Consolidated Total Maximum Daily Load (TMDL) Implementation Plan Interim Report Final Comprehensive Baseline Analysis

Prepared for:
District Department of the Environment

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DISTRICT DEPARTMENT OF THE ENVIRONMENT

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Table of Contents

Table of Contents vii

List of Figures ix

List of Tables x

List of Appendices xii

Executive Summary ES-1

Introduction ES-1
Overview of TMDLs ES-1
Development of the IP Modeling Tool ES-2
Development of the Baseline and Current Conditions and Gap Analysis ES-2
Findings and Implications ES-3

1. Introduction 1

2. Overview of TMDLs 3

2.1 Inventory 3
2.2 Review of TMDLs 4
2.3 Specific Variation in Load Estimate Modeling 5
2.3.1 Runoff Estimation 6
2.3.2 Rainfall Conditions 6
2.3.3 EMCs 6
2.4 Discussion 7

3. Data Collection and Analysis 9

3.1 Literature Reviews 9
3.1.1 Modeling Framework 9
3.1.2 EMCs 9
3.1.3 In-stream Erosion 10
3.1.4 BMPs 10
3.2 BMP Data Compilation 11

4. Development of IP Modeling Tool 13

4.1 Overview 13
4.2 Runoff and Pollutant Load Modules 13
4.2.1 Model Selection 14
4.2.2 Description of the Modified Version of the Simple Method 14
4.2.3 In-Stream Erosion Load Methodology Estimator 22
4.2.4 Trash Load Methodology 24
4.3 BMP Module 26
4.3.1 BMP Inventory 26
4.3.2 BMP Efficiencies 26
4.4 Application of the IP Modeling Tool 28

5. Baseline Condition, Current Condition, and Gap Analysis 29

5.1 Overview 29

5.2 Methodology 29
5.2.1 Baseline Condition 29
5.2.2 Current Condition 30
5.2.3 Gap Analysis 37
5.3 Results 37
5.3.1 Introduction..37
5.3.2 EMC Comparison 37
5.3.3 Area Comparison..39
5.3.4 Runoff Results and Comparison.. 40
5.3.5 Load Results and Comparison..43
6. Next Steps..59
Consolidated TMDL Implementation Plan 59
Revised Monitoring Framework 59
References..123
Appendices..125

List of Figures

Figure ES - 1: Gap Expressed as Percent Reduction Needed to Meet WLA ES-4
Figure 4 - 1: IP Modeling Tool Components 13
Figure 4 - 2: Sewershed Delineations 19
Figure 4 - 3: Chesapeake Bay Delineations 19
Figure 4 - 4: Mainstem Delineations 19
Figure 4 - 5: Tributary Delineations 19
Figure 4 - 6: SBE (as a Percent of Total TSS Load) as a Function of Imperviousness and Stream Degradation Potential 24
Figure 4 - 7: BMP Load Reduction Method Selection 27
Figure 5 - 1: Loads and Gap Analysis 29
Figure 5 - 2: Graphical Representation of the Gap 46
Figure 5 - 3: Gap Expressed as Percent Reduction Needed to Meet WLA 47
Figure 5 - 4: Percent Load Reduction Needed to Meet Annual WLAs 50
Figure 5 - 5: TSS Percent Load Reduction Needed to Meet Annual WLAs 51
Figure 5 - 6: Summary of Depth of Runoff Retention Needed to Meet Annual WLAs 54
Figure 5- 7: Projected WLAs Achieved with Incremental Increase in Runoff Retention Depth Provided ... 55
Figure 5 - 1: Spatial Representation of the Required BMP Retention Depth over the MS4 to Meet all Annual MS4 WLAs 56
Baseline Attachment Figure 1: TN Percent Load Reduction Needed to Meet Annual WLAs 103
Baseline Attachment Figure 2: TP Percent Load Reduction Needed to Meet Annual WLAs 104
Baseline Attachment Figure 3: TSS Percent Load Reduction Needed to Meet Annual WLAs 105
Baseline Attachment Figure 4: E. *coli* Percent Load Reduction Needed to Meet Annual WLAs 106
Baseline Attachment Figure 5: BOD Percent Load Reduction Needed to Meet Annual WLAs 107
Baseline Attachment Figure 6: Trash Percent Load Reduction Needed to Meet Annual WLAs 108
Baseline Attachment Figure 7: Arsenic Percent Load Reduction Needed to Meet Annual WLAs 109
Baseline Attachment Figure 8: Copper Percent Load Reduction Needed to Meet Annual WLAs 110
Baseline Attachment Figure 9: Lead Percent Load Reduction Needed to Meet Annual WLAs 111
Baseline Attachment Figure 10: Mercury Percent Load Reduction Needed to Meet Annual WLAs 112
Baseline Attachment Figure 11: Zinc Percent Load Reduction Needed to Meet Annual WLAs 113
Baseline Attachment Figure 12: Chlordane Percent Load Reduction Needed to Meet Annual WLAs 114
Baseline Attachment Figure 13: DDD Percent Load Reduction Needed to Meet Annual WLAs 115
Baseline Attachment Figure 14: DDE Percent Load Reduction Needed to Meet Annual WLAs 116
Baseline Attachment Figure 15: DDT Percent Load Reduction Needed to Meet Annual WLAs 117
Baseline Attachment Figure 16: Dieldrin Percent Load Reduction Needed to Meet Annual WLAs 118
Baseline Attachment Figure 17: Heptachlor Percent Load Reduction Needed to Meet Annual WLAs 119
Baseline Attachment Figure 18: PAH1 Percent Load Reduction Needed to Meet Annual WLAs 120
Baseline Attachment Figure 19: PAH2 Percent Load Reduction Needed to Meet Annual WLAs 121
Baseline Attachment Figure 20: PAH3 Percent Load Reduction Needed to Meet Annual WLAs 122

DISTRICT DEPARTMENT OF THE ENVIRONMENT

List of Tables

Table ES - 1: Comparison of Stormwater Volume Reductions Needed to Meet WLAs in the CSO and MS4....ES-5
Table 2 - 1: Inventory of TMDL Studies....3
Table 2 - 2: Representative Ranges of EMCs....6
Table 4 - 1: Reference Runoff Coefficients....16
Table 4 - 2: Delineated Drainage Areas....17
Table 4 - 3: Summary of ANOVA Analysis....20
Table 4 - 4: EMCs Used to Establish the Baseline....22
Table 4 - 5: Baseline Trash Loading Rates (lbs/acre/year) for the District MS4....25
Table 4 - 6: Baseline Trash Loading Rates for Nonpoint Source Direct Drainage for the District (lbs/1000 feet/year)....25
Table 5 - 1: Current Condition: Number and Distribution of MS4 Area BMPs by Watershed....35
Table 5 - 2: Area Controlled by BMPs in Each Watershed....36
Table 5 - 3: Selected EMCs for Use in the Implementation Plan Modeling Tool....38
Table 5 - 4: Comparison of Area (acres)....39
Table 5 - 5: Comparison of Runoff Volume (acre-ft/yr)....40
Table 5 - 6: Annual Baseline Load Comparison....43
Table 5 - 7: Reasons for Differences in Baseline Pollutant Loads....44
Table 5 - 8: Range of Percent Load Reduction Provided by Existing BMPs Across all MS4 TMDL Segments....45
Table 5 - 9: Comparison of Stormwater Volume Reductions Needed to Meet WLAs in the CSO and MS4.58
Baseline Attachment Table 1: TMDL for Sediment/TSS for the Anacostia River Basin, Montgomery and Prince George's Counties, MD and the District of Columbia (2007)....61
Baseline Attachment Table 2: Chesapeake Bay TMDL for Nitrogen, Phosphorus, and Sediment (2010)..62
Baseline Attachment Table 3: DC Final TMDL for Metals in Rock Creek (2004)....63
Baseline Attachment Table 4: DC Final TMDL for Fecal Coliform Bacteria in Upper Potomac River, Middle Potomac River, Lower Potomac River, Battery Kemble Creek, Foundry Branch, and Dalecarlia Tributary (2004)....64
Baseline Attachment Table 5: DC Final TMDL for Oil and Grease in the Anacostia River (2003)....65
Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004) 66
Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004) 71
Baseline Attachment Table 7: DC Final TMDL for Organics in Tidal Basin and Washington Ship Channel (2004)....76
Baseline Attachment Table 7: DC Final TMDL for Organics in Tidal Basin and Washington Ship Channel (2004)....77
Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)....78
Baseline Attachment Table 9: DC TMDL for Organics, Metals, and Bacteria in Oxon Run (2003)....88
Baseline Attachment Table 10: District of Columbia Final TMDL for Bacteria in the Chesapeake and Ohio Canal (2004)....89

Baseline Attachment Table 11: District of Columbia Final TMDL for Bacteria in the Tidal Basin and the Washington Ship Channel (2004).. 89
Baseline Attachment Table 12: District of Columbia Final TMDL for Fecal Coliform Bacteria in Kingman Lake (2003).. 90
Baseline Attachment Table 13: District of Columbia Final TMDL for Fecal Coliform Bacteria in Rock Creek (2004).. 90
Baseline Attachment Table 14: District of Columbia Final TMDL for Fecal Coliform Bacteria in Upper Anacostia River, Lower Anacostia River, Watts Branch, Fort Dupont Creek, Fort Chaplin Tributary, Fort Davis Tributary, Fort Stanton Tributary, Hickey Run, Nash Run, Popes Branch, Texas Avenue Tributary (2003).. 91
Baseline Attachment Table 16: District of Columbia Final TMDL for Organics and Metals in Battery Kemble Creek, Foundry Branch, and the Dalecarlia Tributary (2004) 92
Baseline Attachment Table 17: District of Columbia Final TMDL for Organics and Metals in Kingman Lake (2003)..94
Baseline Attachment Table 18: District of Columbia Final TMDL for Total Suspended Solids in Watts Branch (2003)..95
Baseline Attachment Table 19: District of Columbia Final TMDL for TSS, Oil &Grease, BOD in Kingman Lake (2003)..96
Baseline Attachment Table 20: TMDL for PCBs for Tidal Portions of the Potomac and Anacostia Rivers in DC, MD, and VA (2007)..97
Baseline Attachment Table 21: TMDL of Nutrients/BOD for the Anacostia River Basin, Montgomery and Prince George's Counties, MD and the District of Columbia (2008).. 98
Baseline Attachment Table 22: TMDL of Trash for the Anacostia River Watershed, Montgomery and Prince George's Counties, MD and the District of Columbia (2010)..100
Baseline Attachment Table 23: TMDL Upper Anacostia River Lower Anacostia River District of Columbia BOD (2001).. 101
Baseline Attachment Table 24: TMDL for Total Suspended Solids in the Upper and Lower Anacostia River, District of Columbia (2002)..102

List of Appendices

Appendix A, Technical Memorandum: Model Selection and Justification
Appendix B, Technical Memorandum: Sewershed and Watershed Delineations
Appendix C, Technical Memorandum: Stream Erosion Methodology
Appendix D, Technical Memorandum: Selection of Event Mean Concentrations (EMCs)
Appendix E, Technical Memorandum: Review of MS4 Outfall Monitoring and Water Quality Conditions to Assess MS4 WLAs and TMDLs
Appendix F, Technical Memorandum: BMPs and BMP Implementation

Executive Summary

Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in its Municipal Separate Storm Sewer System (MS4) permit. This Comprehensive Baseline Analysis Report describes a series of critical steps toward that end, including:

- Organizing the various TMDLs studies, waste load allocation (WLA) and nonpoint source load allocation (LA) requirements that need to be met.
- Developing an IP Modeling Tool to examine both pollutant runoff and load reductions with best management practices (BMPs).
- Determining the baseline pollutant load condition at the time when the TMDL studies were carried out (roughly 2000 to 2004) and the current condition that reflects the presence of BMPs implemented in recent years.
- Determining the level of implementation, or "gap," remaining to meet MS4 WLAs.

The analysis described in this report provides the District with a framework and tools needed to address stormwater management needs with respect to TMDLs in a comprehensive and coordinated manner.

Overview of TMDLs

A total of 26 TMDL studies were developed for impaired waters in the District - 15 for waterbodies in the Anacostia watershed, six (6) for waterbodies in the Potomac watershed, three (3) for waterbodies in the Rock Creek watershed, and two (2) that encompass impaired waters in both the Anacostia and the Potomac watersheds. Altogether, these TMDL studies provide allocations for 23 different pollutants in 45 different waterbody segments. The TMDL studies include 518 individual MS4 WLAs, including annual, seasonal, monthly, and daily WLAs. Subsequent re-sampling for PAHs, PCBs, pesticides and metals resulted in updated 303(d) listings that moved many of these TMDLs into Category 3, which includes waterbodies for which there is insufficient available data and/or information to make a use support determination. Based on discussions with EPA Region 3 regarding the original impairment listings and TMDLs and the updated sampling results, DDOE concluded that the need for MS4 WLAs for these waterbodies was no longer supported by the data. Therefore, these MS4 WLAs are no longer applicable and the Consolidated TMDL IP will not include further implementation plans to achieve the WLAs.

Review of TMDL documentation confirmed that varied approaches were used to establish the TMDLs in the District. This often led to using different sewershed and watershed areas, characterization of MS4 and non-MS4 areas, models, precipitation records (climate periods), and event mean concentrations (EMCs). The review also revealed that documentation for the many of the TMDL studies was limited and often incomplete. In addition, a number of issues and inconsistencies regarding the cause of impairment, implementation expectations and redundant TMDL studies were identified. Many of these issues are currently unresolved.

Faced with the charge to develop a Consolidated TMDL IP for all of the TMDLs, the District developed a new IP Modeling Tool that could be applied consistently across the city. This IP Modeling Tool utilizes technology and data that was not available when the TMDLs were developed. This includes better geo-spatial information (GIS coverages), an inventory of BMPs, and a record of MS4 outfall monitoring data.

Development of the IP Modeling Tool

The IP Modeling Tool tracks and accounts for pollutant load generation and load reduction across the District for all of the pollutants of interest that have MS4 WLAs. It consists of three parts:

- Runoff Module: calculates the runoff volume using the Modified Version of the Simple Method (CWP and CSN, 2008).
- Pollutant Load Module: calculates the pollutant loads using event mean concentrations (EMCs), stream bank erosion calculations, and/or trash load rates in conjunction with runoff volume from the runoff module described above.
- BMP Module: consists of the current BMP inventory and the assumed BMP pollutant load reduction efficiencies in order to calculate load and runoff reductions provided by the BMPs.

BMPs implemented by DDOE, DDOT, DC Water, one federal agency (GSA), and other public and private sector entities are included in the IP Modeling Tool, and more BMPs will be added as they are constructed and additional information is gathered. The categories of approved structural BMPs incorporated into the IP Modeling Tool are:

- Green Roofs
- Impervious Surface Disconnect
- Bioretention
- Infiltration
- Ponds
- Storage Practices
- Tree Planting and Preservation
- Open Channel Systems
- Wetlands
- Proprietary Practices
- Rainwater Harvesting
- Permeable Pavement Systems
- Filtering Systems
- Trash Traps

Non-structural BMPs consist of programmatic, operational, and restoration practices that help prevent or minimize pollutant loading or runoff generation. The non-structural BMPs included or planned for future inclusion in the IP Modeling Tool are:

- Stream Restoration
- Street Sweeping
- Catch Basin Cleaning
- Pet Waste Removal
- Illicit Discharge Detection and Elimination
- Impervious Surface Reduction
- Coal Tar Sealant Ban
- Phosphorus Fertilizer Ban
- Trash Skimmer Boats
- Plastic Bag Law
- Trash Cleanup Events

Application of the IP Modeling Tool provides a consistent method to track the achievement of TMDLs in a consistent manner for all pollutants and all TMDLs.

Development of the Baseline and Current Conditions and Gap Analysis

The IP Modeling Tool was applied to develop the baseline and current conditions, and to assess the remaining gap in load reduction that is required to attain the WLAs defined by the TMDL.

The baseline condition establishes a starting point for the evaluation of the number, type and distribution of BMPs and other stormwater management practices required to meet WLAs and LAs. For the purposes of this analysis, the baseline condition includes the stormwater loads in place when the majority of

TMDLs were developed (circa 2000 to 2004). A separate baseline condition was established for each of the WLAs and LAs.

The current condition includes current stormwater pollutant loads in the District that are influenced and reduced by existing BMPs and other storm water management practices that are in place. This includes structural and non-structural BMPs installed and put into operation prior to 2014. Runoff and pollutant loads are reduced in areas where treatment by BMPs is provided.

The gap represents the difference between the current stormwater pollutant loads and the individual WLAs. A gap analysis was undertaken to quantify this difference in terms of pollutant load reduction (e.g., lbs) that is needed to meet the established MS4 WLA targets. Quantification of the gap in this manner establishes the amount of pollution reduction that remains to be achieved in order to meet WLAs across the District, and demonstrates the degree to which existing BMPs have reduced pollutant load in regard to the WLAs. Major findings and implications are summarized in the next section.

Findings and Implications

The major findings of the Comprehensive Baseline Analysis are as follows:

- The use of GIS technology greatly improved the District's understanding of the MS4 system with respect to sewershed drainage areas and the land use and land cover makeup of sewersheds.
- The MS4 outfall monitoring program data collected by the District during 2001 through 2013 provided a body of wet weather observations that was applicable for the development of updated EMCs for conventional pollutants and metals.
- The IP Modeling Tool was developed to approximate stormwater runoff, pollutant load generation, and pollutant load reduction in a consistent manner for the entire MS4 area in the District. This tool serves as an accounting framework for tracking MS4 pollutant loads, load reduction, and progress toward attainment of the MS4 WLA targets.
- The IP Modeling Tool produced baseline pollutant loadings that differed from the baseline loads reported in the TMDL studies. This was largely attributable to a combination of the use of a consistent runoff calculation for all TMDLs, the re-delineation of sewershed areas, and the use of updated EMCs. This resulted in approximately three-fourths of individual TMDL segments for which there are MS4 WLAs having larger baseline loads than previously reported, and one-fourth having lower baseline loads.
- The inventory of existing BMPs was useful in determining a current condition that shows the load reduction achieved by these BMPs. In general, the existing BMPs have a very minor impact on reducing pollutant loads across the District. Trash presents an exception, where current control programs remove roughly 65 to 90 percent of the trash load.
- The lack of necessary tracking data for non-structural BMPs such as catch basin cleaning, illicit discharge detection and elimination, and pet waste control makes it difficult to include the pollutant removal capabilities of these practices in the analysis of current conditions.
- A summary of the remaining pollutant load reduction required is presented in Figure ES-1. This figure shows the status of each of the 406 MS4 WLAs in regard to the relative amount of BMP implementation and load reduction that is required to achieve loading levels that attain the MS4 WLAs.

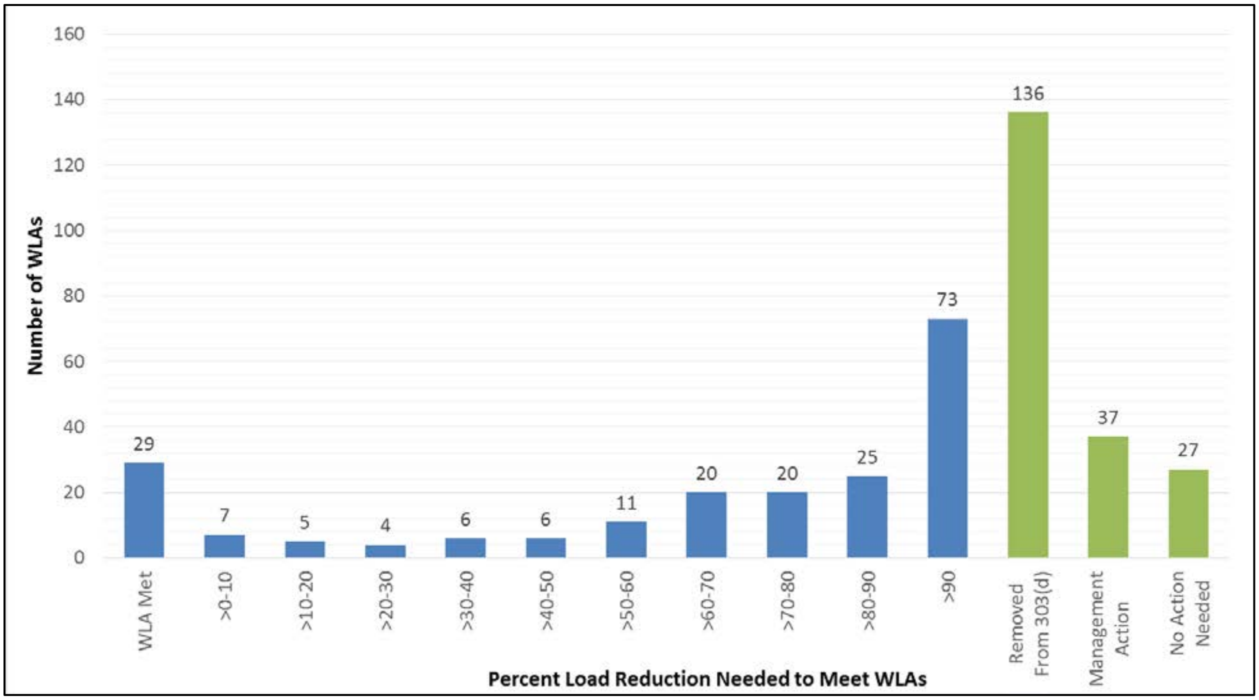

Figure ES - 1: Gap Expressed as Percent Reduction Needed to Meet WLA

- The gap analysis revealed that 29 MS4 TMDL WLAs have been attained.
- The gap analysis also confirmed that a very large amount of stormwater volume and pollutant load reduction will be needed to meet MS4 WLA targets. A total of 76 MS4 TMDL WLAs will require more than a 50 percent reduction in current loads, and 73 of these require reduction that is 90 percent or greater.
- The pollutant load reduction gaps for individual TMDL segments for which there are MS4 WLAs vary substantially in magnitude, and no distinctive spatial patterns were found.
- Bacteria and organic substances are the controlling pollutants that require the greatest amount of stormwater control. These pollutants also makeup the majority of MS4 TMDL WLAs.

The major implications of these finding for the Consolidated TMDL IP are as follows:

- Pollutant load reduction gaps for nearly all of the MS4 TMDL WLAs are substantial. Achieving the WLAs for the majority of the pollutants will require extremely high levels of stormwater management and control.
- The existing inventory of BMPs represents a start, but on average achieves less than 3 percent of the pollutant load reduction that is needed per WLA.
- A requirement to retain 1.2 inches of runoff volume (the standard required by DC's new stormwater regulations), even if applied to the entire MS4 drainage area (not just to new development and redevelopment), would not achieve the prescribed load reduction for nearly 45 percent of the MS4 TMDL WLAs.
- The MS4 area is largely residential (39 percent) and, beyond the RiverSmart programs, there is little incentive for home owners in residential neighborhoods to retrofit stormwater BMPs on their properties.

- The public right of way including streets, sidewalks and alleys represent a very large percentage of the impervious surfaces within the MS4 area (27 percent). Developing a comprehensive program to implement street-side bioretention and use permeable pavement products in the public right of way would likely be very advantageous to the ultimate success of DDOE's Consolidated TMDL IP.
- The cost of meeting the MS4 TMDL WLAs will be exceptionally high. For contextual purposes, the MS4 runoff reduction volumes required to meet the MS4 TMDL WLAs for bacteria across the District are compared in Table ES - **1** with the combined sewer overflow (CSO) volumes controlled under DC Water's CSO Long Term Control Plan (DC WASA, 2002). As shown, the MS4 volumes are greater than the CSO volumes covered in DC Water's control program – a program that will cost approximately $2 billion to implement. The use of bacteria as the driving pollutant is used in this comparison because the required level of CSO control is essentially based on meeting the water quality standards for bacteria, and is represented in the bacteria TMDLs as a CSO WLA.
- Managing large volumes of stormwater to meet MS4 WLAs is further complicated because BMPs, the traditional approach to stormwater and nonpoint source control, have their own inherent limits as volume control practices. Furthermore, opportunities to successfully implement BMPs will also be limited.

Table ES - 1: Comparison of Stormwater Volume Reductions Needed to Meet WLAs in the CSO and MS4

Watershed	CSO Volume Controlled (MG)	CSO Control as a Percent	MS4 Volume to be Controlled (MG)	MS4 Control as a Percent
Anacostia	2,088	97.5	2,895	76.4
Potomac	984	92.5	962	30.8
Rock Creek	44	90.0	1,569	91.3
Total	3,116		5,426	

- Given the required level of control and the volume control limits associated with BMPs, this analysis suggests that an approach focused solely or even primarily on distributed implementation of BMPs will not be sufficient to attain MS4 WLAs in the near-term.
- In light of this analysis, while implementation is underway it will also be prudent to re-examine the scientific basis of the TMDLs and MS4 WLAs. Many of the TMDLs are based on data, analysis and modeling that was performed 10 to 15 years ago. The re-examination could be accomplished with targeted outfall and receiving water monitoring, and overseen by a Scientific Advisory Board. Revisiting the scientific basis of the TMDLs and MS4 WLAs during the early phase of implementation over the next NPDES permit cycle would not slow down implementation, and it would verify the level of control needed.

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1. Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in the District's Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) permit (U. S. EPA 2011 and U. S. EPA 2012). The IP will define and organize a multi-year process centered on reducing pollutant loads originating within the District MS4. The level of pollutant control will be based on past TMDL studies performed to protect impaired water bodies in the District. The IP will include a summary of the regulatory compliance strategy to satisfy TMDL-related permit requirements, a summary of data and methods used to develop the IP, specific prioritized recommendations for stormwater control measures, a schedule for implementation and attainment of Waste Load Allocations (WLAs), and a method for tracking progress. Substantial public involvement will be sought in plan development.

This ***Final Comprehensive Baseline Analysis*** summarizes a critical step in the process to establish the IP. It describes and documents the development of an IP Modeling Tool and its application to quantify "baseline loads." Baseline loads represent the stormwater loads in the District that are not influenced or reduced by BMPs or other storm water management practices. For the purposes of this analysis, baseline loads refer to the stormwater loads occurring (circa 2000 to 2004) when the majority of TMDLs were developed. This standardizes inputs such as land use and precipitation in the IP Modeling Tool, although it also means that the inputs to the IP Modeling Tool are not exactly the same as those used to develop the TMDL baseline loads.

The Final Comprehensive Baseline Analysis documents the number, type and location of existing structural and non-structural BMPs used to control runoff and MS4 pollutant loads in the District. A *current load*s condition representing the pollutant loading situation in 2013-2014 is quantified by including these BMPs and their performance characteristics in the IP Modeling Tool.

The Final Comprehensive Baseline Analysis establishes the remaining MS4 pollutant loads to be reduced for each of the TMDLs. Referred to as "the Gap", this evaluation of the amount of remaining pollutant load reduction that needs to be accomplished is based on a comparison of current loads and individual MS4 WLAs. The Gap provides the all-important pollutant load reduction targets for the IP.

The Final Comprehensive Baseline Analysis also addresses progress made to date with respect to the following:

- An analysis of BMPs that have been implemented since WLAs were first established. *This analysis is described in Section 3 under Data Collection and Analysis.*
- An analysis of pollutant load reductions that have been achieved by those implemented BMPs. *This analysis is described in Section 5 under Results*.
- Adjusted pollutant loads reductions remaining that are necessary to achieve WLAs. *This analysis is described in Section 5 under Results.*
- An evaluation of the development of TMDLs and the District's water quality monitoring record to determine if TMDL WLAs have been achieved. *This evaluation is described in Appendix E: Review of MS4 Outfall Monitoring and Ambient Water Quality Conditions to Assess MS4 WLAs and TMDLs*
- An analysis of pollutant load increases that have occurred since WLAs were first established. *This analysis is described in Appendix E: Review of MS4 Outfall Monitoring and Ambient Water Quality Conditions to Assess MS4 WLAs and TMDLs*

The remainder of this Final Comprehensive Baseline Analysis is organized to provide relevant information on the following topics:

- Overview of TMDLs
- Data Collection
- Development of the MS4 Modeling Tool
- Baseline Condition, Current Condition, Gap Analysis, and Results
- Next Steps

Detailed technical information that supports the Final Comprehensive Baseline Analysis is provided in a series of six topical Technical Memoranda that are appended to this report.

The information compiled in this Final Comprehensive Baseline Analysis provides a framework for the estimation and tracking of storm water runoff, pollutant loads and pollutant loads reduction in a consistent manner across the District. Looking ahead, this framework will be applied to evaluate implementation scenarios with various combinations of structural and non-structural BMPs targeted to reduce “The Gap” of remaining pollutant loads for each MS4 WLA. The end point of this evaluation is an IP for the District that describes and schedules the additional investment in storm water control that is necessary within MS4 areas in order to achieve the WLAs prescribed in the TMDL studies.

2. Overview of TMDLs

2.1 Inventory

A total of 26 TMDL studies have been developed for impaired waters in the District – 15 for waterbodies in the Anacostia watershed, six (6) for waterbodies in the Potomac watershed, three (3) for waterbodies in the Rock Creek watershed, and two (2) that encompass impaired waters in both the Anacostia and the Potomac watersheds. Altogether, these TMDL studies provide allocations for 23 different pollutants in 45 different waterbody segments. The TMDL studies include 518 individual MS4 WLAs. A summary of these TMDL studies is provided in Table 2 - 1.

The first TMDL studies were completed in 1998 by the District Department of Health (DOH) Environmental Health Administration. This agency continued to develop TMDLs in the District through 2004, by which time 21 of 26 TMDL studies were completed. Additional TMDL studies for TSS, nutrients and BOD, and trash in the Anacostia River watershed were completed jointly by DDOE and the Maryland Department of the Environment (MDE) between 2007 and 2010. In 2007, the Interstate Commission on the Potomac River Basin (ICPRB) released the Tidal Potomac and Anacostia PCB TMDL on behalf of DDOE, MDE, and the Virginia Department of Environmental Quality. U.S. EPA Region 3 also finalized the Chesapeake Bay TMDL in 2010.

Table 2 - 1: Inventory of TMDL Studies

TMDL Study	Waterbody
Hickey Run PCB, Oil and Grease, Chlordane – 1998	Anacostia
Anacostia BOD – 2001*	Anacostia
Anacostia TSS – 2002*	Anacostia
Anacostia & Tributaries Bacteria - 2003	Anacostia
Anacostia & Tributaries Metals/ Organics –2003	Anacostia
Anacostia Oil & Grease - 2003	Anacostia
Fort Davis BOD - 2003	Anacostia
Watts Branch TSS 2003	Anacostia
Kingman Lake Bacteria (2003)	Anacostia
Kingman Lake Organics and Metals (2003)	Anacostia
Kingman Lake TSS, Oil and Grease, BOD (2003)	Anacostia
Anacostia TSS – 2007	Anacostia
Anacostia Nutrients/BOD – 2008	Anacostia
Anacostia Trash - 2010	Anacostia
Potomac and Anacostia Tidal PCB - 2007	Potomac and Anacostia
Chesapeake Bay TMDL	Potomac and Anacostia
Potomac & Tributaries Bacteria -2004	Potomac
Potomac Tributaries Organics and Metals - 2004	Potomac
Tidal Basin and Ship Channel Bacteria - 2004	Potomac

Table 2 - 1: Inventory of TMDL Studies	
TMDL Study	**Waterbody**
Tidal Basin and Ship Channel Organics -2004	Potomac
Oxon Run Organics, Metals, and Bacteria - 2004	Potomac
Ship Channel pH - 2004	Potomac
Chesapeake and Ohio Canal Bacteria - 2004	Potomac
Rock Creek Metals -2004	Rock Creek
Rock Creek Bacteria -2004	Rock Creek
Rock Creek Tributary Metals - 2004	Rock Creek
*Replaced by the Anacostia watershed TMDLs in 2007 and 2008	

2.2 Review of TMDLs

Once compiled, the documentation for each TMDL within the District was reviewed in order to understand the approaches and inputs used as part of its development. This review identified several topics (discussed below and in more detail in Section 2.3) that were important to understand as development of the IP Modeling Tool began. Combined, the review and better understanding of these topics helped guide decision-making during the development of the IP Modeling Tool.

The large number of TMDL studies completed over a 12 year period by the five different agencies cited above, along with differences in available datasets, modeling approaches, and documentation, complicates the task of developing a consolidated planning approach to achieving MS4 WLAs. In addition, the bulk of TMDLs were prepared during 2003 and 2004, the timeframe when EPA was clarifying its regulatory requirements for establishing WLAs for stormwater discharges in TMDLs[1]. Consequently, many of the older TMDL studies did not differentiate between stormwater loads from the MS4 system and areas that drained directly to the waterbodies (direct drainage areas). While EPA's Decision Rationale documents, which are part of the TMDL approval process, typically divide stormwater loads into MS4 WLAs and direct drainage LAs, this is not always the case. Some District TMDLs have MS4 and direct drainage loads expressed as an aggregated LA, and in the case of one TMDL, the MS4 load is aggregated with the combined sewer overflow (CSO) load. Finally, multiple TMDLs were also developed for the same pollutant in the same watershed at different times (e.g., TMDLs for TSS in the Anacostia in 2007 and Chesapeake Bay TMDL requirements for TSS in the Anacostia) as new information was developed or the needs for TMDLs changed, but the old TMDLs were not officially replaced by the new TMDLs, meaning that multiple TMDLs are in effect for the same waterbody/pollutant combination.

Furthermore, the approach to TMDL development and modeling differed depending on the type of waterbody for which the TMDL was developed. TMDL studies have been completed for four different types of waterbodies in the District:

- Mainstem waterbodies (the Anacostia and Potomac Rivers and Rock Creek).
- Small tributaries to the mainstems (e.g., Hickey Run, Texas Avenue Tributary, and other small tributaries in the Anacostia watershed; Battery Kemble Creek, Dalecarlia Tributary, and Foundry

[1] EPA Memorandum *Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs*, from Robert H. Wayland, III, Director, Office of Wetlands, Oceans and Watersheds, and James A. Hanlon, Director, Office of Wastewater Management, to Water Division Directors, Regions 1 - 10, dated November 22, 2002.

Branch in the Potomac watershed; and Soapstone Creek, Klingle Valley, and other small tributaries in the Rock Creek watershed).

- Other waterbodies that are not small tributaries but which are hydraulically connected to the mainstems (e.g., Tidal Basin and Ship Channel; the C&O Canal; and Kingman Lake).
- Chesapeake Bay segment-sheds (a set of four segments representing Potomac and Anacostia drainage areas in the District).

Under these circumstances, there were multiple drainage area delineations and varying representations of MS4 areas vs. non-MS4 areas even within the same waterbody, depending on the TMDL.

Refinements over time in GIS technology have led to improved delineation of current sewershed and watershed boundaries, and better identification of impervious surfaces (streets, alleys, sidewalks, parking lots, etc.). This information was not available at the time that many of the TMDL studies were undertaken. In addition, the review and analysis of stormwater outfall monitoring data collected under DDOE's NPDES permit has allowed the use of current data to develop revisions to event mean concentrations (EMCs) used to describe the discharge of pollutants from the MS4 system. Use of these improved datasets in a Consolidated IP Modeling Tool strengthens confidence in the application of load estimates and the reliability of modeling results.

Water quality standards, impairment evaluations and the need for TMDLs and MS4 WLAs continue to evolve over time. For example, as part of the response to the Friends of the Earth vs. the Environmental Protection Agency, 446 F.3d 140, 144 court ruling that required the development of daily limits for TMDLs in the District, additional sampling was done for many District waterbodies to fill data gaps with current information in preparation of converting existing TMDLs for these waterbodies to daily loads. In light of concerns regarding the data used in the original impairment listings, a complimentary goal of this work was to use the data to either verify impairment of these waterbodies, or to indicate the need for additional data to determine the impairment status. Subsequent re-sampling for PAHs, PCBs, pesticides and metals resulted in updated 303(d) listings that moved many of these TMDLs into Category 3, which includes waterbodies for which there is insufficient available data and/or information to make a use support determination. Based on discussions with EPA Region 3 regarding the original impairment listings and TMDLs and the updated sampling results, DDOE concluded that the need for MS4 WLAs for these waterbodies was no longer supported by the data. Therefore, these MS4 WLAs are no longer applicable and the Consolidated TMDL IP will not include further implementation plans to achieve the WLAs. In addition, in 2005, the fecal coliform water quality standard was changed to E. coli. Therefore, all of the original bacteria TMDLs, which had included allocations for fecal coliform, were updated to include E. coli allocations to reflect the new E. coli water quality standard. Thus the analyses conducted for this report reflect the use of most up-to-date inventory of applicable MS4 WLAs.

2.3 Specific Variation in Load Estimate Modeling

The TMDL studies used a variety of methods to calculate runoff and pollutant load. Because multiple models and methods were used in the different TMDL studies, it is not the intent of a consolidated IP Modeling Tool to replicate original TMDL results. The differences in these methods, however, are important to understand when developing and applying a single modeling tool to be used on a city-wide basis for load estimation and reduction purposes in the IP. Examples for runoff estimation, rainfall conditions and load estimation are presented below to illustrate the differences between the original TMDLs and the updated data and methods to be used in the IP Modeling Tool which is described further in Section 4.

2.3.1 Runoff Estimation

A variety of models were used in the existing TMDLs to estimate runoff from the MS4 and non-MS4 areas in the District. Each represents applicable hydrological processes with different degrees of complexity, and each has its own distinct equations and algorithms. These include:

- The Danish Hydraulic Institute MOUSE Model
- The District of Columbia Small Tributary Model
- The Simple Method
- The EPA BASINS (Better Assessment Science Integrating Point & Non-point Sources) modeling framework.
- The EPA Storm Water Management Model (SWMM) in combination with BASINS
- The EPA Chesapeake Bay Watershed Model (HSPF – Hydrologic Simulation Program FORTRAN)

Additional documentation on where the specific models were used is included in Appendix A, *Technical Memorandum: Model Selection and Justification* of this document. The use of different models and other runoff estimation methods to develop TMDLs is understandable given the variety of agencies and contractors involved, and the needs of each individual TMDL when it was developed.

2.3.2 Rainfall Conditions

A variety of rainfall conditions were used to drive the hydrologic and pollutant loading models in the estimation of runoff and load. These included:

- 1985 to 1994
- 1988 to 1990
- 1991 to 2002
- 1995 to 1997
- 1994 to 2005

The use of different time periods for assessing runoff and pollutant loads was necessary because these distinct rainfall periods were identified for specific planning needs (e.g., DC Water's CSO LTCP, Chesapeake Bay Program modeling, etc.).

2.3.3 EMCs

Event Mean Concentrations (EMCs) are considered to be the flow-weighted concentration of a given pollutant parameter during storm events. EMCs are calculated as the total mass of a pollutant in the runoff divided by the total runoff volume. The evaluation and selection of EMCs for the TMDL studies incorporated the applicable research and end-of-pipe stormwater data that was available at the time of TMDL development. Upon review, substantially different EMCs were often used to characterize the same pollutant in different TMDL studies. Ranges of EMCs used in the District's TMDL studies, for a subset of pollutants, are presented in Table 2 - 2 to exhibit this point.

Table 2 - 2: Representative Ranges of EMCs

Pollutant	EMC	Units
Fecal Coliform	17,000 to 28,265	MPN/100 mL
TSS	35 to 227	mg/L
Copper	50 to 78	ug/L
Zinc	104 to 183	ug/L

More detailed discussion of EMCs used in existing TMDLs is discussed further in subsequent sections of this document, as well as in Appendix D, *Technical Memorandum: Selection of Event Mean Concentrations (EMCs)*.

2.4 Discussion

Review of TMDL documentation confirmed that a variety of modeling approaches, drainage areas, precipitation data and EMCs were used within and between the multiple TMDLs in the District. In addition, changes to the MS4 WLA inventory over time reflect updated water quality sampling, impairment listings, and water quality standards. Newer MS4 outfall monitoring datasets and land use GIS coverages are also presently available and relevant to a quality IP modeling effort moving forward. Because of all of these factors, it is deemed appropriate to develop and apply a consistent load estimation methodology and consolidated modeling tool that develops baseline loads (i.e., stormwater loads) in place when the majority of TMDLs were developed (circa 2000 to 2004) using the best information currently available. Understandably, these results may well differ from values developed for each TMDL. However, DDOE is required to develop and test implementation scenarios on a city wide level, and the fact that established WLAs remain unchanged, the use of a consistent modeling approach and (often improved) dataset is deemed in line with the needs of the Consolidated TMDL IP.

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3. Data Collection and Analysis

3.1 Literature Reviews

Literature reviews and research were conducted for several tasks during the development of the baseline conditions, including the selection of the modeling framework, the development of the EMCs, and the identification of the methodology for accounting for in-stream erosion. In each case, the goal was to identify the best science that had been developed on the topic, and to evaluate the feasibility for implementing, adopting, or integrating literature-based data and methods. Literature reviews were conducted using on-line databases, internet searches, review of professional journals, and contacts with experts in the field. For each individual topic, the literature was reviewed and pertinent data and methods were compiled. Particular emphasis was placed on understanding how the various data and methods were developed so that the feasibility/validity of using the data or method could be assessed. A short summary of the literature review undertaken for each of the major topic areas is provided below.

3.1.1 Modeling Framework

A literature review was performed on the capabilities of each of the existing models used in the District's TMDLs, as well as of other publically available models, to determine if any of these models should be chosen for the IP development. The literature review included evaluations of models used in the existing TMDLs, including the HSPF, SWMM, and MOUSE/Mike Urban models, as well as calculator tools such as the Spreadsheet Tool for Estimating Pollutant Load and the Watershed Treatment Model. The literature review included evaluations of information such as the runoff method used, the method for calculating pollutant load, the different types of pollutants that can be accommodated, etc. Evaluation of each model through the literature review supported the recommendation to use the Modified Version of the Simple Method as the runoff and load calculator in the IP Modeling Tool, discussed in more depth in Section 4.

A complete summary of the review of potential modeling frameworks is provided in Appendix A, *Technical Memorandum: Model Selection and Justification.*

3.1.2 EMCs

EMCs used in the original TMDLs were developed from various sources; however, a literature review of EMC data was undertaken to determine if literature-based EMCs might be usable to better represent different aspects of runoff in the District – specifically different land use types. The literature review was thus undertaken to determine if usable, representative EMC values could be determined for each type of land use in the District.

The literature review consisted of evaluation of peer-reviewed research papers and technical reports that were published by federal, state, or local agencies, or through scientific journals. The review was geographically comprehensive and included data from international, national, and regional sources. Regional values reviewed included published data specific to the District, Virginia, and Maryland. Much of the regional data originated from local technical reports, watershed implementation plans (WIPs), and TMDL reports, which made the data particularly relevant to the District's IP.

End-of-pipe MS4 monitoring data were also reviewed to determine if sufficient data existed to develop updated EMCs that could be (1) used in the IP Modeling Tool and (2) compared to the original EMCs used in the District's TMDLs. Sufficient end-of-pipe data was available to calculate EMCs for most conventional pollutants (TN, TP, TSS, bacteria, oil and grease, BOD) and some metals (copper, lead, arsenic, and zinc), but data were insufficient to calculate EMCs for the remaining metals and for the toxic pollutants (e.g., mercury, PAHs, pesticides, PCBs). Note that fecal coliform EMCs were translated into E. coli EMCs using the DC Bacteria Translator using the statistical relationship between paired fecal coliform and E. coli data collected in the District's waters (LimnoTech 2011 and 2012)[2].

A summary discussion of the EMCs chosen for use in the Consolidated TMDL IP and the IP Modeling Tool is provided in the Section 4.2.2.d. A complete summary of the EMC evaluation process is provided in Appendix D, *Technical Memorandum: Selection of Event Mean Concentrations (EMCs)*.

3.1.3 In-stream Erosion

In-stream erosion can be an important source of sediment and nutrient load into District waterbodies. A consistent method to account for in-stream erosion within a broad variety of stream conditions that are present in the District is deemed necessary for the consolidated IP modeling effort. A review of how in-stream erosion was accounted for in the existing TSS TMDLs was undertaken to better understand the historical precedent. A literature review was also conducted to identify potential approaches for estimating the rate of stream erosion. The literature review included review of direct measurement studies, theoretical calculation methods such as the Bank Assessment for Non-point source Consequences of Sediment (BANCS) Method and the Penn State MapShed Method, as well as a review of empirical methods. A literature review was also conducted to review applicable sediment delivery ratios. Sediment delivery ratios represent the fraction of the eroded soils that contribute to the in-stream sediment load. A complete summary of the evaluation of stream erosion is provided in Appendix C, *Technical Memorandum: Stream Erosion Methodology*.

3.1.4 BMPs

A review of structural and non-structural BMP information was undertaken to help develop load reduction methods for the various BMPs that either exist or are planned for use in the District. For structural BMPs, standard load reduction methods include the load reduction efficiency and the volume reduction efficiency approaches.

The literature review for the volume reduction efficiency approach was primarily focused on the volume reduction efficiencies documented in "Recommendations of the Expert Panel to Define Removal Rates for New State Stormwater Performance Standards" developed by Schueler and Lane (2012) for the Chesapeake Bay Program's Urban Stormwater Work Group (CBP Work Group). The CBP Work Group approach developed nutrient and sediment removal rates for these composite categories of BMPs based on the amount of runoff treated or reduced. The removal rates are presented as BMP removal rate adjustor curves based on runoff depth managed (i.e., treated or reduced) per impervious acre.

The literature review for the load reduction efficiency approach consisted of first evaluating the International Stormwater BMP Database (2013) to determine if it could be used to develop pollutant percent removals. Linear regression analysis of both local and national paired BMP data for inflow and outflow concentrations returned extremely poor fits, and thus this data source was not usable for the intended purpose. Additional literature review was undertaken to identify peer reviewed journals and previously approved Watershed Implementation Plans (WIPs) that studied the pollutant removal efficiency of structural BMPs. Data was abundant for some pollutants (e.g., nutrients, TSS, fecal coliform), less abundant for other pollutants (e.g., copper, lead, zinc, BOD), and minimal to non-existent for the

[2] Documentation related to development of the DC Bacteria Translator is in LimnoTech's 2011 Memorandum, Final Memo Summarizing DC Bacteria Data and Recommending a DC Bacteria Translator (Task 2) and LimnoTech's 2012 Memorandum, Update on Development of DC Bacteria Translators.

remaining pollutants (arsenic, mercury, organic toxics). Based on this data gap for organics, additional research was undertaken to identify literature that focused on using TSS as a surrogate for organics, particularly to identify papers or reports that show a correlation between TSS loads and loads of the listed organic compounds.

A literature review was also conducted to help develop load reduction methodologies for non-structural BMPs. The literature review focused on identifying non-structural BMPs for which load reduction impacts could be quantified, either directly or indirectly. The literature review consisted of research of primary and secondary literature (i.e., review of other literature reviews), and, in many cases, follow up communications with the authors of the primary literature.

A complete summary of the various load reduction methods and literature review is provided in Appendix F, *Technical Memorandum: BMPs and BMP Implementation*.

3.2 BMP Data Compilation

Both structural and non-structural BMPs were compiled into comprehensive databases for use in the IP Modeling Tool. The BMP databases includes information on BMPs (BMP type, spatial locations, ownership, information on area treated and/or volume managed, and other data) that provides input data for the IP Modeling Tool and is used to calculate load reductions or inform future implementation scenarios. Data on existing BMPs was used to calculate existing load reductions to help determine current status relative to achieving WLAs.

In order to develop a comprehensive database of existing BMPs in the District, existing BMP data was compiled from multiple sources used for internal and external tracking and reporting, including the existing DDOE BMP Tracking Database; RiverSmart Communities and RiverSmart Homes spreadsheets; Green Roofs spreadsheet; data reported by federal agencies including GSA, the District of Columbia Army National Guard, U.S. Army Installation Management Command, National Park Service, and National Zoological Park; data from the DC Water Clean Rivers Project (DCCR); and a dataset that includes all BMPs operated by the District Department of Transportation (DDOT).

Data from these sources exist in multiple formats, use different schema, and have variable degrees of completeness and accuracy. Therefore, rigorous QA/QC was performed on the data from these different sources to ensure that the required database fields were populated with consistent data. Critical data tracked in the database includes BMP identification information, BMP type, drainage area controlled, build date, and locational information. Data were reviewed to remove duplicate records and evaluate the reliability/accuracy of information for each record. Questions regarding whether individual BMPs included in the database had actually been built, as well as issues with reported drainage areas, were resolved through specific QA/QC steps. In particular, issues regarding reported drainage areas were resolved through a GIS analysis that led to recommended modifications to reported drainage areas for some BMPs (for more information on this issue and the recommendations, see Appendix F, *Technical Memorandum: BMPs and BMP Implementation)*. Any missing spatial location data for individual BMPs was also researched and updated through the use of several methods, including the District's Master Address Repository (MAR) geocoder, a list of previously researched locations from internal DDOE documentation, and a manual geocoding process. A full discussion of the development of the BMP database is provided in Appendix F, *Technical Memorandum: BMPs and BMP Implementation*. (Note: efforts are planned with the goal of verifying and improving information on existing BMPs. This should allow better characterization of the current conditions for future iterations of the BMP modeling.)

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4. Development of IP Modeling Tool

4.1 Overview

The IP Modeling Tool is used to calculate loads and load reductions for use in the development of the baseline and current conditions, and the determination of the "gap" between current conditions and the WLA for an individual pollutant. It will also be used to develop implementation scenarios for use in the Consolidated TMDL IP. The Tool consists of three parts:

- Runoff Module: calculates the runoff volume using the Modified Version of the Simple Method
- Pollutant Load Module: calculates the pollutant loads using event mean concentrations (EMCs), stream bank erosion calculations, and/or trash load rates in conjunction with runoff volume from the runoff module described above
- BMP Module: consists of the current BMP inventory and the BMP pollutant load reduction efficiencies in order to calculate load and runoff reductions provided by the BMPs

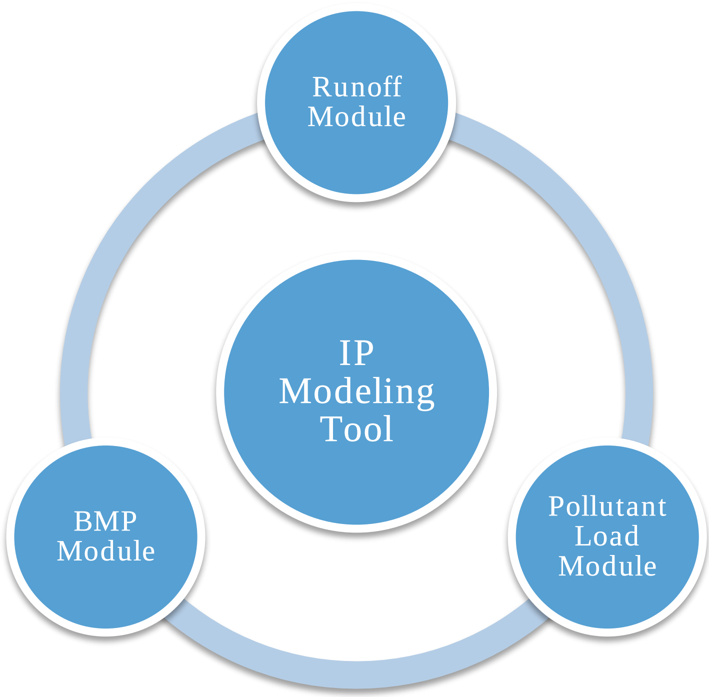

Figure 4 - 1: IP Modeling Tool Components

The development and application of each part is described in the following sections. Additional detail is also provided in various appendices as indicated in the text below.

