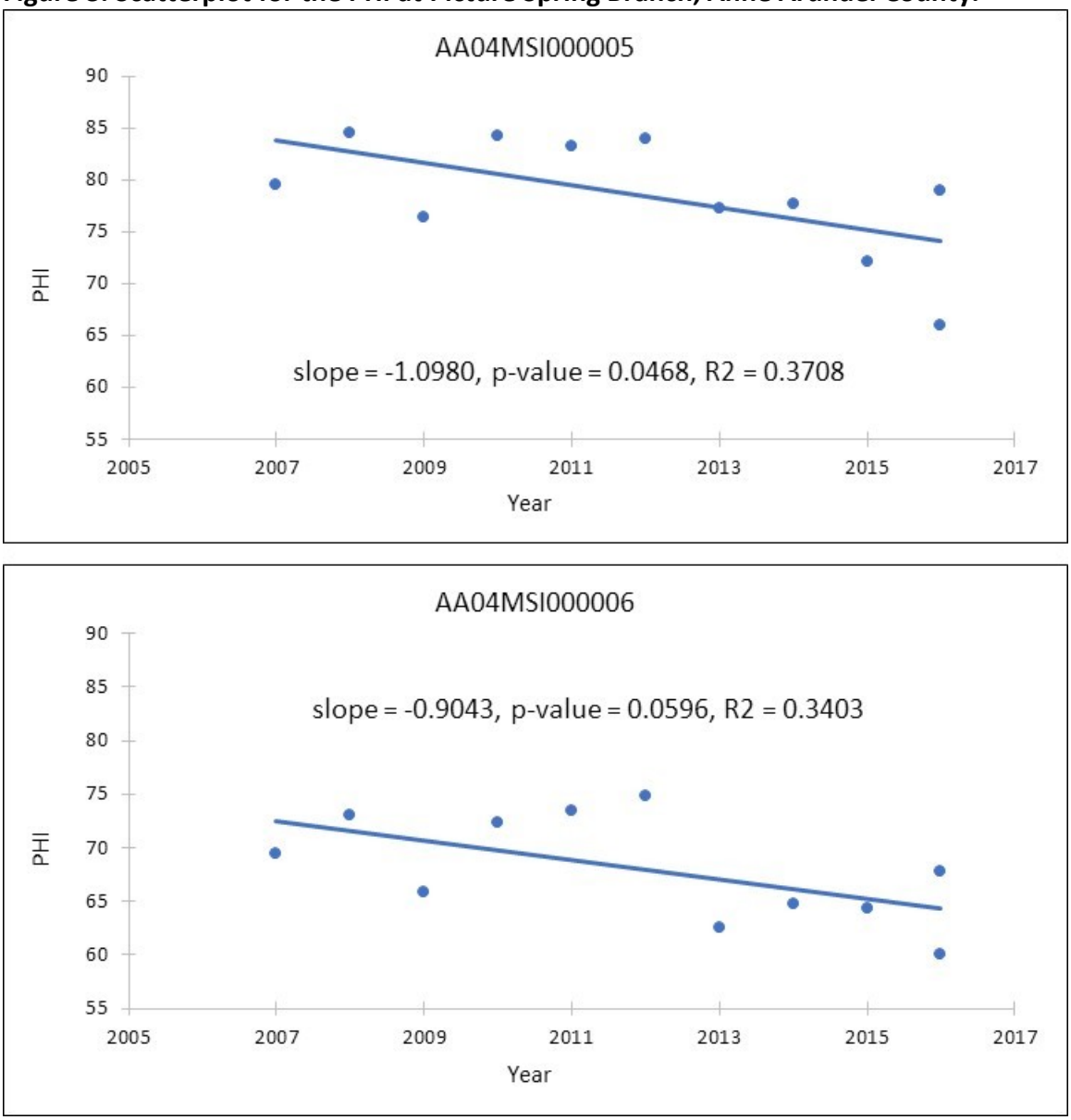
Physical Habitat Index

All twelve WRM sites with PHI scores had data for five or more years. Of these only two sites in the Picture Spring Branch location displayed significant trends as shown by the regression statistics in **Table 16**. The matching scatter plots are provided in **Figure 3**. Between 2007 and 2016, the PHI scores for site AA04MSI000005 varied between minimally degraded and partially degraded and for site AA04MSI000006 between partially degraded and degraded.

Table 16. Linear regression statistics for PHI at Picture Spring Branch, Anne Arundel County.

Agency	Location	Station	Index	Intercept		Slope		R2
				Estimate	p-value	Estimate	p-value	
Anne Arundel	Picture Spring Branch	AA04MSI000005	PHI	124.8492	0.0002	-1.0980	0.0468	0.3708
		AA04MSI000006	PHI	106.1876	0.0002	-0.9043	0.0596	0.3403

Figure 3. Scatterplot for the PHI at Picture Spring Branch, Anne Arundel County.



RECOMMENDATIONS

ICPRB recommends the following actions before more in depth analyses are performed.

1. Obtain missing data. As shown in Table 3, benthic and habitat data prior to 2006 was not provided for Anne Arundel, Charles, Harford, Howard, and Prince George's Counties, and overall, very little data were available for Baltimore City and Montgomery County. In addition, Baltimore County has collected a wealth of benthic and habitat data that unfortunately could not be included in the MS4 database due to a software incompatibility issue described in Data Quality section. Therefore, ICPRB, recommends

that benthic and habitat data and associated metadata should be requested from Baltimore County in a format compatible with the current database version such as MS Access 2010 or later, Excel workbooks, or comma-delimited text files.

2. Use consistent site identifiers. Some site names were changed over time and in some instances the site coordinates also varied, which can impede statistical and trend analyses because the sites cannot be exactly matched. Therefore, it would be helpful if the counties would provide consistent and unique station identifiers in addition to local site names.
3. Include pertinent metadata with data submittal. Important information such as physiographic strata, sampling design and method, and sampling dates were at times not provided. This information, however, is necessary when calculating benthic and habitat metrics and indices from field data or when comparing scores from two sites or over time.
4. Recalculate benthic and habitat metrics and indices using current methodologies. To ensure that the biological and habitat data between sites or over time can be compared directly, it is important that metrics and indices were calculated using the same standards. For example, it is imperative that approximately the same number of macroinvertebrates (e.g., about 100 individuals) are identified and enumerated because a deviation from this number could influence richness and diversity metrics, which in turn could alter the BIBI score.

NEXT STEPS

This phase of the project focused on describing benthic and habitat data collected for the Maryland Phase I MS4 program. The final phase will focus on using raw taxa data from two watersheds for statistical analyses. DNR's MBSStools R package will be used to calculate benthic metrics and indices. An attempt will be made to find temporal trends. If trends exist, ICPRB will try to relate them to restoration efforts in the watersheds. During a meeting on January 10, 2019 between MDE and ICPRB, the Air Business Center watershed in Carroll County and the Bear Branch watershed in Prince George's County were selected as the demonstration watersheds.

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