# Geomorphological Monitoring Data Collected under Maryland's Municipal Separate Storm Sewer System (MS4) Phase I Permits

***Database Design and Preliminary Analyses***

*Prepared for:*
*Maryland Department of the Environment*
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*Prepared by:*
*Andrea Nagel*
*Interstate Commission on the Potomac River Basin*

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## List of Abbreviations

| | |
|---|---|
| Abkf | Cross-Sectional Area |
| AWQMS | Ambient Water Quality Monitoring System |
| BMP | Best Management Practices |
| D50 | Median Particle Size |
| ICPRB | Interstate Commission on the Potomac River Basin |
| MDE | Maryland Department of the Environment |
| MS4 | Municipal Separate Strom Sewer System |
| NPDES | National Pollutant Discharge Elimination System |
| R2 | Regression Coefficient of Determination |
| SWM | Stormwater Management Assessment |
| Wbkf/dbkf | Width-to-Depth Ratio |
| WRM | Watershed Restoration Monitoring |

## Units of Measurement

| | |
|---|---|
| cfs | Cubic foot per second |
| ft | Foot |
| ft/sec | Foot per second |
| ft/yr | Foot per year |
| lb/sq ft | Pound per square foot |
| mm | Millimeter |
| sq ft | Square foot |

# 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 (Anne Arundel, Baltimore, Carroll, Charles, Frederick, Harford, Howard, Montgomery, and Prince George's), and the State Highway Administration (SHA) since the early 1990's. As part of their permit requirements, permittees must 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 a Microsoft Access database to store these monitoring data and related information.

For past projects, ICPRB populated the MS4 database with water chemistry, benthic, and stream habitat data made available by MDE, and analyzed and described these data (Nagel and Mandel, 2018; Nagel, A. 2019; ICPRB, 2019, Jepsen and Caraco, 2020). The current project was focused on adding the geomorphic monitoring data to the MS4 database, modifying the data format to make it compatible with MDE's Ambient Water Quality Monitoring System (AWQMS), and performing preliminary statistical analyses on a few select parameters.

Not all geomorphic survey data can easily be stored in an Access database, and therefore, MDE and ICPRB agreed upon a subset of 37 parameters for inclusion. Most data were provided by MDE, but ICPRB added some additional data extracted from annual NPDES reports found online. Data were provided in PDF format or in commercially available Microsoft Excel workbooks (e.g., *streaMSurvey 8* and *The REFERENCE REACH spreadsheet* v4.0). Some data could not be extracted from these documents or migrated into the Access database for various reasons including:

- Workbooks were corrupt and could not be recovered;
- Discrepancies between the date and/or cross-section identifiers provided with the tabular data and graphs for the same survey event; and
- Data were provided as images, which could not be converted into a compatible format for addition to the database.

The MS4 Access database has been updated with data from nearly 690 cross-sectional surveys. The updated database and a user manual are provided in Appendix A.

MDE and ICPRB selected three parameters (cross-sectional area, width-to-depth ratio, and median particle size) from three watershed restoration monitoring (WRM) areas (Acton-Hamilton in Charles County, Wilde Lake in Howard County, and Peter Pan Run in Frederick County) for preliminary analyses including:

- Basic descriptive statistics (minimum, maximum, mean, median, standard deviation, 10$^{th}$, 25$^{th}$, 75$^{th}$, and 90$^{th}$ percentiles);
- Line and percent-relative-change charts; and
- Preliminary trend analysis using linear regression.

Unfortunately, cross-sectional area and width-to-depth ratio data were not available for the Peter Pan Run WRM. Overall, few statistically significant trends were found.

Although the selected parameters are interrelated, they offer only isolated snapshots of the overall channel shape and functions, and as such do not provide sufficient information to assess what stream processes are occurring with a high degree of confidence.

# INTRODUCTION

Since the early 1990's Phase I Municipal Separate Strom Sewer System (MS4) jurisdictions (Anne Arundel, Baltimore, Carroll, Charles, Frederick, Harford, Howard, Montgomery, and Prince George's counties, Baltimore City, and the State Highway Administration) have conducted discharge characterizations at approved long-term monitoring sites. To stay in compliance with their respective National Pollutant Discharge Elimination System (NPDES) permits, the jurisdictions were required to collected chemical, biological, habitat and geomorphological data at both outfall and in-stream stations. Starting around 2004, the permittees were also requested to monitor drainage areas where restoration projects were expected to be built so that pre- and post- implementation conditions could be assessed.

Potentially, these monitoring results would enable MDE to 1) detect changes in water chemistry, pollutant loads, instream habitat, the benthic community, 2) evaluate overall stream health, and 3) assess the efficacy of stream restoration projects and/or best management practices (BMPs). The data may be used to explore spatial (e.g., upstream to downstream) and/or temporal changes in the biological, chemical, habitat, or geomorphological characteristics of the monitored streams.

Previously, ICPRB worked with MDE to design a Microsoft Access MS4 database to store Phase I MS4 monitoring data and related information. For past projects, ICPRB populated the database with water chemistry, benthic, and stream habitat data made available by MDE, and analyzed and described these data (Nagel and Mandel, 2018; Nagel, 2019; ICPRB, 2019, Jepsen and Caraco, 2020).

The current project had four goals:

1) Modify the existing MS4 database to accommodate geomorphological parameters measured and/or calculated by the permittees;
2) Examine the quality and quantity of these data;
3) Perform exploratory analyses on a few select geomorphological parameters to investigate whether changes in spatial (upstream to downstream) and/or temporal patterns could be detected during the Phase I monitoring period; and
4) Make the geomorphological data compatible with MDE's Ambient Water Quality Monitoring System (AWQMS).

As stated in the Assessment of Controls section of Phase I NPDES permits, *"A geomorphologic stream assessment shall be conducted between the outfall and in-stream monitoring locations … This assessment shall include an annual comparison of permanently monumented stream channel cross-sections and the stream profile."*

A cross-section can be defined as a line across a stream perpendicular to flow along which measurements are taken that explain the morphological and flow characteristics between the right and left banks. Cross-section surveys may be used, for example, to

- Delineate the width and depth of the stream channel
- Establish bankfull flow and floodplain dimensions
- Evaluate bank and channel stability
- Assess areas of aggradation and degradation
- Determine the potential channel migration zone
- Detect changes in particle size and sediment transport
- Establish the Rosgen stream type of the study reach
- Calculate discharge and hydraulic parameters

# DATABASE DESCRIPTION

For the current project, ICPRB worked with MDE to revise the existing MS4 database structure to accommodate geomorphological parameters that where either collected or calculated by the Phase I MS4 permittees. A subset of these parameters was selected for inclusion in MDE's AWQMS database, and the appropriate changes to the database tables are described in Appendix B.

## Database Design

The MS4 Access database is designed to store all relevant data collected by Phase I MS4 jurisdictions, including monitoring site and outfall information as well as chemical, biological, habitat, and geomorphological monitoring data. The MS4 database design was guided by 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, meaning that one record in the "parent" table is related to more than one record 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 function as lookup tables and describe the codes contained in the primary tables.

Table 1 provides an overview of all tables within the database, and a schematic that displays the relationships between the tables is shown in Figure 1.

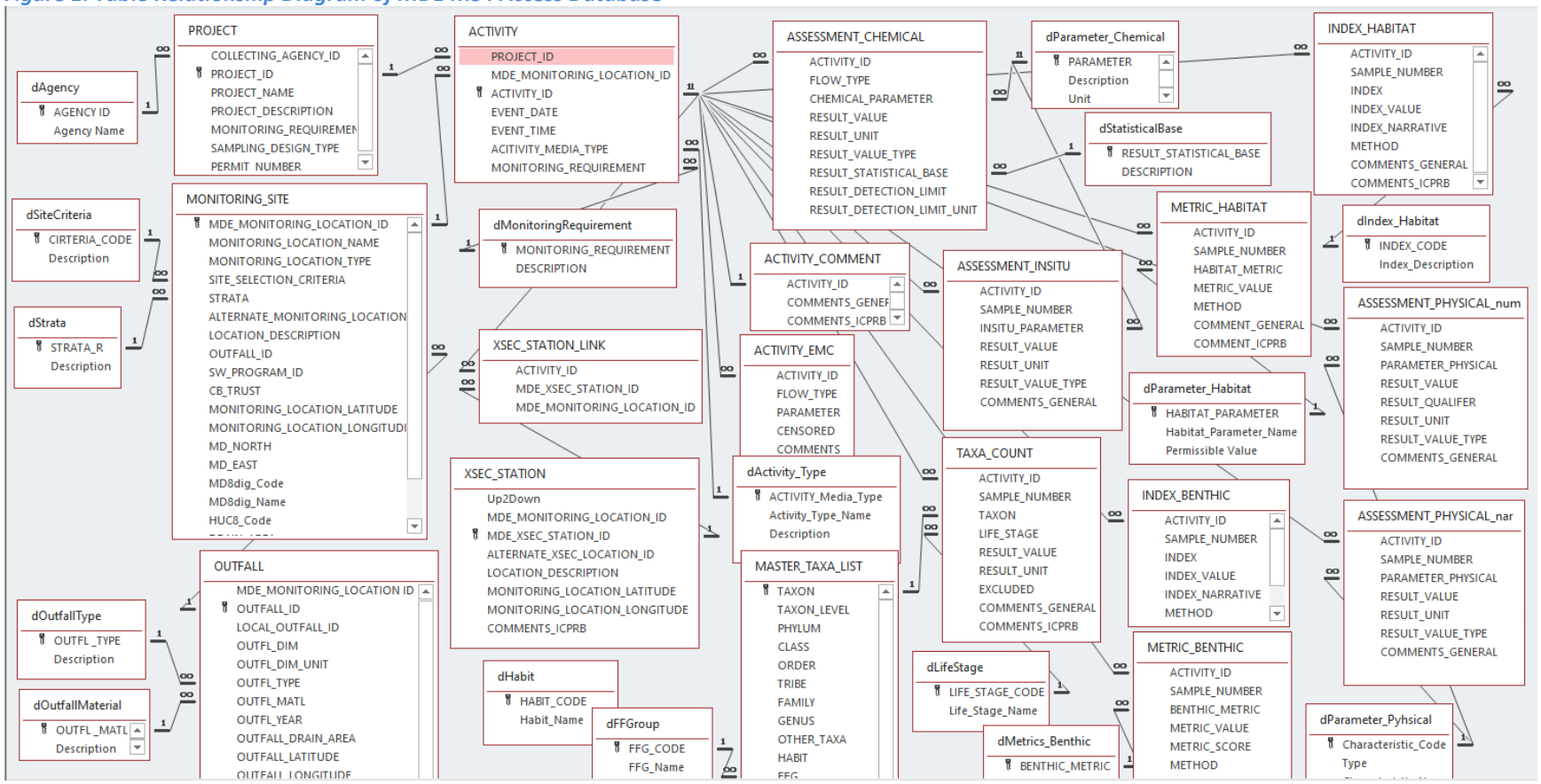
*Table 1. Summary of the Main and Domain Tables in the MDE MS4 Access Database*

| Table Name | Function |
|---|---|
| **Primary Tables** | |
| ACTIVITY | Records the location, date and time, and type of sampling activities. |
| ACTIVITY_COMMENTS | Tracks activity comments provided by collecting agencies or data manipulations 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 taken in conjunction with biological and/or habitat assessments. |
| ASSESSMENT_PHYSICAL_nar* | Stores narrative information related to geomorphologic stream assessments. |
| ASSESSMENT_PHYSICAL_num* | Stores numeric information related to geomorphologic stream assessments. |
| INDEX_BENTHIC | Stores benthic indices and metrics calculated by the MS4 permittees to assess stream health. |
| INDEX_HABITAT | Holds habitat indices and metrics calculated by the MS4 permittees to assess stream health. |
| 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. |
| XSEC_STATION* | Stores information about the geomorphological cross-sections |

| Table Name | Function |
|---|---|
| XSEC_STATION_LINK* | Provides a link between geomorphological cross-sections and the ACTIVITY table |
| **Domain Tables** | |
| dActivity_Media_Type | Provides information about the type of sample collected. |
| dAgency | Lists sampling agencies. |
| 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_Habitat | Defines benthic 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. |
| dOutfall_Material | Provides information about the outfall material at monitoring locations. |
| dOutfall_Type | 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 parameters of the physical assessment. |
| dSite_Criteria | Defines the site selection criteria |
| dStatisticalBase | Describes methods used to calculate the values for the chemical assessment. |
| dStrata | Defines the physiographic stratum in which a site is located. |

* Denotes a table that has been added to the MS4 database for the current project.