4.2 Runoff and Pollutant Load Modules

While the Runoff and Pollutant Load Modules are separate components of the IP Modeling Tool, they are discussed together in this section because data from the Runoff Module feeds directly into the Pollutant Load Module to calculate loads.

4.2.1 Model Selection

The Modified Version of the Simple Method was selected for the IP Modeling Tool to calculate runoff and pollutant loads from land-based sources. This decision followed a detailed review and evaluation of modeling needs and requirements. The Modified Version of the Simple Method was developed by the Center for Watershed Protection and the Chesapeake Stormwater Network to account for the differential impact of turf and forest cover in generating runoff from a site (CWP and CSN, 2008). The Modified Version of the Simple Method only accounts for surface flows, it does not account for subsurface flow and loads. A wide variety of other models were also evaluated in this process, including many of the models used to develop TMDLs in the District. In fact, the Simple Method was amongst the set of models applied to generate stormwater loads and, in particular, direct drainage loads in several of the District TMDL studies.

The Modified Version of the Simple Method is designed to calculate annual or seasonal runoff volumes and loads in urbanized areas and small watersheds. It has been broadly applied in the greater Chesapeake Bay area to support MS4 and TMDL planning studies. Many states, including Maryland, Virginia, New York and New Hampshire, recommend use of the Simple Method or the Modified Version of the Simple Method for stormwater management purposes.

For this effort, the Modified Version of the Simple Method was found to be very well suited to calculate annual or seasonal runoff volumes and loads to support development of a Consolidated TMDL IP for the District. Only wet-weather surface flows and loads will be modeled to support the TMDL IP.

More information on the selection and justification of the Modified Version of the Simple Method can be found in Appendix A, *Technical Memorandum: Model Selection and Justification*.

In addition to using the Modified Version of the Simple Method, a methodology was developed to estimate the load contribution of sediment and nutrients from in-stream erosion. More information on the selection and justification of the in-stream erosion methodology can be found in Appendix C, *Technical Memorandum: Stream Erosion Methodology*.

Lastly, to calculate the trash load generated in the MS4, a separate calculation method was applied that is based on land use (i.e.: commercial, residential, forested, etc.) and trash loading rates (lbs/acre). These three methods are further described below.

4.2.2 Description of the Modified Version of the Simple Method

The Simple Method was originally developed at the Metropolitan Washington Council of Governments by Schueler (1987) using local (metropolitan Washington area) stormwater data collected under EPA's Nationwide Urban Runoff Program, or NURP. The Modified Version of the Simple Method was developed by the Center for Watershed Protection (CWP) and the Chesapeake Stormwater Network (CSN) in order to specifically incorporate the runoff characteristics of turf and forest cover, as well as hydrologic soil groups, into the modeling (CWP and CSN, 2008). The Modified Version of the Simple Method also accommodates the calculation of the daily load expression for TMDLs.

The Modified Version of the Simple Method is described by the following two equations:

$$R = \frac{P \; x \; P_j \; x \; R_{vc}}{12} \times A \qquad (1)$$

$$L = R \times C \times 2.72 \qquad (2)$$

Where:

R = Runoff volume, typically expressed in acre-feet

P = Precipitation, typically expressed in inches

P_j = Precipitation correction factor, typically 0.9

R_{vc} = Composite runoff coefficient

A = Area of the catchment, typically expressed in acres

L = pollutant load, typically expressed in pounds

C = Flow-weighted mean pollutant concentration, typically expressed in mg/l

A unit conversion factor of 12 is used for inches for precipitation, and 2.72 is used for the combination of acres for area and mg/l for pollutant concentration (Note: a separate conversion factor of 1.03E-3 MPN is used for bacteria concentrations).

The four main inputs to the Modified Version of the Simple Method are rainfall, runoff coefficients, drainage areas and EMCs. Each is discussed separately in the following sub-sections.

4.2.2.a Rainfall

Rainfall drives the generation of runoff and pollutant loads. The calculation of runoff and pollutant loads with the Modified Version of the Simple Method is typically based on annual rainfall totals. The use of alternative annual rainfall amounts to assess different planning conditions or global climate change is accommodated in the Modified Version of the Simple Method by simple replacement of rainfall depth in the runoff equation.

The DC WLAs and LAs are typically expressed as annual loading. The baseline loads developed and described in this report use the average annual rainfall amount observed and recorded at Washington National Airport over the entire period of record. The average rainfall of 40 inches was used in the runoff equation to represent the average rainfall condition in the District.

A small set of TMDLs in the District have a seasonal load, which is based on the growing season for aquatic plants (defined as April 1st through October 31st). The rainfall data for this 7-month period was obtained from the rain gage at Washington National Airport, and averaged over the entire period of record. The seasonal rainfall of 25 inches was used in the runoff equation to represent the seasonal rainfall condition in the District.

In addition, several TMDLs in the District have a "daily load expression" to represent a critical condition that is protective of water quality on a daily basis (as opposed to an annual basis). To convert the annual loads to daily loads, the annual load was multiplied by the ratio of the daily WLA to the annual WLA expressed in these TMDLs.

4.2.2.b Runoff Coefficient

The runoff coefficient is a composite value that represents the fraction of rainfall that is converted to runoff for the area being modeled. The recommended reference runoff coefficients for use in the Modified Version of the Simple Method are summarized in Table 4 - 1. As shown, all impervious areas have a high runoff coefficient of 0.95. This reflects the fact that most rainfall that falls on impervious surfaces becomes runoff. On the other hand, turf and forest areas tend to have much lower runoff coefficients, and generate less runoff. The under lying hydrologic soil group (HSG) for turf and forest areas has a strong influence on runoff generation, and is differentiated accordingly.

Table 4 - 1: Reference Runoff Coefficients			
Soil Group	**Impervious**	**Turf**	**Forest**
HSG A Soils	0.95	0.15	0.02
HSG B Soils	0.95	0.20	0.03
HSG C Soils	0.95	0.22	0.04
HSG D Soils	0.95	0.25	0.05

The GIS data used to identify the runoff coefficients for each area modeled is as follows:

- The impervious area is a layer from DC OCTO (known as "ImperviousSurfacePly") and includes roads, driveways, alleys, highways, rooftops, parking lots, sidewalks, and any other impervious cover. This impervious area GIS layer characterizes the total impervious area in the MS4 area. This layer does not characterize the *effective* impervious area, which is the impervious area that is directly connected to stream channels. However, since the MS4 is heavenly urbanized and serviced by a dense network of storm sewers, it is assumed for the purposes of this project that all impervious areas in the MS4 are essentially directly connected to stream channels.
- The forested area is a layer from DC OCTO (known as "Wooded Area"). This layer includes parks, protected easements, conservation areas, and other wooded areas.
- The turf area was created for use in the IP Modeling Tool. Any area not included in DC OCTO's impervious or wooded layer was considered to be turf area. Turf is considered to be open land with no impervious surface. This area includes fields, yards, grassed areas, and rights-of-way.
- The soil type is a layer from DC OCTO (known as "SoilPly"), although the original source behind this layer is actually the Soil Survey Geography (SSURGO) database. Additional information on how to assign the hydrologic soil group was obtained from the USDA NRCS.

The composite runoff coefficients for each area modeled are developed based on weighting the relative presence of each soil and land cover type, and the appropriate runoff coefficient. In the MS4 area, the runoff coefficients for the TMDL waterbodies range from 0.43 to 0.86. In the direct drainage areas, which are predominantly parkland areas, the runoff coefficients for the TMDL waterbodies range from 0.06 to 0.47.

4.2.2.c Drainage Areas

Drainage area in the Modified Version of the Simple Method describes the physical extent of the sewershed or watershed included in the runoff and pollutant load calculation. For the purposes of this Baseline Conditions Report, the applicable areas are the MS4 and direct drainage areas that are assigned WLAs or LAs in the TMDL studies.

The delineation of drainage areas was largely based on DC OCTO GIS coverages (topography and stream-lines) and a DC Water geodatabase that includes sewer pipes and outfalls. Instead of using automated Digital Elevation Model (DEM) techniques, delineation was done manually in order to account for the complexities of delineation in an urban landscape. Other GIS coverages and aerial imagery were used where needed to support delineation. Detailed information on the delineation methodology can be found in Appendix B, *Technical Memorandum: Sewershed and Watershed Delineations*.

All land areas within the District were included in the delineation. The major categories of drainage area delineations needed to categorize land within the District and to match established WLAs and LAs are:

- **MS4 Areas**: These areas represent land in the District that drains to the separate storm sewers.

- **CSS Areas**: These areas represent land that drains to the combined sewer system (CSS) that borders the MS4 area. While it is important to note the existence of the CSS areas, these areas will not be included in the IP Modeling Tool since they are not included under the MS4 permit requirements.
- **Direct Drainage (DD) Areas**: These areas represent areas that are not served by the MS4 or CSS systems. These areas are typically parks that border streams and rivers.

Figure 4-2 shows the delineation of these three major areas.

Additional delineations of the MS4 and direct drainage (DD) areas were necessary in order to establish the areas that currently have an established TMDL. These areas are typically referred to as TMDL waterbodies, and they exist at various spatial scales, including:

- Chesapeake Bay Watershed Segments: These areas represent the areas that have a WLA under the Chesapeake Bay TMDL. This represents the coarsest level of delineation for the District. A map of the Chesapeake Bay Segments is presented in Figure 4-3.
- Mainstem Watersheds: These areas represent the watersheds draining to the Anacostia, Rock Creek and Potomac River. These major watersheds at typically divided into upper and lower segments, and a middle segment for the Potomac River. This is shown in Figure 4-4.
- Tributary and Other Small Waterbody Watersheds: These areas represent the watersheds draining to the small tributaries that have TMDLs, as well as other small waterbodies (such as the Washington Ship Channel and Kingman Lake) that are not tributaries but which also have TMDLs. This is shown in Figure 4-5.

Note that these delineations include both MS4 and direct drainage areas.

The drainage areas associated with the TMDL studies are summarized in Table 4 - 2.

Table 4 - 2: Delineated Drainage Areas

Name	MS4/WLA Area (acres)	DD/LA Area (acres)	Name	MS4/WLA Area (acres)	DD/LA Area (acres)
Anacostia	8679	2827	**Nash Run**	297	12
Anacostia Lower	1567	632	**Normanstone Creek**	166	51
Anacostia Upper	7112	2,195	**Northwest Branch**	1,976	12
ANATF_DC	6893	2,952	**Oxon Run**	1,800	344
ANATF_MD	2522	106	**Pinehurst Branch**	246	201
Battery Kemble Creek	92	140	**Piney Branch**	45	55
Broad Branch	900	245	**Pope Branch**	172	65
C&O Canal	490	97	**Portal Branch**	62	9
Dalecarlia Tributary	977	114	**Potomac Lower**	3,552	346
Dumbarton Oaks	12	124	**Potomac Middle**	783	679
Fenwick Branch	162	57	**Potomac Upper**	2,692	931
Fort Chaplin Tributary	132	21	**POTTF_DC**	9,190	4019

Table 4 - 2: Delineated Drainage Areas					
Name	**MS4/WLA Area (acres)**	**DD/LA Area (acres)**	**Name**	**MS4/WLA Area (acres)**	**DD/LA Area (acres)**
Fort Davis Tributary	60	44	**POTTF_MD**	1,133	150
Fort Dupont Tributary	50	382	**Rock Creek Lower**	1,010	688
Fort Stanton Tributary	29	92	**Rock Creek Upper**	3,022	1756
Foundry Branch	90	106	**Soapstone Creek**	411	104
Hickey Run	826	269	**Texas Avenue Tributary**	74	44
Kingman Lake	296	296	**Tidal Basin**	247	54
Klingle Valley Run	125	46	**Washington Ship Channel**	440	176
Lower Beaverdam Creek	2	29	**Watts Branch**	1,019	231
Luzon Branch	590	53	**Watts Branch - Lower**	261	145
Melvin Hazen Valley Branch	109	65	**Watts Branch - Upper**	758	86

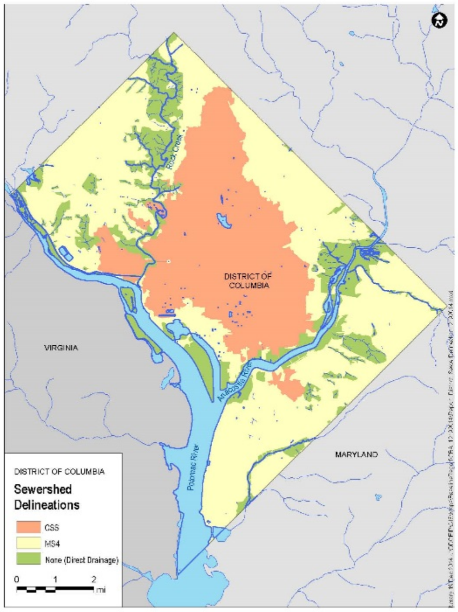

Figure 4 - 2: Sewershed Delineations

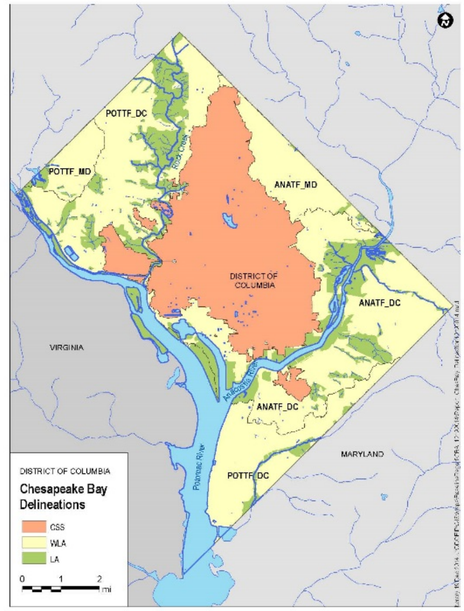

Figure 4 - 3: Chesapeake Bay Delineations

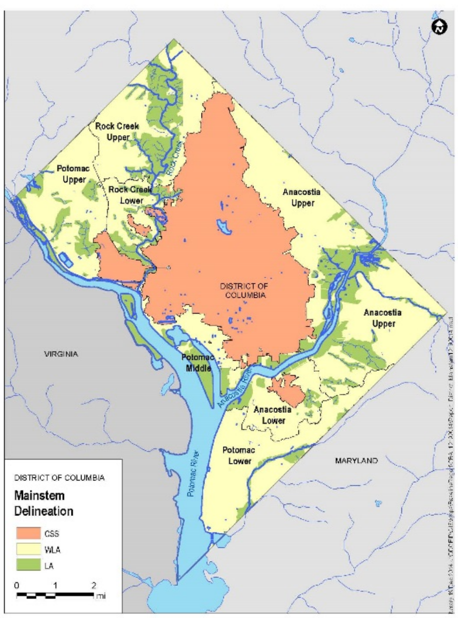

Figure 4 -4: Mainstem Delineations

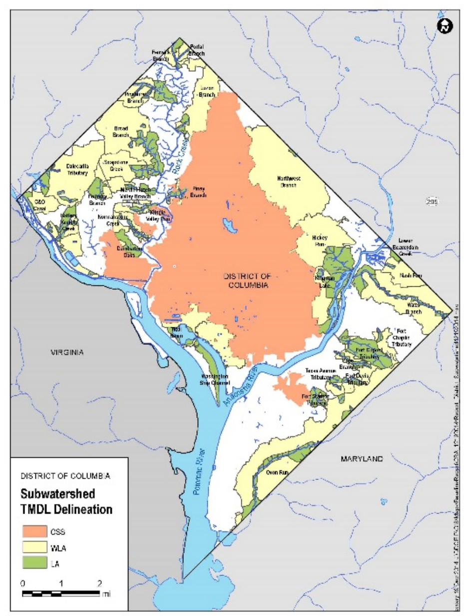

Figure 4 - 5: Tributary Delineations

DISTRICT DEPARTMENT OF THE ENVIRONMENT

4.2.2.d EMCs

EMCs are used in conjunction with runoff calculations to develop pollutant load estimates. Several parallel lines of investigation were used to identify the appropriate set of EMCs to support application of the IP Modeling Tool. These included:

- A review of the EMCs used to develop TMDLs in the District.
- A review of EMCs reported in literature for various land use classes.
- An evaluation of District MS4 monitoring data to develop District-specific EMCs.

The full report on the investigation of EMCs can be found in Appendix D, *Technical Memorandum: Selection of Event Mean Concentrations (EMCs).*

It was established in the review of the existing District TMDLs that a wide variety of EMCs were used to develop the TMDLs for conventional pollutants (TSS, bacteria, etc.). This fact implies that different EMCs are applicable for different parts of the District, but this is not necessarily the case. Instead, differences in EMCs were largely due to the use of different datasets and different methods of EMC development.

It was further determined following the literature review and subsequent analysis and comparison of land use based EMCs to current outfall monitoring data that the use of land use based EMCs from the literature could not be justified. The stormwater outfall concentrations did not match well with the land use based EMCs because the stormwater outfall concentrations are substantially influenced by other factors beyond land use including rainfall intensity, activities such as construction, watershed characteristics such as slope, and sampling protocol.

Evaluation of the District MS4 outfall monitoring data, however, offered promise as a way to establish EMCs for conventional pollutants and metals based on local District data. One reason for this is that the average concentration of the pooled MS4 outfall monitoring data compared well with the EMCs used in District TMDL studies. Statistical analysis was undertaken to determine whether city-wide or watershed specific EMCs should be used for further modeling. The MS4 outfall monitoring data was grouped according to monitoring station location (i.e., Anacostia, Potomac or Rock Creek watershed). Standard EMC summary statistics and median values were calculated for each watershed. Analysis of variance (ANOVA) at the 0.05 significance level (significant differences at the 0.05 level or lower means that there is >95% confidence that the watershed EMCs are truly different and that this difference is not due to chance) was used to examine differences in means of data collected in the three different watersheds. These results show that a significant difference in EMCs at the watershed level was determined for four parameters: BOD, Oil & Grease, TSS and Zinc. No significant difference was found at the watershed level for the other parameters. These results are shown in Table 4 - 3.

Table 4 - 3: Summary of ANOVA Analysis

Parameter	Transformation	F-Statistic	Pr (>F)	Result
Arsenic	N/A	N/A	N/A	No Difference
Biological Oxygen Demand	Log	3.426	0.03463	Significant Difference at the 0.05 Level
Copper	Log	1.895	0.1530	No Difference
Fecal Coliform	Log	1.259	0.2878	No Difference
Lead	N/A	N/A	N/A	No Difference
Total Nitrogen	0.5454	0.036	0.9641	No Difference
Oil & Grease	-0.5858	4.379	0.0142	Significant Difference at the 0.05 Level

Table 4 - 3: Summary of ANOVA Analysis

Parameter	Transformation	F-Statistic	Pr (>F)	Result
Total Phosphorus	0.3434	1.681	0.1889	No Difference
Total Suspended Solids	Log	6.315	0.0022	Significant Difference at the 0.01 Level
Zinc	0.4646	3.804	0.0238	Significant Difference at the 0.05 Level

Notes:

N/A indicates that no appropriate transformation was identified and the ANOVA was not run. Best professional judgment was used to determine difference. Numbers (e.g.: Total Nitrogen λ=0.5454) indicate a power transformation. These transformations were identified using Box-Cox transformation methods. Refer to Appendix D, *Technical Memorandum: Selection of Event Mean Concentrations (EMCs)* for additional information on transformations.

Because the goal of the EMC analysis is to make the best representation of current conditions, it was determined that EMCs derived from MS4 monitoring data should be used whenever these data were of sufficient quality to do so. This decision was made because MS4 monitoring data sets (and EMCs derived from these data sets) could be tailored to specific watersheds/basins and because there are more than ten years of MS4 monitoring data to draw from to develop the EMCs. In contrast, the TMDL EMCs were derived from sampling data that was not as extensive, nor was it always specific to the District. Therefore, based on the analyses described above, the following logic was used to identify EMCs for use in the IP Modeling Tool: 1) where there were significant differences in EMCs between watersheds according to the ANOVA analysis, watershed-specific EMCs are used; 2) , where there were not significant differences in EMCs between watersheds according to the ANOVA analysis, District-wide EMCs are used; and 3) for those parameters where it was not possible to calculate updated EMCs due to lack of data, the TMDL EMC values will be used. Key aspects of this summary of revised EMCs are as follows:

- District-level EMCs are recommended for TN, TP, bacteria, copper, arsenic, and lead.
- Watershed-level EMCs are recommended for BOD, Oil & Grease, TSS and zinc.
- EMCs developed for the original TMDLs are recommended for mercury and all organic compounds.

Note that at the time most bacteria TMDLs were done, the bacteria water quality standard for the District was expressed in fecal coliform colonies. However, in 2005, the fecal coliform water quality standard was changed to E. coli. Therefore, all of the bacteria TMDLs were updated to reflect the new E. coli water quality standard. To support the TMDL revisions, EPA and DDOE developed a DC Bacteria Translator using the statistical relationship between paired fecal coliform and E. coli data collected in the District's waters (LimnoTech 2011 and 2012[3]). The DC Bacteria Translator is representative of ambient and stormwater bacteria concentrations and was used to convert the fecal coliform EMC to E. coli EMC values.

A listing of the EMCs used to establish baseline loads is presented in Table 4 - 4.

[3] Documentation related to development of the DC Bacteria Translator is in LimnoTech's 2011 Memorandum, Final Memo Summarizing DC Bacteria Data and Recommending a DC Bacteria Translator (Task 2) and LimnoTech's 2012 Memorandum, Update on Development of DC Bacteria Translators.

Table 4 - 4: EMCs Used to Establish the Baseline			
Pollutant	**Units**	**EMC Value**	**Source of EMC**
Total Nitrogen	mg/l	3.32	From monitoring data
Total Phosphorus	mg/l	0.38	From monitoring data
Total Suspended Solids (Anacostia)	mg/l	73	From monitoring data
Total Suspended Solids (Rock Creek)	mg/l	60	From monitoring data
Total Suspended Solids (Potomac)	mg/l	42	From monitoring data
Fecal Coliform	MPN/100ml	13,639	From monitoring data
E. coli	MPN/100ml	5,474	From DC Bacteria Translator
Biological Oxygen Demand (Anacostia)	mg/l	35.93	From monitoring data
Biological Oxygen Demand (Rock Creek)	mg/l	23.67	From monitoring data
Biological Oxygen Demand (Potomac)	mg/l	28.08	From monitoring data
Oil & Grease (Anacostia)	mg/l	3.65	From monitoring data
Oil & Grease (Rock Creek)	mg/l	4.15	From monitoring data
Oil & Grease (Potomac)	mg/l	3.35	From monitoring data
Arsenic	ug/l	1.54	From monitoring data
Copper	ug/l	52.88	From monitoring data
Lead	ug/l	15.94	From monitoring data
Mercury	ug/l	0.19	From TMDL
Zinc (Anacostia)	ug/l	120.92	From monitoring data
Zinc (Rock Creek)	ug/l	101.73	From monitoring data
Zinc (Potomac)	ug/l	100.90	From monitoring data
Chlordane	ug/l	0.00983	From TMDL
DDD	ug/l	0.003	From TMDL
DDE	ug/l	0.0133	From TMDL
DDT	ug/l	0.0342	From TMDL
Dieldrin	ug/l	0.00029	From TMDL
Heptachlor Epoxide	ug/l	0.000957	From TMDL
PAH1	ug/l	0.6585	From TMDL
PAH2	ug/l	4.1595	From TMDL
PAH3	ug/l	2.682	From TMDL
TPCB	ug/l	0.0806	From TMDL

4.2.3 In-Stream Erosion Load Methodology Estimator

Stream erosion is common in urban environments. It occurs when the balance between stream flow and stream bank conditions becomes poor due to excess stormwater runoff. The net amount of sediment eroded from native bed and bank material and accumulated sediments contributes to the TSS load. The District TMDLs do not account for stream erosion in a consistent manner, and it is not accounted for at all in some TMDLs. Nevertheless, stream erosion can represent a substantial fraction of the TSS (and nutrient) load generated in urban waters such as those in the District. Because of this, stream erosion should be included in a consistent manner in the IP Modeling Tool and in the development of baseline loads. The stream erosion calculations done for the IP Modeling Tool include not only TSS, but also the fraction of the nutrients nitrogen and phosphorus associated with the TSS load due to stream erosion.

A comparative evaluation of three methods to account for stream erosion was performed. The methods were:

- Direct measurement of in-stream erosion
- Theoretical calculation of in-stream erosion
- Empirical calculation of in-stream erosion

A full report on the evaluation of the three methods is available in Appendix C, *Technical Memorandum: Stream Erosion Methodology*.

Based upon the relative simplicity and compatibility with available data, the empirical calculation of in-stream erosion method is currently incorporated into the IP Modeling Tool. This method combines empirical data or equations developed by the Center for Watershed Protection (CWP) and the Maryland Department of the Environment (MDE). In the CWP's Watershed Treatment Model (WTM), the sediment load from in-stream (channel) erosion (LCE) is expressed as a fraction of the total watershed load. Thus the equation is as follows:

$$LCE = LOS/(100/CE\%-1)$$

where:

LCE = Sediment load from in-stream (channel) erosion (lb/year)

LOS = Sediment load from other urban sources (lb/year)

CE (%) = In-stream (channel) erosion as a percent of the total urban watershed load

Furthermore, MDE developed a relationship correlating watershed imperviousness to percent in-stream erosion as a function of total watershed load. This relationship was further refined to also correlate in-stream erosion to potential stream degradation. A graph depicting this relationship is provided in Figure 4 -6.

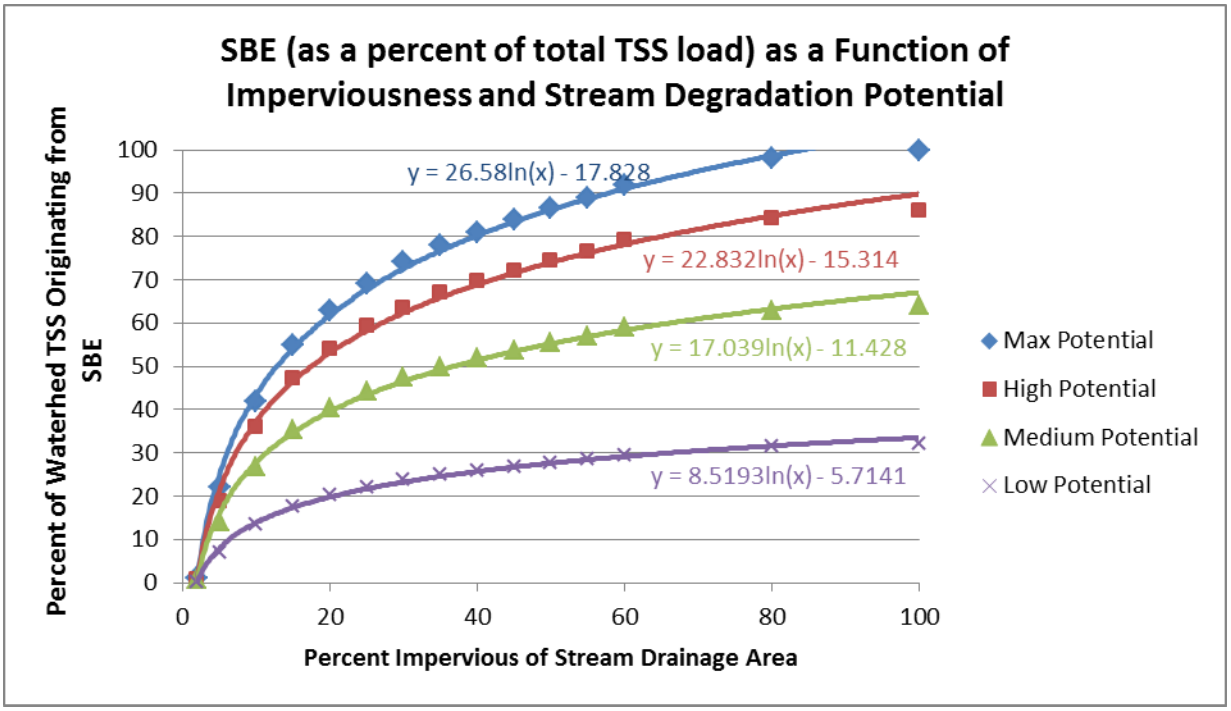

Figure 4 - 6: SBE (as a Percent of Total TSS Load) as a Function of Imperviousness and Stream Degradation Potential

These curves along with the equation above are used in the IP Modeling Tool to calculate the sediment load from in-stream erosion. It is important to recognize that the gross in-stream erosion is not the same as the net export of sediment. In-stream soil erosion represents the amount of soil that is eroded from the banks and beds of stream. Only a fraction of the eroded soil contributes to the sediment yield, while the rest is deposited in downstream water channels. The amount that contributes to the sediment yield can be quantified using a sediment delivery ratio (SDR), expressed as a fraction of gross erosion that is delivered to a particular point in the drainage system. It is recommended that a SDR of 0.175 be applied to estimate the amount of in-stream erosion that is counted towards the Chesapeake Bay WLAs, and that a SDR of 0.23 be applied to estimate the amount of in-stream erosion that is counted towards the District WLAs.

To translate sediment loading to nitrogen and phosphorus loading, the following CBP-approved conversion rates were used for the District (CWP and CSN, 2014):

- 1.05 pounds P/ton sediment
- 2.28 pounds N/ton sediment

4.2.4 Trash Load Methodology

A Trash TMDL was developed by Maryland and the District for the Anacostia Watershed. The IP Modeling Tool accounts for trash generation in the Upper and Lower Anacostia using factors developed for this TMDL. The calculation of the trash load in any given watershed or subwatershed requires information on land use and stream length. Both land use and stream length were obtained from DC OCTO GIS coverages, with the latter a derivative of the stream line coverage.

MS4 loadings in the District are calculated based on land use and the loading rates described in the Trash TMDL report. The various land use categories and their loading rates are described in Table 4 - 5.

Table 4 - 5: Baseline Trash Loading Rates (lbs/acre/year) for the District MS4	
Land use/Landcover Category	**Loading Rate**
Alleys	6.84
Commercial	22.08
Federal public	12.78
High Density Residential	7.93
Industrial	18.9
Institutional	25.45
Local public	25.45
Low Density Residential	4.52
Low-Medium Density Residential	3.96
Medium Density Residential	13.84
Mixed Use	13.84
Parking	6.84
Parks and Open Spaces	0.32
Public, Quasi-Public, Institutional	25.45
Roads	31.12
Transport, Communications, Utilities	31.12
Transportation right of way	13.84
Undetermined	0.32

Nonpoint source loadings from direct drainage in the District are calculated based on linear stream distance and the loading rates described in the Trash TMDL report. The various streams and their trash loading rates are described in Table 4 - 6.

Table 4 - 6: Baseline Trash Loading Rates for Nonpoint Source Direct Drainage for the District (lbs/1000 feet/year)	
River Segment	**lbs/1000ft/yr**
Anacostia Lower Mainstem	52.822
Anacostia Lower Unnamed Tributaries	129.099
Anacostia Upper Mainstem	52.822
Anacostia Upper Unnamed Tributaries	129.099
Fort Chaplin Tributary	181.861
Fort Davis Tributary	62.813
Fort Dupont Tributary	39.938
Fort Stanton Tributary	46.392
Hickey Run	129.099
Kingman Lake	61.768
Lower Beaverdam Creek	129.099

Table 4 - 6: Baseline Trash Loading Rates for Nonpoint Source Direct Drainage for the District (lbs/1000 feet/year)	
River Segment	**lbs/1000ft/yr**
Nash Run	297.463
Pope Branch	59.118
Texas Avenue Tributary	57.356
Watts Branch	354.141

4.3 BMP Module

The BMP Module of the IP Modeling Tool integrates the current inventory of BMPs and assigns a reduction efficiency to each BMP in order to calculate the runoff volume and pollutant load removed on an annual or seasonal basis.

4.3.1 BMP Inventory

The development of the BMP database inventory has captured all of the necessary information on existing structural and non-structural BMPs, including the type of BMP and its location. For structural BMPs, other important information includes the drainage area that the BMP controls, while for non-structural BMPs, other information is used to indicate the extent of the BMP's impact. The BMP database allows an analysis of the extent of current BMP implementation. A full description of the BMP inventory is described in Appendix F, *Technical Memorandum: BMPs and BMP Implementation*.

4.3.2 BMP Efficiencies

Extensive research was conducted to develop pollutant removal rates for both structural and non-structural BMPs. This involved analysis of the International Stormwater BMP database, as well as other literature, to review existing data on pollutant removal percent efficiency rates, as well as development of curves that relate runoff retention to load reduction. Finally, because of the paucity of research on the removal rates for toxics and some metals, partition coefficients were applied that relate the removal of particle bound pollutants such as metals and toxics to the removal of TSS. This research provides information that can be used to evaluate how individual BMPs remove pollutants.

The decision tree depicted in Figure 4 - below is used to determine the approach for modeling load reductions from any individual structural or non-structural BMP. The first step is to determine if the BMP retention volume is known. If the retention volume is known, then the next step is to determine if the BMP is a rain barrel or a new tree (trees are considered BMPs because they help retain runoff). If the BMP is a rain barrel or a new tree, the lumped average annual reduction is used for the rain barrel or tree, respectively. The lumped average annual volume reduction was determined through an analysis of the canopy size and stormwater interception capacity of typical trees in DC, and, for rain barrels, an analysis of typical barrel size and usage (including how often rain barrels are drained)..

If the BMP is not a rain barrel or a new tree, then the runoff reduction curves are applied. Runoff reduction curves were developed for the major categories of retention-based BMPs, including bioretention, permeable pavement, infiltration trenches, cisterns, and green roofs. The efficiency of these BMPs is commensurate with the amount of runoff volume that can be retained by the BMP. For example, a BMP designed to retain runoff from a 0.5-inch storm provides less annual volume reduction than a BMP designed to retain runoff from a 1-inch storm.

The BMP retention volume is not known for many of the existing BMPs because historically this was not an attribute that was typically documented during the permitting process. The BMP retention volume is therefore not known for many of the BMPs implemented before 2013, which is the year during which the new stormwater regulations came into effect and when retention volume was required to be reported as part of the permit application. Additionally, some BMPs such as filters and wet ponds do not provide runoff retention capacity, but rather provide load reductions only. If the BMP treatment volume is not known, then the next step is to determine if the BMP has a prescribed load removal, and if so, to apply this load reduction. A prescribed load removal refers to a load reduction methodology that is based on the design parameters of the BMP. This type of load removal applies to stream restoration, street sweeping, catch basin cleaning, impervious surface removal, and trash reduction strategies, which require information such as the length or area of restoration to calculate the appropriate annual load removal. If the BMP does not have a prescribed removal load, then the percent reduction efficiency values are applied for that BMP. Percent reduction efficiencies were researched for each of the 13 BMP categories and for all 22 pollutants. The result of this research is a lookup matrix with an efficiency value for each BMP and pollutant combination. The percent reduction efficiencies apply uniformly to each BMP category, regardless of how a BMP was designed. As a result, they are regarded as being the least precise in terms of annual load removal estimates.

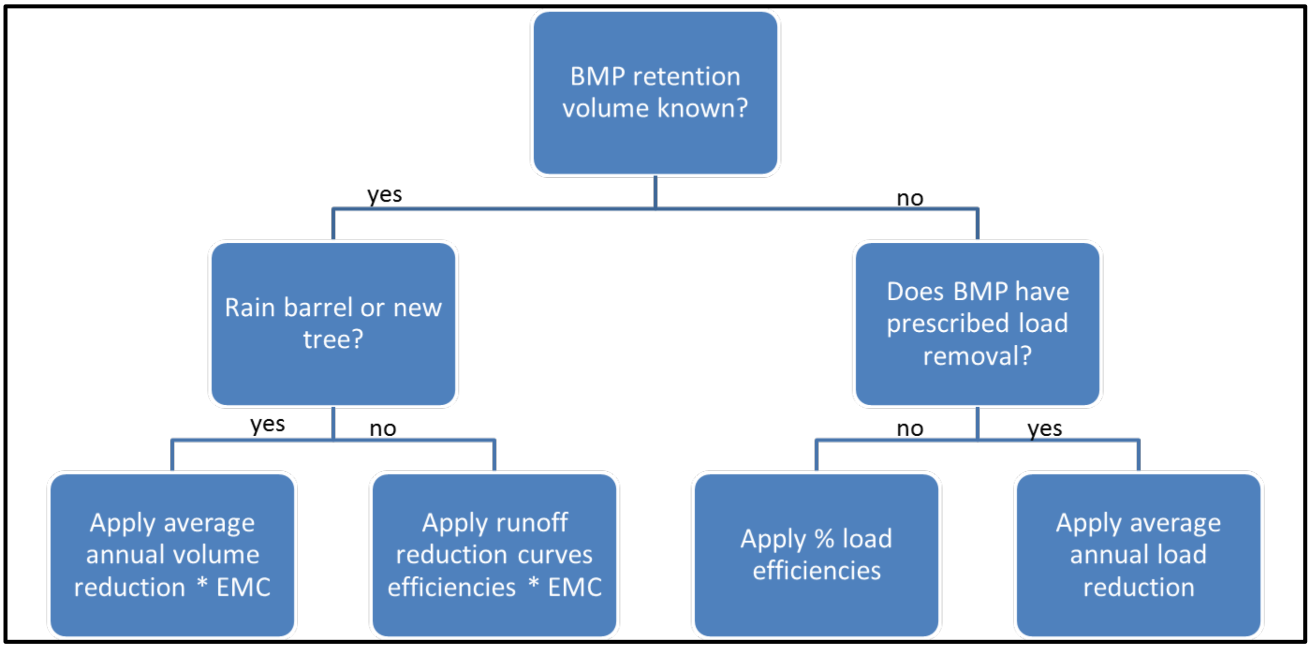

Figure 4 - 7: BMP Load Reduction Method Selection

The existing BMPs and the load reduction methodology will be applied in the IP Modeling Tool to calculate the load reduction from existing BMPs. Since each BMP is spatially located within the MS4, the reductions provided by each BMP can be aggregated by TMDL watershed. Individual pollutant reductions will be summed by TMDL watershed and subtracted from the baseline load to determine the existing load. The existing load can then be compared to the MS4 WLA to provide the basis for the "gap analysis" and show the additional load reduction necessary to achieve each MS4 WLA.

A full description of the BMP efficiencies is described in Appendix F, *Technical Memorandum: BMPs and BMP Implementation*.

4.4 Application of the IP Modeling Tool

The current version of the IP Modeling Tool is a spreadsheet calculator populated with all of the information required to quantify baseline loads. It requires inputs from GIS such as drainage areas and stream lengths. All other inputs discussed in the previous sections, such as precipitation, runoff coefficients, EMC values, BMP inventory, and BMP efficiencies are accessed through look-up tables. The calculator produces several results tables, including runoff volumes (in acre-ft), pollutant loads from the MS4 and direct drainage (DD) areas (expressed in pounds/yr for all pollutants except for bacteria which are expressed in billion MPN/yr), and pollutant loads from stream erosion (expressed in pounds/yr). In addition, it also presents results for the runoff volume and pollutant load reductions provided by the existing BMPs. The IP Modeling Tool displays all these results on an annual basis per TMDL waterbody and, where appropriate, also displays results as a daily or seasonal expression. Note that the calculator produces results only for the TMDL waterbodies that currently have a WLA or LA.

It is expected that, by May 2015, the IP Modeling Tool will be completely converted from an Excel based tool to a more integrated coded tool supported by databases.

5. Baseline Condition, Current Condition, and Gap Analysis

5.1 Overview

The load reduction needed to meet an individual WLA includes analyzing the baseline load (the load without BMPs), the current load (which includes load reductions from BMPs and other stormwater management practices that are currently in place), and the WLA, and establishing the gap between the current load and the WLA. For this analysis, the baseline load establishes a starting point from which load reductions from existing and future BMPs and other stormwater management practices can be evaluated for meeting WLAs and LAs. Next, the current load includes the load reductions that have already been achieved by existing BMPs. Finally, the WLA is the allowable load from the MS4 source that is established directly in the TMDL. The gap between the current load and the WLA for any individual pollutant/ waterbody combination quantifies the load reduction to be included in the Consolidated TMDL IP. Figure 5- 1 provides a conceptual depiction of these components.

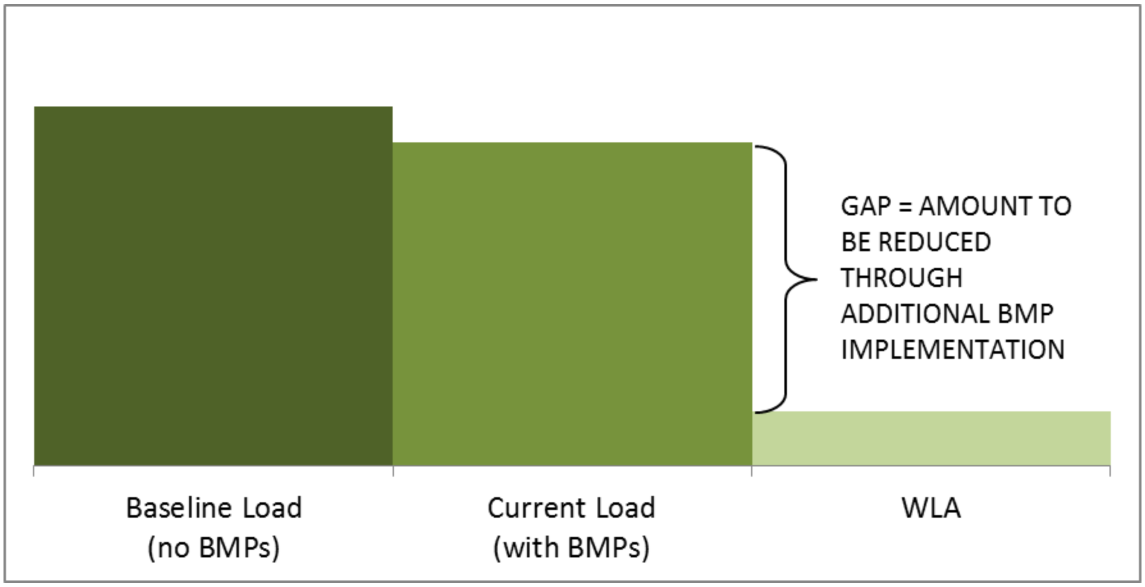

Figure 5 - 2: Loads and Gap Analysis

Analyses of the baseline and current conditions, as well as a discussion of the gap analysis, are presented in separate sub-sections below.

5.2 Methodology

5.2.1 Baseline Condition

The baseline condition includes the baseline loads and establishes a starting point for the subsequent evaluation of the number, type and distribution of BMPs and other stormwater management practices required to meet WLAs and LAs. Baseline loads represent the stormwater loads in the District that are not influenced or reduced by BMPs or other storm water management practices. For the purposes of this analysis, baseline loads refer to the stormwater loads (modeled by the IP Modeling Tool) in place when the majority of TMDLs were developed (circa 2000 to 2004). This standardizes inputs such as land use and precipitation in the IP Modeling Tool, although it also means that the inputs to the IP Modeling Tool are not exactly the same as those used to develop the TMDL baseline loads. A full description of inputs used to develop the baseline loads can be found in Appendix A, *Technical Memorandum: Model Selection and Justification*.

As discussed above, the goal of the Consolidated TMDL IP modeling is to use a single, consistent modeling approach for all of the analyses, and the baseline condition and the baseline loads are the result of that consistent modeling approach. The baseline condition is computed with the IP Modeling Tool using the best GIS and monitoring data available, including EMCs, TMDL drainage areas, runoff, and loads that have been updated compared to the original TMDLs. The application of this consistent modeling approach makes the tracking of pollutant loads consistent, reflective of current conditions, transparent, and easy to understand. It should be noted that the baseline condition is not an attempt to reproduce the original baseline loads from each TMDL study, nor was that deemed necessary for this project.

Full discussions of the updated EMCs, TMDL drainage areas, and runoff and load calculations are provided in Section 4 above. Results of the baseline condition analysis are included with the results of the current condition analysis in Section 5.3 below.

5.2.2 Current Condition

In contrast to the baseline condition, the current condition and the current loads represent the stormwater loads in the District that are influenced and reduced by BMPs and other storm water management practices currently in place. This includes structural and non-structural BMPs installed and put into operation prior to 2014.

The current condition builds upon the baseline condition, and is calculated by adding BMPs to the city-wide estimation of runoff and pollutant load generation within the IP Modeling Tool. Runoff and pollutant loads are reduced in areas where treatment by BMPs is provided.

The remainder of this section defines the BMPs currently in place in the District, describes how they are incorporated into the IP Modeling Tool, and documents the runoff and pollutant load reductions that are achieved with these BMPs. Further evaluation of the current condition to address the effectiveness of existing BMPs is provided at the end of the section.

5.2.2.a Structural BMPs

DDOE's Stormwater Management Guidebook (2013b) has identified 13 acceptable groups of structural BMPs that can be used to meet the stormwater retention volume and/or peak flow criteria included in the 2013 revisions to the District's 1988 stormwater management regulations. The Stormwater Management Guidebook provides guidance on each of these BMPs that will allow design engineers to review, verify, and select the appropriate BMPs to meet individual project needs in the District. Therefore, these BMP groups have been retained for use in the Consolidated TMDL IP and the IP Modeling Tool to maintain consistency with District regulations and other District planning efforts.

The groups of BMPs described in the Stormwater Management Guidebook include:

<u>Green Roofs</u>

Green roofs are practices that capture and store rainfall in an engineered growing media that is designed to support plant growth. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

Rainwater Harvesting

Rainwater harvesting systems store rainfall and release it for future use. Rainwater that falls on a rooftop or other impervious surface is collected and conveyed into an above- or below-ground tank (also referred to as a cistern), where it is stored for non-potable uses or for on-site disposal or infiltration as stormwater. Cisterns can be sized for commercial as well as residential purposes. Residential cisterns are commonly called rain barrels.

Impervious Surface Disconnection

Impervious surface disconnection involves managing runoff close to its source by intercepting, infiltrating, filtering, treating or reusing it as it moves from an impervious surface to the drainage system. Disconnection practices can be used to reduce the volume of runoff that enters the combined or separate sewer systems. Two kinds of disconnection are allowed: (1) simple disconnection, whereby rooftops and/or on-lot residential impervious surfaces are directed to pervious areas (compacted cover), conservation areas (natural cover), or soil amended filter paths; and (2) disconnection leading to an alternative retention practice(s) adjacent to the roof.

Permeable Pavement Systems

Permeable pavement systems are paving systems that capture and temporarily store the Stormwater Retention Volume (SWRv) by filtering runoff through voids in an alternative pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially (or fully) infiltrate into the soil.

Bioretention

Bioretention consists of practices that capture and store stormwater runoff and pass it through a filter bed of engineered soil media composed of sand, soil, and organic matter. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil.

Filtering Systems

Filtering system practices capture and temporarily store the design storm volume and pass it through a filter bed of sand media. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate into the soil.

Infiltration

Infiltration practices capture and temporarily store the design storm volume before allowing it to infiltrate into the soil.

Open Channel Systems

Open channel systems consist of vegetated open channels that are designed to capture and treat or convey the design storm volume.

Ponds

Stormwater ponds are stormwater storage practices that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake and microbial activity. Ponds are widely applicable for most land uses and are best suited for larger drainage areas. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, stormwater ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Stormwater ponds can also provide storage above the permanent pool to help meet stormwater management requirements for larger storms.

Wetlands

Wetlands create shallow marsh areas to treat urban stormwater which often incorporate small permanent pools and/or extended detention storage. Stormwater wetlands are explicitly designed to provide stormwater detention for larger storms (2-year, 15-year or flood control events) above the design storm.

Storage Practices

Storage practices are explicitly designed to provide stormwater detention (2-year, 15-year, and/or flood control). Design variants include underground detention vaults and tanks, dry detention ponds, rooftop storage, or stone storage under permeable pavement or other BMPs.

Proprietary Practices

Proprietary practices are manufactured stormwater treatment practices that utilize settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to manage the impacts stormwater runoff.

Proprietary practices may be used to achieve treatment compliance, provided they have been approved by the District and meet the performance criteria outlined in this specification. Historically, proprietary practices do not provide retention volume. Proprietary practices will not be valued for retention volume unless the practice can demonstrate the occurrence of retention processes.

Tree Planting and Preservation

This practice consists of either preserving existing trees or planting new trees. Tree canopy can intercept a significant amount of rainfall before it becomes runoff, particularly if the tree canopy covers impervious surface, such as in the case of street trees. Through the processes of evapotranspiration and nutrient uptake, trees located on a development site have the capacity to reduce stormwater runoff volumes and improve water quality. Further, through root growth, trees can improve the infiltration capacity of the soils in which they grow. The IP Modeling Tool tracks load and volume reductions provided by planting new trees but does not track the preservation of existing trees, since the effect of existing trees on pollutant loads and load reductions are assumed to be accounted for in the selection of EMC values and runoff coefficients.

5.2.2.b Non-structural BMPs

DDOE's Stormwater Management Guidebook defines a nonstructural BMP as "a land use, development, or management strategy to minimize the impact of stormwater runoff, including conservation of natural cover, or disconnection of impervious surface." Non-structural BMPs consist of programmatic, operational, and restoration practices that help prevent or minimize pollutant loading or runoff generation. Non-structural BMPs to be included in the IP Modeling Tool include stream restoration, street sweeping, catch basin cleaning, pet waste removal, illicit discharge detection and elimination (IDDE), impervious surface reduction, coal tar pavement (sealant) removal, and phosphorus fertilizer ban.

Stream Restoration

Stream restoration is the practice of re-establishing pre-disturbance aquatic functions and related physical, chemical, and biological characteristics to a degraded stream. Stream restoration is a widely-used BMP because it focuses on directly rehabilitating the impacted resource. Stream restoration decreases in-stream erosion, thereby reducing loading of TSS and nutrients. The practice also creates ancillary benefits in addition to load reduction, including improved wildlife habitat, potential increases in public accessibility/use, and upgraded aesthetics. Multiple stream restoration projects have been conducted or are planned for District waterbodies, including Watts Branch (completed), Nash Run (planned), Springhouse Run (planned), Pope Branch (planned), and Broad Branch (planned). The stream restoration projects that have already been completed in the District are included in the current conditions analysis.

Street Sweeping

Street sweeping removes dirt, debris, and trash that have accumulated on streets. Pollutants known to accumulate in street dirt include TSS, nutrients, metals, hydrocarbons, bacteria, pesticides, organochlorine and other toxics. Street sweeping results in direct removal of these potential pollutants from the environment, thereby reducing the pollutants that are available to accumulate in runoff and be discharged to District waterbodies.

The District has also identified street sweeping as an important BMP for removing trash and meeting the Trash TMDL in the Anacostia watershed.

The District currently conducts street sweeping, so this BMP is included in the current conditions analysis.

Catch Basin Cleaning

Storm drain catch basin/inlet cleaning is designed to remove pollutants that have been washed off streets and into storm drains. The material retained in catch basins can vary widely based on multiple factors, including the design of the catch basin, the land use of the surrounding area, and the frequency of street sweeping in the catchment, among other factors. While the District currently conducts catch basin cleaning, it does not collect the information required to include this BMP in the IP Modeling Tool. Therefore, this BMP is not included in the current conditions analysis.

Pet Waste Removal

The pet waste removal BMP focuses on changing the behavior of pet owners to increase the number of owners who clean up after their pets, thereby reducing the amount of pet waste that can be washed off into waterways. While public education is a primary means of changing pet owner behavior, these types of behavior changes are difficult to measure directly. Therefore, the impact of this BMP is often measured indirectly. For the purposes of the Consolidated TMDL IP and the IP Modeling Tool, this BMP focuses on tracking changes in dog owners who use dog parks; specifically, it attempts to measure the increase in the percentage of pet owners who clean up after their dogs when they use dog parks. However, the District does not currently collect the information required to include this BMP in the IP Modeling Tool. Therefore, this BMP is not included in the current conditions analysis.

IDDE

IDDE is a standard MS4 NPDES permit requirement that requires MS4 permittees to do annual, systematic field investigations of their MS4 system to find and eliminate illicit/illegal discharges. These illicit discharges can be sources of pollutants to receiving waters, and thus by eliminating these discharges, the permittee eliminates pollutant loads to streams. While the District is currently implementing its required IDDE program, it is not currently collecting the additional data that will be necessary to calculate load reductions from this BMP. Therefore, no load reductions from this BMP are included in the current conditions analysis.

Impervious Surface Reduction

Impervious surface removal is the practice of removing impervious surfaces and restoring the area to a more natural state. This is a practice that has been used, for example, by DDOT to convert impervious median lane dividers into grassy or planted median dividers. Impervious surface reduction typically requires not only for the impervious surface to be removed, but also for the underlying soil to be amended and restored to a less compacted form, and then planted with hardy, sometimes native, plants. Removing impervious surfaces results in less runoff generated from that surface, and as a result this BMP reduces the loads from all pollutants that are typically found in urban runoff. The District currently conducts street sweeping, so this BMP is included in the current conditions analysis.

Coal Tar Pavement (Sealant) Removal

Under the Comprehensive Stormwater Management Enhancement Amendment Act of 2008, effective July 1, 2009, it is illegal to sell, use, or permit the use of coal tar pavement products in the District. As of December 2014, over 430,000 sq. ft. (approximately 10 acres) of coal tar had been removed over a 3 year period from 13 locations throughout the District, including the MS4. Pollutants associated with coal tar pavement include PAHs. The removal of coal tar pavement results in a reduction of PAHs from the environment, thereby reducing the concentration of PAHs in runoff and District waterbodies. This BMP is included in the current conditions analysis.

Phosphorus Fertilizer Ban

Fertilizers can be important sources of nutrients in an urban environment. Management of fertilizers in the District was implemented through the Sustainable DC Act of 2012, specifically Subtitle II(A) – Anacostia River Clean Up and Protection Fertilizer Act of 2012. This subtitle restricts the application of fertilizers, implements a public education program, imposes specific labeling requirements on manufacturers, and establishes a fine structure for violations. The District set a 2015 milestone of 18,595 acres subject to total phosphorus reduction based on the District's Urban Phosphorus Legislation. Phosphorus legislation is an approved Chesapeake Bay BMP, and the district's 2013 reported progress on meeting this milestone was 17,211 acres. This BMP is included in the current conditions analysis.

5.2.2.c BMPs Currently in Place

The BMP databases described in Section 3.2 (and discussed in more detail in Appendix F, *Technical Memorandum: BMPs and BMP Implementation*) was used to identify the BMPs currently in place in the District. For the structural BMPS, 3,193 BMPs, excluding "new" trees, were originally identified, of which 2,226 (approximately 70%) were retained after QA/QC to remove duplicates, correctly assign drainage areas and physical locations, and other QA/QC procedures. These remaining structural BMPs treat over 15 million square feet, or approximately 364.6 acres within the District's MS4 area (note: because of the way BMPs were accounted, the 2,226 BMPs also include 58 BMPs that are in direct drainage areas. These 58 BMPs are in watersheds with TMDLs, and thus they were included in the count because they contribute to load reduction in TMDL watersheds. But for consistency, the list of BMPs will be described as "within the District's MS4 area"). This represents about 1.4 percent of the MS4 area.

Table 5 - 1 summarizes the current set of structural BMPs in place by watershed and Table 5 - 2 shows each BMP type and the amount of area it controls in each watershed – both in actual area and also as a

percent of the watershed. These tables show that some BMPs are few in number but control large areas (e.g., ponds and wetlands are few in number but control large drainage areas), while other BMPs are high in number but control less area (e.g., rainwater harvesting makes up 53% of the total number of practices, but makes up only 3 percent of the controlled drainage area). Note that ponds, wetlands, and impervious surface disconnect each represent <1% of the total number of practices, and so they are shown as "0" in Table 5 - 1.

Table 5 - 1: Current Condition: Number and Distribution of MS4 Area BMPs by Watershed

BMP	Number in District	Number in Anacostia Watershed	Number in Potomac Watershed	Number in Rock Creek Watershed
Bioretention	353	185	73	95
Filtering Systems	55	25	20	10
Green Roof	75	26	30	19
Impervious Surface Disconnect	4	1	3	0
Infiltration	208	74	86	48
Open Channel Systems	47	14	17	16
Permeable Pavement Systems	53	30	11	12
Ponds	3	2	1	0
Proprietary Practices	214	103	84	27
Rainwater Harvesting	1,186	573	245	368
Storage Practices	17	7	4	6
Tree Planting and Preservation[4]	16,773	7,900	5,281	3,592
Wetland	11	9	2	0
Stream Restoration	4			
Street Sweeping	42.3 miles	32.1 miles	8.4 miles	1.8 miles
Impervious Surface Reduction	1	1	0	0
Coal Tar Pavement Removal	5	2	0	3
Phosphorus Fertilizer Ban	Applies to entire city			

[4] The numbers indicated in this category only show the new trees that have been planted since 2005.

Table 5 - 2: Area Controlled by BMPs in Each Watershed						
BMP	BMP Drainage Area (sq. ft.)	Percent of Watershed Controlled (%)	BMP Drainage Area (sq. ft.)	Percent of Watershed Controlled (%)	BMP Drainage Area (sq. ft.)	Percent of Watershed Controlled (%)
	Anacostia Watershed		Potomac Watershed		Rock Creek Watershed	
Bioretention	1,109,238	0.22%	312,534	0.08%	81,016	0.03%
Filtering Systems	88,462	0.02%	90,965	0.02%	67,131	0.02%
Green Roof	732,281	0.15%	435,918	0.11%	118,689	0.04%
Impervious Surface Disconnect	9,852	<0.01%	11,235	<0.01%	0	0.00%
Infiltration	325,807	0.06%	453,759	0.12%	309,610	0.11%
Open Channel Systems	164,668	0.03%	74,362	0.02%	165,322	0.06%
Permeable Pavement Systems	218,615	0.04%	23,296	0.01%	104,659	0.04%
Ponds	4,236,355	0.85%	8,973	<0.01%	0	0.00%
Proprietary Practices	1,163,410	0.23%	498,183	0.13%	188,202	0.07%
Rainwater Harvesting	243,141	0.05%	122,899	0.03%	181,919	0.06%
Storage Practices	181,859	0.04%	20,128	0.01%	19,336	0.01%
Tree Planting and Preservation[5]	3,871,000	0.77%	2,587,690	0.66%	1,760,080	0.62%
Wetland	4,116,420	0.82%	5,708	0.00%	0	0.00%
Street Sweeping	1,695,298	0.33%	443,654	0.12%	96,933	0.03%
Impervious Surface Reduction	3,432	<0.01%	0	0.00%	0	0.00%
Coal Tar Pavement Removal	63,584	0.01%	0	0.00%	59,958	0.02%
Phosphorus Fertilizer Ban	178,958,039	35%	145,790,366	37%	89,766,494	32%

[5] The numbers indicated in this category only show the drainage areas provided by new trees that have been planted since 2005.

5.2.3 Gap Analysis

The gap analysis is an evaluation of the remaining MS4 pollutant loads to be reduced for each of the TMDLs. Referred to as "the Gap", this evaluation of the amount of remaining pollutant load reduction is based on a comparison of current loads and individual MS4 WLAs. The Gap provides the pollutant load reduction targets for the IP.

The current loads determined through the application of the IP Modeling Tool provide the bases for the gap analysis, as shown in the equation below.

$$\text{Gap} = \text{Current Load} - \text{TMDL WLA}$$

Results of the Gap Analysis are included in Section 5.3 below.

5.3 Results

5.3.1 Introduction

The following sections present the Baseline and Current Condition results from the IP Modeling Tool. Section 5.3.2 and 5.3.3 compare two key input variables, EMCs and area, and show how they are represented differently in the IP Modeling Tool versus the TMDL models. The comparison of runoff volumes and pollutant loads are described and presented in Section 5.3.4 and 5.3.5, respectively.

5.3.2 EMC Comparison

The use of EMCs in the IP Modeling Tool is addressed in Section 4, and a full discussion on the selection of EMCs is found in Appendix D, *Technical Memorandum: Selection of Event Mean Concentration*. Table 5 - **3** below shows the selected EMCs used in the IP Modeling Tool and compares them with the EMCs used to develop the TMDLs. A few observations are worth noting:

- About half of the pollutants had updated EMCs calculated based on recent monitoring data. These updated EMCs are generally lower than the comparable TMDL EMCs.
- The selected nutrient EMCs are higher than what was applied to develop the Chesapeake Bay TMDL. The TN EMC is higher by 66% while the TP EMC is higher by 41%. The impact of this is seen in the comparison of baseline loads for nutrients in the Chesapeake Bay segments, as shown in Baseline Attachment Table 4 (which can be found after Section 6).
- The selected EMCs for organics, toxics, and mercury are the same as those used to develop the TMDLs. The monitoring data could not be used to develop EMCs for these pollutants because the detection limits used during the laboratory analysis were not sufficient to detect the pollutants in the samples provided.
- The E. coli EMC was calculated using the DC Bacteria Translator to convert the fecal coliform EMC to E. coli EMC values.

Table 5 - 3: Selected EMCs for Use in the Implementation Plan Modeling Tool			
Pollutant	**Units**	**EMC value used in IP Modeling Tool**	**EMC value used in TMDL**
Total Suspended Solids	mg/l	73 (Anacostia) 60 (Rock Creek) 42 (Potomac)	34.67 (Kingman); 60 (Watts Branch); ~80 (Chesapeake Bay TMDL)[6]; 94 (Mainstem); 227 (Some Tributaries)
Total Nitrogen	mg/l	3.32	3.7 (DC TMDLs) 2 (Chesapeake Bay TMDL)
Total Phosphorus	mg/l	0.38	0.5 (DC TMDLs) 0.27 (Chesapeake Bay TMDL)
Fecal Coliform	MPN/100ml	13,639	28,265 (Mainstem) 17,300 (Tributaries)
E. coli	MPN/100ml	5,474	-
BOD	mg/l	35.93 (Anacostia) 23.67 (Rock Creek) 28.08 (Potomac)	27 (Kingman) 42.9 (all other)
Oil & Grease	mg/l	3.65 (Anacostia) 4.15 (Rock Creek) 3.35 (Potomac)	3.65 (Kingman) 10 (all other)
Arsenic	ug/l	1.54	1.4
Copper	ug/l	52.88	78 (Rock Creek Mainstem) 57 (all others)
Lead	ug/l	15.94	36 (Rock Creek Mainstem) 29 (all others)
Mercury	ug/l	0.19	0.19 (Rock Creek Mainstem)
Zinc	ug/l	120.92 (Anacostia) 101.73 (Rock Creek) 100.90 (Potomac)	183 (Rock Creek Mainstem) 173 (all others)
Chlordane	ug/l	0.00983	0.00983
DDD	ug/l	0.003	0.003
DDE	ug/l	0.0133	0.0133
DDT	ug/l	0.0342	0.0342
Dieldrin	ug/l	0.00029	0.00029
Heptachlor Epoxide	ug/l	0.000957	0.000957
PAH1	ug/l	0.6585	0.6585
PAH2	ug/l	4.1595	4.1595
PAH3	ug/l	2.682	2.682
TPCB	ug/l	0.0806	0.0806

[6] Exact value could not be found in the Chesapeake Bay TMDL literature.

5.3.3 Area Comparison

A full discussion on the delineation of TMDL drainage areas can be found in *Appendix B, Technical Memorandum: Sewershed and Watershed Delineations*. Table 5 - 4 below shows the drainage areas of the TMDL waterbodies that are used in the IP Modeling Tool (IPMT) and compares them with the drainage areas used to develop the TMDLs. Note that the drainage areas were not always reported in the TMDL documentation, so a comparison could not always be made.

The reasons for the discrepancies between the areas are explained in Appendix B, *Technical Memorandum: Sewershed and Watershed Delineations*. Note that the impact of some of the larger area discrepancies is seen in the comparison of the baseline loads with the TMDL baseline loads. While the discrepancy between areas for individual water body segments can vary from -51% to +62%, the aggregated difference in area for all water segments for which the drainage areas are known is approximately +1%. This suggests that the total area is accounted for but that the distribution of the area across various waterbodies is different than documented in the TMDL studies.

Table 5 - 4: Comparison of Area (acres)

WATERBODY	MS4			Direct Drainage (DD)			All (MS4 + DD)		
	IPMT	TMDL	% Diff	IPMT	TMDL	% Diff	IPMT	TMDL	%Diff.
Anacostia Lower	1,567	7,401	17%	632	2,523	12%	2,199	9,924	16%
Anacostia Upper	7,112			2,195			9,308		
ANATF_DC	6,893	Not found	-	2,952	Not found	-	9,845	11,096	-11%
ANATF_MD	2,522	Not found	-	106	Not found	-	2,628	1,888	39%
Battery Kemble Creek	92	Not found	-	140	Not found	-	232	239	-3%
Broad Branch	900	Not found	-	245	Not found	-	1,145	1,129	1%
C&O Canal	490	426	15%	97	Not found	-	587	Not found	-
Dalecarlia Tributary	977	Not found	-	114	Not found	-	1,091	1,111	-2%
Dumbarton Oaks	12	Not found	-	124	Not found	-	136	168	-19%
Fenwick Branch	162	Not found	-	57	Not found	-	219	203	8%
Fort Chaplin Tributary	132	Not found	-	21	Not found	-	153	204	-25%
Fort Davis Tributary	60	Not found	-	44	Not found	-	104	72	45%
Fort Dupont Tributary	50	Not found	-	382	Not found	-	432	474	-9%
Fort Stanton Tributary	29	Not found	-	92	Not found	-	122	125	-3%
Foundry Branch	90	Not found	-	106	Not found	-	196	168	17%
Hickey Run	826	Not found	-	269	Not found	-	1,094	1,081	1%
Kingman Lake	296	Not found	-	296	Not found	-	591	Not found	-
Klingle Valley Run	125	Not found	-	46	Not found	-	172	354	-51%
Lower Beaverdam Creek	2	Not found	-	29	Not found	-	31	Not found	-
Luzon Branch	590	Not found	-	53	Not found	-	643	648	-1%
Melvin Hazen Valley	109	Not found	-	65	Not found	-	174	184	-5%
Nash Run	297	Not found	-	12	Not found	-	309	286	8%
Normanstone Creek	166	Not found	-	51	Not found	-	217	249	-13%
Northwest Branch	1,976	Not found	-	12	Not found	-	1,988	Not found	-
Oxon Run	1,800	Not found	-	344	Not found	-	2,144	Not found	-
Pinehurst Branch	246	Not found	-	201	Not found	-	446	443	1%

Table 5 - 4: Comparison of Area (acres)

WATERBODY	MS4			Direct Drainage (DD)			All (MS4 + DD)		
	IPMT	TMDL	% Diff	IPMT	TMDL	% Diff	IPMT	TMDL	%Diff.
Piney Branch	45	Not found	-	55	Not found	-	100	61	62%
Pope Branch	172	Not found	-	65	Not found	-	237	232	2%
Portal Branch	62	Not found	-	9	Not found	-	71	73	-3%
Potomac Lower	3,552	Not found	-	346	Not found	-	3,898		
Potomac Middle	783	Not found	-	679	Not found	-	1,462	9,161	-2%
Potomac Upper	2,692	Not found	-	931	Not found	-	3,622		
POTTF_DC	9,190	Not found	-	4,019	Not found	-	13,210	12,396	7%
POTTF_MD	1,133	Not found	-	150	Not found	-	1,283	1,311	-2%
Rock Creek Lower	1,010	826	22%	688	2,707	-10%	1,699	6,131	6%
Rock Creek Upper	3,022	2,598	16%	1,756			4,778		
Soapstone Creek	411	Not found	-	104	Not found	-	514	520	-1%
Texas Avenue	74	Not found	-	44	Not found	-	119	176	-33%
Tidal Basin	247	Not found	-	54	Not found	-	301	Not found	-
Washington Ship	440	Not found	-	176	Not found	-	616	Not found	-
Watts Branch	1,019	1,134	-10%	231	Not found	-	1,250	1,161	8%
Watts Branch - Lower	261	Not found	-	145	Not found	-	406	1,062	18%
Watts Branch - Upper	758	Not found	-	86	Not found	-	844		

5.3.4 Runoff Results and Comparison

A full discussion on the application of the Modified Version of the Simple Method to calculate runoff volumes is found in Appendix A, *Technical Memorandum: Model Selection and Justification*. Table 5 - 5 below shows the runoff volumes that were calculated using the IP Modeling Tool (IPMT) for each TMDL waterbody and compares them with the runoff volumes that were calculated in the TMDLs. Note that the runoff volumes were not always included in the TMDL documentation, so a comparison cannot always be made. The difference in runoff volumes between the IP Modeling Tool and TMDL results, for individual water body segments, can vary from -35% to +223%. The aggregated difference in runoff volumes between the IP Modeling Tool and TMDL results for all water segments for which the runoff volumes are known is approximately 18%. This confirms the observation outlined in Appendix A, *Technical Memorandum: Model Selection and Justification*, that the Modified Version of the Simple Method provides a conservative estimate of the total runoff volume.

Table 5 - 5: Comparison of Runoff Volume (acre-ft/yr)

WATERBODY	MS4			Direct Drainage (DD)			All (MS4 + DD)		
	IPMT	TMDL	% Diff	IPMT	TMDL	% Diff	IPMT	TMDL	%Diff.
Anacostia Lower	2,326	11,579	17%	888	5,414	-56%	3,214	16,993	-6%
Anacostia Upper	11,203			1,520			12,723		
ANATF_DC	11,215	Not found	-	2,594	Not found	-	13,809	Not found	-

Table 5 - 5: Comparison of Runoff Volume (acre-ft/yr)									
WATERBODY	MS4			Direct Drainage (DD)			All (MS4 + DD)		
	IPMT	TMDL	% Diff	IPMT	TMDL	% Diff	IPMT	TMDL	%Diff.
ANATF_MD	3,732	Not found	-	79	Not found	-	3,811	Not found	-
Battery Kemble Creek	124	Not found	-	88	Not found	-	212	134	59%
Broad Branch	1,361	Not found	-	110	Not found	-	1,471	831	77%
C&O Canal	647	Not found	-	100	Not found	-	747	Not found	-
Dalecarlia Tributary	1,450	Not found	-	59	Not found	-	1,509	889	70%
Dumbarton Oaks	26	Not found	-	109	Not found	-	135	170	-21%
Fenwick Branch	229	Not found	-	48	Not found	-	277	128	117%
Fort Chaplin Tributary	193	Not found	-	9	Not found	-	203	114	78%
Fort Davis Tributary	92	Not found	-	9	Not found	-	101	35	185%
Fort Dupont Tributary	78	Not found	-	135	Not found	-	213	187	14%
Fort Stanton Tributary	56	Not found	-	61	Not found	-	117	77	51%
Foundry Branch	164	Not found	-	150	Not found	-	314	161	94%
Hickey Run	1,477	Not found	-	181	Not found	-	1,658	1,128	47%
Kingman Lake	530	Not found	-	261	Not found	-	791	Not found	-
Klingle Valley Run	193	Not found	-	31	Not found	-	223	343	-35%
Lower Beaverdam Creek	5	Not found	-	19	Not found	-	24	Not found	-
Luzon Branch	1,034	Not found	-	31	Not found	-	1,064	610	75%
Melvin Hazen Valley Branch	158	Not found	-	36	Not found	-	193	172	12%
Nash Run	501	Not found	-	12	Not found	-	513	261	97%
Normanstone Creek	255	Not found	-	28	Not found	-	283	219	29%

Table 5 - 5: Comparison of Runoff Volume (acre-ft/yr)									
WATERBODY	MS4			Direct Drainage (DD)			All (MS4 + DD)		
	IPMT	TMDL	% Diff	IPMT	TMDL	% Diff	IPMT	TMDL	%Diff.
Northwest Branch	2,935	Not found	-	12	Not found	-	2,947	Not found	-
Oxon Run	2,938	Not found	-	193	Not found	-	3,131	Not found	-
Pinehurst Branch	355	Not found	-	69	Not found	-	425	249	70%
Piney Branch	63	Not found	-	15	Not found	-	78	24	223%
Pope Branch	221	Not found	-	35	Not found	-	256	138	85%
Portal Branch	87	Not found	-	2	Not found	-	89	45	96%
Potomac Lower	5,658	Not found	-	193	Not found	-	5,851	Not found	-
Potomac Middle	1,519	Not found	-	651	Not found	-	2,169	Not found	-
Potomac Upper	3,969	Not found	-	614	Not found	-	4,584	Not found	-
POTTF_DC	14,129	Not found	-	2,205	Not found	-	16,334	Not found	-
POTTF_MD	1,737	Not found	-	96	Not found	-	1,833	Not found	-
Rock Creek Lower	1,572	1,067	47%	460	110	319%	2,031	1,177	73%
Rock Creek Upper	4,566	3,307	38%	649	215	202%	5,215	3,521	48%
Soapstone Creek	705	Not found	-	83	Not found	-	787	557	41%
Texas Avenue Tributary	99	Not found	-	18	Not found	-	117	118	-1%
Tidal Basin	380	Not found	-	58	Not found	-	438	Not found	-
Washington Ship Channel	965	Not found	-	207	Not found	-	1,172	Not found	-
Watts Branch	1,672	Not found	-	191	Not found	-	1,863	Not found	-
Watts Branch - Lower	414	Not found	-	106	Not found	-	520	Not found	-
Watts Branch - Upper	1,258	Not found	-	84	Not found	-	1,343	Not found	-

5.3.5 Load Results and Comparison

Loads are calculated using the methodology described in Section 4.2 above. Summaries of the baseline pollutant loads calculated with the IP Modeling Tool , the baseline pollutant loads from the TMDL studies, the current load removed through existing BMPs, and the WLAs are tabulated in Baseline Attachment Tables 1-23, which are included after Section 6. These tables and sub-sections are organized by TMDL study document for clarity, and each table includes separate sub-sections for WLAs and LAs. The following sections provide a high-level summary of the baseline and current loads, as well as the gap analysis. Gap analysis results shown below are summarized for the 293 WLAs that are modeled in the IP Modeling Tool. The gap analysis excludes results for WLAs that were removed from the 303d list, that require only source control (e.g.: PCBs), or that were superseded.

5.3.5.a Evaluation of IP Modeling Tool Baseline Loads vs TMDL Baseline Loads

Baseline pollutant loads calculated using the IP Modeling Tool were compared with the baseline loads reported in the TMDL documentation reports in order to assess how differences due to model selection and inputs impact baseline load results. Direct comparison could not always be made because baseline loads were not always included in the TMDL documentation reports. Of the 207 MS4 WLAs that were modeled using the IP Modeling Tool, only 72 of those had MS4 baseline loads reported in the TMDL documentation. This occurred for several reasons, including:

- Baseline loads were not specifically broken out by source (e.g., baseline loads are reported as the sum of MS4 and direct drainage loads).
- Baseline loads were not specifically broken out by watershed segments (e.g., baseline loads are reported for the entire Upper Anacostia, rather than by individual segments like Northwest Branch, Watts Branch, etc.).
- Baseline loads were not reported at all, only WLAs were reported.

No load comparisons are included for TMDLs that did not have numeric MS4 WLAs (e.g., Fort Davis BOD TMDL; Hickey Run TMDLs for Oil and Grease, PCB, and Chlordane).

The results of this comparison for each individual pollutant are presented in Table 5 - 6. For the 72 MS4 baseline loads that were reported, approximately one-fourth of the IP Modeling Tool results are less than the original baseline TMDL results and three-fourths are greater. In the case of the organic pollutants, the IP Modeling Tool baseline results are almost always greater than the TMDL baseline results. Since the EMC values for organic pollutants do not change between the two models (see Table 5 - 3), the differences in loads are largely due to use of different runoff methods or updates to area delineations. For the other pollutants, the differences in results can be attributed to a variety of factors, as shown in Table 5 - 7.

Table 5 - 6: Annual Baseline Load Comparison

	TMDL Baseline Greater	IPMT Baseline Greater
CONVENTIONALS		
Nitrogen	1	3
Phosphorus	0	4
TSS	3	1
Bacteria[1]	-	-
BOD	1	1
Trash	1	1

Table 5 - 6: Annual Baseline Load Comparison		
	TMDL Baseline Greater	**IPMT Baseline Greater**
METALS		
Arsenic	0	1
Copper	0	2
Lead	1	3
Mercury	0	2
Zinc	0	2
ORGANICS		
Chlordane	0	7
DDD	2	0
DDE	0	2
DDT	0	4
Dieldrin	9	2
Heptachlor Epoxide	2	8
PAH1	0	3
PAH2	0	3
PAH3	0	3
TOTAL	**20**	**52**

[1] Fecal Coliform Bacteria baseline loads from the TMDL studies were not translated.

Table 5 - 7: Reasons for Differences in Baseline Pollutant Loads		
Differences in modeling approaches	**Reason for differences**	**Effect of difference**
Different runoff method	Needed consistent method to determine runoff volumes in MS4 and for BMPs	Significant effect. Simple method typically produces slightly higher runoff volumes compared to gaged flow volumes
Different precipitation	Needed consistent value to apply across MS4 and BMPs	Minor effect
Different drainage areas	Better GIS data for delineations	Significant effect if new drainage area is very different. Could result in higher/lower runoff volumes and pollutant loads
Different MS4 characterization	Better GIS data to characterize MS4	Minor effect
Different stream bank erosion method	Understanding of SBE has evolved	Significant effect. Generally results in additional load from SBE
Different EMC	Better/more data to draw from	Significant effect. Could result in higher/lower pollutant loads

5.3.5.b *Evaluation of Current Loads*

The current condition represents stormwater loads in the District that are influenced and reduced by BMPs and other storm water management practices that are in place. The current pollutant loads are calculated by subtracting the load reductions provided by the current BMPs from the baseline pollutant loads as follows:

Current load = baseline load – current BMP load removed

A summary of load reductions achieved by existing BMPs is presented below to provide background information prior to discussing the gap analysis, which is presented in the next section.

The current BMP load removed provided by the aggregate of all current BMPs for each pollutant is summarized in Table 5 - 8. The summary table shows that trash is removed at the highest rate. Management strategies that reduce trash in the MS4 include trash traps, community cleanup days, skimmer boats, the plastic bag law, and street sweeping. The summary table also shows that the current BMP inventory results in only minor reductions for all other pollutants. This summary table suggests that the current inventory of BMPs is insufficient in numbers to significantly reduce the majority of pollutants.

Table 5 - 8: Range of Percent Load Reduction Provided by Existing BMPs Across all MS4 TMDL Segments

Pollutant	Range of Load Reduction Provided by all BMPs
TN	<1%-3%
TP	5%-11%
TSS	<1%-7%
BOD	<1%-12%
Arsenic	<1%-27%
Copper	1%-11%
Lead	<1%-9%
Mercury	<1%-1%
Zinc	1%-2%
Chlordane	<1%-2%
DDD	1%-7%
DDE	<1%-6%
DDT	<1%-6%
Dieldrin	<1%-7%
Heptachlor Epoxide	<1%-3%
PAH1	<1%-2%
PAH2	<1%-2%
PAH3	<1%-5%
E. *coli*	<1%-17%
Trash	66-90%

5.3.5.c Gap Analysis

The current loads determined through the application of the IP Modeling Tool provide the basis for the gap analysis. The gap analysis is an evaluation of the difference between the current load and the individual WLAs, as shown in the equation and Figure 5 - 2 below.

Gap = Current Load – TMDL WLA

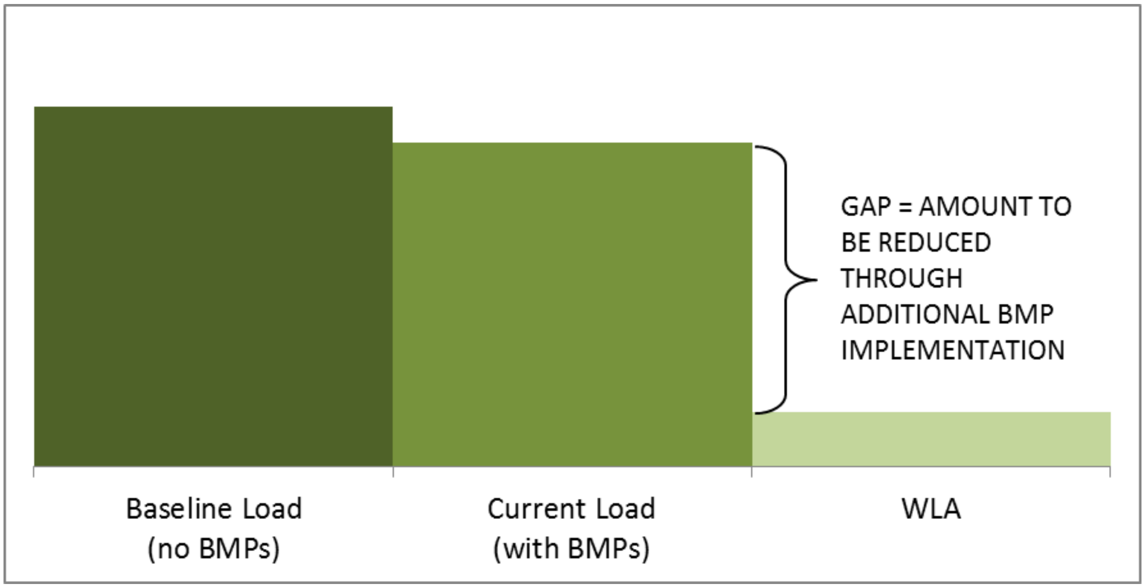

Figure 5 - 3: Graphical Representation of the Gap

Because of the large number of pollutants and impaired water segments in the District, there are many gaps to evaluate. This includes 206 annual, 7 seasonal, 1 monthly, and 79 daily gaps. The baseline loads, current loads, WLAs, and gaps for each of these pollutant/impaired waters segment combinations are tabulated in the Baseline Attachment Tables 1-24 which are included after Section 6. This section of the report provides a few key observations on the annual gaps.

The gap can be expressed as:

- An absolute load (for example, expressed as pounds of total nitrogen to be removed per year),
- A percent reduction from the current load (for example, expressed as a 70% reduction of the current annual load), or
- A runoff volume (as explained in the next section).

Gap Expressed as an Absolute Load

Expressions of the gap as an absolute load are included in Baseline Attachment Tables 1-23, which are included at the end of Section 6. The absolute load reductions of different TMDLs vary in magnitude depending on the pollutant and TMDL segment. It is difficult to provide a comparative assessment of absolute loads for different pollutants since, for example, one pound of total suspended sediment cannot be compared to one pound of arsenic. The next sections express the gaps as percent load reductions and as volume reductions, both of which are expressions of the gaps that are better suited for a comparative analysis of all the various WLAs.

Gap Expressed as a Percent Load Reduction

As an alternative to evaluating the gap as an absolute load reduction, the percent reduction approach provides a simple way to convey the relative amount of additional load reduction needed to meet WLAs. Figure 5 - 3 below shows the percent reduction needed to meet WLAs and ranks them in ascending order. This analysis shows that 29 of the current annual loads show compliance with the WLAs, 28 current annual loads need up to a 50% reduction to be in compliance, 76 current annual loads need between 50 and 90% reduction in to be in compliance, and 73 current annual loads need more than a 90% reduction

DISTRICT DEPARTMENT OF THE ENVIRONMENT

to meet the WLAs. There are also 200 annual WLAs that are not evaluated with the IP Modeling Tool. Each of these categories is explained in more detail below.

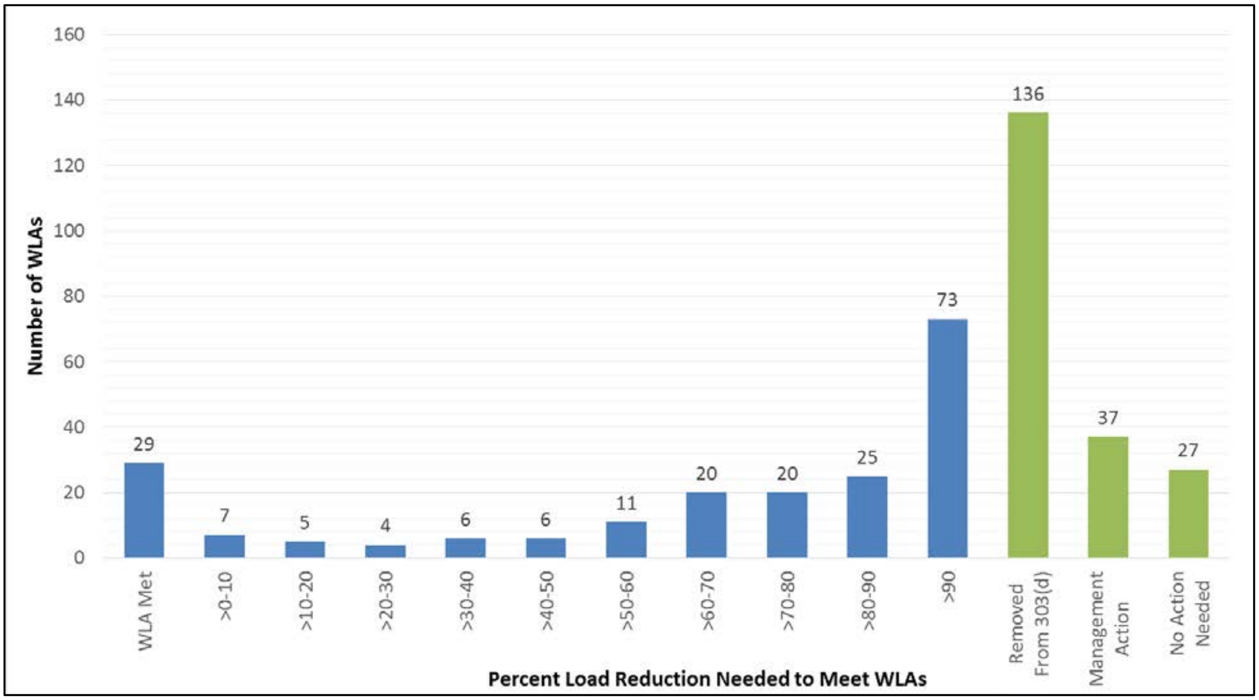

Figure 5 - 4: Gap Expressed as Percent Reduction Needed to Meet WLA

Current Loads that are in Compliance with WLAs

There are currently 29 WLAs that have been met. The current loads that are in compliance with WLAs encompass a variety of pollutants, both conventional and non-conventional, and include loads from across the MS4 area. Pollutants/WLAs included in this category include:

- 10 for organics (out of a total of 105 organic WLAs)
- 11 for metals (out of a total of 46 metal WLAs)
- 3 for nutrients (out of a total of 18 nutrient WLAs)
- 2 for bacteria (out of a total of 20 bacteria WLAs)
- 3 for TSS (out of a total of 11 TSS WLAs)

The reason that these pollutant loads meet WLAs is not specifically because of load reductions from BMP implementation, but rather primarily because of the assumptions underlying model inputs. For example, the analysis shows that most zinc WLAs have been met because the EMC value for zinc used in the IP Modeling Tool is on the order of 30 to 40% less (depending on the water segment) than the zinc EMC value used to develop the original TMDLs. Lower EMCs in the updated modeling lead to lower current loads and thus a smaller gap – and in these cases, no gap at all. As described previously, the EMCs are based on current monitoring data and are thus deemed more representative of the current conditions than the EMCs used in the original TMDLs. Other WLAs have been met because updated drainage areas are smaller than drainage areas included in the original TMDLs. As with lower EMCs, smaller drainage areas in the updated modeling lead to lower current loads and thus a smaller (or zero) gap. As described earlier, the updated drainage areas were based on better GIS data and are thus deemed more representative of the current conditions than the drainage areas used in the original TMDLs. It should be noted that when a drainage area is updated and becomes smaller than in the original TMDL, an adjacent drainage area must necessarily become larger because all land/drainage area is conserved within the IP Modeling Tool.

Current Loads that Need up to 50% Additional Reduction to be in Compliance with WLAs

There are 28 current loads that need up to a 50% reduction to meet their WLAs. These include a variety of pollutants, both conventional and non-conventional, and include loads from across the MS4 area. Pollutants/WLAs included in this category include:

- 9 for organics (out of a total of 105 organic WLAs)
- 11 for metals (out of a total of 46 metal WLAs)
- 2 for nutrients (out of a total of 18 nutrient WLAs)
- 2 for bacteria (out of a total of 20 bacteria WLAs)
- 2 for trash (out of a total of 2 trash WLAs)
- 1 for TSS (out of a total of 11 TSS WLAs)
- 1 for BOD (out of a total of 5 BOD WLAs)

The loads that require the smallest percent reduction (less than 10%) include:

• Nitrogen in the POTTF_MD segment	• Lead in the Fort Chaplin Tributary
• Dieldrin in the Upper Anacostia	• Lead in the Nash Run Tributary
• Dieldrin in the Upper Watts Branch Tributary	• Arsenic in the Texas Avenue Tributary
• Trash in Upper Anacostia	

Current Loads that Need between 50 and 90% Additional Reduction to be in Compliance with WLAs

There are 76 current loads that need between a 50% and 90% reduction to meet their WLAs. These include a variety of pollutants, both conventional and non-conventional, and include loads from across the MS4 area. Pollutants/WLAs included in this category include:

- 40 for organics (out of a total of 105 organic WLAs)
- 16 for metals (out of a total of 46 metal WLAs)
- 11 for nutrients (out of a total of 18 nutrient WLAs)
- 2 for bacteria (out of a total of 20 bacteria WLAs)
- 5 for TSS (out of a total of 11 TSS WLAs)
- 2 for BOD (out of a total of 5 BOD WLAs)

Current Loads that Need More than 90% Additional Reduction to be in Compliance with WLAs

There are 73 current loads that need more than a 90% reduction to meet their WLAs. These include a variety of pollutants, both conventional and non-conventional, and include loads from across the MS4 area. Pollutants/TMDLs included in this category include:

- 46 for organics (out of a total of 105 organic WLAs)
- 6 for metals (out of a total of 46 metal WLAs)
- 3 for nutrients (out of a total of 18 nutrient WLAs)
- 14 for bacteria (out of a total of 20 bacteria WLAs)
- 2 for TSS (out of a total of 11 TSS WLAs)
- 2 for BOD (out of a total of 5 BOD WLAs)

Loads that are removed from 303(d) List

There are 136 WLAs that were placed into Category 3 of the 2014 303(d) list based on sampling that was conducted in 2014. Based on discussions with EPA Region 3 regarding the original impairment listings, TMDLs, and the updated sampling results, DDOE has concluded that the need for these 136 MS4 WLAs was no longer supported by the data. This group contains 118 organic WLAs and 18 metal WLAs covering the Anacostia, Potomac, and Rock Creek tributaries.

Loads Requiring Management Actions

There are 37 WLAs that require management actions as opposed to tracking of numeric load reductions through modeling. These include:

- 30 PCB WLAs, for which reduction in loads will be assessed through source control rather than through conventional modeling;
- Three WLAs from the 1998 Hickey Run oil and grease, PCB and chlordane TMDL that require management plans for implementation;
- Two E. coli allocations (Nash Run, Watts Branch) that are not modeled because no District-specific WLA was calculated (both Nash Run and Watts Branch have segments in the District and in Maryland, but the allocations in the updated TMDL are for the entire waterbody and aren't broken out into District- and Maryland-specific MS4 WLAs); and
- Two copper WLAs (one each for the Upper and Lower Anacostia segments) where the WLAs are incorrect in the original TMDLs (the copper WLAs are exactly the same as the lead MS4 WLAs, thus indicating that there was a transcription error in the original TMDL).

Loads Requiring No Action

There are 27 WLAs that require no action, including 24 Fecal Coliform WLAs that were replaced by E.coli WLAs; one BOD WLA for Fort Davis that is deemed "not an impairment" according to the TMDL; and two WLAs for Kingman Lake (BOD and TSS) which "no longer require a TMDL" according to the TMDL documentation.

The percent load reductions needed to meet the annual WLAs are also displayed qualitatively for each segment and pollutant in Figure 5 - 4. The larger and greener the bubble, the larger the percent reduction required (note that the size and color of the bubbles use sliding scales). Empty squares indicate that the WLA has been achieved. If there is no square, then there is no WLA for that pollutant/waterbody combination.

Figure 5 - 4 shows that, in addition to being abundant, the WLAs for bacteria and organic pollutants require the greatest amount of load reductions. The figure also shows that the Anacostia has the greatest number of WLAs of all watersheds, and that all tributaries, regardless of their location in the MS4, have a multitude of WLAs.

The percent load reductions required to meet annual WLAs can also be displayed spatially for each pollutant. For example, Figure 5 - 5 shows the percent load reduction needed to meet the WLAs for TSS at the different segment levels for which there are MS4 WLAs. Figures for all 20 pollutants are appended to the results table after Section 6 of this report (Baseline Attachment Figures 1 through 20).

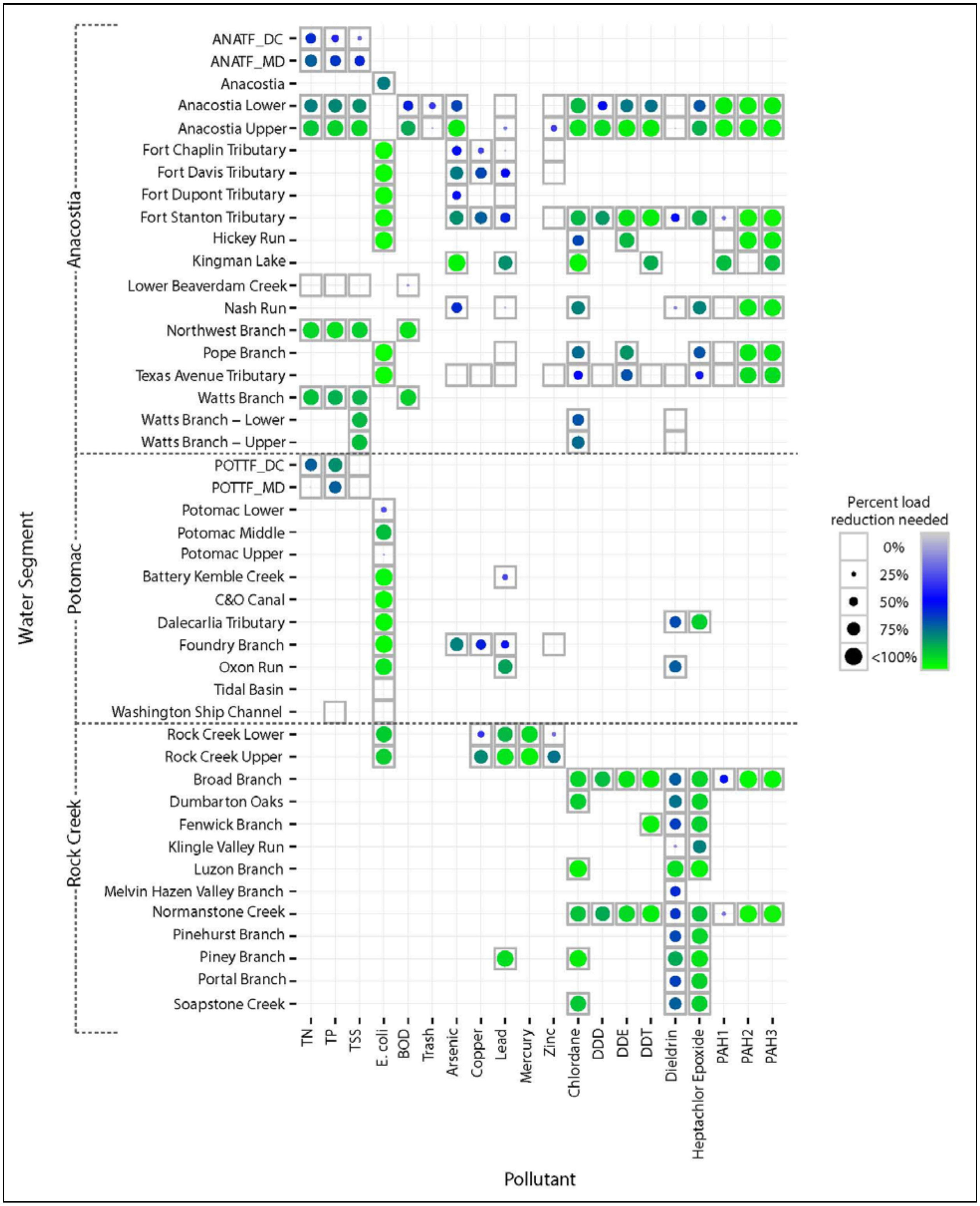

Figure 5 - 5: Percent Load Reduction Needed to Meet Annual WLAs

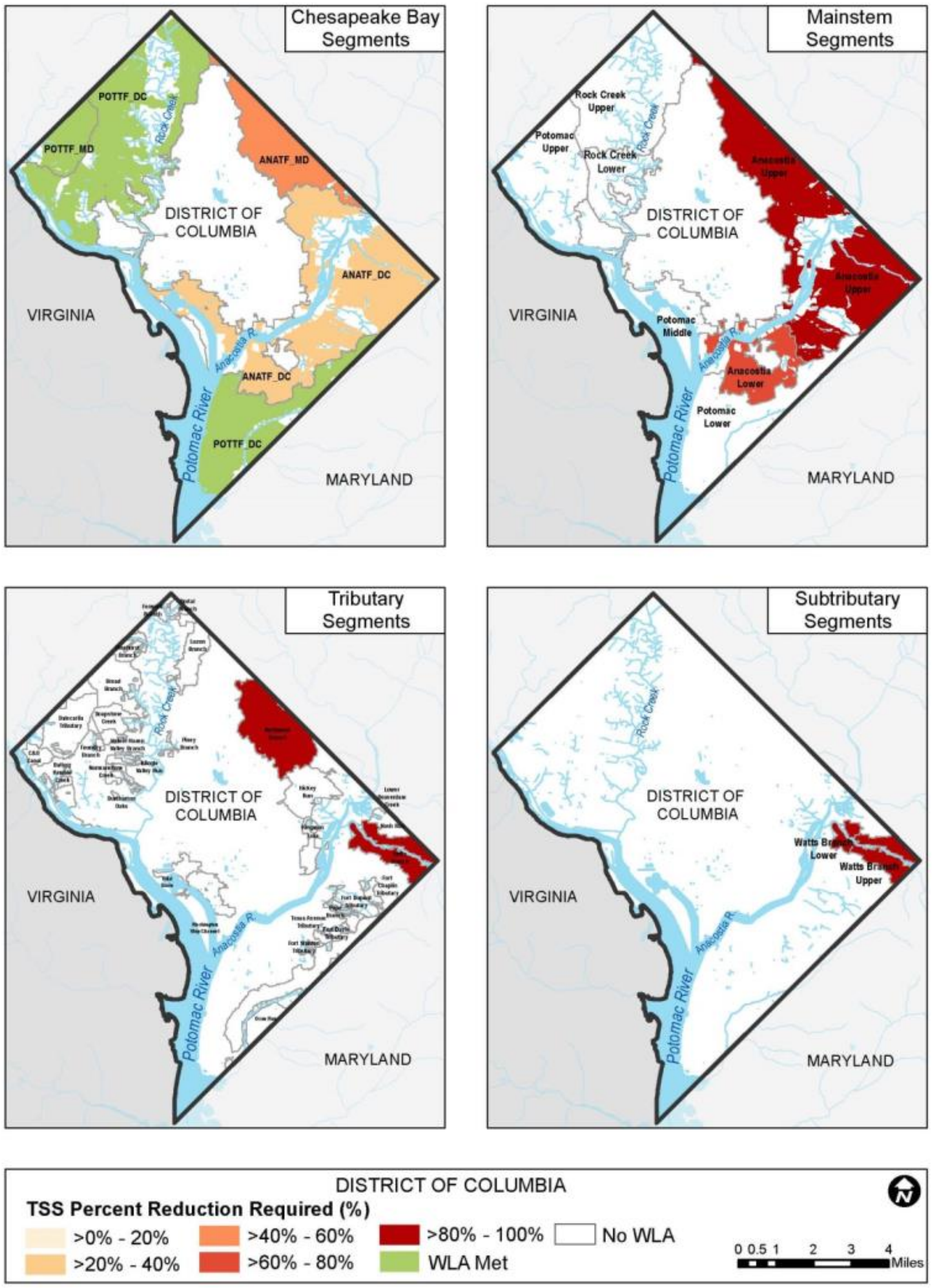

Figure 5 - 6: TSS Percent Load Reduction Needed to Meet Annual WLAs

Gap Expressed as a Depth of Stormwater Volume Retention Needed

The gap can also be calculated in terms of stormwater runoff volume that needs to be retained by BMPs in order to meet the WLA, because, for a given EMC, pollutant load is directly proportional to stormwater volume. Expressing the gap in this way allows a direct comparison to the stormwater volume retention standard required by DC's new stormwater regulations, which (in general) specify that 1.2 inches of stormwater runoff volume must be managed on-site at all development or redevelopment that disturbs more than 5,000 square feet (DDOE 2013b)[7].