*Figure 1. Table Relationship Diagram of MDE MS4 Access Database*



## New MS4 Database Tables

Several new tables have been added to the MS4 database for the current project including XSEC_STATION, ASSESSMENT_PHYSICAL_num, ASSESSMENT_PHYSICAL_nar, and dParameter_Physical. These are marked by an asterisk (*) in

Table 1 and are described in the following paragraphs.

All cross-sections have been added to the MONITORING_SITES table in the MS4 database and received a unique identifier (i.e., MONITORING_LOCATION_ID). The location of a cross-section may, however, have changed over the years because the benchmarks marking the location of cross-sections (also termed cross-section stations in the NPDES reports) may have been moved or replaced after stream restorations or BMP implementations, or because they were lost due to vandalism, natural events, or other reasons.

To facilitate addition of future data as well as data analyses, the coordinates from the first available survey year for a cross-section were chosen to represent its location in the MONITORING_SITE table (Figure 1), and all available coordinates and location descriptions of each cross-section station were preserved in the XSEC_STATION table. This table can be linked via the XSEC_STATION_LINK table to the ACTIVITY table (Figure 1).

Geomorphological survey results were provided as numeric values and/or narrative descriptions. A field in a Microsoft Access database, however, can only contain one data type (e.g., numeric, text, date), and therefore, the assessment results were added to the ASSESSMENT_PHYSICAL_num (numeric) or ASSESSMENT_PHYSICAL_nar (narrative) tables depending on the data type.

Not all geomorphological data can easily be added to a Microsoft Access database, and therefore, MDE and ICPRB agreed upon a subset of 37 parameters for inclusion. These parameters are briefly described in the newly added domain table dParameter_Physical (Table 2). The MS4 database as well as a user manual that describes the database design and tables in more detail can be found in Appendix A.

*Table 2. Geomorphological Parameters Stored in the MDE MS4 Access Database*

This domain table entitled dParameter_Physical in the MS4 database serves as a lookup table for the primary table ASSESSMENT_PHYSICAL

| Code | Parameter Name | Unit | Data Type | Value Type | Definition |
|---|---|---|---|---|---|
| Abkf | Bankfull cross-sectional area | sq ft | Numeric | Calculated | The cross-sectional area of a stream channel at bankfull flow (Qbkf) measured perpendicular to streamflow. |
| AER | Annual erosion rate | ft/yr | Numeric | Estimated | Describes sediment contribution of stream bank erosion to the total annual sediment yield. |
| Afc | Full channel cross-sectional area | sq ft | Numeric | Calculated | Cross-section area of the full channel measured perpendicular to streamflow. |
| Atb | Top of bank cross-sectional area | sq ft | Numeric | Calculated | Cross-section area of measured at top of the bank perpendicular to streamflow. |
| BEHI | Bank erosion hazard index | none | Numeric or Narrative | Calculated | An index of bank erodibility that uses bank height, bankfull height, root depth, root density, bank angle, surface protection, bank materials, and bank stratification. |
| D50 | Median particle size of reach | mm | Numeric | Estimated | The median size of streambed particles as determined by measuring the intermediate axis of numerous particles selected at random. |
| D50mea | Median particle size of meander within reach | mm | Numeric | Estimated | The median particle size of a meander within the reach. |
| D50rif | Median particle size of riffle within reach | mm | Numeric | Estimated | The median particle size of a riffle within the reach. |
| D84 | 84th percentile of the particle size distribution of the reach | mm | Numeric | Estimated | D84 describes the bed material or grain size for which 84% of sample is smaller. D84 represents the larger particle sizes of the channel that are likely to become mobile only during the annual high-water events. |
| D84mea | 84th percentile of the particle size distribution of a meander within reach | mm | Numeric | Estimated | The 84th percentile of the particle size distribution of a meander within the reach. |
| D84rif | 84th percentile of the particle size distribution of a riffle within reach | mm | Numeric | Estimated | The 84th percentile of the particle size distribution of a rifle within the reach. |
| dbkf | Bankfull mean depth | ft | Numeric | Calculated | The ratio of the bankfull cross-sectional area to the bankfull width. |
| dmbkf | Bankfull maximum depth | ft | Numeric | Actual | The maximum depth of the bankfull channel measured perpendicular to streamflow. |
| DomPc | Dominant particle size class | none | Narrative | Calculated | The dominant bed channel material (e.g., silt, sand, gravel) of the cross-section. |
| DomPs | Dominant particle size in percent | mm | Narrative | Estimated | The percentage of the dominant bed channel material. |
| ER | Entrenchment ratio | none | Numeric | Calculated | The entrenchment ratio describes the vertical containment of a stream measured by the ratio of the flood prone width (Wfpa) to the bankfull width (Wbkf). |
| HR | Hydraulic radius | ft | Numeric | Calculated | The ratio of the cross-sectional area to the wetted perimeter. |
| K | Sinuosity | none | Numeric | Calculated | A measure of how much the stream channel meanders within a reach represented by the ratio of stream thalweg distance to the straight-line distance of the valley. |

| Code | Parameter Name | Unit | Data Type | Value Type | Definition |
|---|---|---|---|---|---|
| lbh | Low bank height | ft | Numeric | Actual | Low Bank Height is measured during the longitudinal profile assessment and indicates the degree of channel incision. When not incised, lbh is the same as bankfull. |
| lbh_r | Low bank height ratio | none | Numeric | Calculated | The ratio of the low bank height (lbh) to the maximum riffle depth. |
| n | Manning's n coefficient | none | Numeric | Calculated | A dimensionless measure of the roughness or friction applied to flow by the stream channel. |
| NBS | Near bank stress | none | Narrative | Calculated | The measured or estimated shear stress associated with the third of the channel closest to the study bank. |
| Q | Discharge at baseflow | cfs | Numeric | Actual | Discharge measured at baseflow. |
| Qbkf | Bankfull discharge | cfs | Numeric | Actual | The bankfull discharge is the point where flow begins to top its banks and enter its floodplain. It is the flow that shapes the morphological parameters of the channel and floodplain. |
| Rosgen | Rosgen stream type | none | Narrative | Estimated | The Rosgen stream type classification system categorizes streams into broad stream types identified by the letters Aa, A, B, C, D, DA, E, F, and G and is based on the entrenchment ratio (ER), width/depth ratio (Wbkf/dbkf), sinuosity (K), surface slope (SlopeWS), and channel materials. |
| SlopeSB | Slope of the stream bottom | percent | Numeric | Calculated | The vertical drop of the water relative to the distance water travels in the reach measured at the stream bed. |
| SlopeWS | Slope at the water surface | percent | Numeric | Calculated | The vertical drop of the water relative to the distance water travels in the reach measured at the water surface. |
| T | Shear Stress | lb/sq ft | Numeric | Calculated | The measured or estimated erosional forces associated with stream flow. |
| TW | Thalweg | ft | Numeric | Actual | The line connecting the deepest points along a streambed, which may be to the left or right of the channel center. It represents the low flow channel. |
| TWave | Average thalweg depth | ft | Numeric | Calculated | The average thalweg depth of the reach |
| Vbkf | Bankfull flow velocity | ft/sec | Numeric | | A measure of stream velocity at the bankfull stage. |
| Wbkf | Bankfull width | ft | Numeric | Calculated | The distance between the left and right banks of the channel in contact with flowing water, measured perpendicular to streamflow at bankfull discharge. |
| Wbkf/dbkf | Bankfull width-to-depth ratio | none | Numeric | Calculated | The ratio of the bankfull width (Wbkf) to the bankfull mean depth (dbkf) that describes channel shape and sediment transport capacity. |
| Wfpa | Flood prone area width | ft | Numeric | Calculated | The width across the active floodplain, measured perpendicular to streamflow. It is qualitatively defined as twice the maximum depth of the bankfull channel. |
| WPbkf | Bankfull wetted perimeter | ft | Numeric | Calculated | The portion of the cross-sectional area, including the channel bed and banks, that is in direct contact with water. |
| Wtb | Width at top of bank | ft | Numeric | Actual | The channel width measured at the topof the bank. |
| WWave | Average wetted width | ft | Numeric | Calculated | The average wetted width of the reach. |

## GEOMORPHIC ASSESSMENTS

Geomorphic assessments include delineating the geometry of the floodplain and stream channel at monumented cross-sections, surveying longitudinal profiles, and measuring bed material and discharge. A cross-section can be defined as a line across a stream between the right and left banks perpendicular to stream flow. The cross-section is divided into several subsections where measurements are taken, which typically include wetted, bankfull and floodplain widths and depths; thalweg depth; and slope. These measurements can be used to calculate other characteristics such as the bank erosion hazard index, entrenchment ratio, and others (Table 2).

The longitudinal profile documents stream characteristics along the stream in the direction of flow between an upstream and a downstream point. It describes bedforms (riffles, pools, runs, glides, rapids, plane bed, etc.), bed material, slope, sinuosity, and so forth.

The term reach is also frequently used in conjunction with geomorphic stream assessments but is somewhat vague. For example, the USGS defines it as: "*A reach is a section of a stream or river along which similar hydrologic conditions exist, such as discharge, depth, area, and slope. ... The term is often used by hydrologists when they're referring to a small section of a stream or river rather than its entire length.*" Reach may also be used to describe the extent of a stream restoration project or the length of a stream section that may be affected by a proposed development project. More than one cross-section may be located within a reach.

## DATA DESCRIPTION

This section summarizes both the quality and the quantity of the geomorphological data that have been added to the MS4 Access database.