This analysis is carried out on the specific MS4 area within the tributary or TMDL segment under consideration, and the resulting depth of stormwater volume retention needed is spread across the entire MS4 area within that tributary/TMDL segment. This process involved the following steps:

1. Convert the load gap to a volume gap
2. If the BMP is non-retention based (BMPs that reduce the pollutant load but not the volume of runoff), convert the load reductions to an "equivalent" volume reduction. This conversion takes the EMC and BMP load reduction and converts it to an "equivalent" volume for analysis.
3. Convert the volume gap and "equivalent" volume reduction into a percent stormwater volume reduction needed.

Each of these steps if further explained below.

Convert the load gap to a volume gap

To convert the load gap to a volume gap, the following conversion is applied:

$$volume\ reduction\ gap = \frac{load\ gap}{EMC} \times 0.89$$

Where:

Volume reduction gap is expressed in million gallons/yr

Load gap is expressed in lbs/yr or in billion MPN/yr

EMC is expressed in mg/l or in MPN/100ml

0.89 is used as a conversion factor for the combination of acres for area and mg/l for pollutant concentration (Note: a separate conversion factor of 0.004 is used for bacteria concentrations).

Convert non-retention loads to an "equivalent" volume reduction

The calculation of required volume reductions become complicated when evaluating non-retention based BMPs, because they reduce the pollutant load but do not reduce the volume of runoff. To convert the structural and nonstructural BMP load reductions to an "equivalent" volume reduction (i.e. the volume reduction required after consideration of non-retention based BMPs), the following conversion is applied:

$$BMP\ volume\ reduction = \frac{BMP\ load\ reduction}{EMC} \times 0.89$$

Where:

[7] For a full description of the stormwater retention standards, please consult the stormwater management rules and guidebook available at http://ddoe.dc.gov/swregs.

BMP volume reduction is expressed in million gallons/yr

BMP load reduction is expressed in lbs/yr or in billion MPN/yr

EMC is expressed in mg/l or in MPN/100ml

0.89 is used as a conversion factor for the combination of acres for area and mg/l for pollutant concentration (Note: a separate conversion factor of 0.004 is used for bacteria concentrations).

Express volume gap as a percent stormwater volume reduction needed

Once the volume reduction gap and BMP volume reduction are calculated, that current gap can be expressed as a percent stormwater volume reduction needed by applying the following equation:

$$\text{Percent stormwater volume reduction} = \frac{\text{volume reduction gap}}{\text{baseline volume} - \text{BMP volume reduction}}$$

Where:

Percent stormwater volume reduction is expressed as a percent

Volume reduction gap is expressed in million gallons/yr

Baseline volume is expressed in million gallons/yr

BMP volume reduction is expressed in million gallons/yr

This percent stormwater volume reduction needed can then be converted into an equivalent depth of runoff retention. This is accomplished using the runoff retention curve for an infiltration-based BMP, which correlates annual runoff reduction efficiency to the design runoff retention depth of a BMP. Figure 5 - 6 below shows how intersection on the runoff retention curve would be used to translate, for example, a 70% annual runoff volume reduction to a runoff retention depth of 0.8 inches. Because it is not known ahead of time what type of BMP (i.e., bioretention, permeable pavement, infiltration trench, or other) would provide the retention, this analysis uses the representative enhanced bioretention runoff retention curve for this purpose. The percent reduction associated with 1.2inches of runoff treatment by an enhanced bioretention practice is approximately 83.5%.

Expressing the gap as a retention depth is based on three major assumptions:

1. Load reductions will only occur through stormwater volume management. It does not take into account load reductions through source control.
2. The runoff reduction curve used for this analysis was chosen to represent the average efficiencies for retention-based BMPs.
3. The concentration of pollutants, represented by the EMC, is assumed to be constant over the length of the rain event. In other words, the pollutant load found in stormwater is assumed to be the same from the beginning of a storm to the end of the storm.

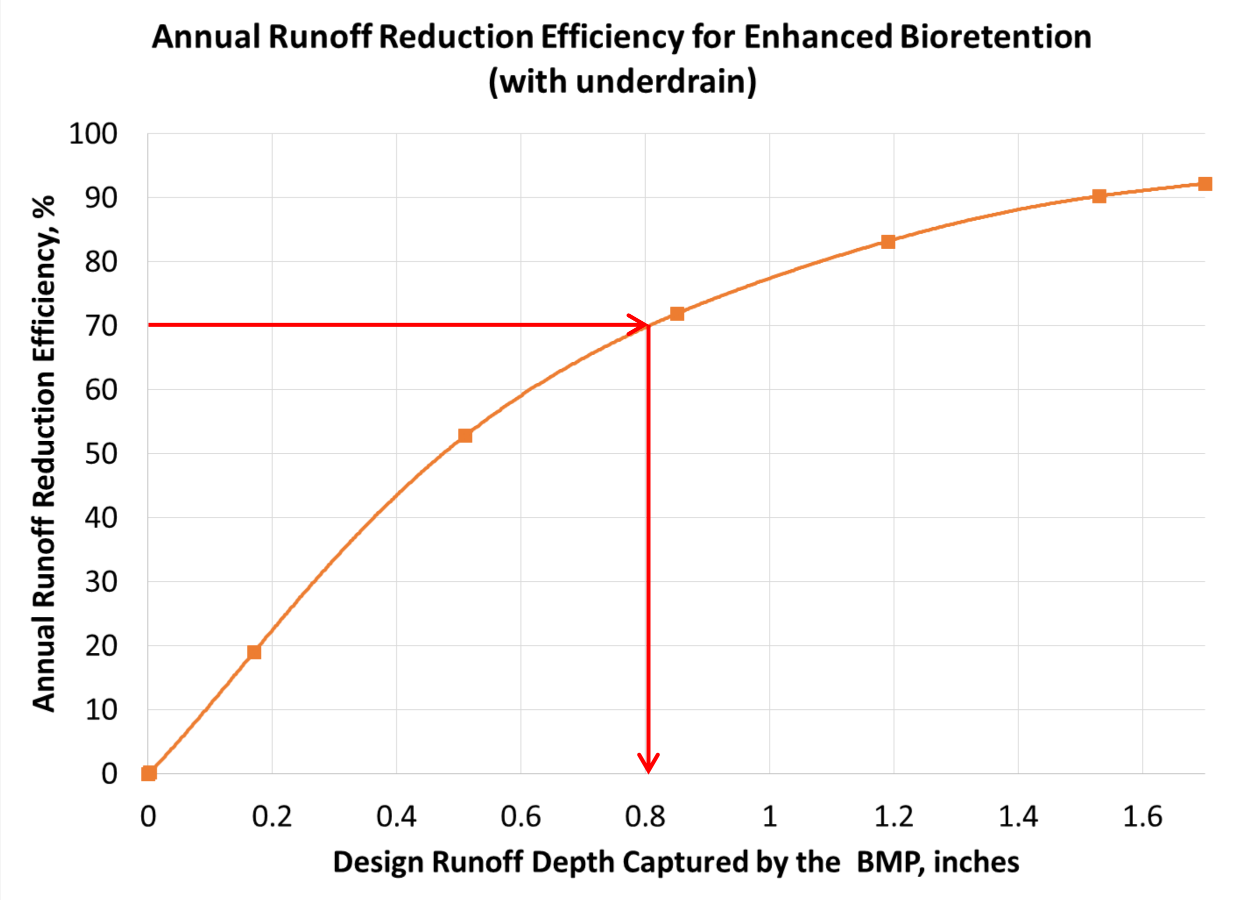

Figure 5 - 7: Summary of Depth of Runoff Retention Needed to Meet Annual WLAs

Despite the need to use several assumptions in developing this analysis, depicting the gap in terms of retention depth provides a useful way to assess implementation needs. As the hypothetical runoff retention depth is increased over the MS4 area, an increasing number of individual WLAs are expected to be met, as shown in Figure 5- 7 below (note that the two trash WLAs are not included in this figure because trash removal is not related to stormwater retention. Thus the figure depicts 204 annual WLAs). Multiple observations can be made from the figure. First, the figure shows that 29 WLAs require zero retention depth; this reflects the 29 WLAs that have already been met. Next, the yellow bar shows a retention depth of 0.003 inches; this is a best estimate of the current level of runoff retention depth that is provided by the aggregate of the existing retention-based BMPs in the MS4 area. This bar shows that no additional WLAs (i.e., no additional WLAs other than the ones that have already been met) have been achieved by the retention depth provided by the existing retention-based BMPs in the MS4 area. The bar depicting 1.2 inches shows that if 1.2 inches of runoff is retained over the entire MS4 area - a scenario that would require substantial retrofitting of BMPs on most properties - a total of 113 WLAs will be met. Meeting all WLAs would require up to 2 inches of retention depth, as is shown in the right-most bar in Figure 5- 7. Note that 2 inches of runoff retention would not be required in all subwatersheds to achieve WLAs; in some subwatersheds, less retention depth is required to meet WLAs. This is illustrated in Figure 5-9, which shows the spatial variation in the BMP retention depth required to meet MS4 WLAs over the MS4 area. For example, as shown in the figure, the Middle Potomac watershed requires 1.4 inches of retention before it meets all of its annual WLAs, whereas all the subwatersheds in the Anacostia watershed require two inches of retention until they meet all of their WLAs.

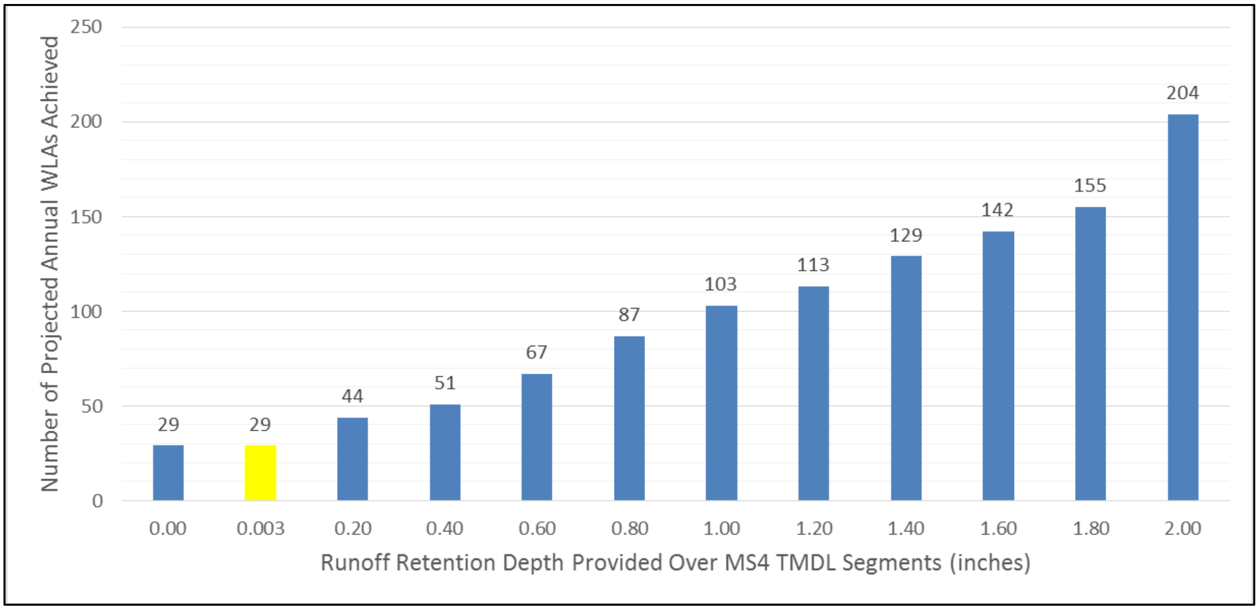

Figure 5 - 8: Projected WLAs Achieved with Incremental Increase in Runoff Retention Depth Provided[8]

[8] Note that this figure shows results for 204 out of the 206 total modeled annual WLAs. The 2 trash WLAs are independent of the runoff retention depth and therefore are not included in this figure.

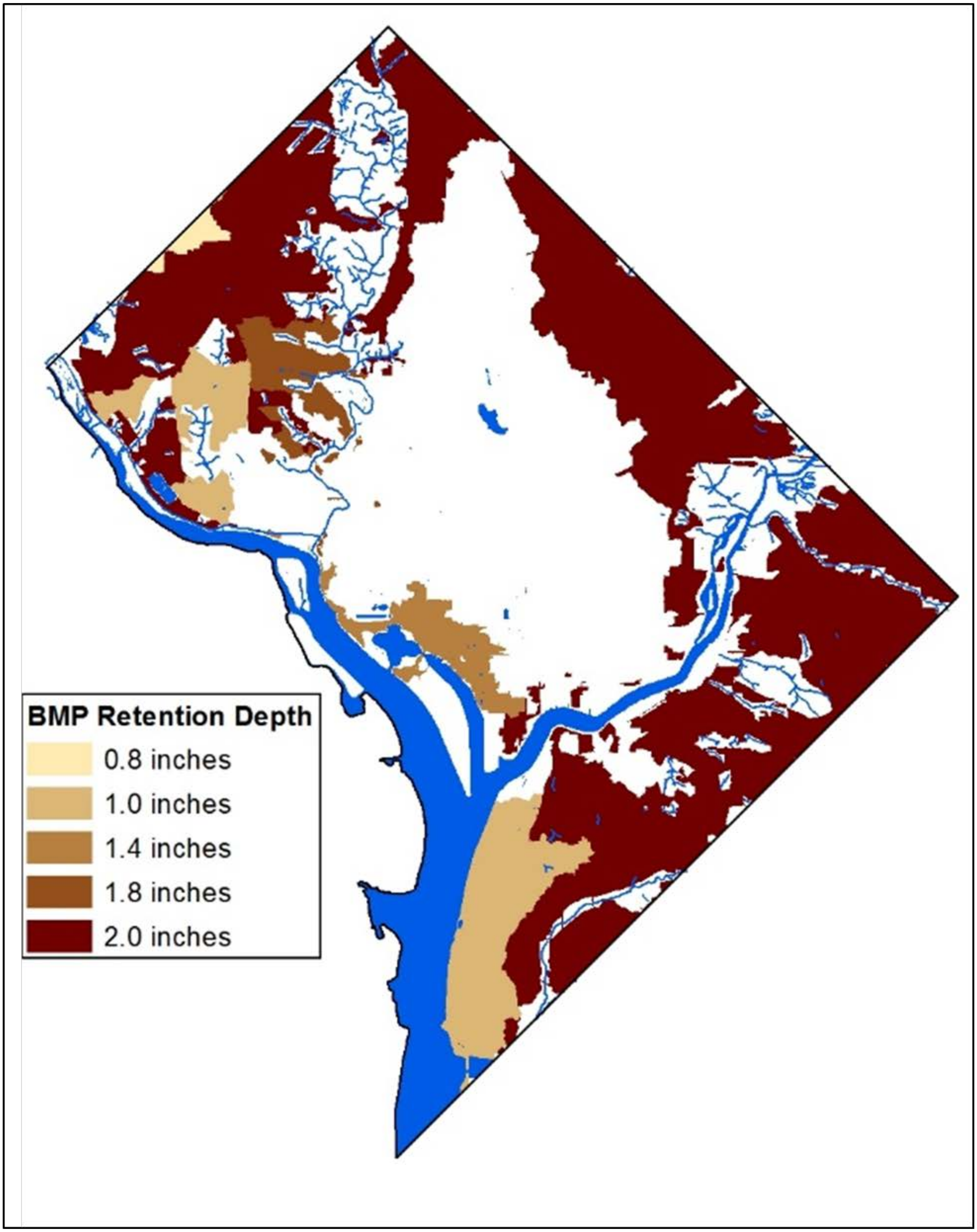

Figure 5 - 9: Spatial Representation of the Required BMP Retention Depth over the MS4 to Meet all Annual MS4 WLAs

5.3.5.d Findings and Implications

The major findings of the Comprehensive Baseline Analysis are as follows:

- The use of GIS technology greatly improved the District's understanding of the MS4 system with respect to sewershed drainage areas and the land use and land cover makeup of sewersheds.
- The MS4 outfall monitoring program carried out by the District during 2001 through 2013 provided a body of wet weather observations that was applicable for the development of updated EMCs for conventional pollutants and metals.
- The IP Modeling Tool was developed to approximate stormwater runoff, pollutant load generation, and pollutant load reduction in a consistent manner for the entire MS4 area in the District. This tool serves as an accounting framework for tracking MS4 pollutant loads, load reduction, and progress toward attainment of the MS4 WLA targets.
- The IP Modeling Tool produced baseline pollutant loadings that differed from the baseline loads reported in the TMDL studies. This was largely attributable to a combination of the use of a different runoff calculation, the re-delineation of sewershed areas, and the use of updated EMCs. This resulted in approximately three-fourths of the individual load allocations across the TMDL segments having larger baseline loads than previously reported, and one third having lower baseline loads.
- The inventory of existing BMPs was useful in determining a current condition that shows the load reduction achieved by these BMPs. In general, the existing BMPs have a very minor impact on reducing pollutant loads across the District. Trash presents an exception, where current control programs remove roughly 65 to 90 percent of the required trash WLA.
- The lack of necessary data for some non-structural BMPs such as catch basin cleaning, illicit discharge detection and elimination, and pet waste control makes it difficult to include the pollutant removal capabilities of these practices in the analysis of current conditions.
- The pollutant load reduction gaps for individual TMDL segments vary substantially in magnitude, and no distinctive spatial patterns were found.
- Bacteria and organic substances are the controlling pollutants that require the greatest amount of stormwater control. These pollutants also makeup the majority of MS4 TMDL WLAs.
- The gap analysis revealed that 29 MS4 TMDL WLAs have been attained, primarily because of the choice of model framework and inputs.
- The gap analysis also revealed that meeting the MS4 WLA targets for most of the remaining TMDLs will require a very large amount of stormwater volume and pollutant load reduction. A total of 149 MS4 TMDL WLAs will require more than a 50 percent reduction in current loads, and 73 of these require reduction that is 90 percent or greater.

The major implications of these finding for the Consolidated TMDL IP are as follows:

- The pollutant load reduction gaps for nearly all of the MS4 TMDL WLAs are substantial. Achieving the WLAs for the majority of the pollutants will require extremely high levels of stormwater management and control.
- The existing inventory of BMPs represents a start, but generally achieves less than 5 percent of the pollutant load reduction that is needed, except for trash which achieves 65% to 90% of the required load reduction.

- The requirement to retain 1.2 inches of runoff volume, even if applied to the entire MS4 drainage area (not just to new development and redevelopment), would still not achieve the prescribed load reduction for nearly 45 percent of the MS4 TMDL WLAs.
- The MS4 area is largely residential (39 percent) and, beyond the RiverSmart programs, there is little incentive for home owners in residential neighborhoods to retrofit stormwater BMPs on their properties.
- The public right of way including streets, sidewalks, and alleys represent a very large percentage of the impervious area in the MS4 area (27 percent). Developing a comprehensive program to implement street-side bioretention and use permeable pavement products in the public right of way would likely be very advantageous to the ultimate success of DDOE's Consolidated TMDL IP.
- While not addressed in the baseline, it is expected that the cost of meeting the MS4 TMDL WLAs will be exceptionally high. To put this cost in context, the MS4 runoff reduction volumes necessary to meet the MS4 TMDL WLAs for bacteria across the District are compared in Table 5 - 9 with the combined sewer overflow (CSO) volumes controlled under DC Water's CSO Long Term Control Plan (DC WASA, 2002). As shown, the MS4 volumes are greater than the CSO volumes covered in DC Water's control program – a program that will cost approximately $2 billion to implement. The use of bacteria as the driving pollutant is used in this comparison because the level of CSO control was essentially based on meeting the water quality standards for bacteria, and is represented in the bacteria TMDLs as a CSO WLA.

Table 5 - 9: Comparison of Stormwater Volume Reductions Needed to Meet WLAs in the CSO and MS4

Watershed	CSO Volume Controlled (MG)	CSO Control as a Percent	MS4 Volume to be Controlled (MG)	MS4 Control as a Percent
Anacostia	2,088	97.5	2,895	76.4
Potomac	984	92.5	962	30.8
Rock Creek	44	90.0	1,569	91.3
Total	3,116		5,426	

- Managing large volumes of stormwater to meet MS4 WLAs is further complicated because BMPs, the traditional approach to stormwater and nonpoint source control, have their own inherent limits as volume control practices. Furthermore, opportunities to successfully implement BMPs will also be limited.
- Given the required level of control and the volume control limits associated with BMPs, this analysis suggests that an approach focused solely or even primarily on distributed implementation of BMPs will not be sufficient to attain MS4 WLAs in the near-term.
- In light of this analysis, while implementation is underway it will also be prudent to re-examine the scientific basis of the TMDLs and MS4 WLAs. Many of the TMDLs are based on data, analysis and modeling that was performed 10 to 15 years ago. The re-examination could be accomplished with targeted outfall and receiving water monitoring, and overseen by a Scientific Advisory Board. Revisiting the scientific basis of the TMDLs and MS4 WLAs during the early phase of implementation over the next NPDES permit cycle would not slow down implementation, and it would verify the level of control needed.

6. Next Steps

This Final Comprehensive Baseline Analysis provides:

- An evaluation of the development of TMDLs and the District's water quality monitoring record to determine if TMDL WLAs have been achieved.
- An analysis of any pollutant load increases that have occurred since WLAs were first established.
- An analysis of BMPs that have been implemented since WLAs were first established.
- An analysis of pollutant load reductions that have been achieved by those implemented BMPs.
- A calculation of pollutant loads reductions remaining that are necessary to achieve WLAs.

The next steps to be taken to prepare a Consolidated TMDL Implementation Plan and a Revised Monitoring Framework are outlined separately below.

Consolidated TMDL Implementation Plan

The next step in the development of the Consolidated TMDL Implementation Plan is to identify specific management scenarios and model those scenarios with the IP Modeling Tool to examine storm water and pollutant removal occurring through:

- Development and redevelopment activity, and implementation of the District's stormwater management regulations.
- Projects known to be planned or implemented by District Agencies.
- Potential projects identified in District Watershed Implementation Plans.

Wherever possible, scenarios will project change over time in five year increments, and results for individual pollutants will be compared with load reductions needed to achieve the MS4 WLAs at the TMDL segment level.

A Final Scenario Analysis Report will be prepared in May of 2015.

In addition to examining the level of stormwater and pollutant control achieved with implementation scenarios, parallel efforts will be made to:

- Continue stakeholder involvement and public outreach.
- Integrate the IP planning with other watershed planning efforts.
- Quantify costs and explore funding options for the Consolidated TMDL Implementation Plan.

A Consolidated TMDL Implementation Plan will be finalized in May 2015.

Revised Monitoring Framework

The next steps in developing the Revised Monitoring Framework are:

- Finalization of the Crosswalk Comparison of Monitoring Needs and Existing Monitoring Components to support the development of the Revised Monitoring Program required by the DDOE's NPDES MS4 permit.
- Assessment of DDOE's existing outfall and ambient monitoring locations.
- Establishment of monitoring protocols to ensure that data is "statistically significant and interpretable."

- Evaluation of monitoring objectives with an Interdepartmental Monitoring Work Group.
- Development of a Final Revised Monitoring Program by May 2015 that addresses programmatic objectives, wet weather monitoring, ambient monitoring, dry weather screening, and program evaluation.

Baseline Attachment Table 1: TMDL for Sediment/TSS for the Anacostia River Basin, Montgomery and Prince George's Counties, MD and the District of Columbia (2007)

WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia Lower	TSS - Annual	lbs/yr	Not found	463,963	24,784	346,379	92,800
Anacostia Lower	TSS - Seasonal	lbs/growing season	Not found	289,977	15,437	207,340	67,200
Anacostia Lower	TSS - Daily	lbs/day	Not found	102,392	5,470	76,442	20,480
Anacostia Upper	TSS - Annual	lbs/yr	Not found	2,234,484	13,544	2,051,740	169,200
Anacostia Upper	TSS - Seasonal	lbs/growing season	Not found	1,396,552	8,200	1,267,552	120,800
Anacostia Upper	TSS - Daily	lbs/day	Not found	484,666	2,938	445,029	36,700
Lower Beaverdam Creek	TSS - Annual	lbs/yr	Not found	959	17	0	1,200
Lower Beaverdam Creek	TSS - Seasonal	lbs/growing season	Not found	600	10	0	800
Lower Beaverdam Creek	TSS - Daily	lbs/day	Not found	149	3	0	186
Northwest Branch	TSS - Annual	lbs/yr	Not found	585,312	2,639	530,273	52,400
Northwest Branch	TSS - Seasonal	lbs/growing season	Not found	365,820	1,574	322,846	41,400
Watts Branch	TSS - Annual	lbs/yr	Not found	333,496	3,158	282,138	48,200
Watts Branch	TSS - Seasonal	lbs/growing season	Not found	208,435	1,940	175,495	31,000
Watts Branch	TSS - Daily	lbs/day	Not found	47,199	447	39,931	6,822
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	TSS - Annual	lbs/yr	Not found	179,063	901	136,762	41,400
Anacostia Lower	TSS - Daily	lbs/day	Not found	39,100	197	29,863	9,040
Anacostia Upper	TSS - Annual	lbs/yr	Not found	490,337	206,769	223,967	59,600
Anacostia Upper	TSS - Daily	lbs/day	Not found	104,155	43,921	47,574	12,660

Baseline Attachment Table 2: Chesapeake Bay TMDL for Nitrogen, Phosphorus, and Sediment (2010)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
ANATF_DC	TSS	lbs/yr	2,429,170	2,248,361	39,125	526,767	1,682,470
ANATF_DC	Phosphorus	lbs/yr	8,958	11,597	583	4,516	6,498
ANATF_DC	Nitrogen	lbs/yr	47,130	101,285	593	59,175	41,517
ANATF_MD	TSS	lbs/yr	572,918	744,473	1,011	429,040	314,421
ANATF_MD	Phosphorus	lbs/yr	2,549	3,858	183	2,231	1,444
ANATF_MD	Nitrogen	lbs/yr	12,617	33,706	30	23,252	10,424
POTTF_DC	TSS	lbs/yr	4,904,197	2,153,124	184,532	0	3,843,848
POTTF_DC	Phosphorus	lbs/yr	3,736	14,709	777	10,958	2,975
POTTF_DC	Nitrogen	lbs/yr	42,011	127,818	473	87,918	39,427
POTTF_MD	TSS	lbs/yr	560,577	228,866	307	0	363,762
POTTF_MD	Phosphorus	lbs/yr	753	1,811	83	1,192	536
POTTF_MD	Nitrogen	lbs/yr	18,288	15,716	16	681	15,019
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
ANATF_DC	TSS	lbs/yr	751,133	517,479	20,258	148,677	348,544
ANATF_DC	Phosphorus	lbs/yr	2,770	2,682	299	923	1,459
ANATF_DC	Nitrogen	lbs/yr	14,573	23,429	343	11,792	11,293
ANATF_MD	TSS	lbs/yr	35,675	15,726	41	5,623	10,062
ANATF_MD	Phosphorus	lbs/yr	159	81	5	35	41
ANATF_MD	Nitrogen	lbs/yr	786	712	1	95	616
POTTF_DC	TSS	lbs/yr	2,908,086	304,587	2,272	0	1,582,051
POTTF_DC	Phosphorus	lbs/yr	2,215	2,279	187	728	1,365
POTTF_DC	Nitrogen	lbs/yr	24,912	19,914	114	0	20,156
POTTF_MD	TSS	lbs/yr	54,146	11,039	13	0	36,900
POTTF_MD	Phosphorus	lbs/yr	73	100	8	50	42
POTTF_MD	Nitrogen	lbs/yr	1,766	871	1	0	2,481

Baseline Attachment Table 3: DC Final TMDL for Metals in Rock Creek (2004)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Rock Creek Lower	Copper	lbs/yr	149.67	226.04	1.22	82.63	142.19
Rock Creek Lower	Lead	lbs/yr	69.08	68.15	0.41	58.55	9.19
Rock Creek Lower	Mercury	lbs/yr	0.36	0.81	0.00	0.76	0.05
Rock Creek Lower	Zinc	lbs/yr	351.14	434.89	2.49	98.82	333.58
Rock Creek Upper	Copper	lbs/yr	155.60	656.66	2.99	505.84	147.82
Rock Creek Upper	Lead	lbs/yr	71.82	197.97	1.01	187.42	9.55
Rock Creek Upper	Mercury	lbs/yr	0.38	2.36	0.01	2.30	0.05
Rock Creek Upper	Zinc	lbs/yr	365.04	1,263.37	6.08	910.50	346.79
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Rock Creek Lower	Copper	lbs/yr	Not found	66.09	0.04	64.82	1.24
Rock Creek Lower	Lead	lbs/yr	Not found	19.93	0.01	19.83	0.08
Rock Creek Lower	Mercury	lbs/yr	Not found	0.24	0.00	0.24	0.00
Rock Creek Lower	Zinc	lbs/yr	Not found	127.16	0.07	124.17	2.91
Rock Creek Upper	Copper	lbs/yr	Not found	93.31	0.66	90.99	1.66
Rock Creek Upper	Lead	lbs/yr	Not found	28.13	0.26	27.76	0.11
Rock Creek Upper	Mercury	lbs/yr	Not found	0.34	0.00	0.33	0.00
Rock Creek Upper	Zinc	lbs/yr	Not found	179.52	1.46	174.19	3.88

Baseline Attachment Table 4: DC Final TMDL for Fecal Coliform Bacteria in Upper Potomac River, Middle Potomac River, Lower Potomac River, Battery Kemble Creek, Foundry Branch, and Dalecarlia Tributary (2004)

WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Potomac Lower	E. coli	Billion MPN/yr	Not translated	13,096.18	58.31	0.00	377,000.00
Potomac Middle	E. coli	Billion MPN/yr	Not translated	44,053.03	298.08	0.00	137,000.00
Potomac Upper	E. coli	Billion MPN/yr	Not translated	41,605.53	163.77	0.00	110,000.00
Battery Kemble Creek	E. coli	Billion MPN/yr	Not translated	5,928.61	67.88	5,858.22	2.50
Dalecarlia Tributary	E. coli	Billion MPN/yr	Not translated	4,005.05	7.28	3,997.77	0.00
Foundry Branch	E. coli	Billion MPN/yr	Not translated	10,161.28	0.00	10,155.46	5.82
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Potomac Lower	E. coli	Billion MPN/yr	Not translated	13,096.18	58.31	0.00	377,000.00
Potomac Middle	E. coli	Billion MPN/yr	Not translated	44,053.03	298.08	0.00	137,000.00
Potomac Upper	E. coli	Billion MPN/yr	Not translated	41,605.53	163.77	0.00	110,000.00
Battery Kemble Creek	E. coli	Billion MPN/yr	Not translated	5,928.61	67.88	5,858.22	2.50
Dalecarlia Tributary	E. coli	Billion MPN/yr	Not translated	4,005.05	7.28	3,997.77	0.00
Foundry Branch	E. coli	Billion MPN/yr	Not translated	10,161.28	0.00	10,155.46	5.82

Baseline Attachment Table 5: DC Final TMDL for Oil and Grease in the Anacostia River (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia Lower	Oil and Grease	lbs/day	-	63	1	0	200
Anacostia Upper	Oil and Grease	lbs/day	-	305	1	0	366
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	Oil and Grease	lbs/day	-	-	-	-	-
Anacostia Upper	Oil and Grease	lbs/day	-	-	-	-	-

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Broad Branch	Chlordane	lbs/yr	0.01895	0.03639	0.00016	0.03342	0.00281
Broad Branch	DDD	lbs/yr	0.01390	0.01111	0.00006	0.00966	0.00138
Broad Branch	DDE	lbs/yr	0.03059	0.04924	0.00030	0.04651	0.00242
Broad Branch	DDT	lbs/yr	0.08271	0.12661	0.00075	0.12340	0.00246
Broad Branch	Dieldrin	lbs/yr	0.00171	0.00107	0.00000	0.00073	0.00034
Broad Branch	Heptachlor Epoxide	lbs/yr	0.00288	0.00354	0.00001	0.00324	0.00028
Broad Branch	PAH1	lbs/yr	1.30300	2.43778	0.00932	1.13797	1.29049
Broad Branch	PAH2	lbs/yr	7.66450	15.39852	0.07235	15.17440	0.15177
Broad Branch	PAH3	lbs/yr	4.87660	9.92880	0.06572	9.76651	0.09656
Broad Branch	PCBs	lbs/yr	0.12748	-	-	-	0.00013
Dumbarton Oaks	Chlordane	lbs/yr	0.00042	0.00069	0.00000	0.00063	0.00006
Dumbarton Oaks	DDD	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	DDE	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	DDT	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	Dieldrin	lbs/yr	0.00003	0.00002	0.00000	0.00001	0.00001
Dumbarton Oaks	Heptachlor Epoxide	lbs/yr	0.00006	0.00007	0.00000	0.00006	0.00001
Dumbarton Oaks	PAH1	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	PAH2	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	PAH3	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	PCBs	lbs/yr	0.00274	-	-	-	0.00000
Fenwick Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	DDD	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	DDE	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	DDT	lbs/yr	0.01511	0.02131	0.00010	0.02075	0.00045

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)

WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Fenwick Branch	Dieldrin	lbs/yr	0.00034	0.00018	0.00000	0.00011	0.00007
Fenwick Branch	Heptachlor Epoxide	lbs/yr	0.00054	0.00060	0.00000	0.00054	0.00005
Fenwick Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	PCBs	lbs/yr	0.02275	-	-	-	0.00002
Klingle Valley Run	Chlordane	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	DDD	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	DDE	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	DDT	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	Dieldrin	lbs/yr	0.00066	0.00015	0.00000	0.00002	0.00013
Klingle Valley Run	Heptachlor Epoxide	lbs/yr	0.00124	0.00050	0.00000	0.00038	0.00012
Klingle Valley Run	PAH1	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	PAH2	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	PAH3	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	PCBs	lbs/yr	0.06045	-	-	-	0.00006
Luzon Branch	Chlordane	lbs/yr	0.00320	0.02763	0.00007	0.02709	0.00048
Luzon Branch	DDD	lbs/yr	-	-	-	-	Category 3
Luzon Branch	DDE	lbs/yr	-	-	-	-	Category 3
Luzon Branch	DDT	lbs/yr	-	-	-	-	Category 3
Luzon Branch	Dieldrin	lbs/yr	0.00024	0.00082	0.00000	0.00077	0.00005
Luzon Branch	Heptachlor Epoxide	lbs/yr	0.00044	0.00269	0.00002	0.00263	0.00004
Luzon Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Luzon Branch	PAH2	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Luzon Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Luzon Branch	PCBs	lbs/yr	0.02100	-	-	-	0.00002
Melvin Hazen Valley Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	DDD	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	DDE	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	DDT	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	Dieldrin	lbs/yr	0.00026	0.00012	0.00000	0.00007	0.00005
Melvin Hazen Valley Branch	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PCBs	lbs/yr	0.02355	-	-	-	0.00002
Normanstone Creek	Chlordane	lbs/yr	0.00523	0.00681	0.00003	0.00600	0.00078
Normanstone Creek	DDD	lbs/yr	0.00336	0.00208	0.00001	0.00173	0.00033
Normanstone Creek	DDE	lbs/yr	0.00815	0.00922	0.00007	0.00850	0.00065
Normanstone Creek	DDT	lbs/yr	0.02180	0.02370	0.00018	0.02287	0.00065
Normanstone Creek	Dieldrin	lbs/yr	0.00040	0.00020	0.00000	0.00012	0.00008
Normanstone Creek	Heptachlor Epoxide	lbs/yr	0.00073	0.00066	0.00000	0.00059	0.00007
Normanstone Creek	PAH1	lbs/yr	0.35780	0.45636	0.00179	0.10026	0.35431
Normanstone Creek	PAH2	lbs/yr	2.13700	2.88268	0.01553	2.82483	0.04232
Normanstone Creek	PAH3	lbs/yr	1.36000	1.85872	0.01615	1.81557	0.02701
Normanstone Creek	PCBs	lbs/yr	0.03457	-	-	-	0.00003
Pinehurst Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	DDD	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)

WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Pinehurst Branch	DDE	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	DDT	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	Dieldrin	lbs/yr	0.00050	0.00028	0.00000	0.00018	0.00010
Pinehurst Branch	Heptachlor Epoxide	lbs/yr	0.00076	0.00092	0.00000	0.00085	0.00008
Pinehurst Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	PCBs	lbs/yr	0.03080	-	-	-	0.00003
Piney Branch	Arsenic	lbs/yr	-	-	-	-	Category 3
Piney Branch	Chlordane	lbs/yr	0.00027	0.00169	0.00001	0.00163	0.00005
Piney Branch	Copper	lbs/yr	-	-	-	-	Category 3
Piney Branch	DDD	lbs/yr	-	-	-	-	Category 3
Piney Branch	DDE	lbs/yr	-	-	-	-	Category 3
Piney Branch	DDT	lbs/yr	-	-	-	-	Category 3
Piney Branch	Dieldrin	lbs/yr	0.00004	0.00005	0.00000	0.00004	0.00001
Piney Branch	Heptachlor Epoxide	lbs/yr	0.00006	0.00016	0.00000	0.00016	0.00001
Piney Branch	Lead	lbs/yr	0.68400	2.74797	0.01024	2.56832	0.16941
Piney Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Piney Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Piney Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Piney Branch	PCBs	lbs/yr	0.00243	-	-	-	0.00000
Piney Branch	Zinc	lbs/yr	-	-	-	-	Category 3
Portal Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Portal Branch	DDD	lbs/yr	-	-	-	-	Category 3

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WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Portal Branch	DDE	lbs/yr	-	-	-	-	Category 3
Portal Branch	DDT	lbs/yr	-	-	-	-	Category 3
Portal Branch	Dieldrin	lbs/yr	0.00013	0.00007	0.00000	0.00004	0.00003
Portal Branch	Heptachlor Epoxide	lbs/yr	0.00020	0.00023	0.00000	0.00021	0.00002
Portal Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Portal Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Portal Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Portal Branch	PCBs	lbs/yr	0.00890	-	-	-	0.00001
Soapstone Creek	Chlordane	lbs/yr	0.01323	0.01884	0.00005	0.01683	0.00197
Soapstone Creek	DDD	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	DDE	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	DDT	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	Dieldrin	lbs/yr	0.00086	0.00056	0.00000	0.00038	0.00017
Soapstone Creek	Heptachlor Epoxide	lbs/yr	0.00170	0.00183	0.00000	0.00166	0.00017
Soapstone Creek	PAH1	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	PAH2	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	PAH3	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	PCBs	lbs/yr	0.08579	-	-	-	0.00009

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LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Broad Branch	Chlordane	lbs/yr	Not found	0.00293	0.00001	0.00210	0.00083
Broad Branch	DDD	lbs/yr	Not found	0.00089	0.00001	0.00048	0.00040
Broad Branch	DDE	lbs/yr	Not found	0.00397	0.00005	0.00321	0.00071
Broad Branch	DDT	lbs/yr	Not found	0.01020	0.00012	0.00937	0.00072
Broad Branch	Dieldrin	lbs/yr	Not found	0.00009	0.00000	0.00000	0.00010
Broad Branch	Heptachlor Epoxide	lbs/yr	Not found	0.00029	0.00000	0.00020	0.00008
Broad Branch	PAH1	lbs/yr	Not found	0.19644	0.00018	0.00000	0.37840
Broad Branch	PAH2	lbs/yr	Not found	1.24085	0.00640	1.18994	0.04451
Broad Branch	PAH3	lbs/yr	Not found	0.80009	0.01168	0.76458	0.02382
Broad Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Dumbarton Oaks	Chlordane	lbs/yr	Not found	0.00291	0.00000	0.00226	0.00066
Dumbarton Oaks	DDD	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	DDE	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	DDT	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	Dieldrin	lbs/yr	Not found	0.00009	0.00000	0.00003	0.00006
Dumbarton Oaks	Heptachlor Epoxide	lbs/yr	Not found	0.00028	0.00000	0.00023	0.00006
Dumbarton Oaks	PAH1	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	PAH2	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	PAH3	lbs/yr	-	-	-	-	Category 3
Dumbarton Oaks	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Fenwick Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	DDD	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	DDE	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	DDT	lbs/yr	Not found	0.00443	0.00033	0.00402	0.00008

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)							
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Fenwick Branch	Dieldrin	lbs/yr	Not found	0.00004	0.00000	0.00003	0.00001
Fenwick Branch	Heptachlor Epoxide	lbs/yr	Not found	0.00012	0.00000	0.00011	0.00001
Fenwick Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Fenwick Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Klingle Valley Run	Chlordane	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	DDD	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	DDE	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	DDT	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	Dieldrin	lbs/yr	Not found	0.00002	0.00000	0.00002	0.00001
Klingle Valley Run	Heptachlor Epoxide	lbs/yr	Not found	0.00008	0.00000	0.00007	0.00001
Klingle Valley Run	PAH1	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	PAH2	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	PAH3	lbs/yr	-	-	-	-	Category 3
Klingle Valley Run	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Luzon Branch	Chlordane	lbs/yr	Not found	0.00082	0.00000	0.00000	0.00211
Luzon Branch	DDD	lbs/yr	-	-	-	-	Category 3
Luzon Branch	DDE	lbs/yr	-	-	-	-	Category 3
Luzon Branch	DDT	lbs/yr	-	-	-	-	Category 3
Luzon Branch	Dieldrin	lbs/yr	Not found	0.00002	0.00000	0.00000	0.00021
Luzon Branch	Heptachlor Epoxide	lbs/yr	Not found	0.00008	0.00000	0.00000	0.00019
Luzon Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Luzon Branch	PAH2	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)							
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Luzon Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Luzon Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Melvin Hazen Valley Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	DDD	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	DDE	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	DDT	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	Dieldrin	lbs/yr	Not found	0.00003	0.00000	0.00001	0.00002
Melvin Hazen Valley Branch	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Melvin Hazen Valley Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Normanstone Creek	Chlordane	lbs/yr	Not found	0.00075	0.00000	0.00058	0.00016
Normanstone Creek	DDD	lbs/yr	Not found	0.00023	0.00000	0.00016	0.00007
Normanstone Creek	DDE	lbs/yr	Not found	0.00101	0.00000	0.00088	0.00014
Normanstone Creek	DDT	lbs/yr	Not found	0.00260	0.00000	0.00246	0.00014
Normanstone Creek	Dieldrin	lbs/yr	Not found	0.00002	0.00000	0.00001	0.00002
Normanstone Creek	Heptachlor Epoxide	lbs/yr	Not found	0.00007	0.00000	0.00006	0.00002
Normanstone Creek	PAH1	lbs/yr	Not found	0.05005	0.00002	0.00000	0.07437
Normanstone Creek	PAH2	lbs/yr	Not found	0.31616	0.00011	0.30717	0.00888
Normanstone Creek	PAH3	lbs/yr	Not found	0.20386	0.00007	0.19812	0.00567
Normanstone Creek	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Pinehurst Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	DDD	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)							
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
Pinehurst Branch	DDE	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	DDT	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	Dieldrin	lbs/yr	Not found	0.00005	0.00000	0.00000	0.00007
Pinehurst Branch	Heptachlor Epoxide	lbs/yr	Not found	0.00018	0.00000	0.00013	0.00005
Pinehurst Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Pinehurst Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Piney Branch	Arsenic	lbs/yr	-	-	-	-	Category 3
Piney Branch	Chlordane	lbs/yr	Not found	0.00040	0.00000	0.00029	0.00010
Piney Branch	Copper	lbs/yr	-	-	-	-	Category 3
Piney Branch	DDD	lbs/yr	-	-	-	-	Category 3
Piney Branch	DDE	lbs/yr	-	-	-	-	Category 3
Piney Branch	DDT	lbs/yr	-	-	-	-	Category 3
Piney Branch	Dieldrin	lbs/yr	Not found	0.00001	0.00000	0.00000	0.00002
Piney Branch	Heptachlor Epoxide	lbs/yr	Not found	0.00004	0.00000	0.00002	0.00002
Piney Branch	Lead	lbs/yr	Not found	0.64622	0.00070	0.32002	0.32550
Piney Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Piney Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Piney Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Piney Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Piney Branch	Zinc	lbs/yr	-	-	-	-	Category 3
Portal Branch	Chlordane	lbs/yr	-	-	-	-	Category 3
Portal Branch	DDD	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 6: DC Final TMDL for Organics and Metals in Broad Branch, Dumbarton Oaks, Fenwick Branch, Klingle Valley Creek, Luzon Branch, Melvin Hazen Valley Branch, Normanstone Creek, Pinehurst Branch, Piney Branch, Portal Branch, and Soapstone Creek (2004)

LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Portal Branch	DDE	lbs/yr	-	-	-	-	Category 3
Portal Branch	DDT	lbs/yr	-	-	-	-	Category 3
Portal Branch	Dieldrin	lbs/yr	Not found	0.00000	0.00000	0.00000	0.00000
Portal Branch	Heptachlor Epoxide	lbs/yr	Not found	0.00000	0.00000	0.00000	0.00000
Portal Branch	PAH1	lbs/yr	-	-	-	-	Category 3
Portal Branch	PAH2	lbs/yr	-	-	-	-	Category 3
Portal Branch	PAH3	lbs/yr	-	-	-	-	Category 3
Portal Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Soapstone Creek	Chlordane	lbs/yr	Not found	0.00221	0.00000	0.00184	0.00037
Soapstone Creek	DDD	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	DDE	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	DDT	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	Dieldrin	lbs/yr	Not found	0.00007	0.00000	0.00003	0.00003
Soapstone Creek	Heptachlor Epoxide	lbs/yr	Not found	0.00022	0.00000	0.00018	0.00003
Soapstone Creek	PAH1	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	PAH2	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	PAH3	lbs/yr	-	-	-	-	Category 3
Soapstone Creek	PCBs	lbs/yr	Not found	-	-	N/A	N/A

Baseline Attachment Table 7: DC Final TMDL for Organics in Tidal Basin and Washington Ship Channel (2004)							
WLA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	WLA
Tidal Basin	Chlordane	lbs/yr	-	-	-	-	Category 3
Tidal Basin	DDD	lbs/yr	-	-	-	-	Category 3
Tidal Basin	DDE	lbs/yr	-	-	-	-	Category 3
Tidal Basin	DDT	lbs/yr	-	-	-	-	Category 3
Tidal Basin	Dieldrin	lbs/yr	-	-	-	-	Category 3
Tidal Basin	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PAH1	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PAH2	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PAH3	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PCBs	lbs/yr	0.1007	-	-	-	0.0003
Washington Ship Channel	Chlordane	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	DDD	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	DDE	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	DDT	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	Dieldrin	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PAH1	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PAH2	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PAH3	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PCBs	lbs/yr	0.3327	-	-	-	0.0002

Baseline Attachment Table 7: DC Final TMDL for Organics in Tidal Basin and Washington Ship Channel (2004)							
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
Tidal Basin	Chlordane	lbs/yr	-	-	-	-	Category 3
Tidal Basin	DDD	lbs/yr	-	-	-	-	Category 3
Tidal Basin	DDE	lbs/yr	-	-	-	-	Category 3
Tidal Basin	DDT	lbs/yr	-	-	-	-	Category 3
Tidal Basin	Dieldrin	lbs/yr	-	-	-	-	Category 3
Tidal Basin	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PAH1	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PAH2	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PAH3	lbs/yr	-	-	-	-	Category 3
Tidal Basin	PCBs	lbs/yr	0.0816	-	-	-	0.0003
Washington Ship Channel	Chlordane	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	DDD	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	DDE	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	DDT	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	Dieldrin	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PAH1	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PAH2	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PAH3	lbs/yr	-	-	-	-	Category 3
Washington Ship Channel	PCBs	lbs/yr	0.1397	-	-	-	0.0002

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
WLA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	WLA
Anacostia Lower	Arsenic	lbs/yr	Not found	9.74	0.34	6.00	3.41
Anacostia Lower	Copper	lbs/yr	-	-	-	-	Category 3
Anacostia Lower	Lead	lbs/yr	Not found	100.86	4.83	0.00	219.20
Anacostia Lower	Zinc	lbs/yr	Not found	765.07	33.12	0.00	1,338.90
Anacostia Lower	Chlordane	lbs/yr	Not found	0.0622	0.0010	0.0534	0.0078
Anacostia Lower	DDD	lbs/yr	Not found	0.0190	0.0007	0.0095	0.0087
Anacostia Lower	DDE	lbs/yr	Not found	0.0841	0.0038	0.0593	0.0211
Anacostia Lower	DDT	lbs/yr	Not found	0.2164	0.0092	0.1502	0.0570
Anacostia Lower	Dieldrin	lbs/yr	Not found	0.0018	0.0000	0.0000	0.0035
Anacostia Lower	Heptachlor Epoxide	lbs/yr	Not found	0.0061	0.0000	0.0040	0.0020
Anacostia Lower	PAH1	lbs/yr	Not found	4.1664	0.0304	4.0299	0.1060
Anacostia Lower	PAH2	lbs/yr	Not found	26.3174	0.6023	25.0741	0.6410
Anacostia Lower	PAH3	lbs/yr	Not found	16.9692	0.8685	15.6917	0.4090
Anacostia Lower	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Anacostia Upper	Arsenic	lbs/yr	Not found	46.93	0.23	45.26	1.44
Anacostia Upper	Copper	lbs/yr	-	-	-	-	Category 3
Anacostia Upper	Lead	lbs/yr	Not found	485.76	2.77	95.39	387.60
Anacostia Upper	Zinc	lbs/yr	Not found	3,684.63	19.92	1,279.41	2,385.30
Anacostia Upper	Chlordane	lbs/yr	Not found	0.2995	0.0011	0.2843	0.0141
Anacostia Upper	DDD	lbs/yr	Not found	0.0914	0.0005	0.0857	0.0052
Anacostia Upper	DDE	lbs/yr	Not found	0.4053	0.0022	0.3903	0.0127
Anacostia Upper	DDT	lbs/yr	Not found	1.0421	0.0055	1.0026	0.0340
Anacostia Upper	Dieldrin	lbs/yr	Not found	0.0088	0.0000	0.0006	0.0082
Anacostia Upper	Heptachlor Epoxide	lbs/yr	Not found	0.0292	0.0004	0.0247	0.0041
Anacostia Upper	PAH1	lbs/yr	Not found	20.07	0.07	19.80	0.19

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
WLA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	WLA
Anacostia Upper	PAH2	lbs/yr	Not found	126.75	0.56	125.04	1.14
Anacostia Upper	PAH3	lbs/yr	Not found	81.72	0.51	80.48	0.73
Anacostia Upper	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Fort Chaplin Tributary	Arsenic	lbs/yr	Not found	0.81	0.01	0.42	0.38
Fort Chaplin Tributary	Copper	lbs/yr	Not found	27.79	0.21	9.28	18.29
Fort Chaplin Tributary	Lead	lbs/yr	Not found	8.38	0.06	0.64	7.67
Fort Chaplin Tributary	Zinc	lbs/yr	Not found	63.55	0.49	0.00	135.20
Fort Davis Tributary	Arsenic	lbs/yr	Not found	0.39	0.00	0.28	0.10
Fort Davis Tributary	Copper	lbs/yr	Not found	13.28	0.12	8.43	4.73
Fort Davis Tributary	Lead	lbs/yr	Not found	4.00	0.04	2.02	1.95
Fort Davis Tributary	Zinc	lbs/yr	Not found	30.38	0.29	0.00	42.40
Fort Dupont Tributary	Arsenic	lbs/yr	Not found	0.33	0.00	0.16	0.17
Fort Dupont Tributary	Copper	lbs/yr	-	-	-	-	Category 3
Fort Dupont Tributary	Lead	lbs/yr	Not found	3.38	0.01	0.00	3.56
Fort Dupont Tributary	Zinc	lbs/yr	-	-	-	-	Category 3
Fort Stanton Tributary	Arsenic	lbs/yr	Not found	0.24	0.00	0.18	0.05
Fort Stanton Tributary	Copper	lbs/yr	Not found	8.10	0.04	5.57	2.48
Fort Stanton Tributary	Lead	lbs/yr	Not found	2.44	0.01	1.38	1.05
Fort Stanton Tributary	Zinc	lbs/yr	Not found	18.51	0.10	0.00	91.10
Fort Stanton Tributary	Chlordane	lbs/yr	Not found	0.0015	0.0000	0.0013	0.0002
Fort Stanton Tributary	DDD	lbs/yr	Not found	0.0005	0.0000	0.0004	0.0001
Fort Stanton Tributary	DDE	lbs/yr	Not found	0.0020	0.0000	0.0019	0.0001
Fort Stanton Tributary	DDT	lbs/yr	Not found	0.0052	0.0000	0.0051	0.0002
Fort Stanton Tributary	Dieldrin	lbs/yr	Not found	0.0000	0.0000	0.0000	0.0000
Fort Stanton Tributary	Heptachlor Epoxide	lbs/yr	Not found	0.0001	0.0000	0.0001	0.0000

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Fort Stanton Tributary	PAH1	lbs/yr	Not found	0.1008	0.0004	0.0224	0.0780
Fort Stanton Tributary	PAH2	lbs/yr	Not found	0.6368	0.0028	0.6250	0.0090
Fort Stanton Tributary	PAH3	lbs/yr	Not found	0.4106	0.0023	0.4023	0.0060
Fort Stanton Tributary	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Hickey Run	Chlordane	lbs/yr	Not found	0.0395	0.0001	0.0252	0.0142
Hickey Run	DDD	lbs/yr	-	-	-	-	Category 3
Hickey Run	DDE	lbs/yr	Not found	0.0534	0.0002	0.0464	0.0069
Hickey Run	DDT	lbs/yr	-	-	-	-	Category 3
Hickey Run	Dieldrin	lbs/yr	-	-	-	-	Category 3
Hickey Run	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Hickey Run	PAH1	lbs/yr	Not found	2.64	0.01	0.00	3.88
Hickey Run	PAH2	lbs/yr	Not found	16.71	0.06	16.17	0.47
Hickey Run	PAH3	lbs/yr	Not found	10.77	0.05	10.42	0.30
Hickey Run	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Nash Run	Arsenic	lbs/yr	Not found	2.10	0.01	1.23	0.86
Nash Run	Copper	lbs/yr	-	-	-	-	Category 3
Nash Run	Lead	lbs/yr	Not found	21.74	0.12	1.97	19.65
Nash Run	Zinc	lbs/yr	-	-	-	-	Category 3
Nash Run	Chlordane	lbs/yr	Not found	0.0134	0.0000	0.0102	0.0032
Nash Run	DDD	lbs/yr	-	-	-	-	Category 3
Nash Run	DDE	lbs/yr	-	-	-	-	Category 3
Nash Run	DDT	lbs/yr	-	-	-	-	Category 3
Nash Run	Dieldrin	lbs/yr	Not found	0.0004	0.0000	0.0001	0.0003
Nash Run	Heptachlor Epoxide	lbs/yr	Not found	0.0013	0.0000	0.0010	0.0003
Nash Run	PAH1	lbs/yr	Not found	0.90	0.00	0.00	1.59

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Nash Run	PAH2	lbs/yr	Not found	5.67	0.02	5.46	0.19
Nash Run	PAH3	lbs/yr	Not found	3.66	0.02	3.51	0.12
Nash Run	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Pope Branch	Arsenic	lbs/yr	-	-	-	-	Category 3
Pope Branch	Copper	lbs/yr	-	-	-	-	Category 3
Pope Branch	Lead	lbs/yr	Not found	9.60	0.06	0.00	10.82
Pope Branch	Zinc	lbs/yr	-	-	-	-	Category 3
Pope Branch	Chlordane	lbs/yr	Not found	0.0059	0.0000	0.0042	0.0017
Pope Branch	DDD	lbs/yr	-	-	-	-	Category 3
Pope Branch	DDE	lbs/yr	Not found	0.0080	0.0000	0.0064	0.0016
Pope Branch	DDT	lbs/yr	-	-	-	-	Category 3
Pope Branch	Dieldrin	lbs/yr	-	-	-	-	Category 3
Pope Branch	Heptachlor Epoxide	lbs/yr	Not found	0.0006	0.0000	0.0004	0.0002
Pope Branch	PAH1	lbs/yr	Not found	0.40	0.00	0.00	0.80
Pope Branch	PAH2	lbs/yr	Not found	2.50	0.01	2.40	0.09
Pope Branch	PAH3	lbs/yr	Not found	1.61	0.01	1.54	0.06
Pope Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Texas Avenue Tributary	Arsenic	lbs/yr	Not found	0.41	0.00	0.01	0.40
Texas Avenue Tributary	Copper	lbs/yr	Not found	14.20	0.13	0.00	19.78
Texas Avenue Tributary	Lead	lbs/yr	Not found	4.28	0.04	0.00	8.31
Texas Avenue Tributary	Zinc	lbs/yr	Not found	32.47	0.31	0.00	138.20
Texas Avenue Tributary	Chlordane	lbs/yr	Not found	0.0026	0.0000	0.0013	0.0013
Texas Avenue Tributary	DDD	lbs/yr	Not found	0.0008	0.0000	0.0000	0.0070
Texas Avenue Tributary	DDE	lbs/yr	Not found	0.0036	0.0000	0.0023	0.0012
Texas Avenue Tributary	DDT	lbs/yr	Not found	0.0092	0.0001	0.0000	0.0401

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
WLA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	WLA
Texas Avenue Tributary	Dieldrin	lbs/yr	Not found	0.0001	0.0000	0.0000	0.0002
Texas Avenue Tributary	Heptachlor Epoxide	lbs/yr	Not found	0.0003	0.0000	0.0001	0.0001
Texas Avenue Tributary	PAH1	lbs/yr	Not found	0.1768	0.0011	0.0000	0.6130
Texas Avenue Tributary	PAH2	lbs/yr	Not found	1.1169	0.0084	1.0374	0.0710
Texas Avenue Tributary	PAH3	lbs/yr	Not found	0.7201	0.0074	0.6677	0.0450
Texas Avenue Tributary	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Watts Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Watts Branch - Lower	Chlordane	lbs/yr	Not found	0.0111	0.0000	0.0073	0.0037
Watts Branch - Lower	DDD	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	DDE	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	DDT	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	Dieldrin	lbs/yr	Not found	0.0003	0.0000	0.0000	0.0004
Watts Branch - Lower	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	PAH1	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	PAH2	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	PAH3	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	Chlordane	lbs/yr	Not found	0.0336	0.0002	0.0239	0.0096
Watts Branch - Upper	DDD	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	DDE	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	DDT	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	Dieldrin	lbs/yr	Not found	0.0010	0.0000	0.0000	0.0009
Watts Branch - Upper	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	PAH1	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	PAH2	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	PAH3	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
Anacostia Lower	Arsenic	lbs/yr	Not found	3.7191	0.0119	3.5972	0.1100
Anacostia Lower	Copper	lbs/yr	-	-	-	-	Category 3
Anacostia Lower	Lead	lbs/yr	Not found	38.4980	0.1751	31.1229	7.2000
Anacostia Lower	Zinc	lbs/yr	Not found	292.0201	1.1845	246.8355	44.0000
Anacostia Lower	Chlordane	lbs/yr	Not found	0.0237	0.0000	0.0234	0.0003
Anacostia Lower	DDD	lbs/yr	Not found	0.0072	0.0000	0.0069	0.0003
Anacostia Lower	DDE	lbs/yr	Not found	0.0321	0.0001	0.0313	0.0007
Anacostia Lower	DDT	lbs/yr	Not found	0.0826	0.0003	0.0803	0.0020
Anacostia Lower	Dieldrin	lbs/yr	Not found	0.0007	0.0000	0.0006	0.0001
Anacostia Lower	Heptachlor Epoxide	lbs/yr	Not found	0.0023	0.0000	0.0022	0.0001
Anacostia Lower	PAH1	lbs/yr	Not found	1.5903	0.0007	1.5865	0.0030
Anacostia Lower	PAH2	lbs/yr	Not found	10.0451	0.0205	10.0037	0.0210
Anacostia Lower	PAH3	lbs/yr	Not found	6.4770	0.0316	6.4324	0.0130
Anacostia Lower	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Anacostia Upper	Arsenic	lbs/yr	Not found	6.3683	0.2496	6.0788	0.0400
Anacostia Upper	Copper	lbs/yr	-	-	-	-	Category 3
Anacostia Upper	Lead	lbs/yr	Not found	65.9216	3.7820	52.4395	9.7000
Anacostia Upper	Zinc	lbs/yr	Not found	500.0372	25.4961	414.8410	59.7000
Anacostia Upper	Chlordane	lbs/yr	Not found	0.0406	0.0006	0.0397	0.0004
Anacostia Upper	DDD	lbs/yr	Not found	0.0124	0.0006	0.0117	0.0001
Anacostia Upper	DDE	lbs/yr	Not found	0.0550	0.0029	0.0518	0.0003
Anacostia Upper	DDT	lbs/yr	Not found	0.1414	0.0071	0.1334	0.0010
Anacostia Upper	Dieldrin	lbs/yr	Not found	0.0012	0.0000	0.0010	0.0002
Anacostia Upper	Heptachlor Epoxide	lbs/yr	Not found	0.0040	0.0000	0.0039	0.0001
Anacostia Upper	PAH1	lbs/yr	Not found	2.7231	0.0048	2.7132	0.0050

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Upper	PAH2	lbs/yr	Not found	17.2007	0.3981	16.7736	0.0290
Anacostia Upper	PAH3	lbs/yr	Not found	11.0908	0.6848	10.3880	0.0180
Anacostia Upper	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Fort Chaplin Tributary	Arsenic	lbs/yr	Not found	0.0390	0.0001	0.0000	0.1000
Fort Chaplin Tributary	Copper	lbs/yr	Not found	1.3393	0.0035	0.0000	4.6700
Fort Chaplin Tributary	Lead	lbs/yr	Not found	0.4038	0.0011	0.0000	1.9600
Fort Chaplin Tributary	Zinc	lbs/yr	Not found	3.0628	0.0080	0.0000	34.5000
Fort Davis Tributary	Arsenic	lbs/yr	Not found	0.0361	0.0007	0.0000	0.0500
Fort Davis Tributary	Copper	lbs/yr	Not found	1.2383	0.0252	0.0000	2.5700
Fort Davis Tributary	Lead	lbs/yr	Not found	0.3733	0.0081	0.0000	1.0600
Fort Davis Tributary	Zinc	lbs/yr	Not found	2.8317	0.0601	0.0000	10.8000
Fort Dupont Tributary	Arsenic	lbs/yr	Not found	0.5664	0.0007	0.0000	0.6800
Fort Dupont Tributary	Copper	lbs/yr	-	-	-	-	Category 3
Fort Dupont Tributary	Lead	lbs/yr	Not found	5.8628	0.0075	0.0000	14.7500
Fort Dupont Tributary	Zinc	lbs/yr	-	-	-	-	Category 3
Fort Stanton Tributary	Arsenic	lbs/yr	Not found	0.2550	0.0004	0.0000	0.2600
Fort Stanton Tributary	Copper	lbs/yr	Not found	8.7539	0.0137	0.0000	12.9400
Fort Stanton Tributary	Lead	lbs/yr	Not found	2.6392	0.0042	0.0000	5.4700
Fort Stanton Tributary	Zinc	lbs/yr	Not found	20.0191	0.0317	0.0000	23.3000
Fort Stanton Tributary	Chlordane	lbs/yr	Not found	0.0016	0.0000	0.0007	0.0009
Fort Stanton Tributary	DDD	lbs/yr	Not found	0.0005	0.0000	0.0000	0.0005
Fort Stanton Tributary	DDE	lbs/yr	Not found	0.0022	0.0000	0.0014	0.0008
Fort Stanton Tributary	DDT	lbs/yr	Not found	0.0057	0.0000	0.0049	0.0008
Fort Stanton Tributary	Dieldrin	lbs/yr	Not found	0.0000	0.0000	0.0000	0.0001
Fort Stanton Tributary	Heptachlor Epoxide	lbs/yr	Not found	0.0002	0.0000	0.0001	0.0001

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Fort Stanton Tributary	PAH1	lbs/yr	Not found	0.1090	0.0002	0.0000	0.4040
Fort Stanton Tributary	PAH2	lbs/yr	Not found	0.6886	0.0010	0.6406	0.0470
Fort Stanton Tributary	PAH3	lbs/yr	Not found	0.4440	0.0007	0.4133	0.0300
Fort Stanton Tributary	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Hickey Run	Chlordane	lbs/yr	Not found	0.0048	0.0000	0.0048	0.0000
Hickey Run	DDD	lbs/yr	-	-	-	-	Category 3
Hickey Run	DDE	lbs/yr	Not found	0.0066	0.0000	0.0020	0.0046
Hickey Run	DDT	lbs/yr	-	-	-	-	Category 3
Hickey Run	Dieldrin	lbs/yr	-	-	-	-	Category 3
Hickey Run	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Hickey Run	PAH1	lbs/yr	Not found	0.3245	0.0000	0.0000	2.5770
Hickey Run	PAH2	lbs/yr	Not found	2.0499	0.0005	1.7373	0.3120
Hickey Run	PAH3	lbs/yr	Not found	1.3217	0.0009	1.1218	0.1990
Hickey Run	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Nash Run	Arsenic	lbs/yr	Not found	0.0499	0.0000	0.0398	0.0100
Nash Run	Copper	lbs/yr	-	-	-	-	Category 3
Nash Run	Lead	lbs/yr	Not found	0.5163	0.0005	0.2658	0.2500
Nash Run	Zinc	lbs/yr	-	-	-	-	Category 3
Nash Run	Chlordane	lbs/yr	Not found	0.0003	0.0000	0.0003	0.0000
Nash Run	DDD	lbs/yr	-	-	-	-	Category 3
Nash Run	DDE	lbs/yr	-	-	-	-	Category 3
Nash Run	DDT	lbs/yr	-	-	-	-	Category 3
Nash Run	Dieldrin	lbs/yr	Not found	0.0000	0.0000	0.0000	0.0000
Nash Run	Heptachlor Epoxide	lbs/yr	Not found	0.0000	0.0000	0.0000	0.0000
Nash Run	PAH1	lbs/yr	Not found	0.0213	0.0000	0.0003	0.0210

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
Nash Run	PAH2	lbs/yr	Not found	0.1347	0.0001	0.1326	0.0020
Nash Run	PAH3	lbs/yr	Not found	0.0869	0.0001	0.0848	0.0020
Nash Run	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Pope Branch	Arsenic	lbs/yr	-	-	-	-	Category 3
Pope Branch	Copper	lbs/yr	-	-	-	-	Category 3
Pope Branch	Lead	lbs/yr	Not found	1.4985	0.0403	0.6282	0.8300
Pope Branch	Zinc	lbs/yr	-	-	-	-	Category 3
Pope Branch	Chlordane	lbs/yr	Not found	0.0009	0.0000	0.0008	0.0001
Pope Branch	DDD	lbs/yr	-	-	-	-	Category 3
Pope Branch	DDE	lbs/yr	Not found	0.0013	0.0000	0.0011	0.0001
Pope Branch	DDT	lbs/yr	-	-	-	-	Category 3
Pope Branch	Dieldrin	lbs/yr	-	-	-	-	Category 3
Pope Branch	Heptachlor Epoxide	lbs/yr	Not found	0.0001	0.0000	0.0001	0.0000
Pope Branch	PAH1	lbs/yr	Not found	0.0619	0.0003	0.0000	0.0620
Pope Branch	PAH2	lbs/yr	Not found	0.3910	0.0050	0.3790	0.0070
Pope Branch	PAH3	lbs/yr	Not found	0.2521	0.0073	0.2398	0.0050
Pope Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Texas Avenue Tributary	Arsenic	lbs/yr	Not found	0.0768	0.0002	0.0066	0.0700
Texas Avenue Tributary	Copper	lbs/yr	Not found	2.6379	0.0068	0.0000	3.5600
Texas Avenue Tributary	Lead	lbs/yr	Not found	0.7953	0.0020	0.0000	1.5000
Texas Avenue Tributary	Zinc	lbs/yr	Not found	6.0325	0.0155	0.0000	35.3000
Texas Avenue Tributary	Chlordane	lbs/yr	Not found	0.0005	0.0000	0.0003	0.0002
Texas Avenue Tributary	DDD	lbs/yr	Not found	0.0001	0.0000	0.0000	0.0013
Texas Avenue Tributary	DDE	lbs/yr	Not found	0.0007	0.0000	0.0005	0.0002
Texas Avenue Tributary	DDT	lbs/yr	Not found	0.0017	0.0000	0.0000	0.0072

Baseline Attachment Table 8: DC TMDL for Organics and Metals in the Anacostia River and Tributaries (2003)							
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
Texas Avenue Tributary	Dieldrin	lbs/yr	Not found	0.0000	0.0000	0.0000	0.0000
Texas Avenue Tributary	Heptachlor Epoxide	lbs/yr	Not found	0.0000	0.0000	0.0000	0.0000
Texas Avenue Tributary	PAH1	lbs/yr	Not found	0.0329	0.0001	0.0000	0.1100
Texas Avenue Tributary	PAH2	lbs/yr	Not found	0.2075	0.0005	0.1940	0.0130
Texas Avenue Tributary	PAH3	lbs/yr	Not found	0.1338	0.0003	0.1255	0.0080
Texas Avenue Tributary	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Watts Branch	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Watts Branch - Lower	Chlordane	lbs/yr	Not found	0.0028	0.0000	0.0027	0.0001
Watts Branch - Lower	DDD	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	DDE	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	DDT	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	Dieldrin	lbs/yr	Not found	0.0001	0.0000	0.0001	0.0000
Watts Branch - Lower	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	PAH1	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	PAH2	lbs/yr	-	-	-	-	Category 3
Watts Branch - Lower	PAH3	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	Chlordane	lbs/yr	Not found	0.0023	0.0000	0.0021	0.0002
Watts Branch - Upper	DDD	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	DDE	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	DDT	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	Dieldrin	lbs/yr	Not found	0.0001	0.0000	0.0000	0.0000
Watts Branch - Upper	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	PAH1	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	PAH2	lbs/yr	-	-	-	-	Category 3
Watts Branch - Upper	PAH3	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 9: DC TMDL for Organics, Metals, and Bacteria in Oxon Run (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Oxon Run	E. coli	Billion MPN/yr	Not translated	198,920	1,253	197,668	9,520
Oxon Run	Arsenic	lbs/yr	-	-	-	-	Category 3
Oxon Run	Copper	lbs/yr	-	-	-	-	Category 3
Oxon Run	Chlordane	lbs/yr	-	-	-	-	Category 3
Oxon Run	Lead	lbs/yr	Not found	127.38	0.87	103.81	22.70
Oxon Run	Zinc	lbs/yr	-	-	-	-	Category 3
Oxon Run	DDT	lbs/yr	-	-	-	-	Category 3
Oxon Run	Dieldrin	lbs/yr	Not found	0.0023	0.0000	0.0016	0.0007
Oxon Run	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Oxon Run	PAH1	lbs/yr	-	-	-	-	Category 3
Oxon Run	PAH2	lbs/yr	-	-	-	-	Category 3
Oxon Run	PAH3	lbs/yr	-	-	-	-	Category 3
Oxon Run	PCBs	lbs/yr	Not found	-	-	-	0.0024
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Oxon Run	E. coli	Billion MPN/yr	Not translated	13,063.01	58.31	12,004.69	1,000.00
Oxon Run	Arsenic	lbs/yr	-	-	-	-	Category 3
Oxon Run	Copper	lbs/yr	-	-	-	-	Category 3
Oxon Run	Chlordane	lbs/yr	-	-	-	-	Category 3
Oxon Run	Lead	lbs/yr	Not found	8.37	0.04	5.93	2.40
Oxon Run	Zinc	lbs/yr	-	-	-	-	Category 3
Oxon Run	DDT	lbs/yr	-	-	-	-	Category 3
Oxon Run	Dieldrin	lbs/yr	Not found	0.0002	0.0000	0.0000	0.0002
Oxon Run	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3

Baseline Attachment Table 9: DC TMDL for Organics, Metals, and Bacteria in Oxon Run (2003)							
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
Oxon Run	PAH1	lbs/yr	-	-	-	-	Category 3
Oxon Run	PAH2	lbs/yr	-	-	-	-	Category 3
Oxon Run	PAH3	lbs/yr	-	-	-	-	Category 3
Oxon Run	PCBs	lbs/yr	Not found	-	-	-	0.0005

Baseline Attachment Table 10: District of Columbia Final TMDL for Bacteria in the Chesapeake and Ohio Canal (2004)							
WLA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	WLA
C&O Canal	E. coli	Billion MPN/yr	Not translated	43,788	354	43,338	96
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
C&O Canal	E. coli	Billion MPN/yr	Not translated	6,783	47	6,591	145

Baseline Attachment Table 11: District of Columbia Final TMDL for Bacteria in the Tidal Basin and the Washington Ship Channel (2004)							
WLA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	WLA
Tidal Basin	E. coli	Billion MPN/yr	Not translated	25,703	34	0	55,300
Washington Ship Channel	E. coli	Billion MPN/yr	Not translated	65,337	267	0	183,000
LA							
Tributary/Segment	Pollutant	Units	TMDL Baseline Load	Model Baseline Load	Current Load Removed	Gap	LA
Tidal Basin	E. coli	Billion MPN/yr	Not translated	3,943	0	0	455,800
Washington Ship Channel	E. coli	Billion MPN/yr	Not translated	14,007	1	0	241,700

Baseline Attachment Table 12: District of Columbia Final TMDL for Fecal Coliform Bacteria in Kingman Lake (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Kingman Lake	E. coli	Billion MPN/yr	Not translated	-	-	-	-
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Kingman Lake	E. coli	Billion MPN/yr	Not translated	-	-	-	-

Baseline Attachment Table 13: District of Columbia Final TMDL for Fecal Coliform Bacteria in Rock Creek (2004)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Rock Creek Lower	E. coli	Billion MPN/yr	Not translated	106,419	609	95,710	10,100
Rock Creek Upper	E. coli	Billion MPN/yr	Not translated	309,154	1,486	278,968	28,700
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Rock Creek Lower	E. coli	Billion MPN/yr	Not translated	31,116	18	10,798	20,300
Rock Creek Upper	E. coli	Billion MPN/yr	Not translated	43,930	356	42,023	1,550

Baseline Attachment Table 14: District of Columbia Final TMDL for Fecal Coliform Bacteria in Upper Anacostia River, Lower Anacostia River, Watts Branch, Fort Dupont Creek, Fort Chaplin Tributary, Fort Davis Tributary, Fort Stanton Tributary, Hickey Run, Nash Run, Popes Branch, Texas Avenue Tributary (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia	E. coli	Billion MPN/yr	Not translated	916,059	10,961	905,097	230,000
Anacostia Lower	E. coli	Billion MPN/yr	-	-	-	-	-
Anacostia Upper	E. coli	Billion MPN/yr	-	-	-	-	-
Fort Chaplin Tributary	E. coli	Billion MPN/yr	Not translated	13,082	101	12,981	0.0013
Fort Davis Tributary	E. coli	Billion MPN/yr	Not translated	6,254	60	6,194	0.0008
Fort Dupont Tributary	E. coli	Billion MPN/yr	Not translated	5,276	12	5,265	0.0023
Fort Stanton Tributary	E. coli	Billion MPN/yr	Not translated	3,811	20	3,791	0.0011
Hickey Run	E. coli	Billion MPN/yr	Not translated	99,979	282	99,697	0.0063
Nash Run	E. coli	Billion MPN/yr	Not translated	-	-	-	-
Pope Branch	E. coli	Billion MPN/yr	Not translated	14,984	93	14,892	0.0017
Texas Avenue Tributary	E. coli	Billion MPN/yr	Not translated	6,684	64	6,620	0.0014
Watts Branch	E. coli	Billion MPN/yr	Not translated	-	-	-	-
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	Fecal Coliform Bacteria	Billion MPN/yr	Not Translated	-	-	-	-
Anacostia Upper	Fecal Coliform Bacteria	Billion MPN/yr	0	-	-	-	-
Fort Chaplin Tributary	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Fort Davis Tributary	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Fort Dupont Tributary	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Fort Stanton Tributary	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Hickey Run	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Nash Run	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-

Baseline Attachment Table 15: District of Columbia Final TMDL for Fecal Coliform Bacteria in Upper Anacostia River, Lower Anacostia River, Watts Branch, Fort Dupont Creek, Fort Chaplin Tributary, Fort Davis Tributary, Fort Stanton Tributary, Hickey Run, Nash Run, Popes Branch, Texas Avenue Tributary (2003)

LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Pope Branch	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Texas Avenue Tributary	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Watts Branch - Lower	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-
Watts Branch - Upper	Fecal Coliform Bacteria	Billion MPN/yr	Not found	-	-	-	-

Baseline Attachment Table 16: District of Columbia Final TMDL for Organics and Metals in Battery Kemble Creek, Foundry Branch, and the Dalecarlia Tributary (2004)

WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Battery Kemble Creek	Arsenic	lbs/yr	-	-	-	-	Category 3
Battery Kemble Creek	Copper	lbs/yr	-	-	-	-	Category 3
Battery Kemble Creek	Lead	lbs/yr	Not found	5.39	0.02	1.73	3.63
Battery Kemble Creek	Zinc	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	Chlordane	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	DDD	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	DDE	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	DDT	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	Dieldrin	lbs/yr	Not found	0.0011	0.0000	0.0007	0.0004
Dalecarlia Tributary	Heptachlor Epoxide	lbs/yr	Not found	0.0038	0.0000	0.0034	0.0003
Dalecarlia Tributary	PAH1	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	PAH2	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	PAH3	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	PCBs	lbs/yr	Not found	-	-	N/A	N/A

Baseline Attachment Table 15: District of Columbia Final TMDL for Organics and Metals in Battery Kemble Creek, Foundry Branch, and the Dalecarlia Tributary (2004)

WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Foundry Branch	Arsenic	lbs/yr	Not found	0.69	0.00	0.52	0.17
Foundry Branch	Copper	lbs/yr	Not found	23.55	0.09	13.14	10.33
Foundry Branch	Lead	lbs/yr	Not found	7.10	0.03	3.24	3.83
Foundry Branch	Zinc	lbs/yr	Not found	44.95	0.17	0.00	77.38
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Battery Kemble Creek	Arsenic	lbs/yr	-	-	-	-	Category 3
Battery Kemble Creek	Copper	lbs/yr	-	-	-	-	Category 3
Battery Kemble Creek	Lead	lbs/yr	Not found	3.80	0.05	3.62	0.13
Battery Kemble Creek	Zinc	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	Chlordane	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	DDD	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	DDE	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	DDT	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	Dieldrin	lbs/yr	Not found	0.0000	0.0000	0.0000	0.0000
Dalecarlia Tributary	Heptachlor Epoxide	lbs/yr	Not found	0.0002	0.0000	0.0001	0.0000
Dalecarlia Tributary	PAH1	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	PAH2	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	PAH3	lbs/yr	-	-	-	-	Category 3
Dalecarlia Tributary	PCBs	lbs/yr	Not found	-	-	N/A	N/A
Foundry Branch	Arsenic	lbs/yr	Not found	0.63	0.00	0.63	0.00
Foundry Branch	Copper	lbs/yr	Not found	21.58	0.00	21.58	0.00
Foundry Branch	Lead	lbs/yr	Not found	6.51	0.00	6.51	0.00
Foundry Branch	Zinc	lbs/yr	Not found	41.19	0.00	41.19	0.00

Baseline Attachment Table 17: District of Columbia Final TMDL for Organics and Metals in Kingman Lake (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Kingman Lake	Arsenic	lbs/yr	0.27	2.22	0.01	2.17	0.04
Kingman Lake	Copper	lbs/yr	-	-	-	-	Category 3
Kingman Lake	Lead	lbs/yr	4.87	22.99	0.18	17.94	4.87
Kingman Lake	Zinc	lbs/yr	-	-	-	-	Category 3
Kingman Lake	Chlordane	lbs/yr	0.0018	0.0142	0.0000	0.0139	0.0002
Kingman Lake	DDD	lbs/yr	-	-	-	-	Category 3
Kingman Lake	DDE	lbs/yr	-	-	-	-	Category 3
Kingman Lake	DDT	lbs/yr	0.0078	0.0493	0.0003	0.0412	0.0078
Kingman Lake	Dieldrin	lbs/yr	-	-	-	-	Category 3
Kingman Lake	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Kingman Lake	PAH1	lbs/yr	0.1226	0.9495	0.0022	0.8273	0.1200
Kingman Lake	PAH2	lbs/yr	0.7200	5.9977	0.0268	0.0000	7.0800
Kingman Lake	PAH3	lbs/yr	0.4590	3.8672	0.0321	3.3851	0.4500
Kingman Lake	PCBs	lbs/yr	Not found	-	-	N/A	N/A
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Kingman Lake	Arsenic	lbs/yr	Not found	1.09	0.11	0.96	0.03
Kingman Lake	Copper	lbs/yr	-	-	-	-	Category 3
Kingman Lake	Lead	lbs/yr	Not found	11.32	1.71	6.49	3.12
Kingman Lake	Zinc	lbs/yr	-	-	-	-	Category 3
Kingman Lake	Chlordane	lbs/yr	Not found	0.0070	0.0003	0.0066	0.0001
Kingman Lake	DDD	lbs/yr	-	-	-	-	Category 3
Kingman Lake	DDE	lbs/yr	-	-	-	-	Category 3
Kingman Lake	DDT	lbs/yr	Not found	0.0243	0.0032	0.0161	0.0050

Baseline Attachment Table 16 District of Columbia Final TMDL for Organics and Metals in Kingman Lake (2003)							
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Kingman Lake	Dieldrin	lbs/yr	-	-	-	-	Category 3
Kingman Lake	Heptachlor Epoxide	lbs/yr	-	-	-	-	Category 3
Kingman Lake	PAH1	lbs/yr	Not found	0.4675	0.0014	0.0000	0.7680
Kingman Lake	PAH2	lbs/yr	Not found	2.9531	0.1775	0.0000	4.5200
Kingman Lake	PAH3	lbs/yr	Not found	1.9041	0.3100	1.3061	0.2880

Baseline Attachment Table 18: District of Columbia Final TMDL for Total Suspended Solids in Watts Branch (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Watts Branch - Lower	TSS - Annual	lbs/yr	Not found	82,517	177	71,140	11,200
Watts Branch - Lower	TSS - Seasonal	lbs/growing season	Not found	51,573	106	44,067	7,400
Watts Branch - Upper	TSS - Annual	lbs/yr	Not found	250,979	2,981	218,398	29,600
Watts Branch - Upper	TSS - Seasonal	lbs/growing season	Not found	156,862	1,834	135,228	19,800
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Watts Branch - Lower	TSS - Annual	lbs/yr	Not found	76,087	4	68,483	7,600
Watts Branch - Lower	TSS - Seasonal	lbs/growing season	Not found	47,554	2	42,552	5,000
Watts Branch - Upper	TSS - Annual	lbs/yr	Not found	230,978	214,224	0	19,800
Watts Branch - Upper	TSS - Seasonal	lbs/growing season	Not found	144,361	133,889	0	12,200

Baseline Attachment Table 19: District of Columbia Final TMDL for TSS, Oil &Grease, BOD in Kingman Lake (2003)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Kingman Lake	BOD	-	-	-	-	N/A	N/A
Kingman Lake	Oil and Grease - Daily	lbs/day	-	14.42	0.18	0.00	1,278.35
Kingman Lake	TSS	-	-	-	-	N/A	N/A
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Kingman Lake	BOD	-	-	-	-	N/A	N/A
Kingman Lake	Oil and Grease - Daily	lbs/day	-	-	-	-	-
Kingman Lake	TSS	-	-	-	-	N/A	N/A

Baseline Attachment Table 20: TMDL for PCBs for Tidal Portions of the Potomac and Anacostia Rivers in DC, MD, and VA (2007)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia Lower	PCBs - Annual	lbs/yr	Not found	-	-	-	0.0013
Anacostia Lower	PCBs - Daily	lbs/day	-	-	-	-	-
Anacostia Upper	PCBs - Annual	lbs/yr	Not found	-	-	-	0.0039
Anacostia Upper	PCBs - Daily	lbs/day	-	-	-	-	-
Potomac Lower	PCBs - Annual	lbs/yr	Not found	-	-	-	0.0119
Potomac Lower	PCBs - Daily	lbs/day	-	-	-	-	-
Potomac Middle	PCBs - Annual	lbs/yr	Not found	-	-	-	0.0164
Potomac Middle	PCBs - Daily	lbs/day	-	-	-	-	-
Potomac Upper	PCBs - Annual	lbs/yr	Not found	-	-	-	0.0032
Potomac Upper	PCBs - Daily	lbs/day	-	-	-	-	-
Oxon Run	PCBs - Annual	lbs/yr	Not found	-	-	-	0.0024
Washington Ship Channel	PCBs - Annual	lbs/yr	0.33	-	-	-	0.0002
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	PCBs	lbs/yr	Not found	-	-	-	0.0004
Anacostia Upper	PCBs	lbs/yr	Not found	-	-	-	0.0006
Potomac Lower	PCBs	lbs/yr	Not found	-	-	-	0.0020
Potomac Middle	PCBs	lbs/yr	Not found	-	-	-	0.0019
Potomac Upper	PCBs	lbs/yr	Not found	-	-	-	0.0003
Oxon Run	PCBs	lbs/yr	Not found	-	-	-	0.0005
Washington Ship Channel	PCBs	lbs/yr	0.1397	-	-	-	0.0002

Baseline Attachment Table 21: TMDL of Nutrients/BOD for the Anacostia River Basin, Montgomery and Prince George's Counties, MD and the District of Columbia (2008)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia Lower	BOD - Annual	lbs/yr	342,519	227,331	1,717	127,179	98,435
Anacostia Lower	Nitrogen - Annual	lbs/yr	Not found	21,006	549	15,285	5,172
Anacostia Lower	Phosphorus - Annual	lbs/yr	Not found	2,404	199	1,696	509
Anacostia Lower	BOD - Daily	lbs/day	33,363	22,143	167	12,388	9,588
Anacostia Lower	Nitrogen - Daily	lbs/day	Not found	1,759	46	1,280	433
Anacostia Lower	Phosphorus - Daily	lbs/day	Not found	225	19	159	48
Anacostia Upper	BOD - Annual	lbs/yr	648,576	1,094,845	3,857	909,147	181,841
Anacostia Upper	Nitrogen - Annual	lbs/yr	Not found	101,166	504	90,169	10,493
Anacostia Upper	Phosphorus - Annual	lbs/yr	Not found	11,579	562	10,051	966
Anacostia Upper	BOD - Daily	lbs/day	65,378	110,363	389	91,644	18,330
Anacostia Upper	Nitrogen - Daily	lbs/day	Not found	9,294	46	8,284	964
Anacostia Upper	Phosphorus - Daily	lbs/day	Not found	1,249	61	1,084	104
Lower Beaverdam Creek	BOD - Annual	lbs/yr	Not found	470	8	59	403
Lower Beaverdam Creek	Nitrogen - Annual	lbs/yr	Not found	43	1	0	45
Lower Beaverdam Creek	Phosphorus - Annual	lbs/yr	Not found	5	0	0	6
Northwest Branch	BOD - Annual	lbs/yr	Not found	286,790	973	271,396	14,421
Northwest Branch	Nitrogen - Annual	lbs/yr	Not found	26,500	106	24,439	1,955
Northwest Branch	Phosphorus - Annual	lbs/yr	Not found	3,033	153	2,718	162
Watts Branch	BOD - Annual	lbs/yr	Not found	163,405	540	148,613	14,252
Watts Branch	Nitrogen - Annual	lbs/yr	Not found	15,099	95	13,273	1,731
Watts Branch	Phosphorus - Annual	lbs/yr	Not found	1,728	93	1,387	248

Baseline Attachment Table 20: TMDL of Nutrients/BOD for the Anacostia River Basin, Montgomery and Prince George's Counties, MD and the District of Columbia (2008)							
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	BOD - Annual	lbs/yr	-	86,770	269	56,797	29,704
Anacostia Lower	Nitrogen - Annual	lbs/yr	Not found	8,020	20	6,132	1,868
Anacostia Lower	Phosphorus - Annual	lbs/yr	Not found	919	50	706	162
Anacostia Lower	BOD - Daily	lbs/day	-	7,724	197	0	9,040
Anacostia Lower	Nitrogen - Daily	lbs/day	Not found	605	2	463	141
Anacostia Lower	Phosphorus - Daily	lbs/day	Not found	179	10	138	32
Anacostia Upper	BOD - Annual	lbs/yr	-	148,580	9,201	72,831	66,548
Anacostia Upper	Nitrogen - Annual	lbs/yr	Not found	13,942	550	9,270	4,123
Anacostia Upper	Phosphorus - Annual	lbs/yr	Not found	1,670	327	982	361
Anacostia Upper	BOD - Daily	lbs/day	-	13,869	43,921	0	12,660
Anacostia Upper	Nitrogen - Daily	lbs/day	Not found	1,129	45	751	334
Anacostia Upper	Phosphorus - Daily	lbs/day	Not found	63	12	37	14
Lower Beaverdam Creek	BOD - Annual	lbs/yr	Not found	1,860	0	995	865
Lower Beaverdam Creek	Nitrogen - Annual	lbs/yr	Not found	172	0	118	54
Lower Beaverdam Creek	Phosphorus - Annual	lbs/yr	Not found	20	2	13	5
Northwest Branch	BOD - Annual	lbs/yr	Not found	1,186	9	844	333
Northwest Branch	Nitrogen - Annual	lbs/yr	Not found	110	1	88	21
Northwest Branch	Phosphorus - Annual	lbs/yr	Not found	13	1	10	2
Watts Branch	BOD - Annual	lbs/yr	Not found	18,624	12	11,623	6,988
Watts Branch	Nitrogen - Annual	lbs/yr	Not found	2,023	305	1,285	433
Watts Branch	Phosphorus - Annual	lbs/yr	Not found	336	163	135	38

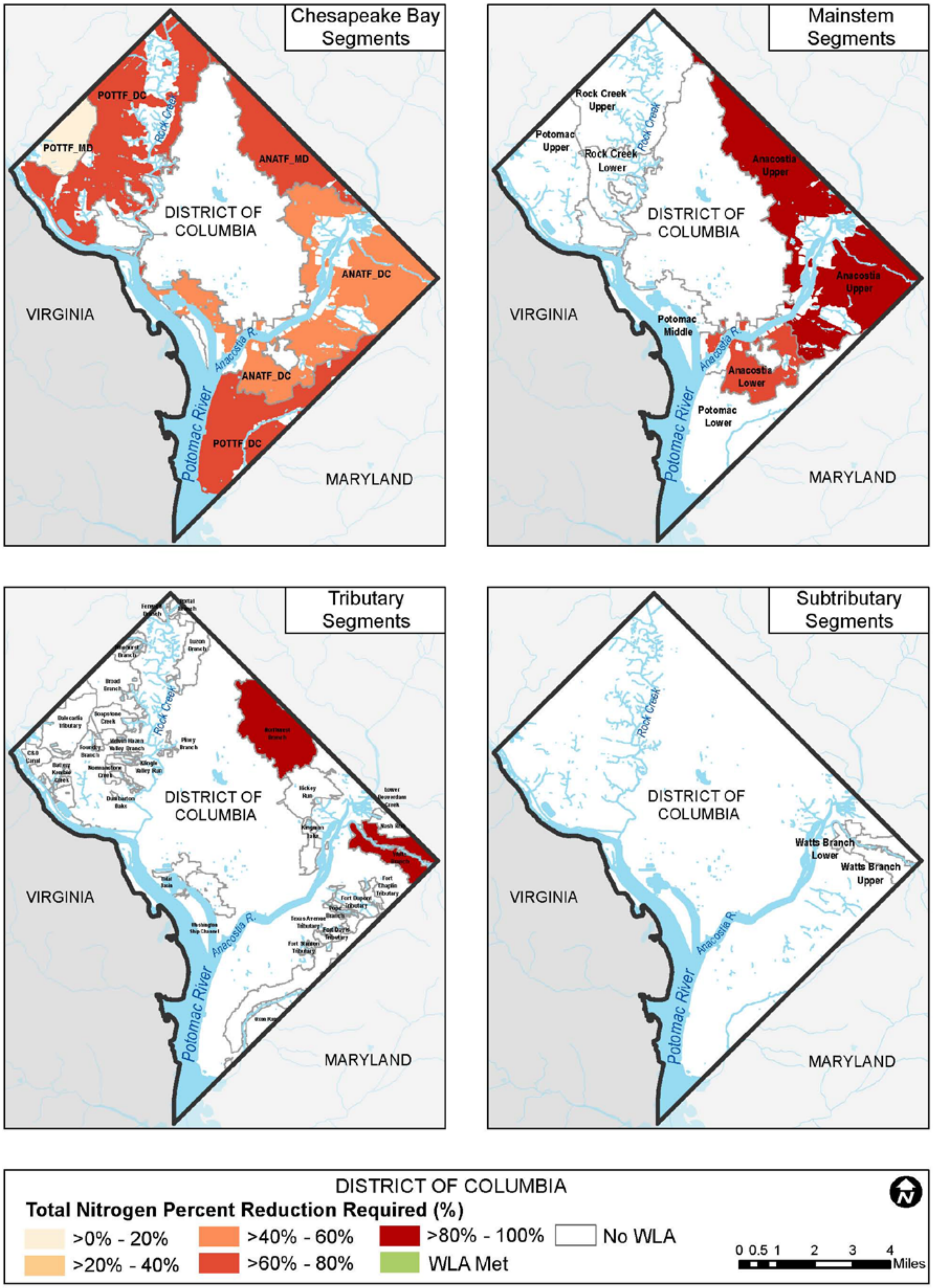
Baseline Attachment Table 22: TMDL of Trash for the Anacostia River Watershed, Montgomery and Prince George's Counties, MD and the District of Columbia (2010)

WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load + 5% MOS**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia Lower	Trash	lbs/yr	24,480	23,985	15,651	0	24,480
Anacostia Lower	Trash	lbs/day	67	66	43	0	67
Anacostia Upper	Trash	lbs/yr	83,868	99,220	75,820	0	83,868
Anacostia Upper	Trash	lbs/day	230	272	208	0	230
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load + 5% MOS**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	Trash	lbs/yr	1,790	2,017	0	227	1,790
Anacostia Lower	Trash	lbs/day	5	6	0	1	5
Anacostia Upper	Trash	lbs/yr	19,260	18,352	0	0	19,260
Anacostia Upper	Trash	lbs/day	53	50	0	0	53

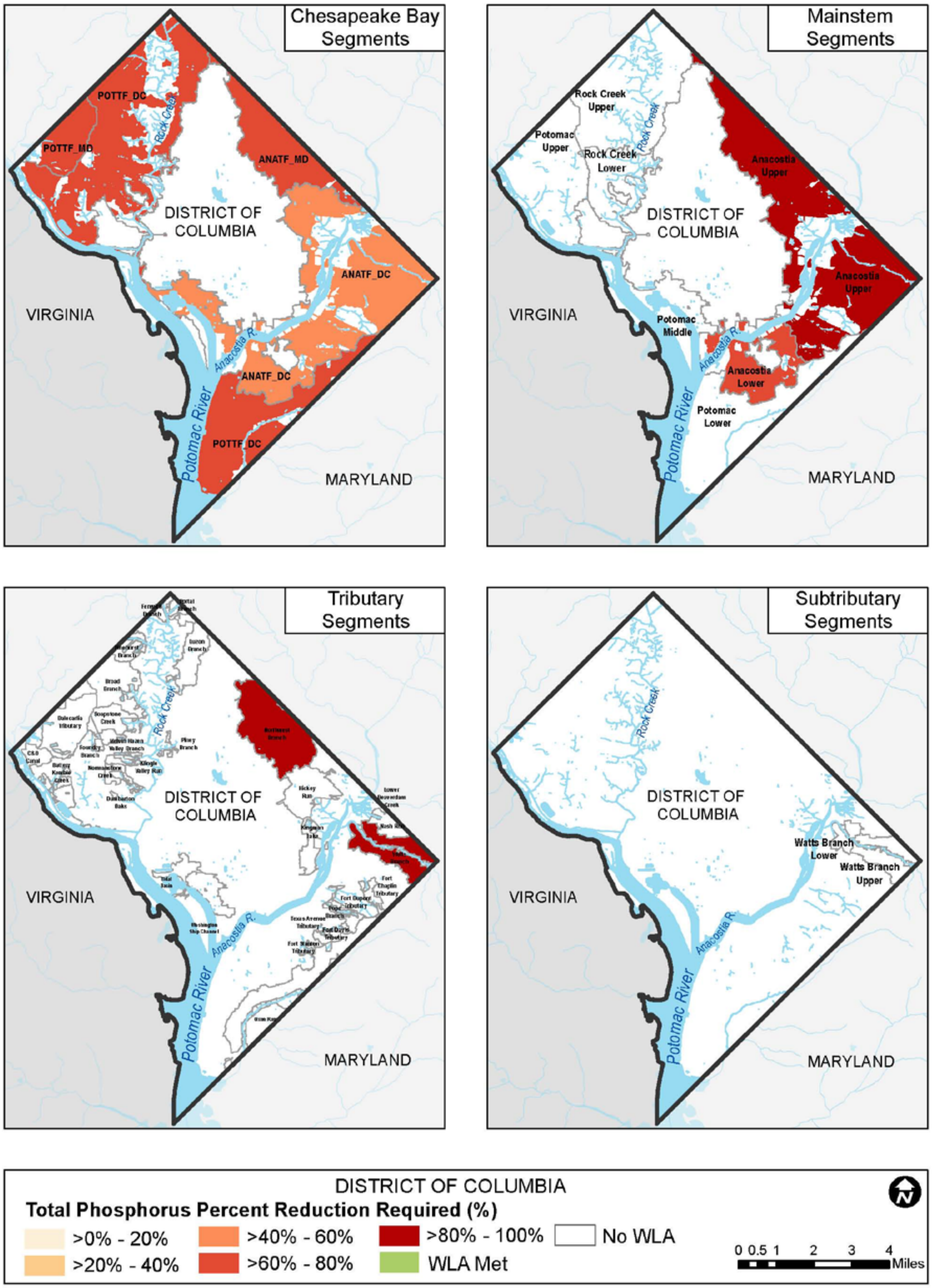
Baseline Attachment Table 23: TMDL Upper Anacostia River Lower Anacostia River District of Columbia BOD (2001)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia Lower	BOD	lbs/yr	342,519	227,331	1,717	N/A	N/A
Anacostia Lower	Nitrogen	lbs/yr	Not found	21,006	549	N/A	N/A
Anacostia Lower	Phosphorus	lbs/yr	Not found	2,404	199	N/A	N/A
Anacostia Upper	BOD	lbs/yr	648,576	1,094,845	3,857	N/A	N/A
Anacostia Upper	Nitrogen	lbs/yr	Not found	101,166	504	N/A	N/A
Anacostia Upper	Phosphorus	lbs/yr	Not found	11,579	562	N/A	N/A
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	BOD	lbs/yr	-	86,770	269	56,797	29,704
Anacostia Lower	Nitrogen	lbs/yr	Not found	8,020	20	6,132	1,868
Anacostia Lower	Phosphorus	lbs/yr	Not found	919	50	706	162
Anacostia Upper	BOD	lbs/yr	-	148,580	9,201	72,831	66,548
Anacostia Upper	Nitrogen	lbs/yr	Not found	13,942	550	9,270	4,123
Anacostia Upper	Phosphorus	lbs/yr	Not found	1,670	327	982	361

Baseline Attachment Table 24: TMDL for Total Suspended Solids in the Upper and Lower Anacostia River, District of Columbia (2002)							
WLA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**WLA**
Anacostia Lower	TSS	lbs/growing season	Not found	289,977	15,437	N/A	N/A
Anacostia Lower	TSS	lbs/day	Not found	102,392	5,470	N/A	N/A
Anacostia Upper	TSS	lbs/growing season	Not found	1,396,552	8,200	N/A	N/A
Anacostia Upper	TSS	lbs/day	Not found	484,666	2,938	N/A	N/A
LA							
Tributary/Segment	**Pollutant**	**Units**	**TMDL Baseline Load**	**Model Baseline Load**	**Current Load Removed**	**Gap**	**LA**
Anacostia Lower	TSS	lbs/growing season	Not found	179,063	901	136,762	41,400
Anacostia Lower	TSS	lbs/day	Not found	179,063	901	136,762	41,400
Anacostia Upper	TSS	lbs/growing season	Not found	490,337	206,769	223,967	59,600
Anacostia Upper	TSS	lbs/day	Not found	490,337	206,769	223,967	59,600