### Data Quality

Most of the geomorphological cross-section survey data were provided by MDE, although ICPRB extracted some from annual NPDES reports found online. Most data were extracted from the permittees annual NPDES documents in PDF format, with the exception of Baltimore and Charles counties for which annual survey data were available commercially available Microsoft Excel workbooks. Baltimore County used *streaMSurvey 8* to record and calculate geomorphological parameters, while Charles County used *The REFERENCE REACH spreadsheet* v4.0.

Unfortunately, not all data could be extracted from the provided documents and workbooks. An examination of the Baltimore County *streaMSurvey 8* workbooks revealed numerous discrepancies between the date and/or cross-section identifier provided with the tabular data and graphs for the same survey event. In addition, several workbooks were corrupt and either could not be opened or some of the data and/or graphs could not be recovered by available software.

Carroll County's NPDES reports contained data tables and graphs that were mere images and therefore could not be converted into a format suitable for addition to the MS4 Access database. Furthermore, data were limited to slope and elevation data for every other year between 2004 and 2016. Montgomery County NPDES reports were available for the years 2004, 2007, 2009, 2014, 2015, and 2017. The data could not be compiled, however, because the graphs were also just images.

Coordinates are missing for 13 of the 88 cross-sections that have been entered into the MS4 database. These cross-sections are located on a tributary to Peter Pan Run in Frederick County, MD and were surveyed during 2003 to 2006, however, the purpose of the surveys is not known.

Baltimore City provided coordinates for the right and left banks at each cross-section. These coordinates were averaged to obtain a unique location point. The action was noted in the COMMENTS_ICPRB field of the MONITORING_SITE table in the MS4 database (Figure 1).

Frequently, only the survey year or the year and month were provided but not the actual date. In these cases, a likely date was assigned to the surveys based on the narratives found in NPDES reports or the known dates of surveys conducted in prior or subsequent years. This action was noted in the ACTIVITIES_COMMENTS table (Figure 1).

## Data Quantity

During prior meetings, MDE and ICPRB agreed on a preliminary list of geomorphological parameters to be included in the MS4 Access database. This list has been expanded from the initial 19 to 37 parameters, however, not all are available for all survey locations or are available only sporadically. Table 2 provides brief descriptions of the parameters.

The MS4 database contains data from nearly 690 cross-sectional surveys, and Table 3 provides a summary of these by jurisdiction and location, length of survey record, and geomorphological parameter. Parameters shown in red ink are available for at least five of the ten drainage areas for which geomorphological assessment data have been entered into the MS4 database and include bankfull cross-sectional dimensions (area, mean depth, width, width to depth ratio), particle size, entrenchment ratio, hydraulic radius, sinuosity, slope, and flood prone area width. Green highlights point to WRM drainage areas for which nine or more years of survey data are available, including Acton-Hamilton in Charles County, Wilde Lake in Howard County, Peter Pan Run in Frederick County, and Black Branch in Prince Georges County. Data, however, may not be available for every cross-section for the entire survey period because new cross-sections may have been added during the survey period to document changes in geomorphic conditions of the stream or for some other purposes.

*Table 3. Period of Record and Survey Counts of the Geomorphological Parameters Included in the MS4 Access Database*

Numbers represent the number of geomorphic assessments available for the period of record. Green highlights point to data that are available for nine years or more. Parameters shown red ink are available for at least five of the ten drainage areas for which data have been entered into the MS4 database.

| Jurisdiction | Anne Arundel County[1] | | Baltimore City | Charles County | Frederick County[2] | Harford County | | Howard County[3] | Prince Georges County[4] | |
|---|---|---|---|---|---|---|---|---|---|---|
| Drainage area | Church Creek | Picture Spring Branch | Moore's Run | Acton-Hamilton | Peter Pan Run | Wheel Creek | Rumsey Run | Wilde Lake | Black Branch | Bear Branch |
| Period of Record | 2009 - 2015 | 2003 - 2016 | 2003 - 2015 | 2005 - 2016 | 1999 - 2017 | 2010 - 2015 | 2011 - 2016 | 2006 - 2016 | 2001 - 2015 | 2008 - 2016 |
| Abkf | 4 | 5 | 8 | 10 | 4 | 4 | 5 | 11 | 11 | 8 |
| AER | | | | | | | | | 6 | 2 |
| Afc | | | | | | | | | 10 | 8 |
| Atb | | 13 | | 10 | | 4 | | | | |
| BEHI | | | 2 | | | | | | 12 | 4 |
| Chn_Type | | | | | | | 4 | 11 | | |
| D50 | 4 | 5 | | 10 | 19 | 4 | 5 | 11 | 13 | 8 |
| D50mea | | | | | | 4 | | | | |
| D50rif | | | | | 4 | 4 | | | | |
| D84 | | | | 10 | 4 | 4 | 1 | | | |
| D84mea | | | | | | 4 | | | | |
| D84rif | | | | | 4 | 4 | | | | |
| dbkf | 4 | 5 | 8 | 10 | 4 | 4 | 5 | 11 | | 8 |
| dmbkf | | | 8 | 10 | 4 | 4 | | | | |
| DomPc | | | | | | | 4 | 11 | | |
| DomPs | | | | | | | 4 | 10 | | |
| ER | 4 | 5 | | 10 | | 4 | 5 | 11 | 13 | 8 |
| HR | | | 8 | 10 | | 4 | 1 | | 7 | |
| K | 4 | 5 | | 10 | | | 5 | 11 | 13 | 8 |
| lbh | | | | 10 | | 4 | 1 | | | |
| lbh_r | | | | 10 | | 4 | 1 | | | |
| n | | | | 10 | | | 1 | | | |
| NBS | | | 1 | | | | | | 12 | 2 |
| Q | | | | | 19 | | | | | |
| Qbkf | | | | 10 | 4 | | 1 | | 7 | 7 |
| Rosgen | 4 | 5 | | | | | | | 13 | 8 |
| SlopeSB | | 5 | | 10 | 19 | 4 | 5 | 11 | 13 | 8 |
| SlopeWS | 4 | | | | | | | | | |

| Jurisdiction | Anne Arundel County[1] | | Baltimore City | Charles County | Frederick County[2] | Harford County | | Howard County[3] | Prince Georges County[4] | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Drainage area** | **Church Creek** | **Picture Spring Branch** | **Moore's Run** | **Acton-Hamilton** | **Peter Pan Run** | **Wheel Creek** | **Rumsey Run** | **Wilde Lake** | **Black Branch** | **Bear Branch** |
| **Period of Record** | **2009 - 2015** | **2003 - 2016** | **2003 - 2015** | **2005 - 2016** | **1999 - 2017** | **2010 - 2015** | **2011 - 2016** | **2006 - 2016** | **2001 - 2015** | **2008 - 2016** |
| **T** | | | | | | | | | 7 | |
| **TW** | | | | | | | 5 | 11 | | |
| **TWave** | | | | | 19 | | | | | |
| **Vbkf** | | | | 10 | | | 1 | | 7 | |
| Wbkf | 4 | 5 | 8 | 10 | 4 | 4 | 5 | 11 | | 8 |
| Wbkf/dbkf | 4 | 5 | 8 | 10 | 4 | 4 | 5 | 11 | 13 | 8 |
| Wfpa | 4 | 5 | | 10 | | 4 | 5 | 11 | | 8 |
| **WPbkf** | | | 8 | 10 | | 4 | 1 | | | |
| **Wtb** | | | | 10 | | | | | | |
| **WWave** | | | | | 19 | | | | | |

[1] Anne-Arundel County conducts geomorphological monitoring as required by their MS4 permit in the Church Creek and Picture Spring Branch drainage areas. The assessments in the Church Creek drainage area are done in conjunction with biological and habitat monitoring for their WRM requirement, while the surveys in the Picture Spring Branch are part of the Stormwater Management Monitoring (SWM), which is designed to determine the effectiveness of stormwater management practices for stream channel protection.
[2] The Peter Pan Run data includes assessments at several cross-sections that are not associated with WRM.
[3] In Howard County, the assessments in Wilde Lake are associated with WRM and in Rumsey Run with SWM.
[4] In Prince Georges County, the assessments in Bear Branch are associated with WRM and in Black Branch with SWM.

# PARAMETER AND MONITORING AREA SELECTION

MDE and ICPRB jointly selected three WRM areas and three parameters for preliminary statistical analyses. Brief descriptions of the WRM areas followed by an overview of the parameters are provided in the sections below.

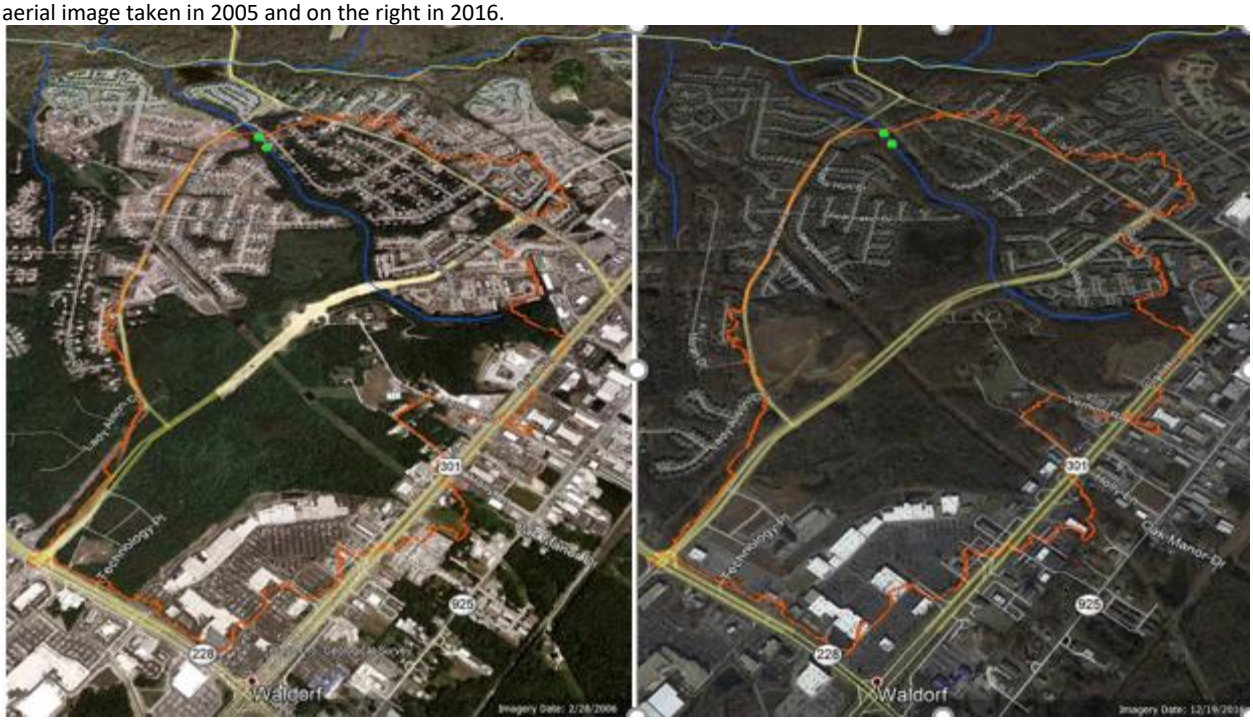
## Monitoring Area and Cross-section Descriptions

### Acton-Hamilton, Charles County, MD

The Acton-Hamilton WRM area includes the headwater region of an unnamed tributary that joins Mattawoman Creek to the West of Acton Lane. The area includes undeveloped forest in its central part, residential and commercial spaces in its northern and eastern portions, and actively developing commercial properties in the southern section. The tributary flowing through the high-density residential area is buffered on both banks by a 100-foot-wide swatch of forest. The buffer widens on the left bank in its headwater region (CCG, 2016). The stream receives multiple inflows of untreated stormwater from the high-density residential areas in its headwaters as well as flow from stormwater management ponds associated with residential and business properties. The Acton-Hamilton WRM area has been monitored annually since 2005. Figure 2 shows aerial images of the WRM area from 2005 on the left and 2016 on the right.

***Figure 2. Aerial Images of the Acton-Hamilton WRM Area from 2005 and 2016***

The WRM area is outlined in orange, and the location of the two cross-sections are noted with green circles. On the left is an aerial image taken in 2005 and on the right in 2016.




The County collected geomorphic measurements between the outfall and in-stream chemical monitoring locations at two cross-sections (Table 4) near the outlet of the Acton-Hamilton WRM area. The cross-sections are approximately 260 ft apart as measured in ArcGIS and are located above and

below a pool. Data for nine monitoring events are available in the MS4 database for the period of 2005 to 2016.

*Table 4. Description of Cross-Sections in the Acton-Hamilton WRM Area*

| Cross-section | Location | Latitude | Longitude |
|---|---|---|---|
| CH05AHMX1 | The upstream cross-section is located at the upstream end of a pool | 38.646768 | -76.911298 |
| CH05AHMX2 | The downstream cross-section is located at the downstream end of a pool | 38.647412 | -76.911701 |

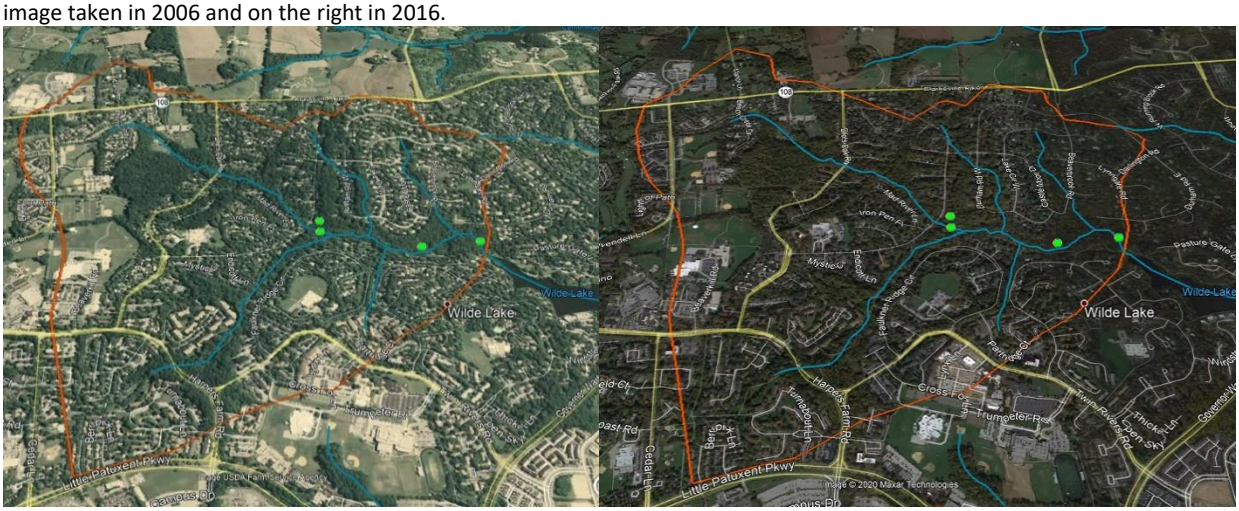
## Wilde Lake, Howard County, MD

Wilde Lake, located in Columbia, MD, was constructed in 1967 and receives drainage from several tributaries. The area is highly urbanized, with medium- to high-density developments consisting of residential, commercial, and institutional spaces. Development occurred largely without stormwater management and consequently caused moderate to severe channel erosion in the tributaries and sedimentation and nutrification of the lake (HCG, 2016). Following an assessment of these problems in 1995, a restoration plan was developed, which recommended restoration of three reaches.

The County implemented annual geomorphological monitoring starting in 2006 with the primary goal to "*assess the geomorphic variability of the streams above the lake as they adjust to restoration activities and other changes in the drainage area* "(HCG, 2016). Figure 3 displays an aerial image of the WRM from 2006 on the left and from 2016 on the right.

*Figure 3. Aerial images of the Wilde Lake WRM Area from 2006 and 2016*

The WRM area is outlined in orange, and the location of the cross-sections are noted with green circles. On the left is an aerial image taken in 2006 and on the right in 2016.




The County collected geomorphic measurements at four cross-sections, two located on the main stem tributary to Wilde Lake and two on upstream tributaries to the main tributary (Table 5). Data from eleven geomorphological assessments are available in the MS4 database for the period of 2006-2016.

*Table 5. Description of Cross-Sections in the Wilde Lake WRM Area*

| Cross-Section | Location | Latitude | Longitude |
|---|---|---|---|
| HO05WLTR2X9 | Near the confluence of the North tributary to the main stem (Reach A2) | 39.22730 | -76.87510 |
| HO05WLTR1X10 | Near the confluence of the South tributary to the main stem (Reach C1) | 39.22670 | -76.87510 |
| HO05WLMR1X8 | Upstream of Wilde Lake on a meander with riprap stabilization (Reach A1) | 39.22590 | -76.86990 |
| HO05WLMR1X7 | Downstream end of the main tributary (Reach A1), just above the main stem confluence with Wilde Lake. | 39.22620 | -76.86680 |

## Peter Pan Run, Frederick County, MD

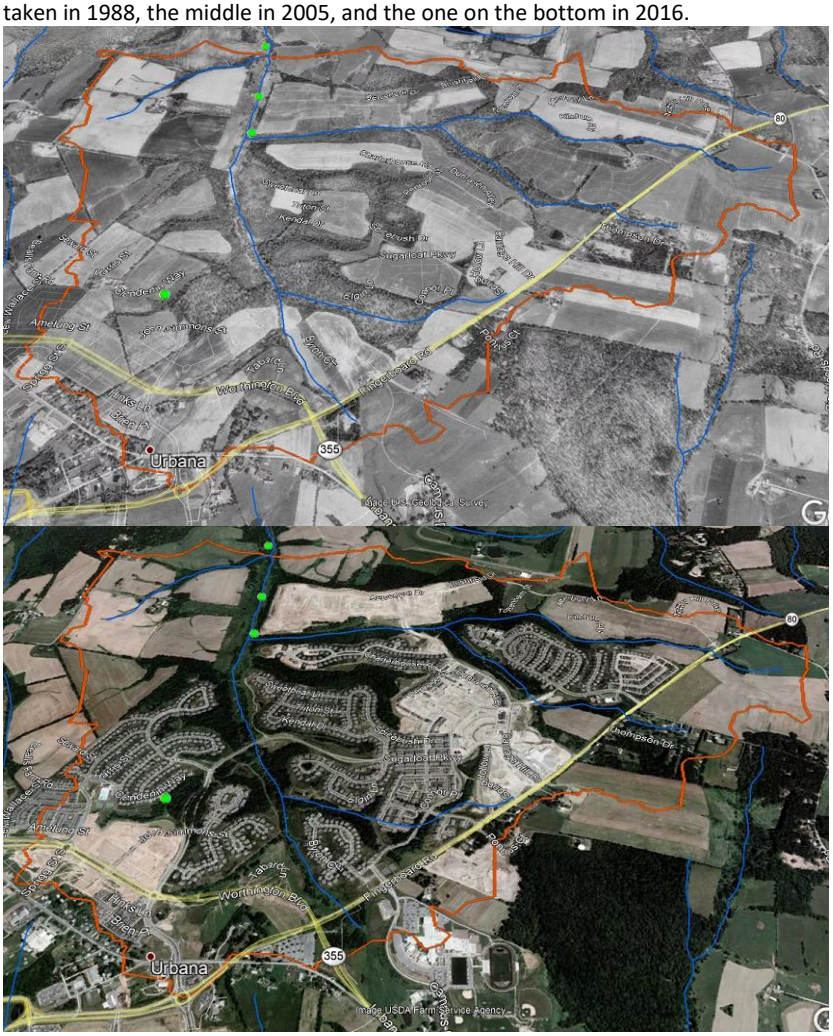
Peter Pan Run is a tributary to Bush Creek, which flows towards the West to join the Monocacy River near Frederick Junction, MD. The area was largely rural until 1999 but has become increasingly urbanized since then.

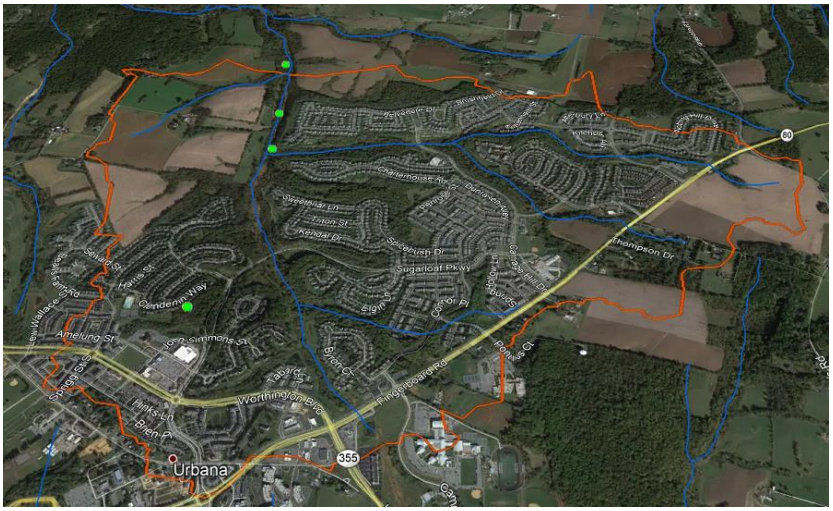
Frederick County has conducted monitoring in the Peter Pan Run WRM area since 1999 to assess baseline conditions prior to the construction of The Villages of Urbana. The Villages is a mixed-use development consisting of high-density residential, office, and commercial spaces (FCG, 2016). Numerous BMPs have been installed in the WRM area over the years, including 43 structural stormwater management (SWM) facilities and three non-structural BMPs (FCG, 2016).

The monitoring design may provide insights into the long-term impacts associated with urban development and its associated increase in imperviousness as well as the efficiencies of the various BMPs. Figure 4 shows the cross-section locations superimposed on aerial imagery from 1988, 2005, and 2016. Unfortunately, an image from 1999 was not available.