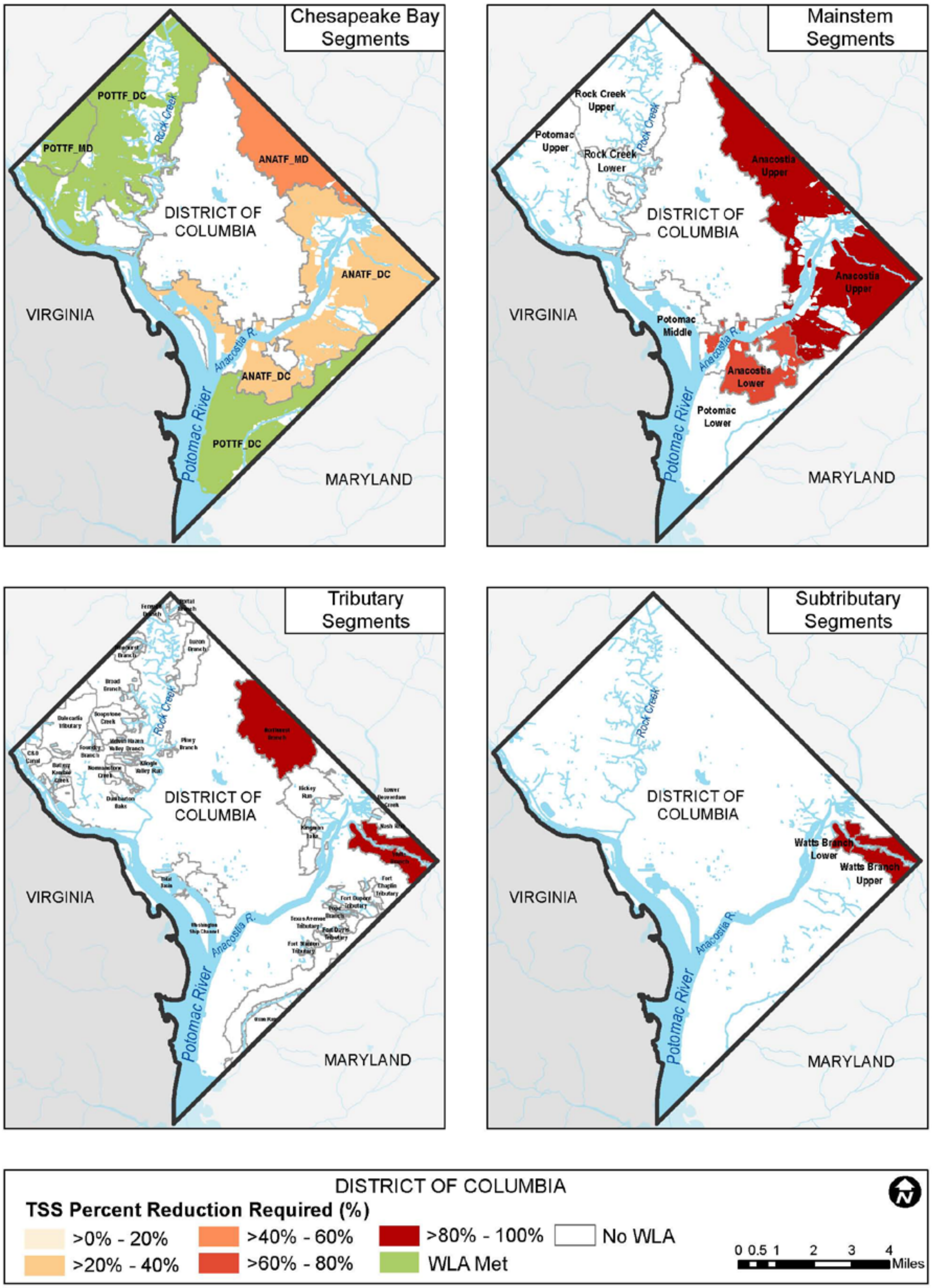
Baseline Attachment Figure 1: TN Percent Load Reduction Needed to Meet Annual WLAs



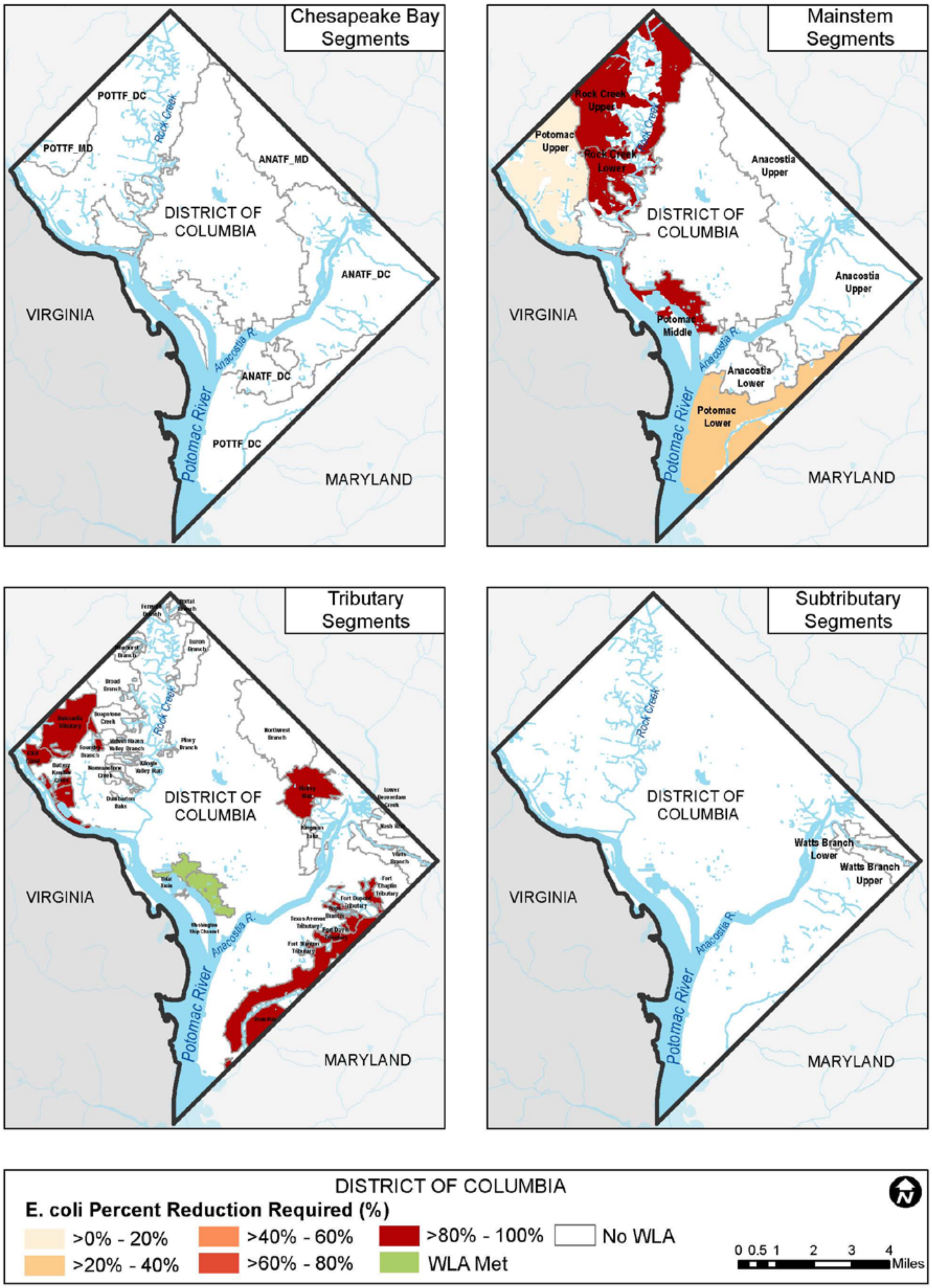
Baseline Attachment Figure 2: TP Percent Load Reduction Needed to Meet Annual WLAs



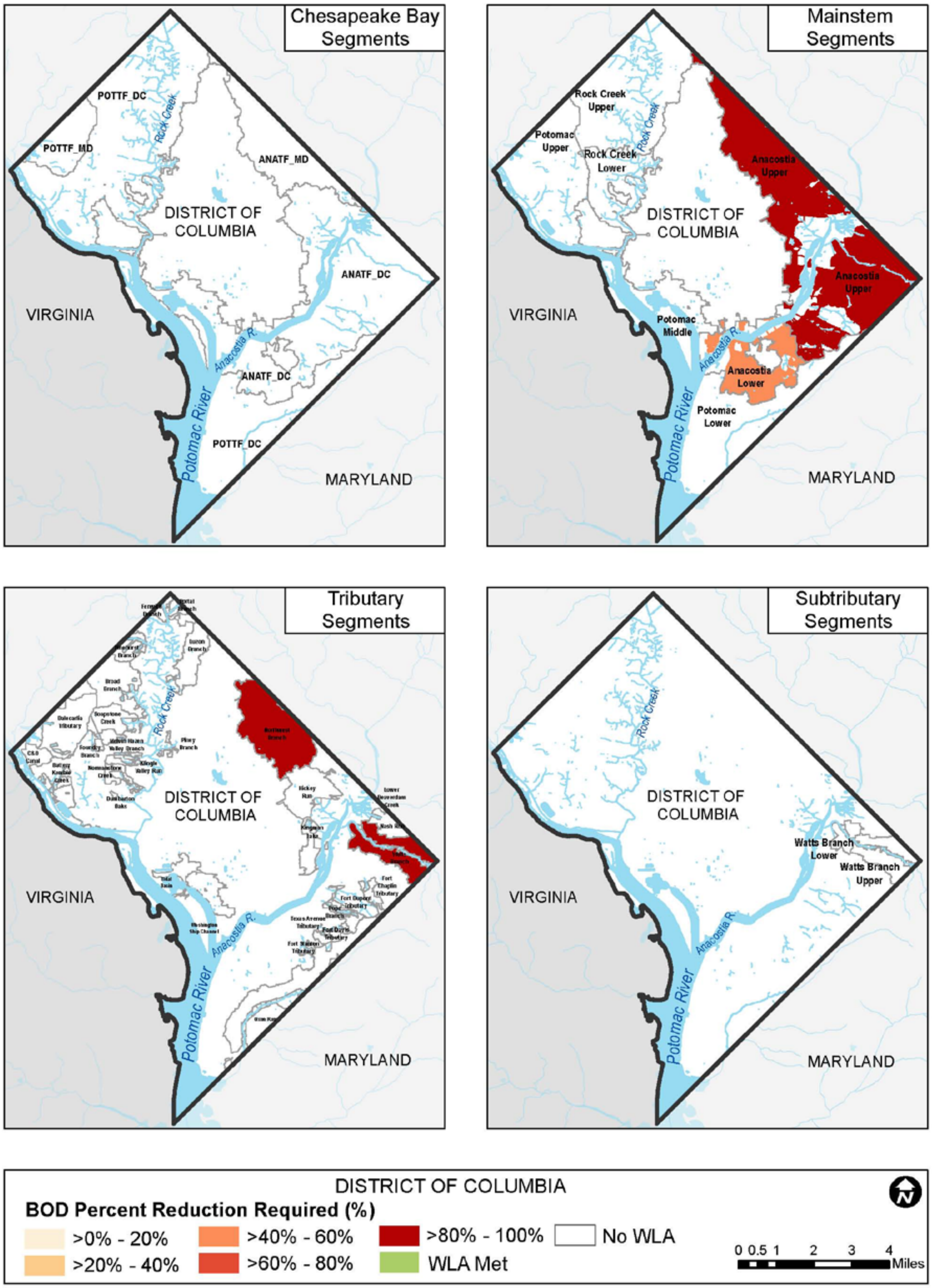
Baseline Attachment Figure 3: TSS Percent Load Reduction Needed to Meet Annual WLAs



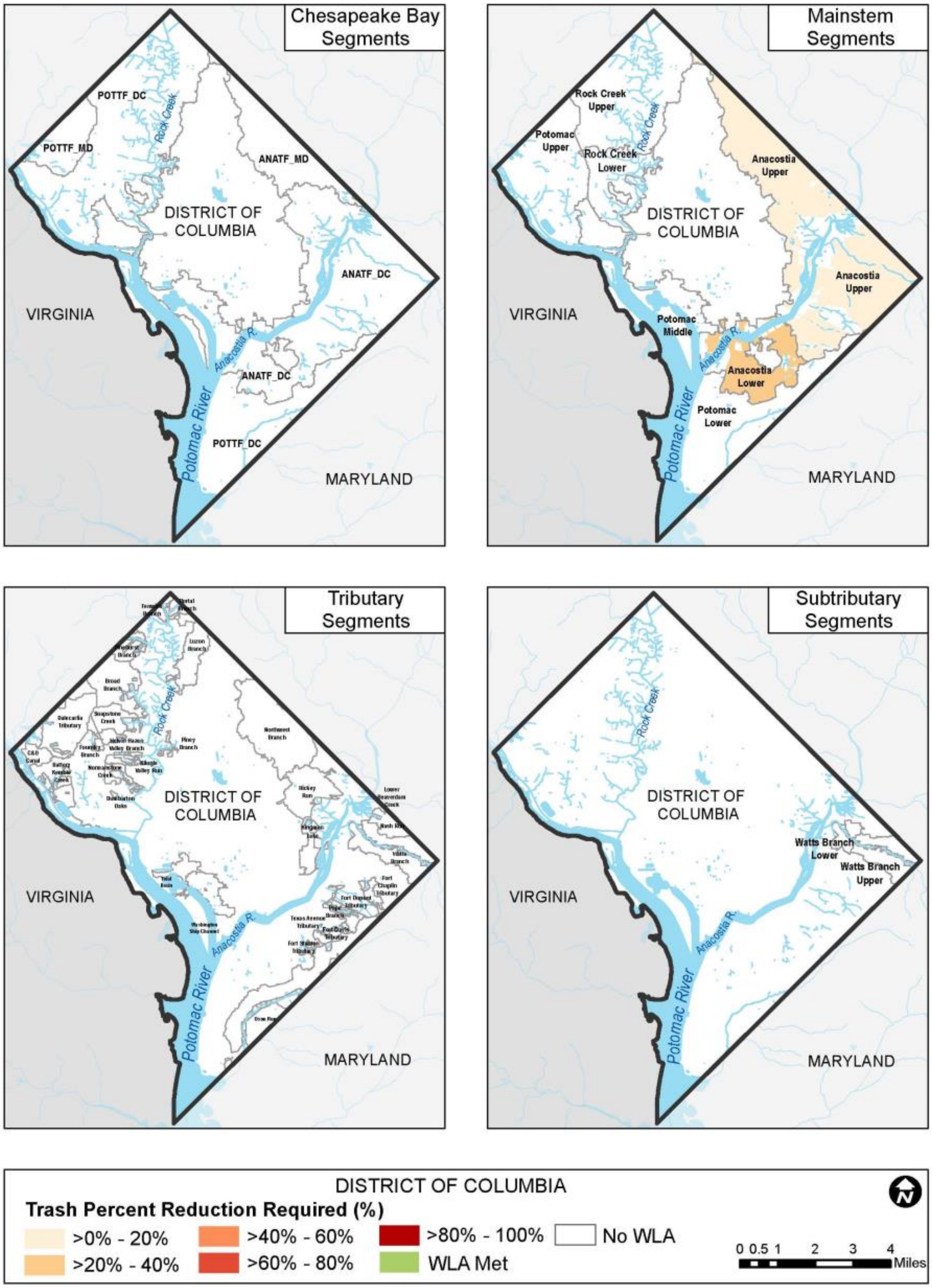
Baseline Attachment Figure 4: E. *coli* Percent Load Reduction Needed to Meet Annual WLAs



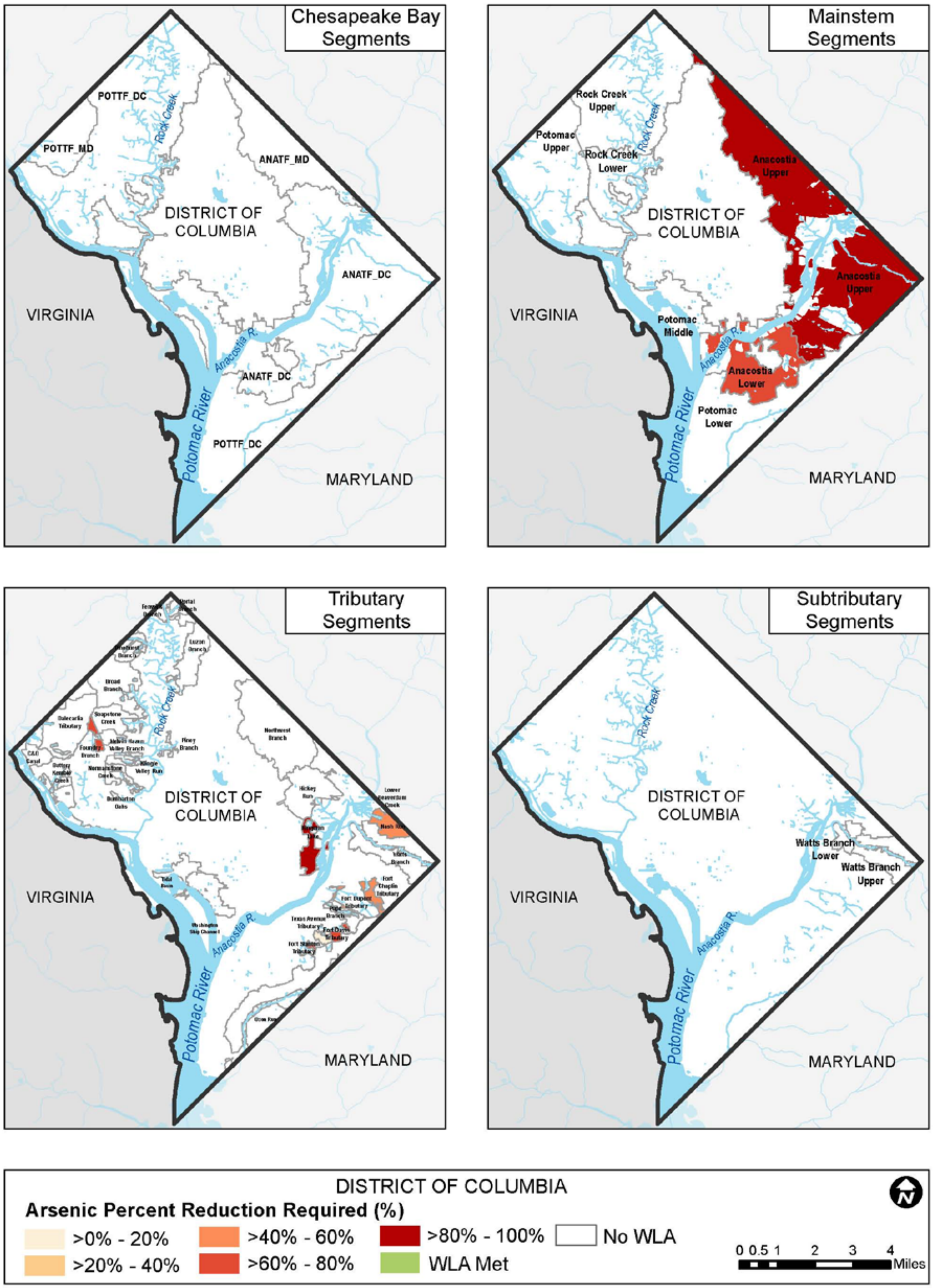
Baseline Attachment Figure 5: BOD Percent Load Reduction Needed to Meet Annual WLAs



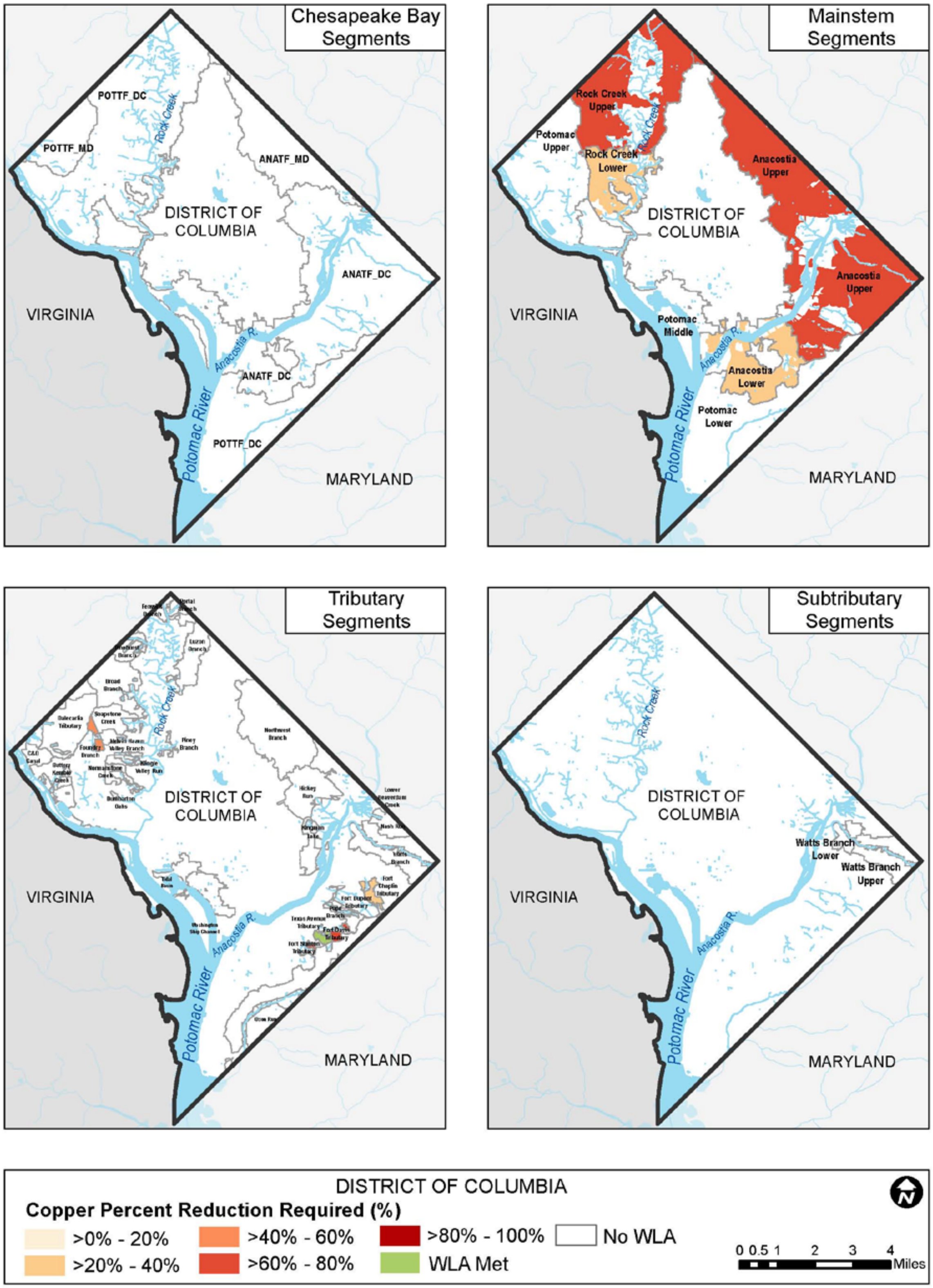
Baseline Attachment Figure 6: Trash Percent Load Reduction Needed to Meet Annual WLAs



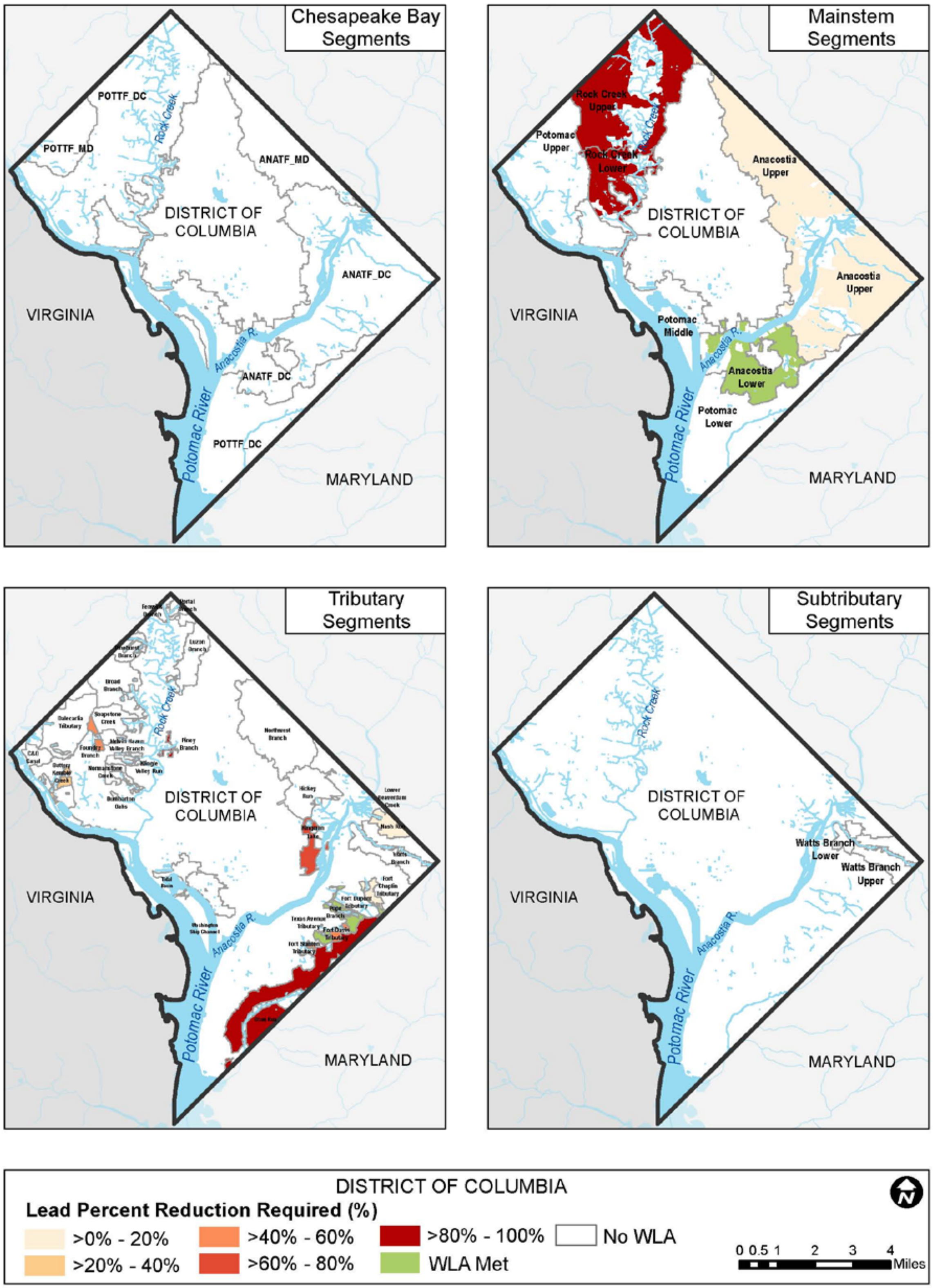
Baseline Attachment Figure 7: Arsenic Percent Load Reduction Needed to Meet Annual WLAs



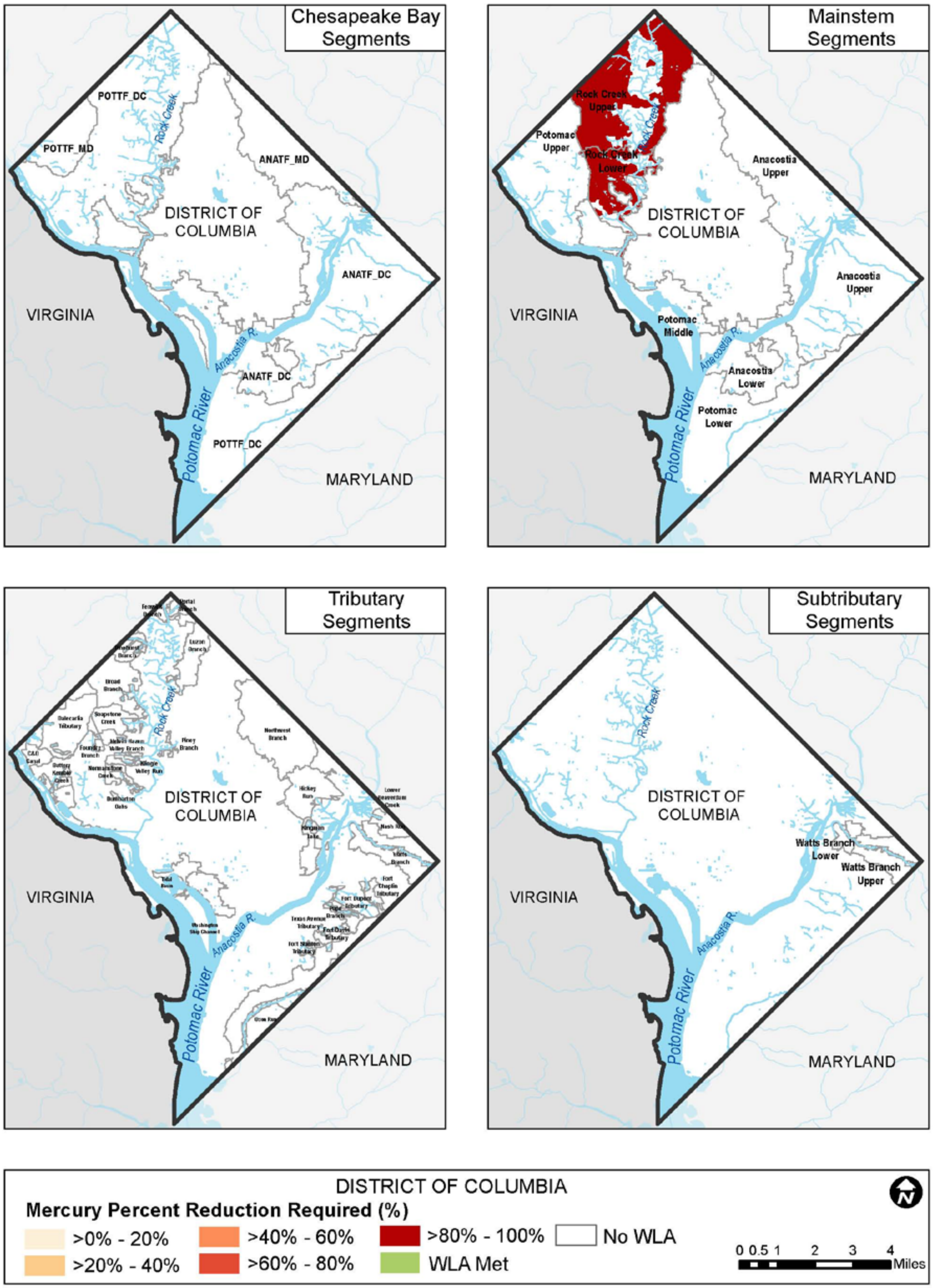
Baseline Attachment Figure 8: Copper Percent Load Reduction Needed to Meet Annual WLAs



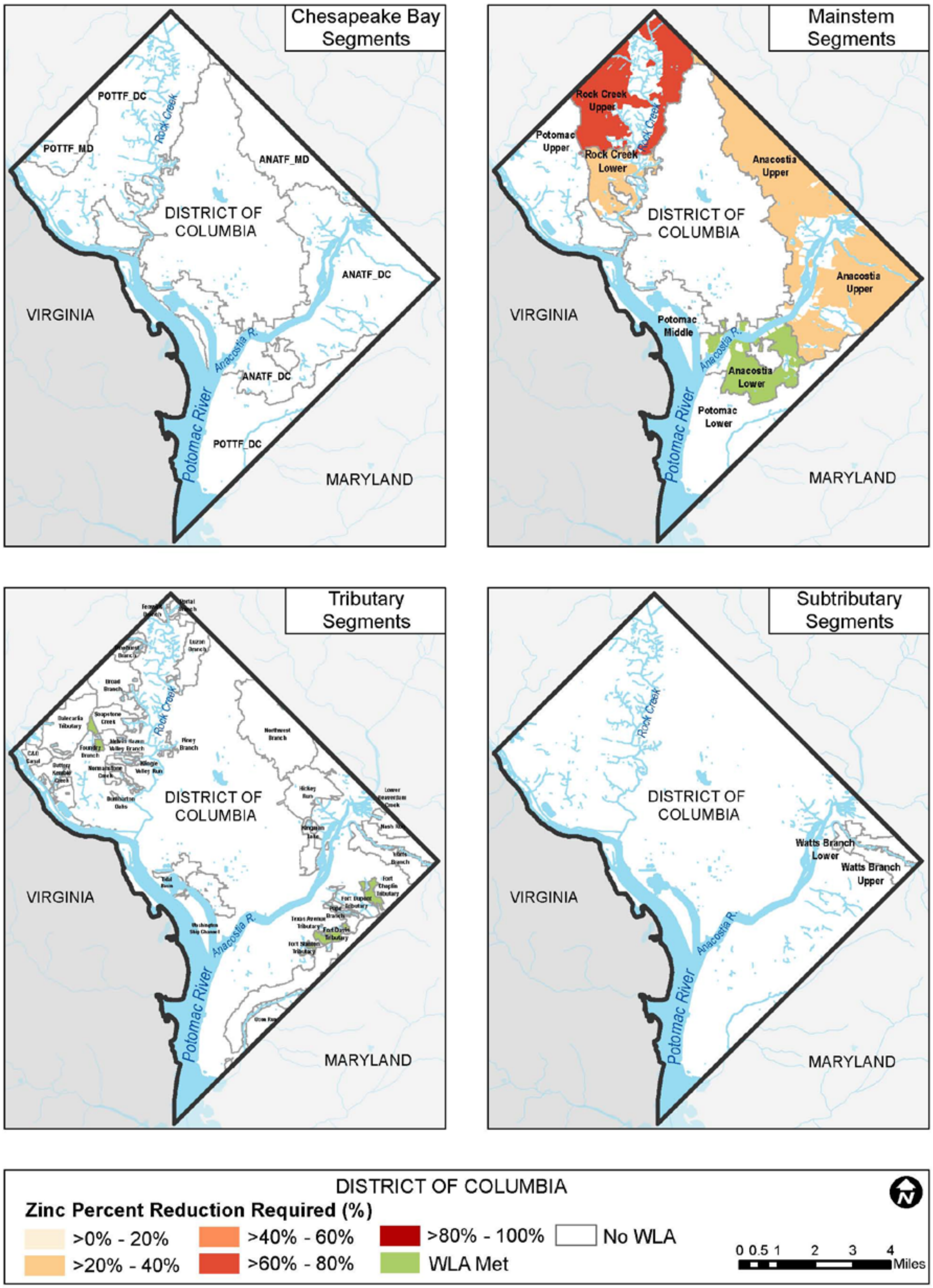
Baseline Attachment Figure 9: Lead Percent Load Reduction Needed to Meet Annual WLAs



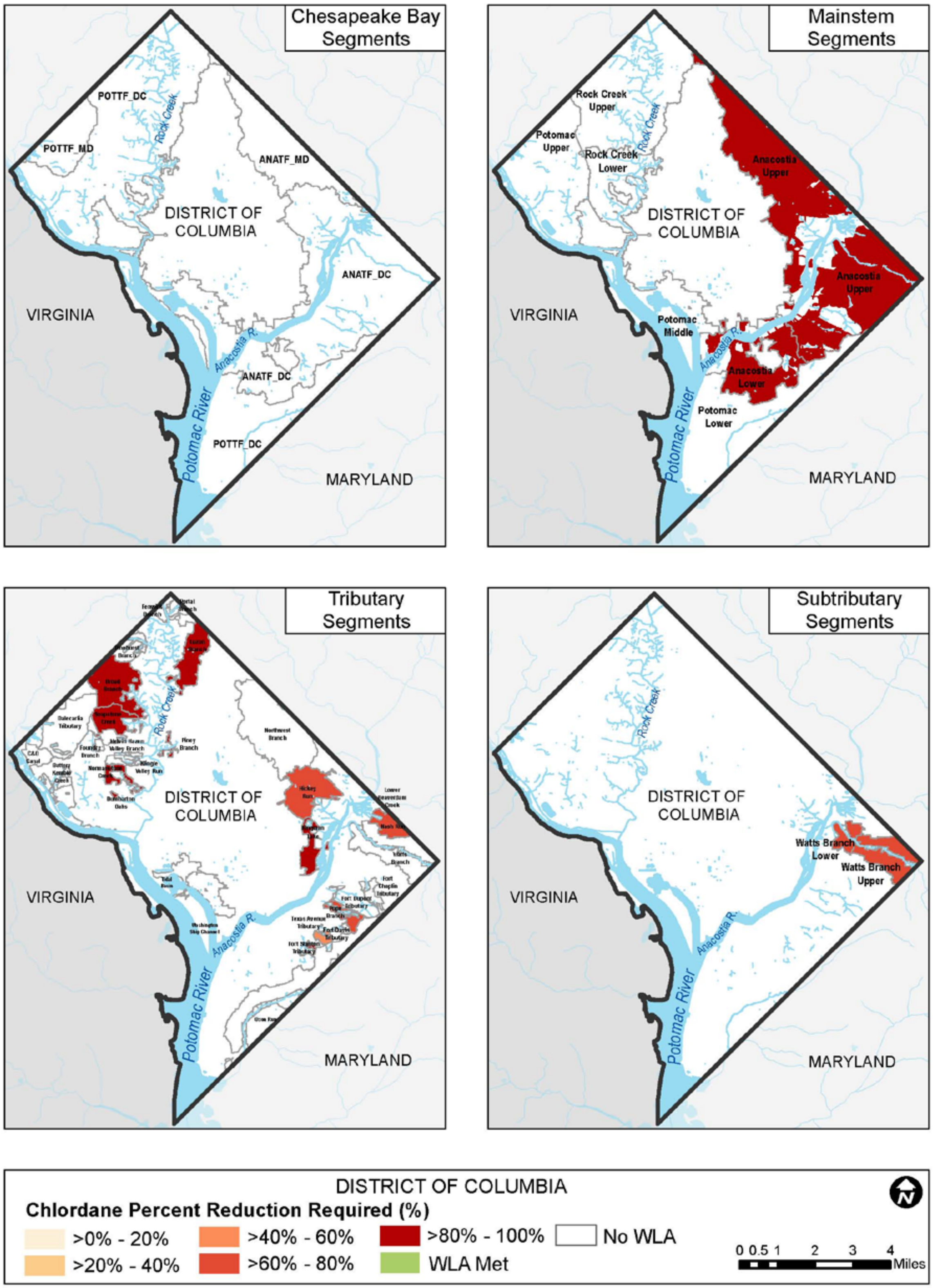
Baseline Attachment Figure 10: Mercury Percent Load Reduction Needed to Meet Annual WLAs



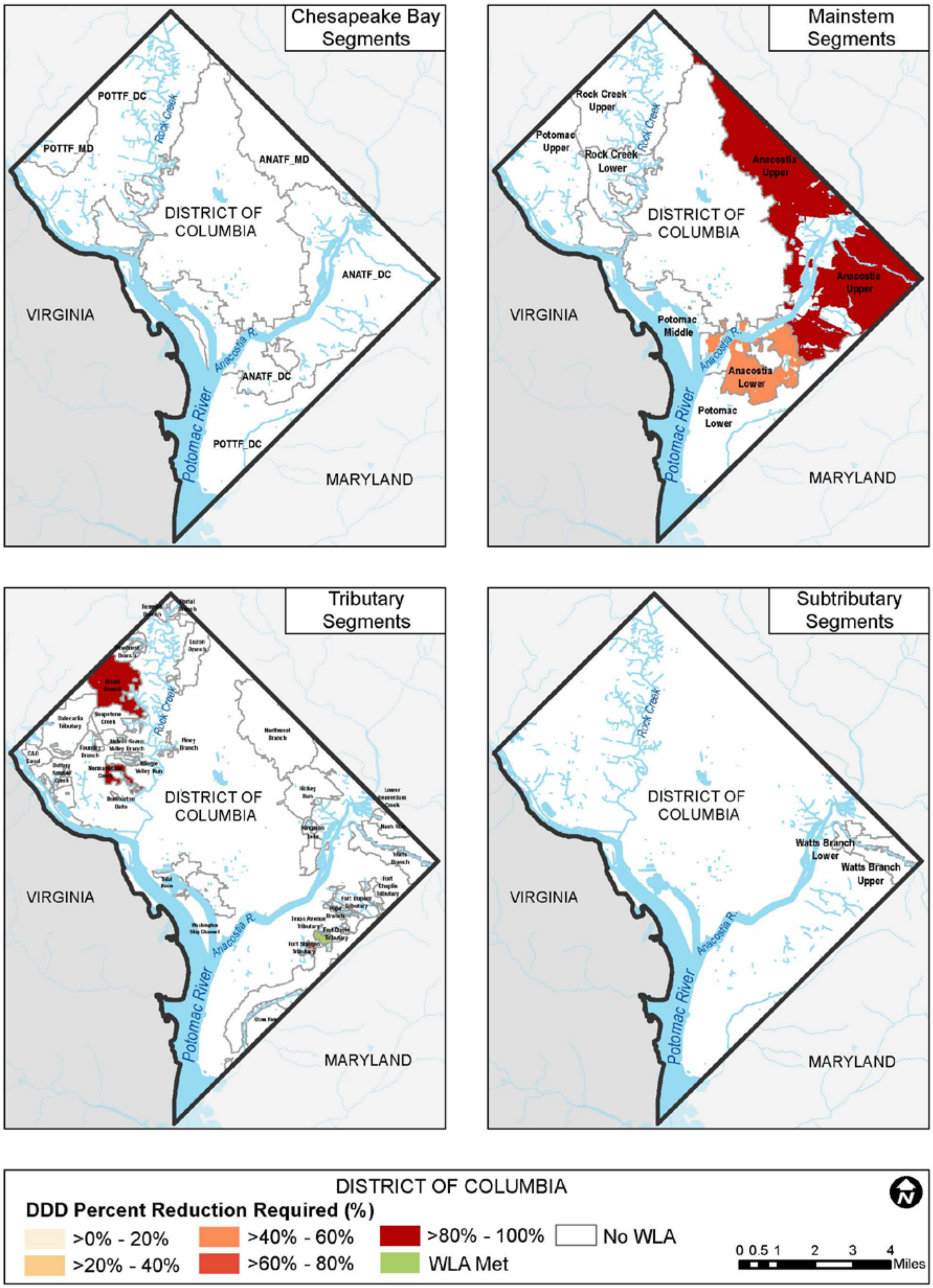
Baseline Attachment Figure 11: Zinc Percent Load Reduction Needed to Meet Annual WLAs



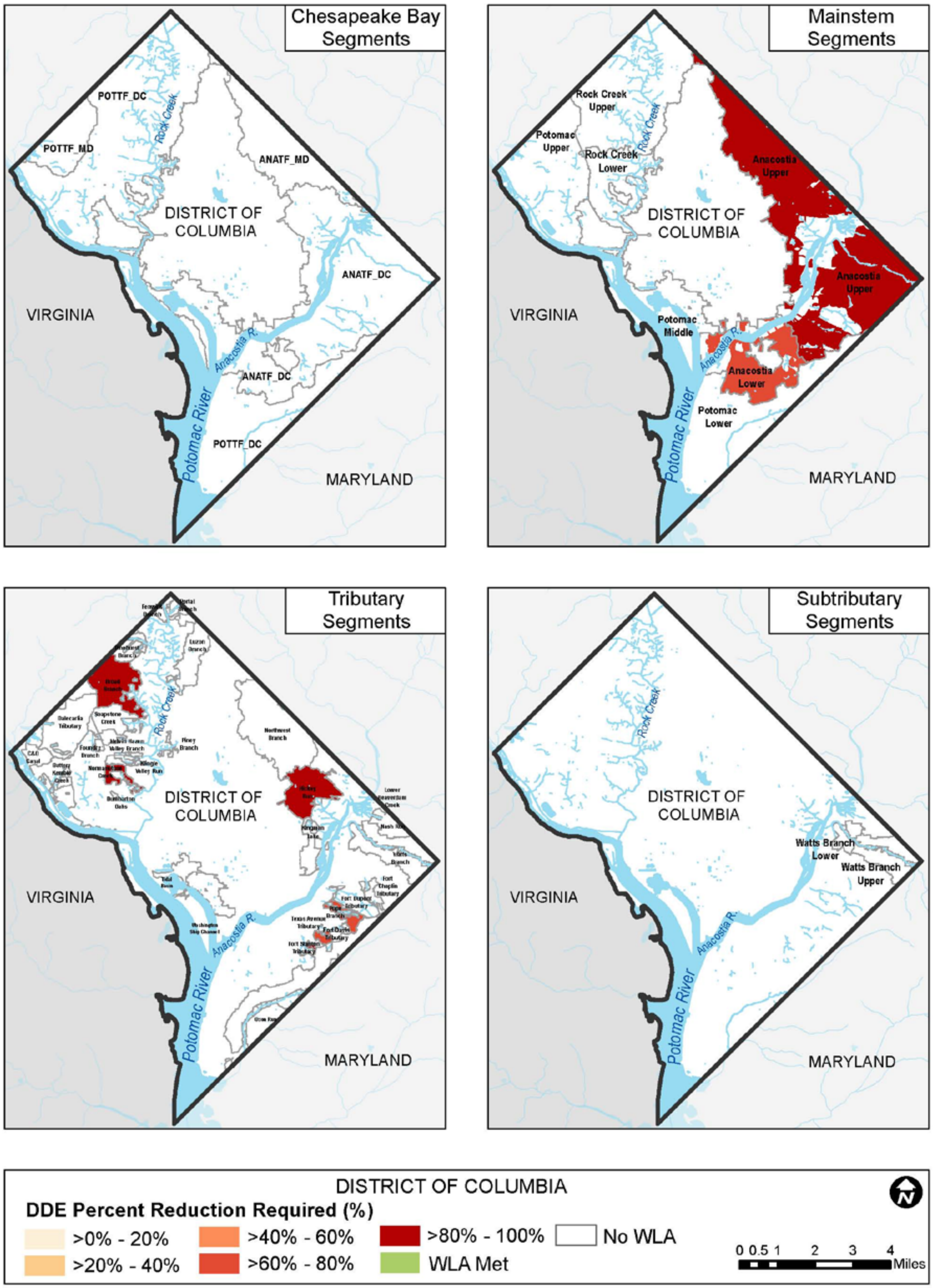
Baseline Attachment Figure 12: Chlordane Percent Load Reduction Needed to Meet Annual WLAs



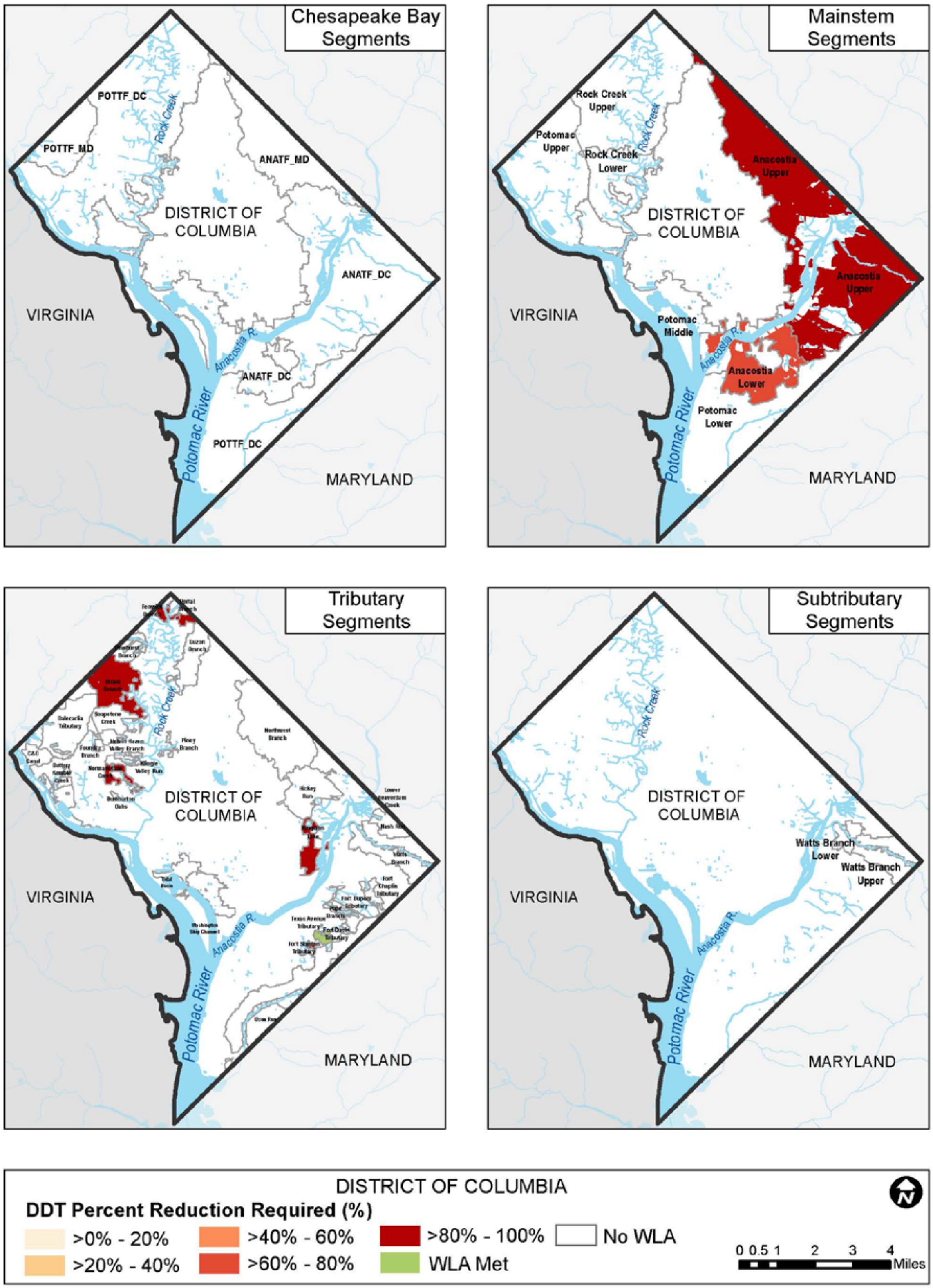
Baseline Attachment Figure 13: DDD Percent Load Reduction Needed to Meet Annual WLAs