***Figure 4. Aerial images of the Peter Pan WRM Area from 1999 and 2016***

The WRM area is outlined in orange, and the location of the cross-sections are noted with green circles. The top image was taken in 1988, the middle in 2005, and the one on the bottom in 2016.






The County conducted geomorphic assessment at four cross-section, in the Peter Pan Run WRM area; two are located on the main stem and two on upstream tributaries (Table 6). Data from eleven geomorphological assessments are available in the MS4 database for the period of 1999-2016.

*Table 6. Description of Cross-Sections in the Peter Pan Run WRM Area*

| Cross-Section | Location | Latitude | Longitude |
|---|---|---|---|
| FR99MSI000043 | In the headwaters of Tributary 3 above Pond R. | 39.33269 | -77.35240 |
| FR99MSI000042 | On Tributary 1 near the confluence with the main stem below Pond R. | 39.34250 | -77.34972 |
| FR99MSI000045 | On the Peter Pan Run main stem | 39.34518 | -77.34971 |
| FR99MSI000044 | On Peter Pan Run main stem at the downstream end of the assessment area below the outfall. | 39.34922 | -77.34991 |

## Parameter Descriptions

Three geomorphic parameters were selected for exploratory analyses:

- Cross-sectional area of the stream channel at bankfull flow (Abkf),
- Width-to-depth ratio at the bankfull stage (Wbkf/dbkf), and
- Median particle size (D50).

Although the selected parameters are interrelated, they offer only isolated snapshots of the overall channel shape and functions, and as such do not provide sufficient information to evaluate in-stream processes with a high degree of confidence.

### Cross-Sectional Area (Abkf)

The cross-sectional area (Abkf) is calculated from the channel width and depth measurements at bankfull discharge. The geometry of the cross-sectional area responds to the amount, frequency, and duration of water and sediment flowing thru the channel. Changes in the flow regime that lead, for example, to bank erosion on the outside of a meander bend may be offset by accumulation of bed material on the inside of the bend, thereby changing the width and/or depth of the channel. When bank erosion exceeds sediment accumulation and bank rebuilding, the channel widens. This effect may be observed in drainage areas with urban and/or agriculture land uses.

### Width-to-Depth Ratio (Wbkf/dbkf)

The width-to-depth ratio (Wbkf/dbkf) is taken at the bankfull stage and is the ratio of the top width to mean depth. The ratio describes the shape of the stream channel and its water and sediment transport capacity. It is a relative index that is independent of changes in the cross-sectional area. A large number is indicative of a wide and shallow channel and a small number of a narrow and deep channel. As a stream continues to widen, the slope of the stream bed decreases, leading to a reduced capacity to transport sediment. At that point, depositional features (i.e., mid-channel and transvers bars) start to develop, forcing velocity vectors closer to the banks, which may cause a widening of the channel or bank erosion (Harman et al., 2012).

### Median Particle Size (D50)

The D50 bed material size represents the most prevalent particle size at the survey location. The notation means that 50 percent of the bed material is smaller, and 50 percent is larger than the D50 bed material size calculated for the survey location. Based on the D50, the bed material is classified into several particle size categories (Table 7).

*Table 7. Substrate Material Classification*

| Particle Size Category | Size Range (mm) |
|---|---|
| Bedrock | >2,048 |
| Boulder | 256 - 2,048 |
| Cobble | 64 - 256 |
| Gravel | 2 - 64 |
| Sand | 0.062 - 2 |
| Silt/Clay | <0.062 |

While the bed-material size and distribution is correlated with local flow dynamics and sediment supply and transport, the relationship can be quite complex and can be affected by other factors such as channel slope and type (e.g., meandering, braided), presence of in-stream blockages (large woody debris, boulders, dams, etc.), shear stress, erosional or depositional processes, and so on.

In general, grain size becomes larger with increasing flow strength, but the common assumption that the threshold of movement of the median grain size coincides with bankfull flow does not hold for all channel types. For example, Pfeiffera et al. (2017) report that bed-material size in gravel-bedded alluvial channels is linked to the amount of sediment transported from the upstream reaches, and that "*threshold channels may … simply reflect settings with low sediment supplies, while high sediment supply channels are adjusted to transport large volumes of material during bankfull floods*."

## Data Analyses

Preliminary analyses were performed on the selected parameters in each of the three WRM areas including:

- Basic descriptive statistics (minimum, maximum, mean, median, standard deviation, 10$^{th}$, 25$^{th}$, 75$^{th}$, and 90$^{th}$ percentiles);
- Temporal trends analysis using simple linear regression; and
- Line and percent-relative-change charts.

A summary of the descriptive statistics is provided in Table 8. The linear regressions were done using the Regression Data Analysis Tool in Microsoft Excel with the parameter as the independent variable and date as the dependent variable. The coefficient of determination ($R^2$) and the p-value of the slope for each cross-section are reported in Table 9. A p-value of 0.1 or less was considered statistically significant and is shown in **bold**.

It should be noted that the data have not undergone a rigorous QA/QC review.

*Table 8. Descriptive Statistics for Select Geomorphic Parameters by Location and Cross-Section*

| County/ WRM | Cross-section | Parameter | Count | Min | Median | Mean | Max | Std Dev | Percentile | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 10th | 25th | 75th | 90th |
| Charles/ Acton-Hamilton | CH05AHMX1 | Abkf | 10 | 23.5 | 27.15 | 27.18 | 33.8 | 3.46 | 23.77 | 24.15 | 28.4 | 31.46 |
| | | D50 | 10 | 14 | 18.5 | 18.5 | 23 | 2.55 | 15.8 | 17.25 | 19.75 | 21.2 |
| | | Wbkf/dbkf | 10 | 14.3 | 16.8 | 17.09 | 21.1 | 2.02 | 14.84 | 16 | 18 | 19.39 |
| | CH05AHMX2 | Abkf | 10 | 17 | 18.7 | 20.77 | 26.6 | 3.55 | 17.99 | 18.12 | 23.7 | 25.43 |
| | | D50 | 10 | 14 | 18.5 | 18.5 | 23 | 2.55 | 15.8 | 17.25 | 19.75 | 21.2 |
| | | Wbkf/dbkf | 10 | 7.9 | 11.55 | 10.65 | 12.6 | 1.88 | 8.44 | 8.825 | 12.15 | 12.51 |
| Frederick/ Peter Pan Run | FR99MSI000043 | D50 | 19 | 4.5 | 17.1 | 18.00 | 29.06 | 7.02 | 10.64 | 12.88 | 23.79 | 27.7 |
| | FR99MSI000042 | D50 | 19 | 4.8 | 20.84 | 19.98 | 40.67 | 10.21 | 7.78 | 12.75 | 26.01 | 29.41 |
| | FR99MSI000045 | D50 | 16 | 3 | 12.4 | 14.42 | 34.6 | 8.06 | 7.44 | 8.80 | 18.13 | 24.18 |
| | FR99MSI000044 | D50 | 19 | 0.2 | 23 | 20.28 | 30.7 | 8.76 | 8.04 | 17.8 | 25.44 | 29 |
| Howard/ Wilde Lake | HO05WLTR2X9 | Abkf | 11 | 9 | 14.1 | 14.32 | 17.9 | 2.76 | 10.2 | 13.6 | 16.3 | 17 |
| | | D50 | 11 | 10 | 18 | 20.91 | 45 | 10.36 | 13 | 15 | 23.5 | 33 |
| | | Wbkf/dbkf | 11 | 10.6 | 14.4 | 15.66 | 27.1 | 4.95 | 11.5 | 12.05 | 16.8 | 21.8 |
| | HO05WLTR1X10 | Abkf | 11 | 10.1 | 19.9 | 18.95 | 27.2 | 5.45 | 12.9 | 14.25 | 23.4 | 24 |
| | | D50 | 11 | 8.5 | 21 | 22.68 | 37 | 10.17 | 12 | 14 | 32 | 35 |
| | | Wbkf/dbkf | 11 | 13.2 | 16.1 | 15.87 | 22.2 | 2.45 | 13.8 | 14.3 | 16.35 | 17.1 |
| | HO05WLMR1X8 | Abkf | 11 | 17.4 | 30.5 | 28.06 | 39 | 7.60 | 18.2 | 21.25 | 33.15 | 36.8 |
| | | D50 | 11 | 0.5 | 9.1 | 7.43 | 12 | 4.23 | 1.8 | 3.7 | 11 | 11 |
| | | Wbkf/dbkf | 11 | 9 | 10.7 | 11.61 | 15.6 | 2.04 | 9.1 | 10.65 | 12.85 | 13.7 |
| | HO05WLMR1X7 | Abkf | 11 | 15.1 | 21.4 | 23.37 | 42.4 | 7.51 | 18.6 | 19.45 | 23.25 | 31.5 |
| | | D50 | 11 | 1.8 | 12 | 15.95 | 34 | 10.44 | 6 | 9.15 | 23.5 | 30 |
| | | Wbkf/dbkf | 11 | 17.4 | 20.7 | 21.21 | 30.2 | 3.35 | 18.5 | 19.7 | 21.5 | 22.8 |

*Table 9. Summary of Regression Statistics for Select Geomorphic Parameters by Location and Cross-Section*

A p-value of 0.1 or less is considered statistically significant and is shown in **bold**.

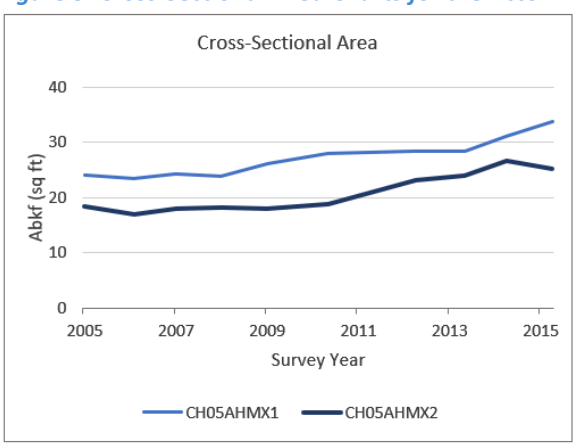
| County | WRM | Cross-section | Cross-Sectional Area | | Width-To-Depth Ratio | | Median Particle Size | |
|---|---|---|---|---|---|---|---|---|
| | | | $R^2$ | p-Value | $R^2$ | p-Value | $R^2$ | p-Value |
| Charles | Acton-Hamilton | CH05AHMX1 | 0.88536 | **0.00005** | 0.41080 | **0.04584** | 0.21242 | 0.18005 |
| | | CH05AHMX2 | 0.84464 | **0.00017** | 0.82514 | **0.00028** | | |
| Frederick | Peter Pan Run | FR99MSI000043 | | | | | 0.01258 | 0.64759 |
| | | FR99MSI000042 | | | | | 0.37245 | **0.00552** |
| | | FR99MSI000045 | | | | | 0.03851 | 0.46634 |
| | | FR99MSI000044 | | | | | 0.13277 | 0.12510 |
| Howard | Wilde Lake | HO05WLMR1X7 | 0.07817 | 0.40505 | 0.24593 | 0.12082 | 0.68275 | **0.00172** |
| | | HO05WLMR1X8 | 0.16329 | 0.63141 | 0.09478 | 0.35703 | 0.30695 | **0.07698** |
| | | HO05WLTR1X10 | 0.18342 | 0.18879 | 0.16111 | 0.22113 | 0.00079 | 0.93454 |
| | | HO05WLTR2X9 | 0.24075 | 0.12542 | 0.63125 | **0.00348** | 0.01038 | 0.76561 |

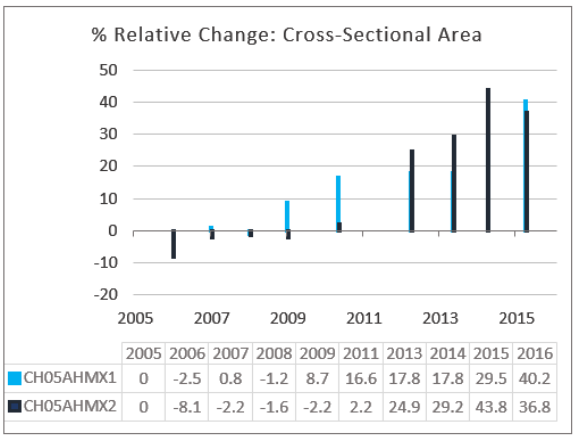
To visually explore potential trends in parameter values both spatially (i.e., upstream to downstream) and overtime, line and percent-relative-difference charts were plotted for the selected parameters.

## Acton-Hamilton, Charles County, MD

Figure 5 displays both line and percent-relative-change charts for the cross-sectional areas at bankfull stage (Abkf) in the Acton-Hamilton WRM area for the period of 2005 to 2016. Data, however, were not available for 2010 and 2012.

*Figure 5. Cross-Sectional Area Charts for the Acton-Hamilton WRM Area*



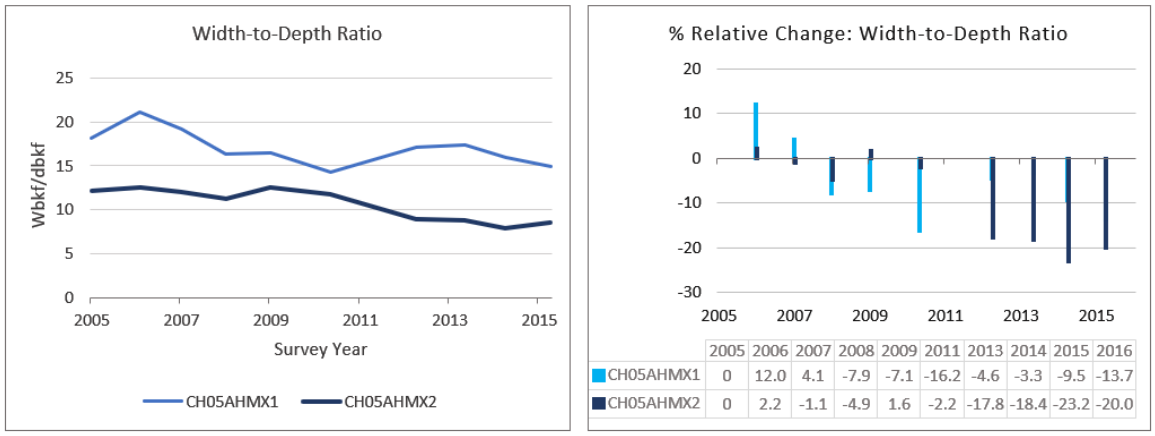

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2011 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|
| CH05AHMX1 | 0 | -2.5 | 0.8 | -1.2 | 8.7 | 16.6 | 17.8 | 17.8 | 29.5 | 40.2 |
| CH05AHMX2 | 0 | -8.1 | -2.2 | -1.6 | -2.2 | 2.2 | 24.9 | 29.2 | 43.8 | 36.8 |

The Abkf at cross-section CH05AHMX1, located upstream of a pool, is somewhat larger during the survey period than at CH05AHMX2, situated at the downstream end of the pool. Initially, the Abkfs at both cross-sections remained fairly constant until the 2009 survey at the upstream cross-section and 2011 survey at the downstream cross-section. Thereafter, the Abkfs at both cross-sections increased steadily over the next few years. Both trends are statistically significant as indicated by p-values of 0.00005 and 0.00017 for CH05AHMX1 and CH05AHMX2 respectively.

Figure 6 shows the line and percent-relative-change charts for the width-to-depth ratios (Wbkf/dbkf). The ratio of the downstream cross-section remained consistently smaller during the survey period. After an initial increase, the ratios at both cross-sections decreased starting in 2008, inversely mimicking the

increases in the cross-sectional areas. The downward trends in the width-to-depth ratios are statistically significant for both cross-sections as indicated by the p-values of 0.004584 for CH05AHMX1 and 0.00028 for CH05AHMX2.

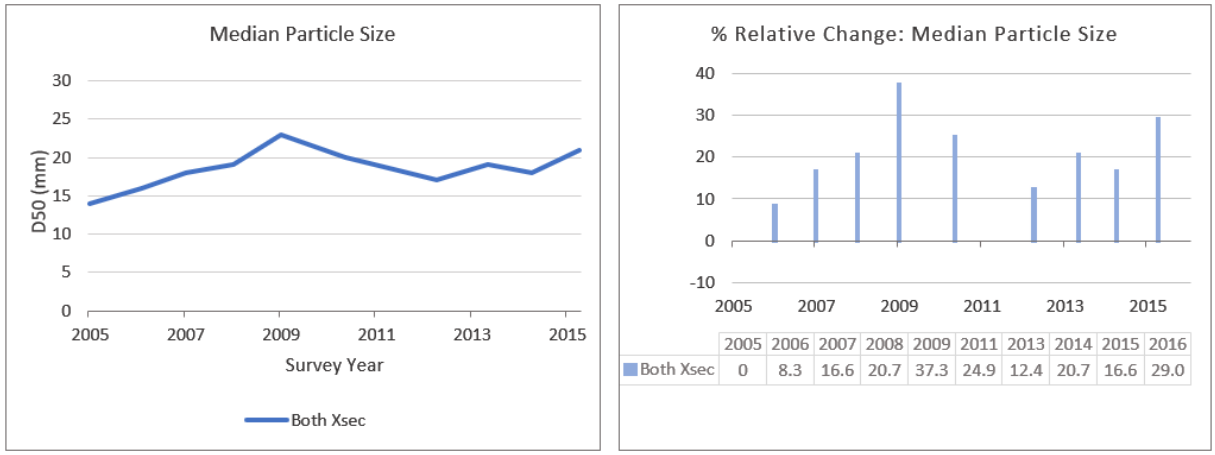
*Figure 6. Width-to-Depth Ratio Charts for the Cross-sections in the Acton-Hamilton WRM Area*




| | 2005 | 2006 | 2007 | 2008 | 2009 | 2011 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|
| CH05AHMX1 | 0 | 12.0 | 4.1 | -7.9 | -7.1 | -16.2 | -4.6 | -3.3 | -9.5 | -13.7 |
| CH05AHMX2 | 0 | 2.2 | -1.1 | -4.9 | 1.6 | -2.2 | -17.8 | -18.4 | -23.2 | -20.0 |

Figure 7 displays line and percent-relative-change charts of the median particle size (D50). The D50 values for both cross-sections were identical throughout the survey period as reported in the 2016 Acton-Hamilton report (KCI, 2016) from which the data were extracted. This may indicate that the values represent the reach rather than the cross-sections, but this should be verified with the data provider.

*Figure 7. Median Particle Size Charts for the Cross-sections in the Acton-Hamilton WRM Area*




| | 2005 | 2006 | 2007 | 2008 | 2009 | 2011 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|
| Both Xsec | 0 | 8.3 | 16.6 | 20.7 | 37.3 | 24.9 | 12.4 | 20.7 | 16.6 | 29.0 |

The D50 value fluctuated over the survey period between 14 mm and 23 mm, placing it into the medium to coarse gravel substrate category (Table 7). The D50 values were consistently higher during the period of 2006 to 2016 than for the baseline measurements taken in 2005. The p-value of the regression on D50, however, was not significant.

During the years 2011 to 2013, construction took place at the road culvert at Hamilton Road, just downstream of CH05AHMX2 (CCG, 2016), which may have altered the flow regime and/or slope of the channel. It is interesting to note that coinciding with the construction, the cross-sectional areas increased, and the width-to-depth ratios decreased, indicating that stream depth may have increased.

Additional geomorphic and flow data need to be examined, however, to ascertain whether the channel adjusted in response to the culvert construction or some other event within the WRM area. Of note is also that the cross-section station locations shifted somewhat over the years, which may have influenced geomorphic measurements and calculations.

## Wilde Lake, Howard County, MD

A line chart displaying the cross-sectional areas of the four cross-sections in the Wilde Lake WRM area is shown in Figure 8 and percent-relative-change charts in Figure 9. Data for the two cross-sections on the main tributary are shown in blue and those on the two upstream tributaries to the main tributary in red and orange. All four cross-sections are located above Wilde Lake as shown in Figure 3, and descriptions of their locations are provided in Table 5.

***Figure 8. Line Chart of the Cross-Sectional Areas in the Wilde Lake WRM Area***

Cross-sections located on the main tributary are drawn in blue and those on the upstream tributaries are in red and orange.