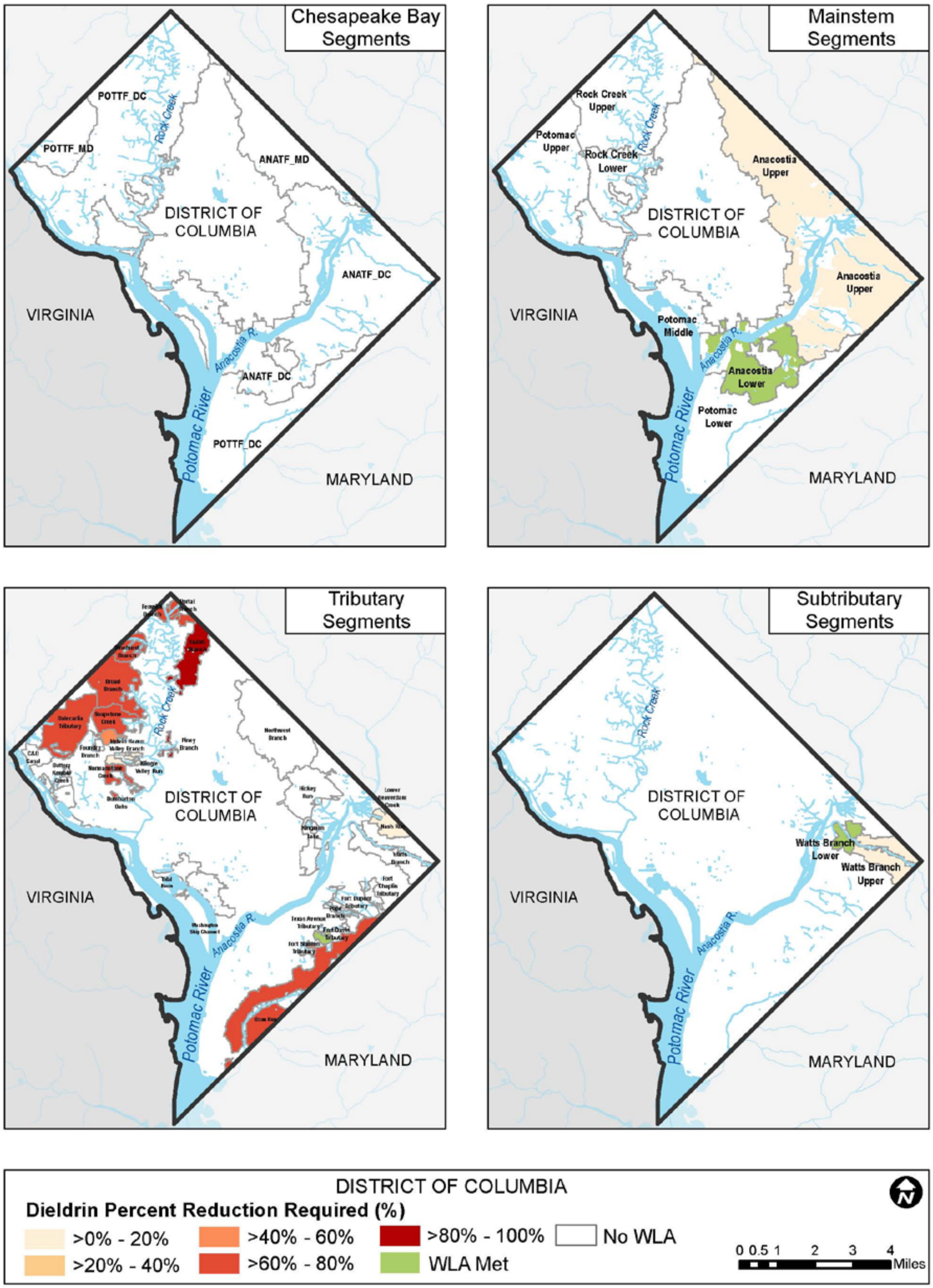
Baseline Attachment Figure 14: DDE Percent Load Reduction Needed to Meet Annual WLAs



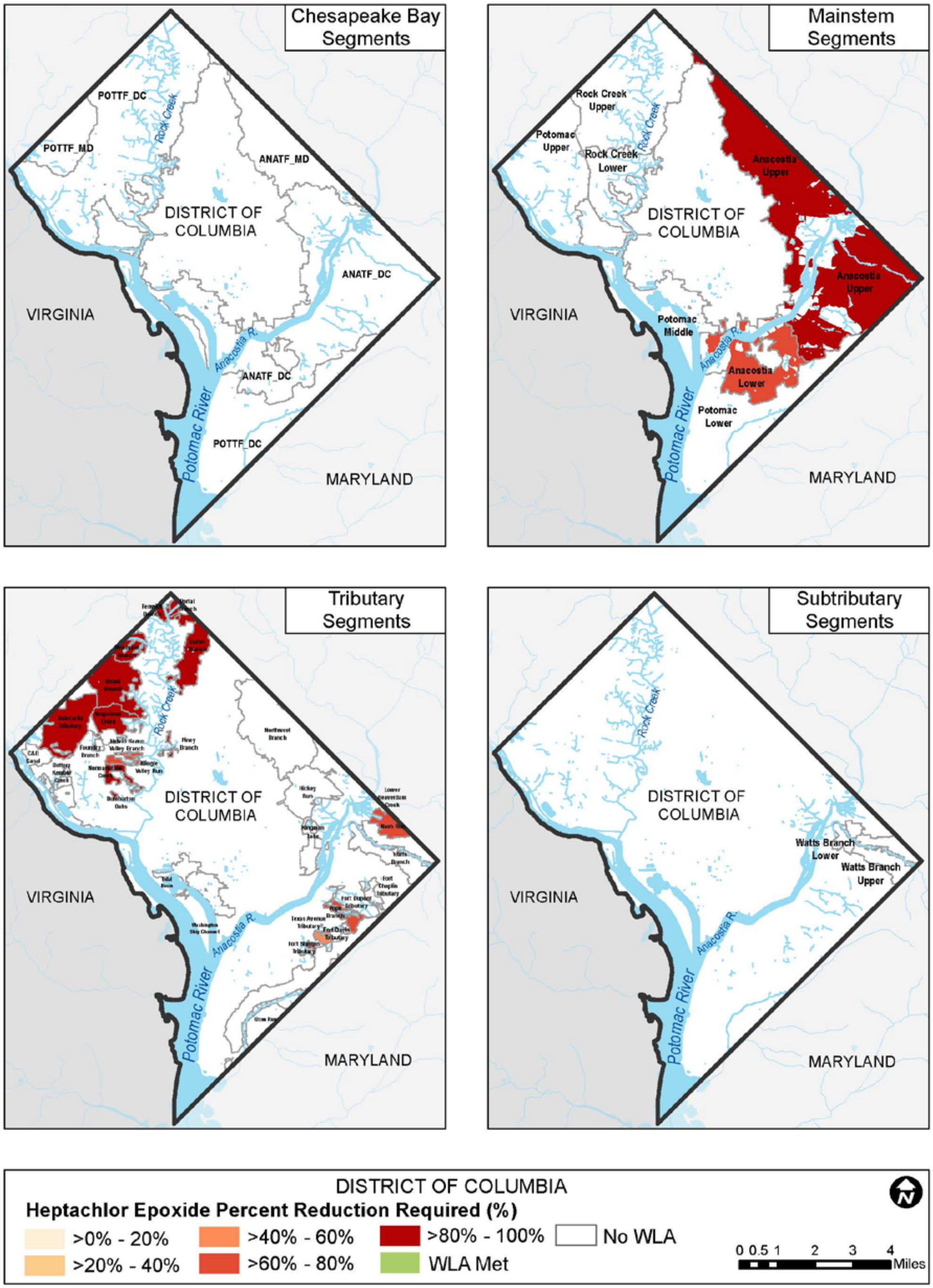
Baseline Attachment Figure 15: DDT Percent Load Reduction Needed to Meet Annual WLAs



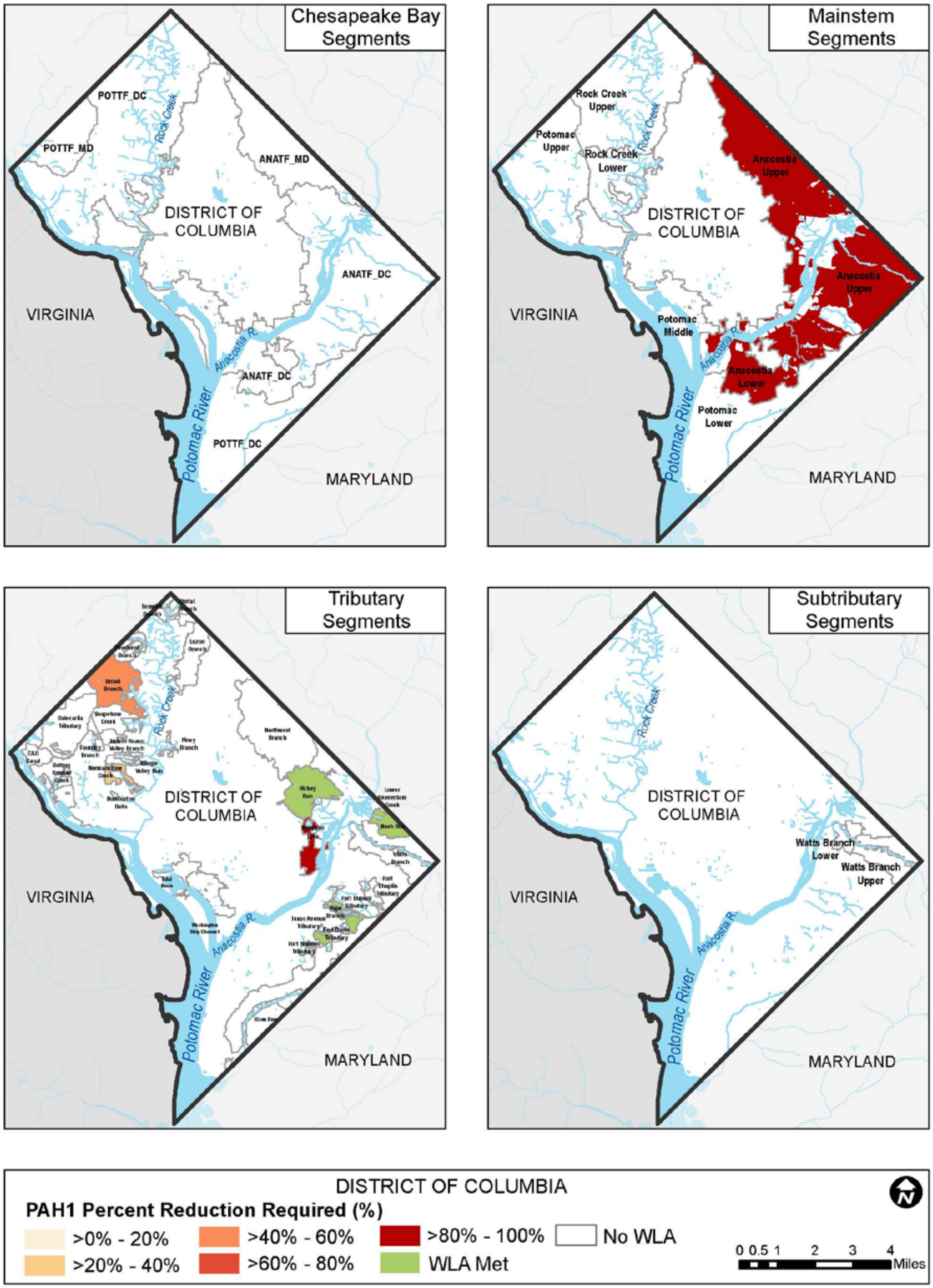
Baseline Attachment Figure 16: Dieldrin Percent Load Reduction Needed to Meet Annual WLAs



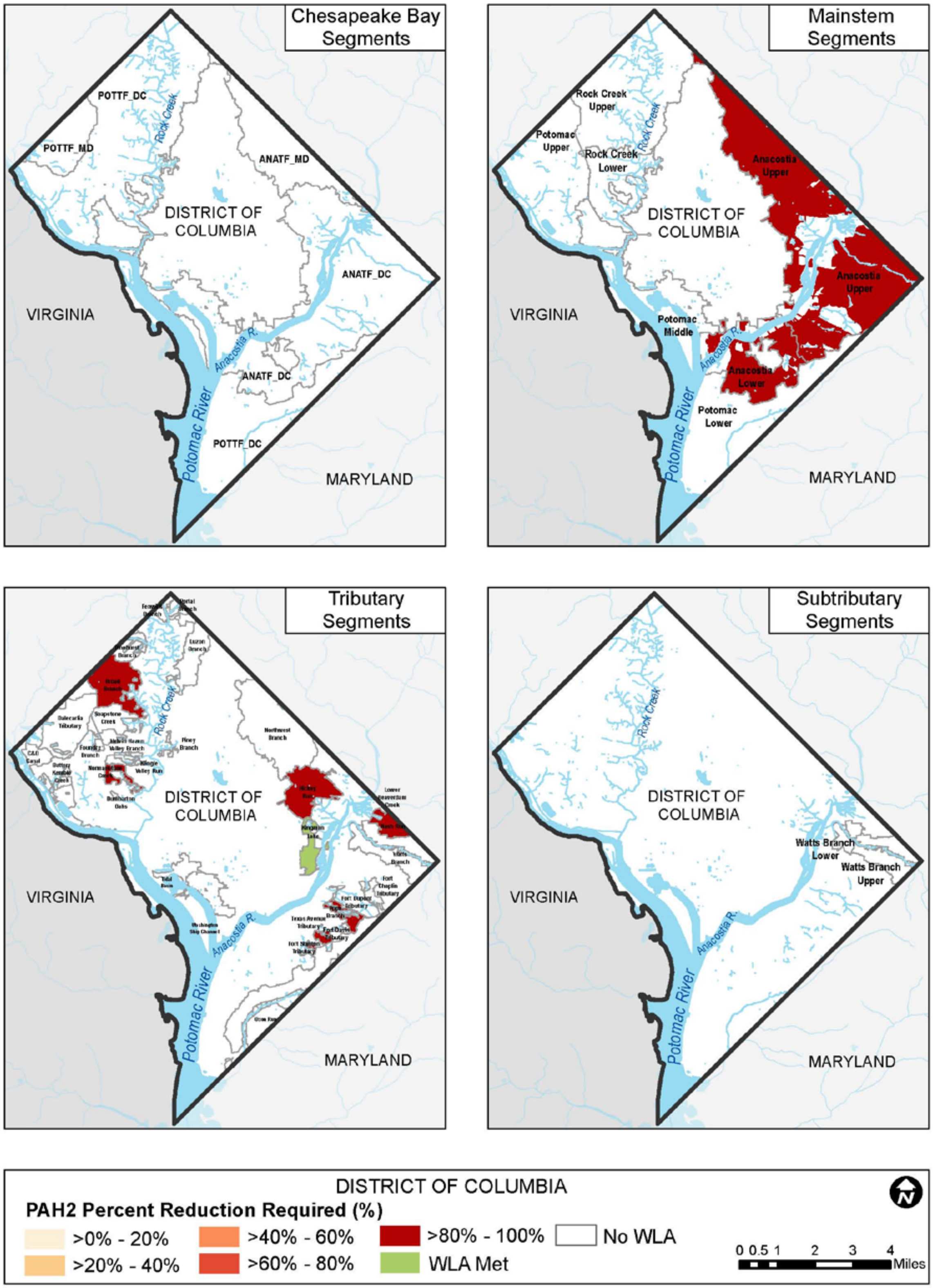
Baseline Attachment Figure 17: Heptachlor Percent Load Reduction Needed to Meet Annual WLAs



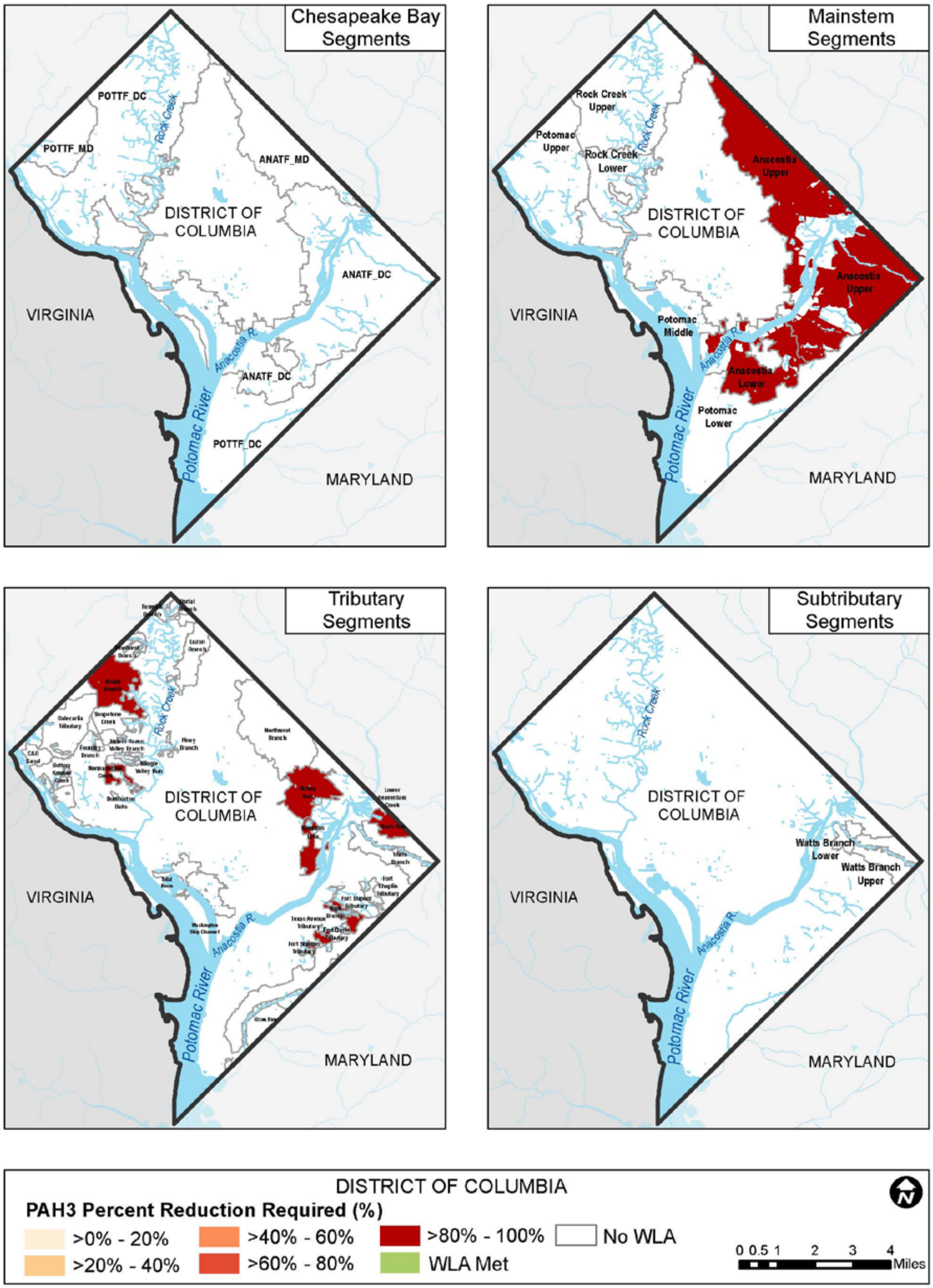
Baseline Attachment Figure 18: PAH1 Percent Load Reduction Needed to Meet Annual WLAs



Baseline Attachment Figure 19: PAH2 Percent Load Reduction Needed to Meet Annual WLAs



Baseline Attachment Figure 20: PAH3 Percent Load Reduction Needed to Meet Annual WLAs



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Appendices

Appendix A, Technical Memorandum: Model Selection and Justification

Appendix B, Technical Memorandum: Sewershed and Watershed Delineations

Appendix C, Technical Memorandum: Stream Erosion Methodology

Appendix D, Technical Memorandum: Selection of Event Mean Concentrations (EMCs)

Appendix E, Technical Memorandum: Review of MS4 Outfall Monitoring and Water Quality Conditions to Assess MS4 WLAs and TMDLs

Appendix F, Technical Memorandum: BMPs and BMP Implementation

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Appendix A
Technical Memorandum

Model Selection and Justification

Table of Contents

1. Introduction 1
2. Purpose 1
3. Technical Approach.. 2
4. Results and Discussion .... .15

References 17

Attachments 19

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Consolidated TMDL Implementation Plan – Comprehensive Baseline Analysis

May 08, 2015

List of Tables

Table 1: Modeling Approach used in Mainstem Waterbodies for MS4 Areas 4
Table 2: Modeling Approach used in Tributary Waterbodies for MS4 Areas 4
Table 3: Modeling Approach used in Other Waterbodies for MS4 Areas 5
Table 4: Results of Statistical Analysis of Precipitation Data at DCA, 1948-2013 12
Table 5: Typical Precipitation Depths (inches) at DCA 12
Table 7: Reference Runoff Coefficients from Schueler (1987) 13

List of Figures

Figure 1: Main Categories of District TMDL Waterbodies 3
Figure 2: Model Framework Diagram 9
Figure 3: DCA Annual Rainfall 11

1. Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in the District of Columbia's (District's) Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) permit (U. S. EPA 2011 and U. S. EPA 2012). The IP will define and organize a multi-year process centered on reducing pollutant loads originating within the District MS4. The level of pollutant control will be based on past TMDL studies performed to protect impaired water bodies in the District. The IP will include a summary of the regulatory compliance strategy to satisfy TMDL-related permit requirements, a summary of data and methods used to develop the IP, specific prioritized recommendations for stormwater control measures, a schedule for implementation and attainment of Waste Load Allocations (WLAs), and a method for tracking progress. Substantial public involvement will be sought in plan development.

This Technical Memorandum on *Model Selection and Justification* is one in a series of technical memoranda that provide detailed information on research, analysis, programs and procedures that support development of the Consolidated TMDL IP.

2. Purpose

Pollutant load estimation models are used extensively to develop TMDLs and to support municipal stormwater management programs. A variety of models have been used in the District for these purposes. These models use mathematical calculations to simulate rainfall generated runoff across a sewershed or watershed. Pollutant mass or load is subsequently produced by multiplying the runoff flow volume by a pollutant concentration, usually an event mean concentration (EMC). Pollution reduction is achieved by taking into consideration the effect that various best management practices (BMPs) and non-structural practices have on runoff generation or pollutant concentration.

The requirement to develop a Consolidated TMDL IP for the District includes a provision to identify and apply a model to support pollutant load estimation and pollutant reduction, and to track progress in achieving WLAs. In particular, the main requirements for developing a modeling tool specify that the model will:

- estimate baseline and current pollutant loads;
- tabulate loads on an annual basis;
- estimate pollutant load reductions achievable via various BMP implementation scenarios; and
- be able to represent the daily expression of the TMDL.

This Technical Memorandum documents the selection, justification, and description of the model (henceforth called the "IP Modeling Tool" or "IPMT") that will be used to help develop the Consolidated TMDL IP. This Technical Memorandum also provides information on the IP Modeling Tool inputs and comparison to other models, and includes a **Technical Approach** that addresses:

- review of previous modeling studies of the MS4 Area;
- review of publically available modeling tools and calculators;
- model needs;
- model selection and justification;
- model description and requirements;
- model comparisons; and
- model limitations.

It also includes a **Results and Discussion** section that presents and discusses the model selection and model comparisons in the context of the Consolidated TMDL IP.

3. Technical Approach

3.1 Review of Previous Modeling Studies of the MS4 Area

The District has completed 26 TMDL studies for various 303(d)-list impaired waterbodies. TMDL studies typically consist of multiple related individual TMDLs, such as TMDLs for related pollutants in a single waterbody (e.g., TMDLs for multiple metal species in a waterbody) or TMDLs for related waterbodies (e.g., a TMDL for a specific pollutant for a mainstem waterbody and its tributaries). The 26 TMDL studies vary in complexity with respect to both the modeling performed to establish loads and also in the assignment of MS4 WLAs. This section provides an overview of the modeling approaches used in the TMDL studies. It summarizes the key differences between the various TMDL models with respect to how loads are developed and describes how the MS4 WLAs are calculated and expressed for each TMDL. This section also summarizes the information used to delineate the MS4 drainage areas and describes the data and methods used to compute runoff from these areas, because this information is integral to the modeling of MS4 loads. A full explanation of all the models and model inputs that were used to develop the TMDLs is provided in Attachment A.1.

3.1.a District Waterbody Characterization for TMDL Modeling

As described above, there are three major types of waterbodies in the District: mainstem waterbodies; tributary waterbodies; and other waterbodies that are connected to a mainstem but are not tributaries, such as the Tidal Basin (see Figure 1). The following sections describe each waterbody type and provide some basic information on how the waterbodies are modeled.

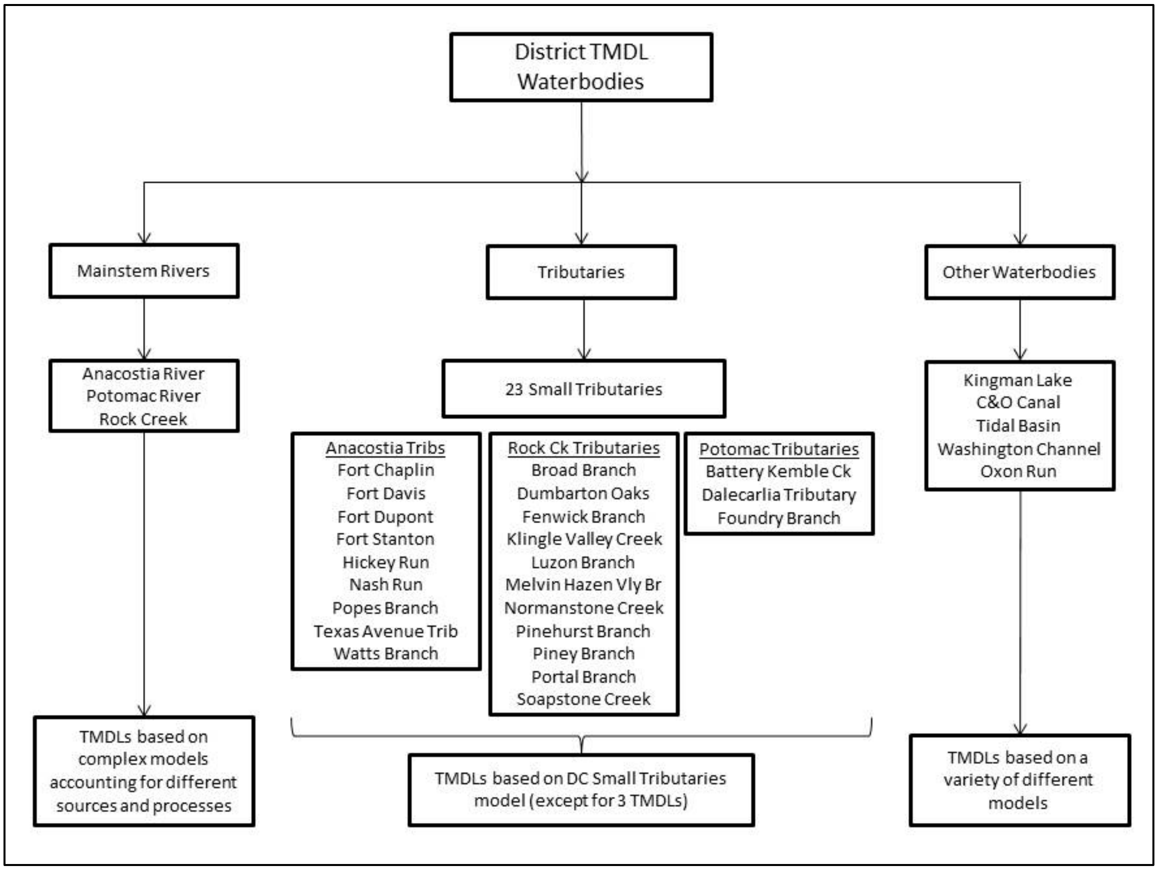

Figure 1: Main Categories of District TMDL Waterbodies

3.1.b Mainstem TMDL Models

There are 12 TMDL studies for the mainstem waterbodies in the District. Table A-1 below shows the list of TMDL studies for mainstem waterbodies and the main modeling approach used to calculate runoff from the respective MS4 drainage areas in each study. Modeling approaches for the mainstem included use of an HSPF model originally developed for Watts Branch, and the MOUSE model used for the CSO LTCP.

The Watts Branch HSPF model was originally developed by ICPRB in 2000 to help provide flow inputs for other Anacostia models because Watts Branch is the only stream in the District with a long term record of stream discharge. In the Watts Branch HSPF model framework, all land areas are categorized into one of three land use types: Impervious, Urban Pervious, and Forested Pervious. For each land use type, the model predicts the daily flow volume per unit area of base flow and surface runoff (storm flow) during a simulation period. Because many of the small water and sewersheds in the District were assumed to be hydrologically similar to Watts Branch, the Watts Branch model was applied to these sub-drainage areas to calculate runoff by first categorizing the land use types in the sub-drainage areas according to land use types, and then by using the runoff calculations in the model.

Several TMDLs also use the land model based on DHI's MOUSE that was developed for the Long Term Control Plan (LTCP). The District of Columbia Water and Sewer Authority (DC Water) built a complex hydrologic and hydraulic model of the DC sewer system as part of its development of the LTCP for the combined sewer system. The MOUSE (now known as Mike Urban) software was used to develop the LTCP model. As part of the LTCP process, the separate storm sewer area was also studied to characterize the storm runoff generated throughout the city. The LTCP model was calibrated for flow at various key points within the CSO sewer system, which allowed the runoff inputs to be calibrated as well. The runoff component of the model is simulated using Horton's equation, which requires inputs such as precipitation, imperviousness, soil infiltration rates and recovery, surface slopes, and surface depression volume. The LTCP model has not only been used to simulate the combined sewer system and overflows, but has also been applied to model surface flooding issues across the city, including in the MS4 area. As noted previously, the LTCP model was also applied to develop some of the Rock Creek and Potomac TMDLs.

Table 1: Modeling Approach used in Mainstem Waterbodies for MS4 Areas

TMDL Study	Mainstem Waterbody	Hydrologic Model for District MS4 Runoff	Source of MS4 Drainage Area used in TMDL
Anacostia BOD - 2001	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia TSS – 2002	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia & Tributaries Bacteria - 2003	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia & Tributaries Metals/ Organics –2003	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia Oil & Grease - 2003	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia TSS – 2007	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia Nutrients/BOD – 2008	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia Trash - 2010	Anacostia River	None (monitoring data used)	2005 land use data used
Potomac & Anacostia Tidal PCB - 2007	Potomac and Anacostia River	Not reviewed in full	Not reviewed in full
Rock Creek Metals -2004	Rock Creek	LTCP land model using DHI's MOUSE	LTCP sewershed delineations
Rock Creek Bacteria -2004	Rock Creek	LTCP land model using DHI's MOUSE	LTCP sewershed delineations
Potomac & Tributaries Bacteria -2004	Potomac River	LTCP land model using DHI's MOUSE	LTCP sewershed delineations

3.1.c Tributary TMDL Models

There are eight tributary TMDL studies in the District, of which five use the DC Small Tributaries (DCST) model to calculate loads. The five TMDLs that use the DCST model cover multiple tributaries of a mainstem and therefore establish TMDLs on multiple tributary waterbodies. Table 2 shows the list of tributary TMDLs and the model used for each to establish pollutant loads.

Table 2: Modeling Approach used in Tributary Waterbodies for MS4 Areas

Tributary TMDL	TMDL Model
Hickey Run PCB, Oil and Grease, Chlordane - 1998	Monitoring data used (no modeling)
Anacostia and Tributaries Bacteria - 2003	DC Small Tributaries Model
Anacostia and Tributaries Metals and Organics – 2003	DC Small Tributaries Model
Fort Davis BOD - 2003	Monitoring data used (no modeling)

Table 2: Modeling Approach used in Tributary Waterbodies for MS4 Areas	
Tributary TMDL	**TMDL Model**
Watts Branch TSS 2003	SWMM (inflows) and HEC-6 (erosion)
Potomac and Tributaries Bacteria - 2004	DC Small Tributaries Model
Potomac and Tributaries Metals and Organics – 2004	DC Small Tributaries Model
Rock Creek Tributary Metals - 2004	DC Small Tributaries Model

The DCST model is simpler compared to mainstem TMDL models, in part because it does not account for in-stream processes. The input loads to the DCST model are considered fully mixed in the stream and are used directly to calculate TMDL allocations. However, the model used for the Watts Branch TSS TMDL does have added complexity relative to the DCST model because it includes stream bank erosion among the sources of total TSS load in the stream. There are also two key differences between tributary models and mainstem models that pertain to input flow and load establishment in TMDLs. These are:

- Tributary models only establish the flow from the tributary drainage area, as that is the only source of pollutant loads that needs to be identified. This load is split between WLA and LA based on the sewered and unsewered areas within the drainage area. In contrast, mainstems have varied sources of input, such as upstream flow, major tributary flows, and sub-drainage area flows.
- Tributary models are concerned only with the daylighted portion of a tributary and therefore delineate the drainage area only up to the last daylighted point of a tributary stream. Any downstream piped sections are not considered as part of the tributary drainage area. Therefore, for those tributaries that have significant piped sections, tributary drainage areas do not match the sub-drainage area mapped for that same tributary in the mainstem model because mainstem sub-drainage areas were delineated up to the pipe outfall on the mainstem. This issue primarily impacts the Anacostia tidal watershed, in which many of the tributaries are piped before they flow into the river.

The Fort Davis BOD and the Hickey Run PCB, Oil and Grease, and Chlordane TMDLs do not use modeling to establish flows or allocations. The Fort Davis TMDL used monitoring data to establish that the stream is no longer impaired for BOD and therefore that a TMDL was no longer required. The Hickey Run TMDL uses monitoring data to set a TMDL allocation for each pollutant. For oil and grease it is set at that level which will not cause a sheen, and for PCB and chlordane, no discharges are allowed into the stream. Therefore, no models are developed for these TMDLs.

3.1.d Other Waterbodies

There are four waterbodies that fall into the "other waterbody" category. Table 3 shows the different TMDLs issued for these waterbodies and the modeling approach used in the development of the TMDLs.

Table 3: Modeling Approach used in Other Waterbodies for MS4 Areas		
TMDL	**In-stream Model**	**Drainage Area Runoff Estimation**
Tidal Basin and Ship Channel Bacteria (2004)	Environmental Fluid Dynamics Model (EFDC)	Using precipitation, infiltration loss percentage, and drainage area
Tidal Basin and Ship Channel Organics (2004)	EFDC	Using precipitation, infiltration loss percentage, and drainage area
Ship Channel pH (2004)	No numerical modeling	Monitoring data used to estimate loads
Kingman Lake Bacteria (2003)	No numerical modeling	Based on flow to TAM/WASP segments 15-19 of the Anacostia River

Table 3: Modeling Approach used in Other Waterbodies for MS4 Areas

TMDL	In-stream Model	Drainage Area Runoff Estimation
Kingman Lake Organics and Metals (2003)	No numerical modeling	Based on flow to TAM/WASP segments 15-19 of the Anacostia River
Kingman Lake TSS, Oil and Grease, BOD (2003)	No numerical modeling	Based on a simple hydrologic model
Oxon Run Organics, Metals, and Bacteria (2004)	No numerical modeling	Watts Branch HSPF Model used in the DC Small Tributaries Model
Chesapeake and Ohio Canal Bacteria 2004	No numerical modeling	An HSPF Model is used with two land use categories: forested and urban lands

3.1.e Bacteria Modeling and Translation of E. coli from Fecal Coliform

At the time most bacteria TMDLs were done, the bacteria water quality standard for the District was expressed in fecal coliform colonies. However, in 2005, the fecal coliform water quality standard was changed to E. coli. Therefore, all of the bacteria TMDLs were updated to reflect the new E. coli water quality standard. To support the TMDL revisions, EPA and DDOE developed a DC Bacteria translator using the statistical relationship between paired fecal coliform and E. coli data collected in the District's waters (LimnoTech 2011 and 2012[1]). The DC Bacteria translator is representative of ambient and stormwater bacteria concentrations and was used to convert the original fecal coliform TMDL allocations into E. coli allocations.

3.2 Review of Publically Available Modeling Tools and Calculators

As described in the previous section, a variety of models have been used in the District to calculate stormwater runoff volumes and pollutant loads. These models were considered in the selection of a calculator for the IP Modeling Tool. In addition, a broader suite of calculators and models was also reviewed. These included:

- Spreadsheet Tool for Estimating Pollutant Load (STEPL) (EPA, 2007)
- Watershed Treatment Model (WTM) (CWP, 2013)
- VA Runoff Reduction Model (CWP, 2011)
- EPA National Stormwater Calculator (U. S. EPA, 2013)
- GRTS Load Reduction Tool (DDOE, date unknown)
- Green Values Stormwater Management Calculator (CNT, 2004)
- Pollutant Load Reduction Model (USACE, 2000)
- PLOAD (EPA, 2011)
- Long-Term Hydrologic Impact Assessment (L-THIA) (Purdue, date unknown)

A comparison of these models was undertaken to examine:

- the intended use of the calculators and models;
- the hydrologic runoff method used;
- the method of calculating pollutant load;
- the different types of pollutants that can be accommodated;
- the different sources of pollution that can be input into the model (i.e. land use, roads, etc.);

[1] Documentation related to development of the DC Bacteria translator is in LimnoTech's 2011 Memorandum, Final Memo Summarizing DC Bacteria Data and Recommending a DC Bacteria Translator (Task 2) and LimnoTech's 2012 Memorandum, Update on Development of DC Bacteria Translators.

- the graphical user interface (GUI) capabilities;
- the BMP types that can be used in the model;
- the method for applying BMP reductions;
- the ability to account for overlapping BMPs; and
- the ability to account for BMPs in series.

The results of the review are included in Attachment A.2.

3.3 Model Needs

As described earlier, many models currently exist to simulate runoff and loads for various parts of the District, and each of these models was designed with a specific purpose. The Consolidated TMDL IP requires a model that can be applied across the entire District, not just sections of it, in order to provide a consistent and consolidated approach to calculate runoff and pollutant load in the MS4 and direct drainage areas. Several other additional needs and requirements for the IPMT are summarized in the following paragraphs.

3.3.a The model will estimate baseline and current pollutant loads

Baseline loads represent the stormwater loads in the District that are not influenced or reduced by BMPs or other stormwater management practices. For the purposes of this analysis, baseline loads refer to the stormwater loads in place (circa 2000 to 2004) when the majority of TMDLs were developed. Current loads represent the present existing condition across the District, and take into consideration all of the BMPs and other non-structural practices implemented in the years up to and including 2013. The difference between the current condition and the WLA represents the "gap" or the amount of pollution reduction required to achieve WLAs.

3.3.b The model will tabulate and account for loads on an annual basis

A primary requirement for the IPMT is that is must be able to track pollutant reduction to achieve WLA targets that are expressed in units of lbs/year, tons/year, etc. The IPMT must also be able to tabulate and account for seasonal WLAs expressed over a period of months (e.g., the chlorophyll *a* growing season).

3.3.c The model will be able to represent the daily load expression of the TMDL

In addition to longer term annual and seasonal WLAs, TMDLs may also be developed with daily load expressions. "Daily load expressions" are defined as a single static daily load value (e.g., lbs/day) that is expected to be protective of water quality criteria. This value is usually identified or extracted from an annual or seasonal time series (a daily load data set) used to develop WLAs. Replication of a daily load expression of a given TMDL by the model will be needed to assess the ability of implementation scenarios to achieve this load reduction target.

3.3.d The model will estimate pollutant load reductions achievable via various BMP implementation scenarios

The most important use of the model is to guide development of the Consolidated TMDL IP with respect to an appropriate mix of BMPs and non-structural practices and the implementation schedule. The model must therefore properly account for pollution load reduction that is associated with various BMPs and non-structural practices in a reliable manner.

3.3.e The model will estimate and track runoff volume as well as pollutant load

This capability is aligned with the need to track reductions in stormwater volume, as this is a requirement of District stormwater regulations and programs.

3.3.f Other important considerations

Other important model requirements include the ability to:

- calculate and track pollutant loads and reductions spatially and temporally by watershed, catchment (a defined MS4 drainage area), pollutant, or other specification;
- account for site-specific characteristics of watersheds and catchments such as land use, land cover, and soil type;
- quantify pollutant load reductions associated with various IP scenarios, including the implementation of the District stormwater management regulations over defined time periods;
- incorporate spatial changes over time to the District's land use/land cover and BMP implementation and their effect on pollutant loads and reductions;
- support quantification of the cost of various implementation scenarios;
- evaluate progress towards WLA compliance by enabling comparison of current and future condition pollutant loads with benchmarks and milestones;
- screen, rank, and prioritize catchments suitable for specific BMP implementation ("opportunity areas");
- screen and rank potential BMPs to address pollutants in the opportunity areas;
- utilize a GIS component to allow spatial visualization of modeling scenarios;
- be user-friendly and not require expert knowledge of modeling concepts to run the modeling tool and understand the output;
- be adaptive so that future information can be incorporated into the tool as knowledge and data sources improve; and
- be linked directly with input data sources (such as the BMP database) to allow for continuous or periodic updates as sources are updated.

3.3.g Conceptual Model Framework

Given the model needs and other considerations listed in the previous section, a conceptual model framework for the IP Modeling Tool was crafted and is presented in Figure 2. In this framework, various databases, GIS and a runoff/load calculator are combined in a GUI and linked to post processing programs to tabulate, display, and compare model results. The calculator is a critical component of the modeling framework - the part that produces the runoff and pollutant loads needed for IP planning and implementation.

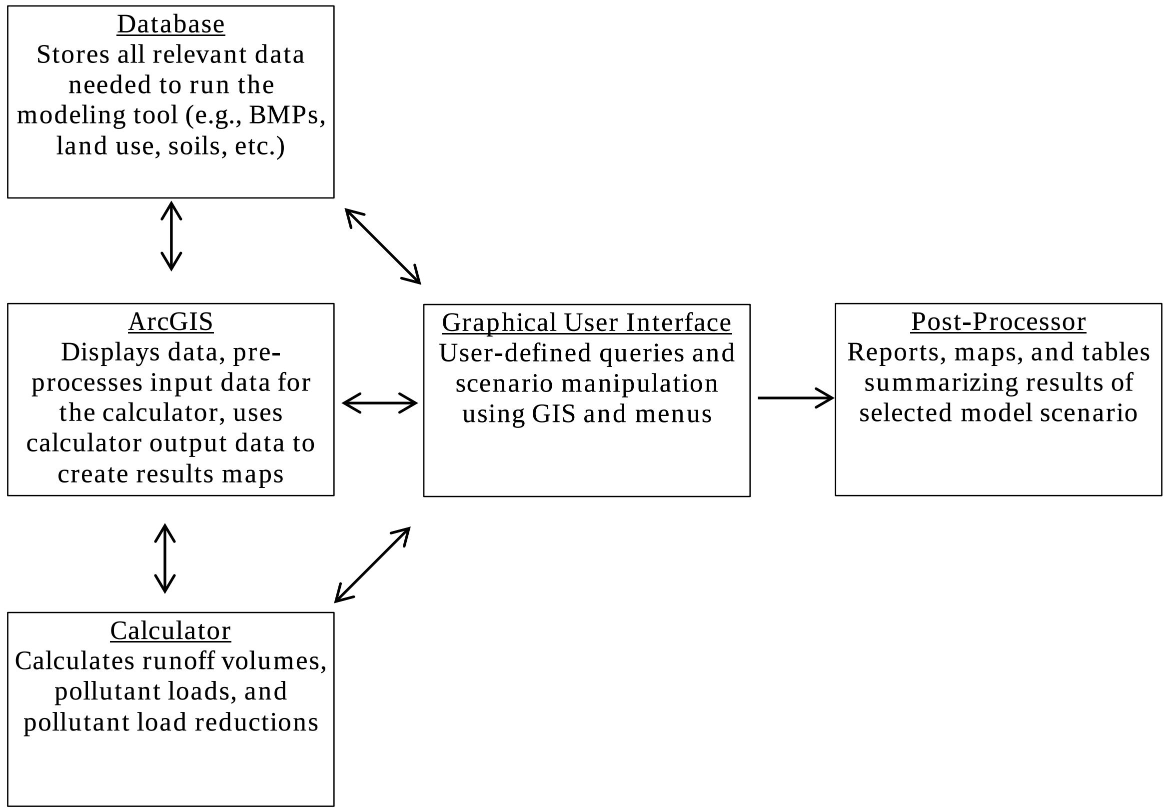

Figure 2: Model Framework Diagram

3.4 **Model Selection and Justification**

Based upon extensive review and comparison with regard to model needs, including evaluation of the models used in the original TMDLs and the calculators reviewed, the Modified Version of the **Simple Method** was selected as the calculator of choice in the IP Modeling Tool. The original Simple Method was developed at the Metropolitan Washington Council of Governments by Schueler (1987) using local (metropolitan Washington area) stormwater data collected under EPA's Nationwide Urban Runoff Program, or NURP. The Simple Method is a lumped-parameter empirical model used to estimate stormwater pollutant loadings under conditions of limited data availability (EPA, 2008). Because it is a lumped approach, it assumes the physical characteristics for land units within a subwatershed are homogeneous, thereby simplifying the physical representation of the subwatershed.

The Modified Version of the Simple Method was developed by the Center for Watershed Protection (CWP) and the Chesapeake Stormwater Network (CSN) in order to specifically incorporate the runoff characteristics of turf and forest cover as well as hydrologic soil groups into the modeling (CWP and CSN, 2008). This model is very well suited to calculate annual or seasonal runoff volumes and loads in urbanized areas and small watersheds. It also accommodates the calculation of daily values associated with a particular rainfall amount or design storm.

Many states, including Maryland, Virginia, New York and New Hampshire, recommend use of the Simple Method or the Modified Version of the Simple Method for stormwater management purposes. In his review and comparison of simple and complex pollutant load models, Ohrel (1996) found strong agreement in comparisons of annual stormwater nutrient loads between the Simple Method and the HSPF model, which remains the basic core of the Chesapeake Bay Watershed Model.

The key reasons for selection of the Modified Version of the Simple Method include:

- Appropriate for assessing and comparing relative stormflow pollutant load changes of different land use and stormwater management scenarios. Provides a general planning estimate of likely storm pollutant export from areas at the scale of a catchment or subwatershed (SMRC, date unknown)
- Appropriate for the limited data available to characterize the MS4 area. Available data includes land use, landcover, soil type, precipitation, and wet-weather water quality data. The lack of monitored MS4 flow data precludes the use of more complex continuous simulation models such as SWMM or HSPF that require detailed flow data for calibration purposes.
- Simple approach but reasonably accurate and widely applied regionally as well as across the United States
- Endorsed for use to address load allocations under the Chesapeake Bay TMDL (CSN, 2011)
- Amongst the set of models applied to generate stormwater loads and in particular LAs in several of the TMDL studies.
- Can easily be transferred to DDOE without licensing issues or requirement for extensive knowledge of model operations.
- Does not require a much time to set up and run, so aligns with the tight deadline for delivering the Consolidated TMDL IP.

3.5 **Model Description and Required Inputs**

The Modified Version of the Simple Method estimates stormwater runoff volume and pollutant loads for urban areas and is described by the following two equations:

$$R = \frac{P \ x \ P_j \ x \ R_{vc}}{12} \times A \qquad (1)$$

$$L = R \times C \times 2.72 \qquad (2)$$

Where:

R = Runoff volume, typically expressed in acre-feet

P = Precipitation, typically expressed in inches

P_j = Precipitation correction factor

R_{vc} = Composite runoff coefficient

A = Area of the catchment, typically expressed in acres

L = pollutant load, typically expressed in pounds

C = Flow-weighted mean pollutant concentration, typically expressed in mg/l

12 and *2.72* are unit conversion factors if the units used are inches for precipitation, acres for area, and mg/l for the pollutant concentration.

The model inputs are explained in further detail below.

3.5.a Precipitation (P)

The precipitation values applied in the Modified Version of the Simple Method are typically annual values, but could also be seasonal (e.g., growing season). Official rainfall and other meteorological records for

Washington, DC are observed at Ronald Reagan National Airport (DCA) by the National Weather Service, and recorded by the National Climate Data Center (NCDC, 2014). Observations at DCA have been kept continuously since 1948. The airport is located on the Virginia (western) bank of the Potomac River, approximately 3 miles south of the White House and downtown Washington, DC, and adjacent to the confluence of the Potomac and Anacostia Rivers. Continuous records of hourly and daily rainfall amounts are available in electronic format from the NCDC from 1948 to the present.

A variety of rainfall conditions were used to drive the development of the DC TMDLs. These included:

- 1985 to 1994
- 1988 to 1990
- 1991 to 2002
- 1995 to 1997
- 1994 to 2005

The use of different time periods for assessing runoff and pollutant loads was necessary because these distinct rainfall periods were identified for specific planning needs (e.g., DC Water's CSO LTCP, Chesapeake Bay Program modeling, etc.).

Most TMDL WLAs were typically developed using either daily rainfall data from 1988-1990 or from 1995-1997. Those time periods include three years each, and each year represents either a typical "dry" year, a typical "wet" year, or a typical "average" year. These three representative years are used to determine pollutant loads under a variety of rainfall conditions in the District, to better represent the range of annual predicted loads. Figure 3 shows the annual rainfall depths at the DCA gage over the entire period of record (1948-2013). The green columns show the rainfall data for 1988 through 1990 whereas the orange columns show the rainfall data for 1995 through 1997.

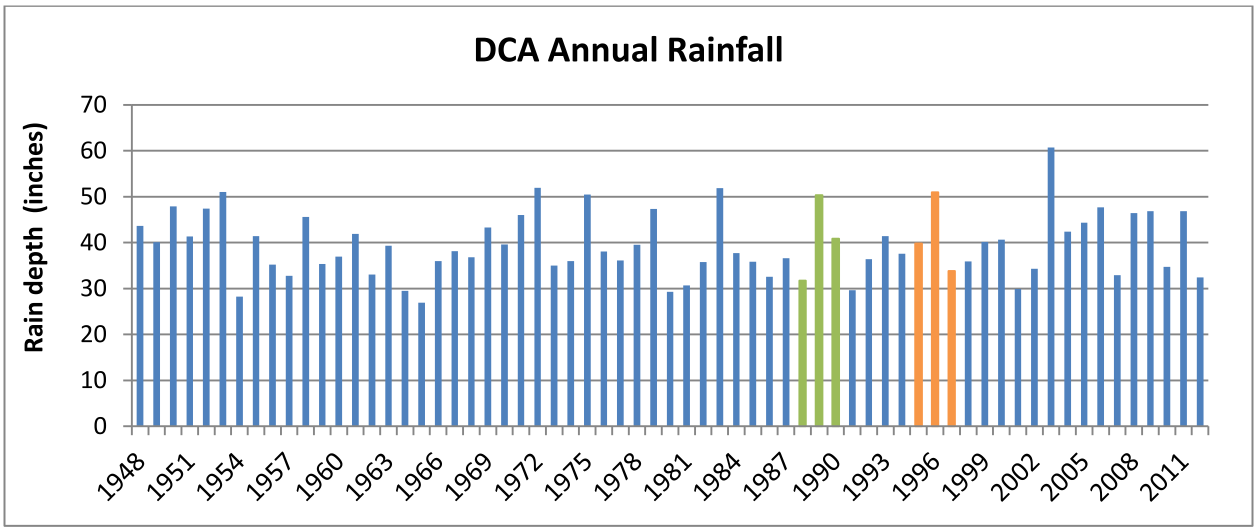

Figure 3: DCA Annual Rainfall

A statistical analysis over the entire period of record was conducted to define the typical dry, average, and wet year. A typical dry year is determined as the average of the lower quartile of the entire record of precipitation, a typical average year is the average of second and third quartiles of the entire record of precipitation, and a typical wet year is the average of the upper quartile of the entire record of precipitation. The quartiles are shown in Table 4.