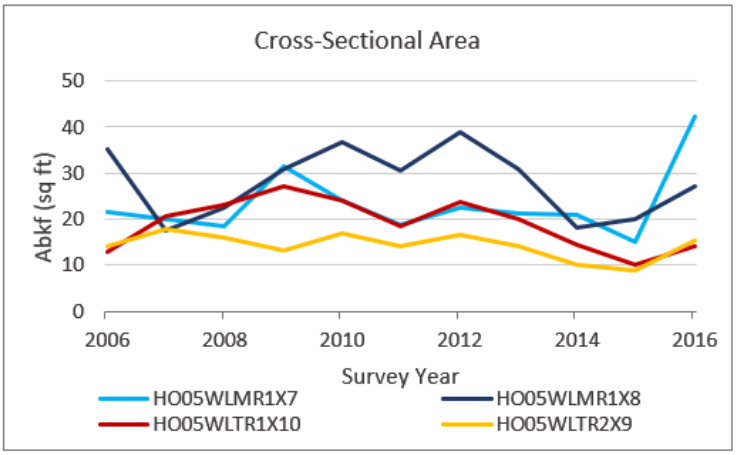
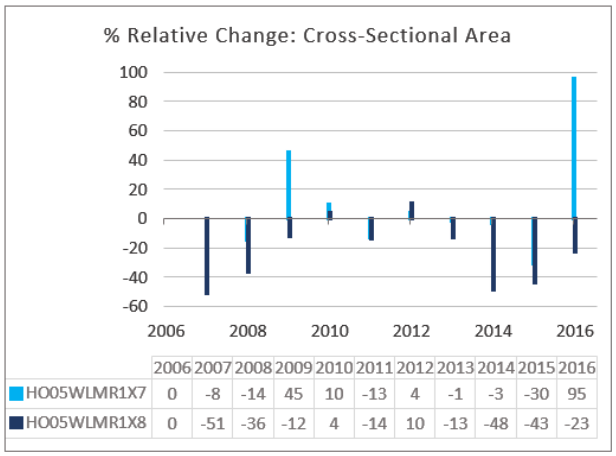
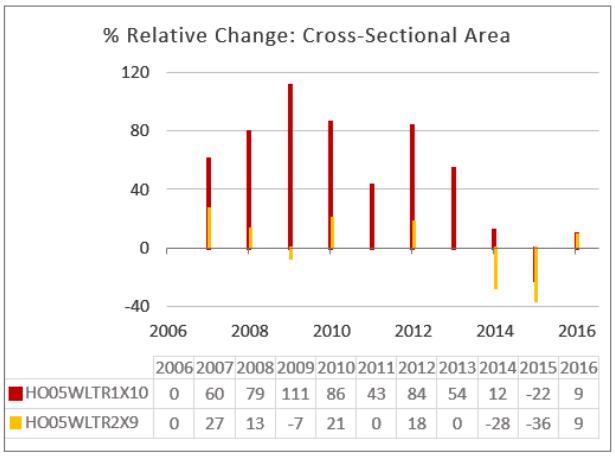



***Figure 9. Percent-Relative-Change Charts for Cross-Sectional Areas in the Wilde Lake WRM Area***

Cross-sections located on the main tributary are drawn in blue and those on the upstream tributaries are in red and orange.




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HO05WLMR1X7 | 0 | -8 | -14 | 45 | 10 | -13 | 4 | -1 | -3 | -30 | 95 |
| HO05WLMR1X8 | 0 | -51 | -36 | -12 | 4 | -14 | 10 | -13 | -48 | -43 | -23 |




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HO05WLTR1X10 | 0 | 60 | 79 | 111 | 86 | 43 | 84 | 54 | 12 | -22 | 9 |
| HO05WLTR2X9 | 0 | 27 | 13 | -7 | 21 | 0 | 18 | 0 | -28 | -36 | 9 |

Overall, fluctuations in the cross-sectional areas during the survey period were relative minor at all cross-section as evident by the percent relative changes in Figure 9. Regression analyses also did not reveal any statistically significant trends (see Table 9).

Line and percent-relative-change charts for the width-to-depth ratio are displayed in Figure 10 and Figure 11. Data for cross-sections located on the main tributary are drawn in blue and those on the upstream tributaries in red and orange.

***Figure 10. Line chart of the Width-to Depth Ratio (Wbkf/dbkf) at Cross-Sections in the Wilde Lake WRM Area***

Cross-sections located on the main tributary are drawn in blue and those on the upstream tributaries in red and orange.

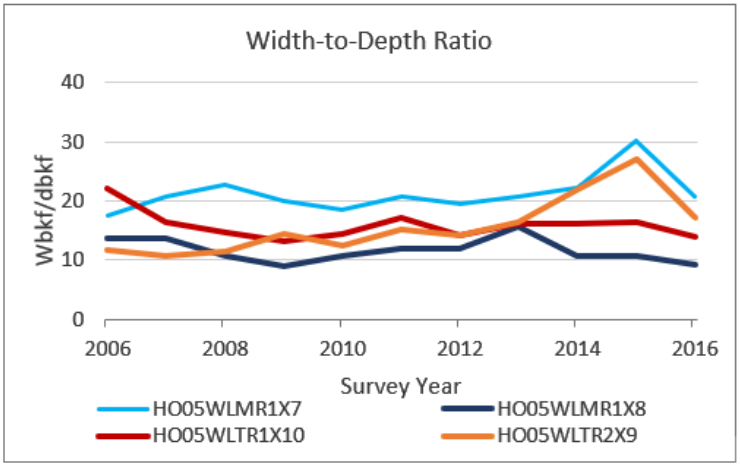
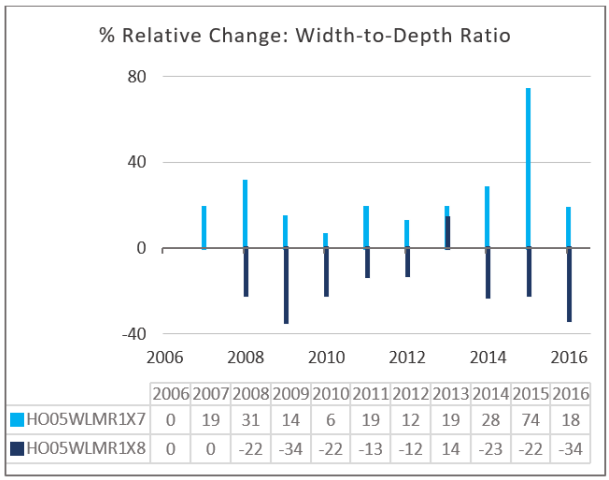
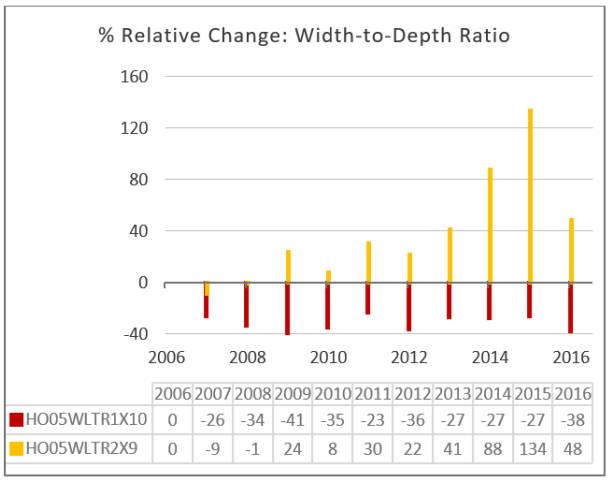



***Figure 11.Percent-Relative-Change Charts for the Width-to Depth Ratio (Wbkf/dbkf) at Cross-Sections in the Wilde Lake WRM Area***

Cross-sections located on the main tributary are drawn in blue and those on the upstream tributaries in red and orange.




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HO05WLMR1X7 | 0 | 19 | 31 | 14 | 6 | 19 | 12 | 19 | 28 | 74 | 18 |
| HO05WLMR1X8 | 0 | 0 | -22 | -34 | -22 | -13 | -12 | 14 | -23 | -22 | -34 |




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HO05WLTR1X10 | 0 | -26 | -34 | -41 | -35 | -23 | -36 | -27 | -27 | -27 | -38 |
| HO05WLTR2X9 | 0 | -9 | -1 | 24 | 8 | 30 | 22 | 41 | 88 | 134 | 48 |

Overall, the width-to-depth ration changed little overtime at all cross-sections, until about 2013 when the ratio increased at both the downstream cross-section on the main tributary (HO05WLMR1X7) and at the cross-section in the North tributary (HO05WLTR2X9). However, a statistically positive trend (with p-value of 0.00348) was only observed at HO05WLTR2X9.

Streams tend to get wider and shallower as their sediment supply exceeds their transport capacity, which may be reflected by an increase in the width-to-depth ratio. An increase in width, however, may also be due to bank erosion, undercutting, and other factors, and therefore, it is not possible to say what may have caused the increase in the ratio without examining additional hydrological and geomorphic characteristics as well as meteorological events.

Line and percent-relative-change charts for the median particle size are displayed in Figure 12 and Figure 13 respectively. Cross-sections located on the main tributary are drawn in blue and those on the upstream tributaries are in red and orange.

*Figure 12. Line chart of the Median Particle Size (D50) at cross-sections in the Wilde Lake WRM Area Median Particle Size (D50)*

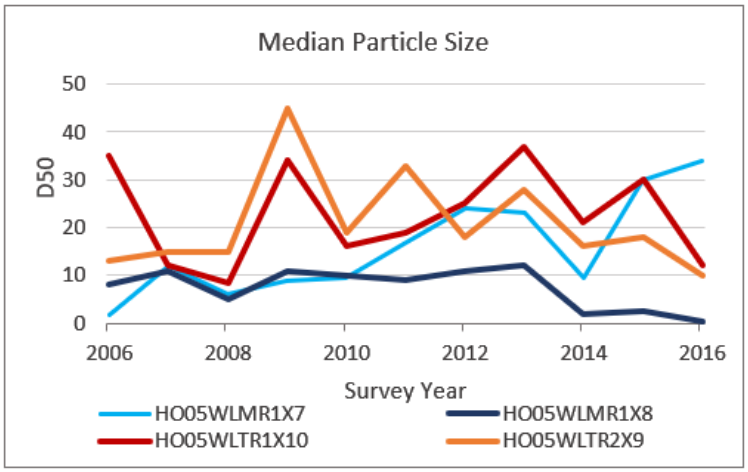
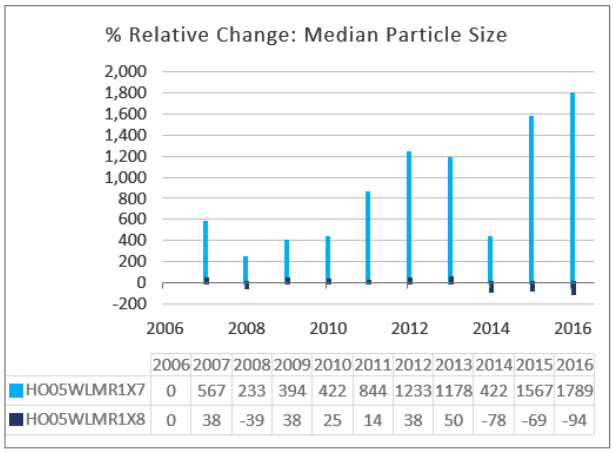
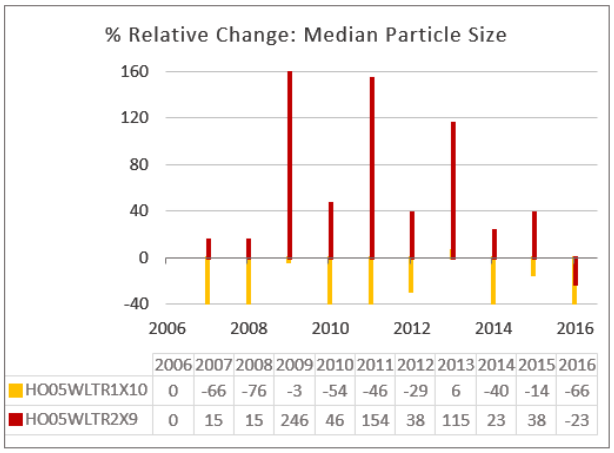



*Figure 13. Percent-relative-change charts of the Median Particle Size (D50) at cross-sections in the Wilde Lake WRM Area Median Particle Size (D50)*




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HO05WLMR1X7 | 0 | 567 | 233 | 394 | 422 | 844 | 1233 | 1178 | 422 | 1567 | 1789 |
| HO05WLMR1X8 | 0 | 38 | -39 | 38 | 25 | 14 | 38 | 50 | -78 | -69 | -94 |




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HO05WLTR1X10 | 0 | -66 | -76 | -3 | -54 | -46 | -29 | 6 | -40 | -14 | -66 |
| HO05WLTR2X9 | 0 | 15 | 15 | 246 | 46 | 154 | 38 | 115 | 23 | 38 | -23 |

At one of the cross-sections (HO05WLMR1X8) located on the main tributary, the D50 changed from medium gravel during the earlier years of stream assessments to coarse sand/very fine gravel around 2014, reflecting perhaps increasing sedimentation due to changes in the flow regime or bank erosion. This trend is statistically significant based on a p-value of 0.07698 (Table 9).

In the two upstream tributaries, the median particle size varied between medium to very coarse gravel over the years, but no significant trends were observed based on the p-values of the regression analysis (Table 9).

## Peter Pan Run, Frederick County, MD

Frederick County has monitored the Peter Pan Run WRM area since 1999 at two cross-sections on the main stem, one in Tributary 1 and one in Tributary 3 (Table 6). Cross-sectional area and width-to-depth ratio data were not available. Line and percent-relative-change charts for the median particle size (D50)

are provided in Figure 14 and Figure 15 respectively. Data for cross-sections on the main stem are drawn in blue and in the tributaries in red and orange. As can be seen, the D50 varied over the years at all cross-sections, but generally remaining in the fine to coarse gravel particle size class (Table 7). Trend analyses only found a statistically significant upwards trend for cross-section FR99MSI000042 based on a p-value of 0.00552 (Table 9).

***Figure 14. Line Chart for the Median Particle Size Distribution in the Peter Pan Run Monitoring Area***

Cross-sections on the main stem are drawn in blue and those in tributaries in red and orange.

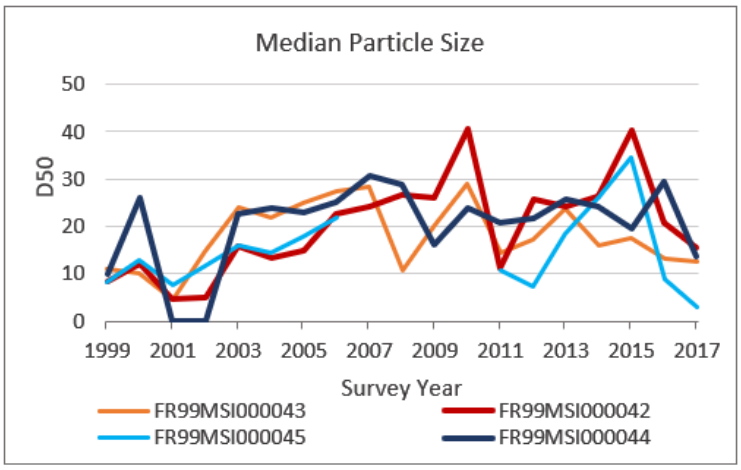
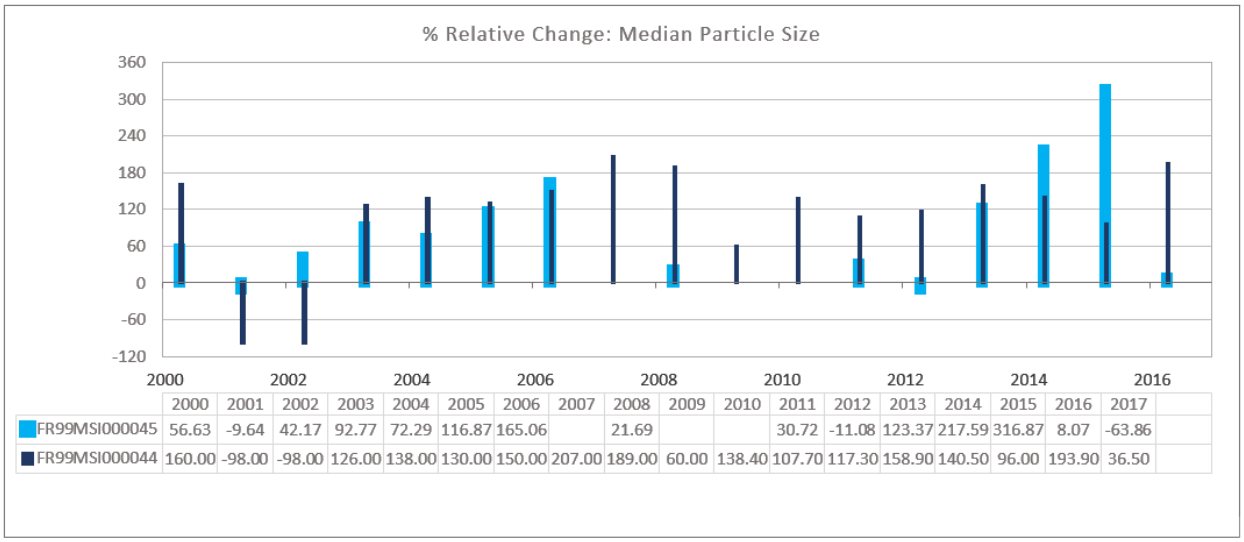
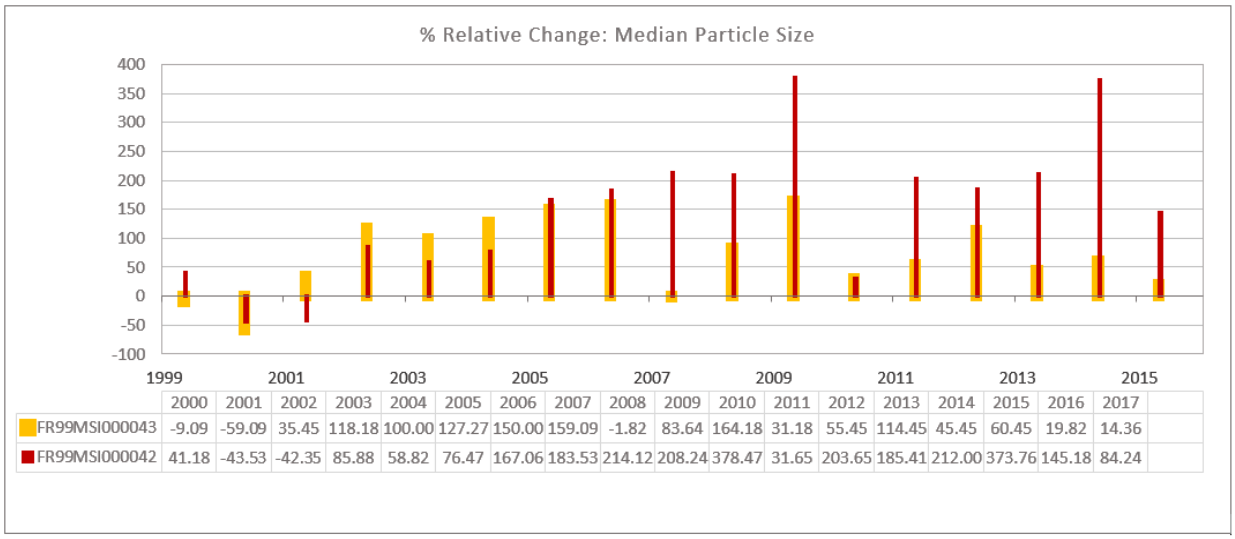



***Figure 15. Percent-Relative-Change Charts for the Median Particle Size Distribution in the Peter Pan Run Monitoring Area***

Cross-sections on the main stem are drawn in blue and those in tributaries in red and orange.




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FR99MSI000045 | 56.63 | -9.64 | 42.17 | 92.77 | 72.29 | 116.87 | 165.06 | | 21.69 | | | 30.72 | -11.08 | 123.37 | 217.59 | 316.87 | 8.07 | -63.86 |
| FR99MSI000044 | 160.00 | -98.00 | -98.00 | 126.00 | 138.00 | 130.00 | 150.00 | 207.00 | 189.00 | 60.00 | 138.40 | 107.70 | 117.30 | 158.90 | 140.50 | 96.00 | 193.90 | 36.50 |




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FR99MSI000043 | -9.09 | -59.09 | 35.45 | 118.18 | 100.00 | 127.27 | 150.00 | 159.09 | -1.82 | 83.64 | 164.18 | 31.18 | 55.45 | 114.45 | 45.45 | 60.45 | 19.82 | 14.36 |
| FR99MSI000042 | 41.18 | -43.53 | -42.35 | 85.88 | 58.82 | 76.47 | 167.06 | 183.53 | 214.12 | 208.24 | 378.47 | 31.65 | 203.65 | 185.41 | 212.00 | 373.76 | 145.18 | 84.24 |

## RECOMMENDATIONS

The work for this project was a first attempt to migrate geomorphological data into Microsoft Access and AWQMS database structures. Geomorphic parameters that were commonly measured or calculated by the permittees were selected (Table 2). If it has not already been done, MDE might considered consulting with a hydrogeologist to select additional parameters related to cross-section and longitudinal profile surveys, reach length, and particle size analyses for a more complete dataset that would enable MDE to evaluate changes in stream channel and floodplain characteristics; detect changes in the flow regime; notice spatial and temporal patterns; evaluate stream health; and assess the efficacy of BMPs and stream restoration projects.

MDE may consider developing software or modifying or using one the numerous commercial tools available that can streamline storing, calculating, and analyzing cross-sectional and longitudinal profile data, and can generate both tabular and graphical output. Having standardize software would ensure that the MS4 jurisdictions submit all relevant data in a consistent manner.

Examples of such tools include the *streaMSurvey* Excel workbook and *The REFERENCE REACH Spreadsheet* (Mecklenburg, 2006) that were used by Baltimore County and Charles County respectively to calculate and graph stream channel characteristics. Recently Shelly and Baily (2018) introduced "*the Cross Section Viewer, a software tool for storing, displaying, and automating common geomorphic analysis with riverine cross section data... automates: (1) longitudinal profiles of average bed elevation, (2) longitudinal cumulative volume change curves, and (3) depth distributions.*" The tool can also be used to export data to an Access database. With post-processing these tables could be modified for addition to MDE's NPDES geodatabase, which permittees are already using to report their annual MS4 data.

Redesigning the MDE NPDES geodatabase to store geomorphological data, however, may be a complex task depending on the desired results and warrants careful consideration. At a minimum, new database elements may include, but not limited to,

- feature classes to hold cross-section (point) and longitudinal profile and reach (line) coordinates and descriptions,
- main data tables to store survey data and calculated characteristics, and

- domain tables providing associated information.

MDE should also ensure that appropriate metadata are included with the data submittals, such as

- Cross-section and reach coordinates;
- Location descriptions including stream type, bedform, channel type, modifications to the stream channel (e.g. riprap);
- Sample collection method and equipment; and
- Calculation methods.

This would facilitate migration of the data into the AWQMS database.

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