Table 4: Results of Statistical Analysis of Precipitation Data at DCA, 1948-2013	
Quartile 1	< 35.0 inches
Quartile 2	35.0 - 38.8 inches
Quartile 3	38.8 - 44.3 inches
Quartile 4	> 44.3 inches

Table 5 summarizes the precipitation information for the long term record.

Table 5: Typical Precipitation Depths (inches) at DCA	
	1948-2013
Typical “Dry” Year	31.6”
Typical “Average” Year	39.6”
Typical “Wet” Year	49.0”
Average over entire time period (1948-2013)	40.0”

For the purposes of the application of the Simple Method, the long term record (1948-2013) annual average rainfall depth (40.0 inches) will be used to calculate the average runoff and pollutant loads.

The use of alternative annual rainfall amounts to assess different planning conditions or global climate change is accommodated in the Modified Version of the Simple Method by simple replacement of rainfall depth in the runoff equation.

A small set of TMDLs in the District have a “daily load expression” to represent a critical condition that is protective of water quality on a daily basis (as opposed to an annual basis). The daily expression of load is often derived from an annual dataset (time series) of daily loads, with each day associated with a particular rainfall amount. To express annual loads into daily loads, the ratio of the daily WLA to the annual WLA was applied to the annual load calculations. This is represented in the equation below.

$$Daily\ Load = Annual\ Load \times \frac{Daily\ WLA}{Annual\ WLA}$$

This approach will be applied as the District goes through the process to develop additional daily load expressions for TMDLs that do not currently have daily expressions.

3.5.b Correction factor (P_j)

The Pj factor is used to account for the fraction of the annual rainfall that does not produce any measurable runoff. Many of the storms that occur during the year are so minor that all of the rainfall is stored in surface depressions and eventually evaporates. As a consequence, no runoff is produced. An analysis conducted by the Maryland Department of the Environment of regional rainfall/runoff patterns indicates that only 90% of the annual rainfall volume produces any runoff at all (MDE, 2003). Therefore, Pj is set at 0.9. This is also the standard value recommended in the Modified Version of the Simple Method model documentation (CSN, 2008).

3.5.c Runoff coefficient (R_{vc})

The runoff coefficient is a measure of the site’s likelihood of producing runoff. A site with a high degree of imperviousness will produce more runoff compared to a site that is pervious (e.g., forested land). The runoff coefficient is calculated for each site using information to represent the site’s soil type and land cover. The equation for the composite runoff coefficient is as follows:

$$R_{vc} = A_i * R_{vi} + A_{tA} * R_{vtA} + A_{tB} * R_{vtB} + A_{tC} * R_{vtC} + A_{tD} * R_{vtD} + A_{fA} * R_{vfA} + A_{fB} * R_{vfB} + A_{fC} * R_{vfC} + A_{fD} * R_{vfD}$$

Where:

R_{vi} = runoff coefficient, impervious cover	A_i = Impervious Area
R_{vtA} = runoff coefficient, turf cover, HSG A	A_{tA} = Turf area, HSG A
R_{vtB} = runoff coefficient, turf cover, HSG B	A_{tB} = Turf area, HSG B
R_{vtC} = runoff coefficient, turf cover, HSG C	A_{tC} = Turf area, HSG C
R_{vtD} = runoff coefficient, turf cover, HSG D	A_{tD} = Turf area, HSG D
R_{vfA} = runoff coefficient, forest cover, HSG A	A_{fA} = Forested area, HSG A
R_{vfB} = runoff coefficient, forest cover, HSG B	A_{fB} = Forested area, HSG B
R_{vfC} = runoff coefficient, forest cover, HSG C	A_{fC} = Forested area, HSG C
R_{vfD} = runoff coefficient, forest cover, HSG D	A_{fD} = Forested area, HSG D

Representations of impervious, turf, and forested cover, as well as soil type, are available from GIS layers published by the DC Office of the Chief Technology Officer (OCTO) as follows:

- The impervious area is a layer from DC OCTO (known as "ImperviousSurfacePly") and includes roads, driveways, alleys, highways, rooftops, parking lots, sidewalks, and any other impervious cover.
- The forested area is a layer from DC OCTO (known as "Wooded Area"). This layer includes parks, protected easements, conservation areas, and other wooded areas.
- The turf area was created for use in the IP Modeling Tool. Any area not included in DC OCTO's impervious or wooded layer was considered to be turf area. Turf is considered to be open land with no impervious surface. This area includes fields, yards, grassed areas, and rights-of-way.
- The soil type is a layer from DC OCTO (known as "SoilPly"), although the original source behind this layer is actually the Soil Survey Geography (SSURGO) database. Additional information on how to assign the hydrologic soil group was obtained from the USDA NRCS.

As described in the beginning of this Section, the runoff coefficients used in the Modified Version of the Simple Method differ from those used in the standard Simple Method. The runoff coefficients for the Modified Version of the Simple Method are published through the Chesapeake Stormwater Network (CSN, 2008) and are shown in Table 7.

Table 6: Reference Runoff Coefficients from Schueler (1987)

	Impervious	Turf	Forest
HSG A Soils	0.95	0.15	0.02
HSG B Soils	0.95	0.20	0.03
HSG C Soils	0.95	0.22	0.04
HSG D Soils	0.95	0.25	0.05

The composite runoff coefficients for each area modeled are developed based on weighting the relative presence of each soil and land cover type, and the appropriate runoff coefficient. In the MS4 area, the runoff coefficients for the TMDL waterbodies range from 0.43 to 0.86. In the direct drainage areas, which are predominantly parkland areas, the runoff coefficients for the TMDL waterbodies range from 0.06 to 0.47.

3.5.d Area (A)

Drainage area in the Modified Version of the Simple Method describes the physical extent of the sewershed or watershed included in the runoff and pollutant load calculation. For the purposes of this Baseline Conditions Report, the applicable areas are the MS4 and direct drainage areas that are assigned WLAs or LAs in the TMDL studies. The delineation of drainage areas was largely based on DC OCTO GIS coverages (topography and stream-lines) and a DC Water geodatabase that includes sewer pipes and outfalls. Instead of using automated Digital Elevation Model (DEM) techniques, delineation was done manually in order to account for the complexities of delineation in an urban landscape. Other GIS coverages and aerial imagery were used where needed to support delineation. A full description of this delineation can be found in Appendix B: *Technical Memorandum: Sewershed and Watershed Delineations*.

The Modified Version of the Simple Method model limitations state that the model was designed for use on the level of a subwatershed or smaller. It should be noted that 19 out of the 43 TMDL water segments are larger than the recommended size. These include all of the mainstem reaches and some of the larger tributary areas. However, these larger areas will be subdivided into smaller catchments with areas that are commensurate with the recommendations of the Modified Version of the Simple Method. Loads from these smaller areas will be summed by TMDL waterbody for reporting purposes and to compare to the TMDL waterbody WLA.

3.5.e Flow-weighted mean pollutant concentration (C)

EMCs are used in conjunction with runoff calculations to develop pollutant load estimates. Several parallel lines of investigation were used to identify the appropriate set of EMCs to support application of the IP Modeling Tool. These included:

- A review of the EMCs used to develop TMDLs in the District.
- A review of EMCs reported in literature for various land use classes.
- An evaluation of District MS4 monitoring data to develop District-specific EMCs.

The full report on the investigation of EMCs can be found in Appendix D, *Technical Memorandum: Selection of Event Mean Concentrations (EMCs)*.

3.6 **Model Comparisons**

The Modified Version of the Simple Method has been used widely across the region and nationally, and is generally regarded as a model that can simulate runoff volumes and pollutant loads to an acceptable degree of confidence. To provide an additional level of comfort with selecting and applying the Modified Version of the Simple Method, model results were compared to storm flows measured by USGS gages in the Washington, DC area. Modeled runoff volumes were also compared to those calculated during the development of various TMDLs that used more complex models such as HSPF and the LTCP model.

The full methodology and results of the model comparisons process are explained in Attachment A.3. The results comparisons show that:

- The Modified Version of the Simple Method, on average, overestimates the runoff volumes compared to wet-weather flows measured by in-stream gages. In this sense, the Modified Version of the Simple Method provides a conservative estimate of the total runoff volume.

- In general, the Modified Version of the Simple Method can replicate runoff volumes better when the contributing drainage area is smaller and easier to characterize. This is consistent with the known limitations of the Modified Version of the Simple Method, as further explained in section 3.7.

This additional comparison step provides the necessary degree of confidence to use the Modified Version of the Simple Method for the runoff volume and load calculations in the IP Modeling Tool.

3.7 Model Limitations

The Modified Version of the Simple Method has several limitations that must be considered when the model is applied (SMRC, date unknown). These include:

- The Modified Version of the Simple Method provides estimates of storm pollutant export that are expected to be probably close to the "true" but unknown value for the site of interest. It is important that the precision of the results are not overemphasized.
- Because the precision of results should not be overemphasized, it would be inappropriate to compare runoff or pollutant loads from relatively similar development scenarios (e.g.: 34% vs 36% impervious cover) using the Modified Version of the Simple Method.
- The Modified Version of the Simple Method works best at the level of development sites, catchments, or subwatersheds. It becomes less reliable when the area exceeds 1 square mile. As the area of interest gets larger, the physical characteristics and rainfall distributions becomes less homogeneous, and the Modified Version of the Simple Method's "lumped approach" becomes less reliable.
- The Modified Version of the Simple Method, by virtue of both its lumped approach and use of more current datasets to describe the TMDL areas (e.g., delineations, watershed-based EMCs, etc.), will not reproduce the pollutant loads generated by the models used to develop the TMDL.

4. Results and Discussion

One of the main objectives of the Consolidated TMDL Implementation Plan is to determine the extent of BMP implementation necessary in order to achieve the WLAs prescribed by each TMDL. In order to do so, a modeling tool is needed to determine the baseline (no BMPs), existing (with current BMPs), and future loads (with additional BMP implementation). Section 3 discusses the technical approach used to select the Modified Version of the Simple Method as the model of choice to calculate the runoff and pollutant loads. As noted throughout the document, the Modified Version of the Simple Method has been used extensively throughout the region to assess the impact of various management strategies such as BMP implementation to reduce pollutant loads. The Modified Version of the Simple Method is easy to apply, requires limited data, and yet can predict pollutant loads with reasonable accuracy. The ease with which the Modified Version of the Simple Method can be applied makes it an ideal model to simulate and screen the multitude of predicted management scenarios.

As part of this project, predictions by the Modified Version of the Simple Method were compared with wet-weather data from USGS gages and with runoff volume results predicted by a few of the more complex models that were used to develop the TMDLs. This evaluation demonstrated that the Modified Version of the Simple Method is conservative in terms of the runoff volumes predicted, but predicts flows more closely in areas that are smaller in size and possess good land use/land cover data to characterize the drainage area.

It should be noted that the Modified Version of the Simple Method will not reproduce the original TMDL loads that were developed with other models. It is not the intent of the IP Modeling Tool to provide a precise reproduction of TMDL results. Rather, the intent is to provide a modeling tool that can be used as a planning tool by DDOE to estimate in a reasonable way the expected load reductions from BMP implementation and assess whether WLAs have been met.

The Modified Version of the Simple Method model limitations state that the model was designed for use on the level of a subwatershed or smaller. It should be noted that 19 out of the 43 TMDL water segments are larger than the recommended size. These include all of the mainstem reaches and some of the larger tributary areas. However, the assessment of BMP implementation will be done on a smaller catchment level, commensurate with the recommended area noted by the Modified Version of the Simple Method. Loads from these smaller areas will continue to be summed by TMDL waterbody for reporting purposes and to compare to the TMDL waterbody WLA.

Another limitation of the Modified Version of the Simple Method is that it should not be used to assess conditions that are very similar to each other (e.g.: assess the change in loads from at 34% impervious cover to a 36% impervious cover). This limitation should not be an issue for the IP Modeling Tool since the predicted management scenarios will likely be very different from the baseline and current conditions, especially with a time horizon that may potentially project decades into the future.

Given the careful review and assessment of both its advantages and disadvantages, it is recommended that the Modified Version of the Simple Method be used to calculate the runoff volume and pollutant load for the IP Modeling Tool.

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TABLE OF CONTENTS

Attachment 1: DC TMDL Modeling Approach for Mainstems and Tributaries ... A1-1

Figure 1: Main Categories of District TMDL Waterbodies ... A1-2

Table 1: Modeling Approach used in Mainstem Waterbodies for MS4 Areas ... A1-4

Table 2: Models used in Anacostia Mainstem TMDLs ... A1-5

Table 3: Sub-Drainage Areas used in Anacostia TAM Model ... A1-7

Table 4: TAM/WASP based TMDL MS4 Load Assignments ... A1-9

Table 5: Tributary TMDLs ... A1-13

Table 6: Tributaries in DCST Model ... A1-14

Table 7: Other Waterbodies TMDLs ... A1-16

Table 8: Drainage Area Descriptions ... A1-16

Attachment 2: Review of Publically Available Calculator Tools to Estimate Pollutant Loads ... A2-1

Table 1: Review of Publically Available Calculator Tools ... A2-2

Table 1: Review of Publically Available Calculator Tools (continued) ... A2-3

Table 1: Review of Publically Available Calculator Tools (continued) ... A2-4

Table 1: Review of Publically Available Calculator Tools (continued) ... A2-5

Attachment 3: Comparison of the Modified Version of the Simple Method to USGS Gage Data and Models Used in DC TMDL Development ... A3-1

Figure 1: Location of USGS gages used for comparison of runoff volumes ... A3-2

Figure 2: USGS HYSEP Local Minimum Method (USGS 1996) ... A3-3

Table 1: Comparison of Hickey Run Gaged and Simple Method Runoff Volumes ... A3-4

Figure 3: Comparison of Hickey Run Gaged and Simple Method Runoff Volumes ... A3-5

Table 2: Comparison of Watts Branch Gaged and Simple Method Runoff Volumes ... A3-5

Figure 4: Comparison of Watts Branch Gaged and Simple Method Runoff Volumes ... A3-6

Table 3: Comparison of Sligo Creek Gaged and Simple Method Runoff Volumes ... A3-7

Figure 5: Comparison of Sligo Creek Gaged and Simple Method Runoff Volumes ... A3-7

Table 4: Comparison of Four Mile Run Gaged and Simple Method Runoff Volumes ... A3-8

Figure 6: Comparison of Four Mile Run Gaged and Simple Method Runoff Volumes A3-9

Table 5: Results of Comparison Between the DCSTM model and the Modified Version of the Simple Method A3-10

Table 6: Results of Comparison Between the DCSTM model and the Modified Version of the Simple Method A3-10

Attachment 1: DC TMDL Modeling Approach for Mainstems and Tributaries

The District of Columbia (District) has completed 26 TMDL studies for various 303(d) impaired waterbodies. TMDL studies typically consist of multiple related individual TMDLs, such as TMDLs for related pollutants in a single waterbody (e.g., TMDLs for multiple different metals in a waterbody) or TMDLs for related waterbodies (e.g., a TMDL for a specific pollutant for a mainstem waterbody and its tributaries). The 26 TMDL studies vary in complexity with respect to both the modeling performed to establish loads and also in the assignment of MS4 Wasteload Allocations (WLAs). This memorandum provides an overview of the modeling approaches used in the TMDL studies. It summarizes the key differences between the various TMDL models with respect to how loads are developed and describes how the MS4 WLAs are calculated and expressed for each TMDL. The memorandum also summarizes the information used to delineate the MS4 drainage areas and describes the data and methods used to compute runoff from these areas, because this information is integral to the modeling of MS4 loads.

One of the primary goals of the memo is to evaluate the TMDL modeling to determine whether the MS4 WLAs for mainstems include or exclude the tributary areas. This has very important ramifications for TMDL implementation, because if the mainstem WLAs include the tributary areas, then any load reduction achieved in the tributary areas can be applied to the load reduction needed to meet the mainstem WLA, as well as towards meeting any load reductions needed to meet a tributary WLA. In contrast, if the mainstem WLAs do not include the tributary areas, then any work done in the tributaries can only be applied to meeting the load reductions required in the tributaries, but not towards any load reductions required in the mainstem.

For the purpose of this memorandum, the waterbodies in the District are divided into three broad categories: mainstem waterbodies; tributary waterbodies; and 'other waterbodies' that are connected to a mainstem but are not tributaries, such as the Tidal Basin. This division helps to explain the structure of the TMDL modeling in the District and the relationships of specific waterbody MS4 WLAs to each other (i.e., the relationship of MS4 WLAs for tributaries to MS4 WLAs for mainstems). Generally for the mainstem waterbodies, such as the Potomac River or Anacostia River, the TMDL studies use multiple numerical models. Typically, one model simulates the in-stream processes while other models simulate the runoff and loads to the stream from different sources. This contrasts with modeling done for the tributary waterbodies, where typically only one model is used to simulate runoff and loads, and no in-stream processes are modeled (fully mixed conditions assumed in the receiving water).

Because this memorandum specifically addresses the models used to establish MS4 loads and how they are incorporated within a watebody's TMDL, any TMDL-related models that are not used to generate MS4 loads (i.e., the models used to evaluate in-stream conditions for the mainstems) are discussed only as necessary to understand the MS4 load models.

Of the 26 TMDL studies, all except the Chesapeake Bay TMDL (2010) (the Bay TMDL) are reviewed in this memorandum. The Bay TMDL modeling was not reviewed because the MS4 WLAs stemming from the Bay TMDL are applied at a large scale (the Bay segment-shed scale) and there are no questions about whether these WLAs include or exclude certain tributary areas, as they are for the other TMDLs in the District.

District Waterbody Characterization for TMDL Modeling

As described above, there are three major types of waterbodies in the District: mainstem waterbodies; tributary waterbodies; and other waterbodies that are connected to a mainstem but are not tributaries, such as the Tidal Basin (see Figure 1). The following sections describe each waterbody type and provide some basic information on how impairments are assessed for each class of waterbody, and how the waterbodies are modeled and MS4 WLAs are assigned. More specific information on the methods for modeling each type of waterbody is provided in the following sections of this memo.

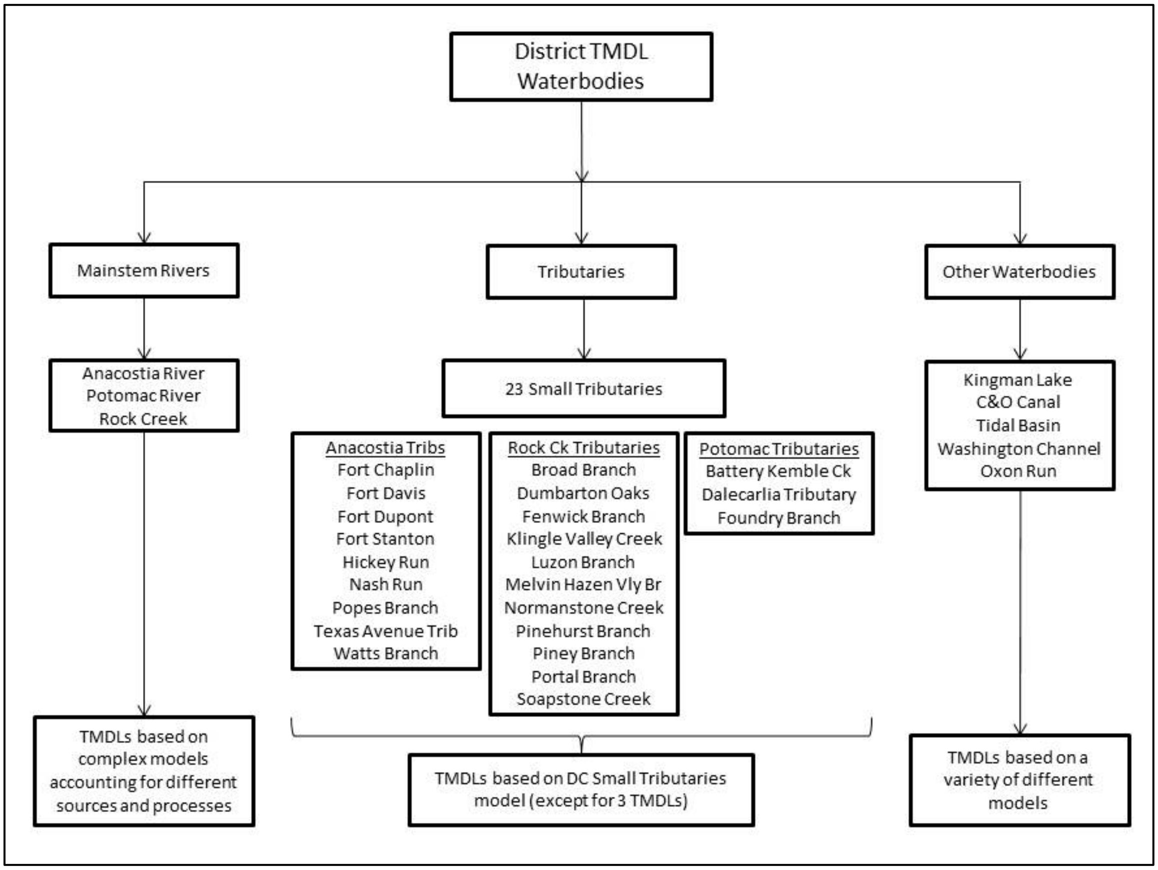

Figure 1: Main Categories of District TMDL Waterbodies

Mainstem Waterbodies and Their Representation in TMDL Modeling

Mainstem waterbodies (see Figure 1) are the large scale waterbodies in the District to which all District waters flow. There are three mainstem waterbodies in the District: the Potomac and Anacostia Rivers and Rock Creek, each of which also have tributaries. All three mainstems are modeled in much more detail than their tributaries, primarily because significantly more monitoring data is available on the mainstems than on the tributaries.

With respect to TMDLs, mainstems and their tributaries are assessed for impairments separately and any impairment listings for the mainstems and the tributaries are therefore independent of each other. In addition, depending on how the mainstem TMDL is developed, TMDLs assigned to a mainstem may or may not include the tributary area loads. This can cause confusion with respect to where the TMDLs apply within the mainstem watershed (i.e., do mainstem MS4 WLAs apply to the entire mainstem MS4 area or only to the MS4 area that drains directly to the mainstem and not any areas that drain to the mainstem from its tributaries). Therefore, much of the mainstem modeling evaluation was focused on resolving this issue for each mainstem TMDL.

All mainstem TMDL models establish the overall contributing drainage area to the portion of the mainstem that is within the District boundaries. These areas are further delineated into "sub-drainage areas" based on locations of the tributaries and major pipe outfalls. The sub-drainage areas include both tributary watersheds (drainage areas of tributaries to the mainstem) and sewersheds (drainage areas of separate storm [MS4] or combined sewer [CSO] systems that do not involve tributaries). When sub-drainage areas extend significantly beyond the District boundaries, as in Watts Branch drainage area, the ratio of drainage area in the District is used to calculate the District contribution of the total sub-drainage area load. In addition to these sub-drainage areas, all mainstems also receive direct overland runoff (direct drainage), which is delineated as a separate sub-drainage area. Together, the tributary, sewershed, and direct drainage sub-drainage areas make up the total drainage area from the District to the mainstem.

Mainstem input flows used in the TMDL models include upstream flows delivered to the upstream District boundary, sewershed flows (both MS4 and CSO), tributary flows, point source discharges (e.g., wastewater treatment plants), and direct drainage flows. While all mainstem TMDLs account for these flows (to the extent that each type of flow occurs to that mainstem) and resulting pollutant loads, there are differences in how MS4 flows are represented for different mainstem TMDLs. The complex drainage pattern of the mainstem waterbodies, in general, complicates how the MS4 drainage areas and loads are represented in their TMDLs. Many mainstem TMDLs aggregate the MS4 loads from small tributaries along with the MS4 loads discharged directly to the mainstem (sewershed loads) and use these loads to calculate an aggregated MS4 WLA that encompasses both the smaller tributaries and non-tributary sewershed areas, but others separate out the small tributary loads and assign the mainstem MS4 WLA only to the non-tributary sewershed areas. While this methodology of generating an aggregated MS4 WLA on the mainstem applies to the small tributary flow and load contributions, individual allocations are typically generated for larger tributaries (such as Watts Branch on the Anacostia River or Rock Creek on the Potomac River). Because these types of diverse drainage inputs do not exist for the tributary and the other waterbody categories, these types of flow and allocation differentiations do not occur for these waterbodies.

Tributary Waterbodies and Their Representation in TMDL Modeling

Tributary waterbodies are the smaller waterbodies in the District that flow to a mainstem waterbody. Thus, all tributary drainage areas are included within the drainage area of their mainstem river. For the District's TMDLs, modeling approaches used in the tributaries are independent of the mainstem modeling. Thus in cases where a mainstem TMDL exists for the same pollutant as does a tributary TMDL, MS4 WLAs calculated for the tributaries are separate and independent of the MS4 WLAs calculated for the respective mainstem waterbody. In most cases the tributaries are modeled using the DC Small Tributaries model (see Figure 1), which is explained in more detail in a subsequent section of this memorandum.

Other Waterbodies and Their Representation in TMDL Modeling

There are several other small waterbodies in the District which do not fall into the tributaries category. These waterbodies are:

- Tidal Basin and Ship Channel – Part of the Potomac River watershed that acts as a parallel channel and is contained entirely within the District.
- Kingman Lake – Part of the Anacostia River watershed. It is part of a parallel channel to the river and is contained entirely within the District.
- Oxon Run – A tributary of Potomac River that has a majority of its watershed and its confluence in Maryland.

- Chesapeake and Ohio Canal – Part of the Potomac River watershed that acts as a parallel channel and extends upstream beyond the District border.

With the exception of Oxon Run, the waterbodies noted above fall within the District's portion of their mainstem drainage areas, and load contributions from these waterbodies are accounted for in the mainstem loads for the District. In contrast, Oxon Run load contributions are not accounted as District loads in the mainstem Potomac River TMDLs. Since Oxon Run has its confluence with the Potomac River in Maryland, and since only approximately a quarter of its drainage area is within the District, Oxon Run loads are either entirely allocated to Maryland (e.g., Potomac River Bacteria TMDL) or are simply allocated as a separate MS4 WLA (e.g., Potomac and Anacostia PCB TMDL). In the latter case, the TMDL notes that the waterbody is in both Maryland and the District without assigning specific load numbers to either jurisdiction (Note: the discussion above relates only to how Oxon Run flows and loads are handled in the mainstem Potomac TMDLs; the District's portion of Oxon Run also has its own TMDLs for which the District is responsible).

Different TMDL models are used to calculate the loads for these "other waterbodies." Only the Kingman Lake TMDLs use a model that is derived from its mainstem TMDL model. The other three waterbodies are modeled using different TMDL models that are unrelated to their mainstem models. However, all of the models used to model these "other waterbodies" are simpler than the mainstem models.

TMDL Modeling

The waterbody categorization described above helps to elucidate how TMDLs are done and how allocations are made for the different waterbodies in the District. While review of the relationship between mainstem and tributary and other waterbody models demonstrates that mainstem MS4 WLAs are exclusive of the MS4 WLAs for the tributaries and the other waterbodies, the question of whether the mainstem MS4 WLAs include or exclude the tributary and other waterbody areas is not directly answered by this evaluation. In order to answer this question, the actual TMDL modeling must be reviewed. The following sections explain in more detail how the different TMDL models assign MS4 drainage areas, describe the data and models used to generate loads, and discuss how MS4 WLAs are calculated and presented for each of the mainstem, tributary and other waterbody TMDLs.

Mainstem TMDL Models

There are 12 TMDL studies for the mainstem waterbodies in the District. Table 1 below shows the list of TMDL studies for mainstem waterbodies and the main modeling approach used to calculate runoff from the respective MS4 drainage areas in each study.

Table 1: Modeling Approach used in Mainstem Waterbodies for MS4 Areas

TMDL Study	Mainstem Waterbody	Hydrologic Model for District MS4 Runoff	Source of MS4 Drainage Area used in TMDL
Anacostia BOD - 2001	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia TSS – 2002	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia & Tributaries Bacteria - 2003	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia & Tributaries Metals/ Organics –2003	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia Oil & Grease - 2003	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia TSS – 2007	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Table 1: Modeling Approach used in Mainstem Waterbodies for MS4 Areas			
TMDL Study	**Mainstem Waterbody**	**Hydrologic Model for District MS4 Runoff**	**Source of MS4 Drainage Area used in TMDL**
Anacostia Nutrients/BOD – 2008	Anacostia River	Watts Branch HSPF	MWCOG sub-shed delineations
Anacostia Trash - 2010	Anacostia River	None (monitoring data used)	2005 land use data used
Potomac and Anacostia Tidal PCB - 2007	Potomac and Anacostia River	Not reviewed in full	Not reviewed in full
Rock Creek Metals -2004	Rock Creek	LTCP land model using DHI's MOUSE	LTCP sewershed delineations
Rock Creek Bacteria -2004	Rock Creek	LTCP land model using DHI's MOUSE	LTCP sewershed delineations
Potomac & Tributaries Bacteria -2004	Potomac River	LTCP land model using DHI's MOUSE	LTCP sewershed delineations

The sections below describe more specifically the modeling done for each mainstem waterbody.

Anacostia Mainstem

District TMDL models for the Anacostia River are set up for the entire tidal portion of the river, which extends upstream from the District border to the Town of Bladensburg in Maryland. While tidal influence extends into the Northeast and Northwest Branches upstream of the District boundary, the modeling done for the District TMDLs generally assumes the confluence of the branches as the limit of tidal influence. Therefore, the Anacostia River reach modeled for the District TMDLs extends from its mouth at the Potomac River to the confluence of the Northeast and Northwest branches. Approximately 84% of the drainage area to the tidal reach is within the District, with the remainder falling within Maryland.

A total of nine TMDL studies have been completed to date for the mainstem Anacostia River in the District. Of these, seven TMDL studies use versions of an MWCOG model called Tidal Anacostia Model/Water Analysis Simulation Program (TAM/WASP) that has been revised by ICPRB and others; one TMDL study uses the Chesapeake Watershed Model; and one TMDL study does not use a numerical model. Table 2 below outlines the different TMDL models used in these studies and the drainage areas of the mainstem used in each model.

Table 2: Models used in Anacostia Mainstem TMDLs		
TMDLs	**Mainstem Model**	**Tidal Drainage Area, excluding CSO, and major tributaries (Lower Beaverdam Creek & Watts Branch)**
Anacostia BOD - 2001	TAM/WASP (simulation period 1988-1990)	No drainage area or runoff provided
Anacostia TSS – 2002, Anacostia and Tributaries Bacteria - 2003	TAM/WASP Version 2.1 (simulation period 1988-1990)	10,501 ac (runoff = 20,952,000 cu. m)
Anacostia and Tributaries Metals & Organics – 2003 Anacostia Oil & Grease - 2003	TAM/WASP Version 2.3 (simulation period 1988-1990)	10,501 ac (runoff = 20,952,000 cu. m)

Table 2: Models used in Anacostia Mainstem TMDLs		
TMDLs	**Mainstem Model**	**Tidal Drainage Area, excluding CSO, and major tributaries (Lower Beaverdam Creek & Watts Branch)**
Anacostia Sediment/TSS – 2007 Anacostia Nutrients/BOD – 2008	TAM/WASP Version 3 (simulation period 1995-1997)	12,375 ac (runoff not provided)
Potomac and Anacostia Tidal PCB - 2007	Chesapeake Bay Watershed Model Version 5 (simulation period 2005)	No drainage area or runoff provided
Anacostia Trash - 2010	No Numerical model	No drainage area or runoff provided

As noted above, with the exception of the Potomac and Anacostia PCB TMDL and the Anacostia Trash TMDL, most mainstem Anacostia TMDLs use some version of the TAM/WASP framework. In contrast, the Potomac and Anacostia PCB TMDL was developed for both the tidal Potomac River and the Anacostia River and the documentation in the TMDL is limited in how the drainage area delineation was performed for the mainstem waterbodies. The model used in this TMDL is therefore not reviewed further here. The Trash TMDL does not use a numerical model to establish loads on the Anacostia River. It is based on monitoring data and 2005 land use data and uses this information to establish an annual trash loading rate for each land use type. MS4 pipe outfall monitoring data was used to calculate the point source loads and in stream monitoring data was used to calculate the non-point source loads.

Drainage Areas, Flow Estimates, and Allocation Development in the TAM/WASP Models

The TAM/WASP models are complex models that simulate an array of physical processes that occur in the tidal Anacostia River. The TAM framework simulates the hydrodynamic processes and the WASP framework models the water quality processes. The TAM/WASP models were reviewed in this memorandum only as far as determining how the input loads are allocated towards the District MS4 load contributions.

While there are some differences in how the different TAM model versions assign flows, in general, they include input flows and loads to the tidal Anacostia River from the following sources:

- Upstream flow from the Northeast and Northwest Branches
- Combined sewer system flows (all CSOs are in DC)
- Major tributary flows
    - Lower Beaverdam Creek (LBC)
    - Watts Branch
- Separate sewer system flows and minor tributary flows
- Direct drainage (overland direct runoff)

Based on the above categorization of input flows/loads, all tributaries of the tidal Anacostia River except for Watts Branch and Lower Beaverdam Creek are classified as “minor.” Watts Branch and Lower Beaverdam Creek are considered major tributaries and are modeled using different methods from those used on the minor tributaries. The input flows and loads for separate sewer system and minor tributaries, CSO, and direct drainage are developed from sub-drainage area delineations performed for the tidal Anacostia River. The TAM models refer to the separate sewer system and minor tributary sub-drainage areas as “SSTrib” areas and this abbreviation is used in this memorandum for brevity.

Sub-drainage areas for the SSTrib areas and CSO outfalls are based on a delineation of sub-drainage areas of the tidal drainage area developed by MWCOG in 2000. The MWCOG study refers to these areas as “sub-sheds” as they are a combination of minor tributary drainage areas (watersheds) and MS4/CSO outfall drainage areas (sewersheds). Thirty sub-drainage areas were delineated based on the major pipe outfalls and on the minor tributary confluences along the tidal Anacostia River (there are a total of 32 sub-drainage areas when the two major tributaries – Watts Branch and Lower Beaverdam Creek – are included). The identification of sub-drainage areas associated with sewer outfalls was made by ICPRB using best engineering judgment based on GIS layers for the District developed by LimnoTech in 1995 and on the DC sewerage system maps. Sub-drainage areas for minor tributaries which are piped before flowing into the Anacostia include both the upstream ("open channel") tributary drainage area and the downstream MS4 pipe drainage area. In these instances, the piped and the open channel areas of the minor tributary were aggregated into one flow input to the TAM/WASP model. This was done, in part, due to the prevalence of piped minor tributaries where the downstream pipe flow includes both the tributary flow and the storm sewer flow. Only two minor tributaries – Nash Run and Hickey Run - have open channels up to the mainstem.

Delineations of the two major tributary watersheds (Watts Branch and Lower Beaverdam Creek) were not made by MWCOG, but were instead obtained from other sources, as they have significant drainage areas in Maryland. Table 3 shows the 30 sub-sheds, plus the two major tributaries.

Table 3: Sub-Drainage Areas used in Anacostia TAM Model

Sub-shed ID	Name	Type[1]
1	Fort Lincoln	SSTrib
2	Hickey Run	SSTrib
3	Langston North	SSTrib
4	Langston South	SSTrib
5	Spingam High School	SSTrib
6	Oklahoma Avenue	SSTrib
7	RFK Stadium	SSTrib
8	NE Boundary Sewer	CSO
9	Barney Circle	CSO
10	Area North of Navy Yard	CSO
11	6th Street Area	SSTrib
12	B Street/New Jersey Avenue/Tiber Creek	CSO
13	First Street	SSTrib
14	Buzzard Point	SSTrib
15	Nash Run via Kenilworth	SSTrib
16	Watts Branch	Major Tributary
17	Clay Street	SSTrib
18	Piney Run Area	SSTrib
19	Ely's Run	SSTrib
20	Fort Dupont	SSTrib
21	Pope Branch	SSTrib
22	Texas Avenue Tributary	SSTrib
23	Pennsylvania Avenue	SSTrib
24	22nd Street Area	SSTrib

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Table 3: Sub-Drainage Areas used in Anacostia TAM Model		
Sub-shed ID	Name	Type[1]
25	Naylor Road Area	SSTrib
26	Fort Stanton	SSTrib
27	Old Anacostia	CSO
28	Suitland/Stickfoot	SSTrib
29	Poplar Point/Howard	CSO
30	I-295/St. Elizabeth's Hospital (South)	SSTrib
33	Lower Beaverdam Creek	Major Tributary
35	Dueling Creek	SSTrib

[1]SSTrib = separate storm sewer system and minor tributaries

CSO = Combined Sewer Overflow

Major Tributary – major tributaries that are designated separately from minor tributaries

In addition to the sub-drainage areas in Table 3, the area surrounding the mainstem that drains directly to the River (i.e. not via pipes or tributaries) was delineated by ICPRB as the direct drainage area. The direct drainage area flows represent the nonpoint source flows to the mainstem. For the purposes of TMDL modeling, the direct drainage area for the tidal Anacostia River extends beyond the District boundary to the Town of Bladensburg in Maryland.

Flows for the SSTrib sub-drainage areas were computed using the drainage area delineation described above and an HSPF model for Watts Branch developed by ICPRB in 2000. The Watts Branch HSPF model was originally constructed to help provide flow inputs for the Anacostia models because Watts Branch is the only stream in the District with a long term record of stream discharge. In the Watts Branch HSPF model, all land within the Watts Branch watershed is categorized into one of three land use types: Impervious, Urban Pervious, and Forested Pervious. For each land use type, the model predicts the daily flow volume per unit area of base flow and surface runoff (storm flow) during a simulation period. Because the SSTrib sub-drainage areas in Table 3 are hydrologically similar to Watts Branch, the Watts Branch model was applied to these sub-drainage areas to calculate runoff by first categorizing the land use types in the sub-drainage areas according to the Watts Branch land use types, and then by using the runoff calculations in the model.

Once flows and pollutant loads were generated for the different input sources, including the SSTrib sub-drainage areas, loads were fed into the TAM/WASP model. The output from the TAM/WASP model was then used to assign "allowable loads" for the TMDLs, and load reductions were assigned to meet water quality standards. While the individual SSTrib sub-drainage area data exist in the model documentation, the TMDLs do not typically include separate loads and load reductions for each SSTrib sub-drainage area. Rather, aggregated loads and load reductions were made for all SSTrib and all CSO sub-drainage areas. While all CSO sub-drainage areas are in the District, approximately 84.1% of the SSTrib sub-drainage areas are in the District. The remaining SSTrib areas fall within Maryland (Note: while not all SSTrib areas fall within the District, some TMDLs assign all SSTrib loads to the District [e.g., Anacostia BOD 2001], while some divide the loads between the District and Maryland [e.g., Anacostia TSS 2002].

While the above framework was used in most of the Anacostia mainstem TMDLs (the exceptions being the Potomac and Anacostia PCB TMDL and the Anacostia Trash TMDL as described in Table 2) to develop flows and load assignments for the different sources to the Anacostia River, the TMDLs differ in how the loads are allocated towards the District MS4 load contributions, and in how they refer to these loads. With respect to how MS4 loads are referenced, different TMDLs refer to the MS4 loads using different terminology, such as “Storm Water” or “Sub-watersheds”. With respect to how MS4 loads were allocated, for the most part, the year the TMDL was developed determined how the MS4 loads were assigned. Some of the earlier TMDLs did not separate out the MS4 Waste Load Allocations (WLA) from the direct drainage Load Allocations (LA) and this step was carried out by EPA in the TMDL Decision Rationale. These differences in the TMDLs add a layer of confusion to understanding how the MS4 assignments are made. Table 4 shows how MS4 loads were allocated in the various Anacostia River TMDLs that use TAM/WASP models.

Table 4: TAM/WASP based TMDL MS4 Load Assignments

TMDL	TMDL Model Anacostia Loads	MS4 load assignment in TMDL Report	MS4 Load Assignment in EPA Decision Rationale Report
BOD (2001)	- Upstream loads (assigned to Maryland; includes all of LBC load plus 53% of Watts Branch load) - DC Upper Anacostia SW (includes 47% of Watts Branch load) - DC Lower Anacostia SW - DC Lower Anacostia CSO	MS4 loads are not specifically identified in a WLA. Instead, they are included in “SW” loads for Upper and Lower Anacostia.	MS4 loads are included as “SW” for Upper and as “DC SW” for Lower Anacostia. These loads are assigned LAs. No WLAs assigned.
TSS (2002)	- Upstream loads (assigned to Maryland; includes 15.9% of the small tribs, LBC and 53% of Watts Branch) - 84.1% of Small Tributaries loads - 47% of Watts Branch loads - CSO loads	MS4 loads are not specifically identified in a WLA. Instead, they are included in the “Small Tribs” designation in the TMDL, which in turn is based on the SSTrib drainage area. The Small Tribs designation also includes the direct drainage area loads.	Loads are based on the 1989 growing season only. MS4 loads are included as part of the “SW” designation, which also includes direct drainage and is assigned a LA. No WLAs assigned.
Bacteria (2003)	- Upstream loads (assigned to Maryland; includes LBC) - Direct Storm Runoff - Tributary Storm Water - CSO	MS4 loads are included in “Tributary Storm Water” designation, which is based on the SSTrib loads.	CSO and Tributary Storm Water loads are reported as WLA and Direct Storm Runoff loads are reported as LA. Separate MS4 WLAs are provided for the Upper and Lower Anacostia.
Metals/ Organics (2003)	- Upstream loads (assigned to Maryland; includes LBC, 53% of Watts Branch and 15.9% of Sub watershed loads) - 84.1% of Sub watershed loads - 47% of Watts Branch loads - CSO loads	District MS4 loads are included in the “Sub watersheds” loads assigned to the District. “Sub watersheds” load is based on the SSTrib drainage area and includes the direct drainage area.	MS4 loads are included in the “Storm Water” designation and are assigned WLAs for the Upper and Lower Anacostia. Direct drainage loads are assigned LAs.

Table 4: TAM/WASP based TMDL MS4 Load Assignments			
TMDL	**TMDL Model Anacostia Loads**	**MS4 load assignment in TMDL Report**	**MS4 Load Assignment in EPA Decision Rationale Report**
Oil & Grease (2003)	- Upstream loads (assigned to MD) - Stormwater (separate values assigned to Upper and Lower Anacostia) - CSO (separate values assigned to Upper and Lower Anacostia)	"Stormwater" includes the SSTrib areas.	"Stormwater" and CSO loads are reported as WLA and "Upstream" load is reported as LA. The document also indicates that areas still subject to stormwater runoff that are not covered by the MS4 such as forested areas would not be expected as sources of this pollutant. This indicates that non-MS4 direct drainage areas are not included in this TMDL.
Sediment/ TSS (2007)	- Upstream loads (assigned to MD, including Watts Branch and LBC) - MS4 (separate values assigned to Upper and Lower Anacostia) - CSO (separate values assigned to Upper and Lower Anacostia) - Point sources - Nonpoint sources (separate values assigned to Upper and Lower Anacostia)	MS4 WLA consists of the SSTrib loads. MS4 WLAs are provided separately for Upper and Lower Anacostia. The District's portions of Watts Branch and LBC are included in Upper Anacostia MS4 WLA. Permitted point source loads are listed as separate WLAs.	Reported similarly to TMDL report.
Nutrients/ BOD (2008)	- Upstream loads (assigned to MD, including Watts Branch and LBC) - MS4 (separate values assigned to Upper and Lower Anacostia) - CSO (separate values assigned to Upper and Lower Anacostia) - Point sources - Nonpoint sources (separate values assigned to Upper and Lower Anacostia)	MS4 WLA consists of the SSTrib loads. MS4 WLAs are provided separately for Upper and Lower Anacostia. The District's portions of Watts Branch and LBC are included in Upper Anacostia MS4 WLA. Permitted point source loads are listed as separate WLAs.	Reported similarly to TMDL report.

Tidal Drainage Area Differences between Version 2 and Version 3 of the TAM/WASP Models

There are four versions of TAM/WASP models used by the different TMDLs as shown in Table 2. While all versions indicate that they use the same sub-drainage area delineations performed by MWCOG, Table 2 also shows that there is a difference in the calculation of the tidal drainage area between Versions 2.1 and 2.3 and Version 3. TMDLs that use Version 3 report a drainage area of 12,375 acres as the tidal drainage area (excluding Watts Branch and Lower Beaverdam Creek and CSOs). The TMDLs using Versions 2.1

and 2.3 report this area as 10,501 acres, or approximately 1,900 acres less than what is used in Version 3. Since only the TMDLs that use Versions 2.1 and 2.3 provides only main tributary drainage areas and upstream (Maryland) drainage areas, but it does not provide a full breakdown of the various sub-shed drainage areas, it is not possible to explain the difference in areas between the different TAM versions precisely. However, Version 3 lists smaller drainage areas for Lower Beaverdam Creek and Watts Branch than do Versions 2.1 and 2.3. Thus, it is likely that areas of Lower Beaverdam Creek and Watts Branch, along with areas in the Bladensburg area of Maryland, were included in the tidal drainage area in TAM Version 3, thus resulting in an increase in the reported tidal drainage area compared to TAM Version 2. This is one plausible explanation; however, more information will be needed to validate this conclusion.

Rock Creek Mainstem

District TMDL models of the mainstem Rock Creek extend from the confluence with the Potomac River to the upstream limit in the District. The watershed consists of the mainstem Rock Creek plus 11 tributaries. All tributaries to Rock Creek in the District are open channel streams. The tributaries receive MS4 drainage from the surrounding separate storm sewer areas; in addition, one tributary (Piney Branch) also receives CSO flows as well.

There are two TMDLs for the mainstem Rock Creek. These are:

- Rock Creek Mainstem Metals (2004)
- Rock Creek Mainstem Bacteria (2004)

Both TMDLs use a similar modeling approach, which includes two main components. A land model component (rainfall-runoff model) was used to generate loads from the Rock Creek drainage area within the District and convey them through drainage systems to the receiving waters, and a stream model component was used to simulate the in-stream processes using EPA's Storm Water Management Model (SWMM) model.

The land model was formulated as part of the DC Water's CSO Long Term Control Plan (LTCP) study and includes two separate models - one for the combined sewer system and another for the separate storm sewer system. The models generate runoff based on various hydrologic input parameters from the drainage basin, including precipitation, land use, and soil characteristics. For the CSO areas, the model also routes the runoff through the collection system. These models were calibrated and verified using data collected for the LTCP between October 1999 and June 2000. The models were run for a three year period from 1988 to 1990 and outputs were entered as input to the Rock Creek SWMM model.

Drainage Areas, Flow Estimates, and Allocation Development

The following sources of input flow are defined in the Rock Creek SWMM model:

- Upstream flow data from Maryland – based on the USGS gage at Sherrill Drive
- CSO and stormwater flow data –from LTCP models
- Direct drainage – The Simple Method was used to calculate flows from parklands along the Creek and its tributaries that do not enter the sewer system but drain directly into the channel

The LTCP study identified the pipe outfalls on Rock Creek and the pipe outfalls on its tributaries and calculated the contributing drainage area for each outfall (sewersheds). Based on hydrologic parameters, the LTCP study calculates a runoff value at each outfall using the DHI MOUSE program. Loads are then calculated by multiplying EMCs by the runoff values. Loads from each sewershed are applied to the mainstem in the segment of the mainstem to which their outfall discharges; for sewershed loads from the tributaries, loads are applied to the mainstem at the tributary confluence Areas outside of these sewersheds consist primarily of parklands that flank Rock Creek and its tributaries. These areas contribute direct runoff to the Rock Creek and are assigned as direct drainage areas in the TMDL studies.

Similar to the Anacostia models, all separate stormwater loads to the tributaries and to the mainstem are aggregated together and assigned as one MS4 WLA to the mainstem Rock Creek. There is one subtle difference between the Anacostia TAM models and the Rock Creek models regarding calculating direct drainage areas. In contrast to the Anacostia mainstem TAM model, which includes direct drainage only from those areas that contribute direct runoff to the mainstem, the Rock Creek mainstem models also include the direct drainage areas to the tributaries in addition to the direct drainage areas to the mainstem.

Specific MS4 drainage areas are not available from the Rock Creek TMDL documents. Therefore, a breakdown of the different sub-drainage areas used for the mainstem Rock Creek TMDLs is not provided here. This information is most likely available in the LTCP related study documents.

Potomac Mainstem

District TMDL models of the mainstem Potomac extend from the downstream boundary at the Wilson Bridge to the upstream boundary at the District line past Chain Bridge. There are two TMDLs for the mainstem Potomac River. These are:

- Potomac and Tributaries Bacteria (2004)
- Potomac and Anacostia Tidal PCB (2007)

The PCB TMDL was developed for both the tidal Potomac River and the Anacostia River, and the documentation in the TMDL is limited regarding how the drainage area delineation was performed. This model is therefore not reviewed further in this memorandum. The Bacteria TMDL includes two main components: a land component and a stream component. The land model component (rainfall-runoff model) was used to generate loads from the Potomac drainage area within the District and convey them through drainage systems to the receiving waters. The stream model component was used to simulate the in-stream process using EPA's Dynamic Estuary Model (DEM) model.

The land model used for the Potomac River is the same model that was used in the Rock Creek TMDLs. Details of this model can be found in the Section 2.3 above.

Drainage Areas, Flow Estimates, and Allocation Development

The following sources of input flow are defined in the Potomac River DEM model:

- Upstream flow/load data from Maryland – based on the USGS gage at the Little Falls pumping station.
- Storm water from the District's storm sewers and CSO discharges- from the DC WASA LTCP models. These storm water flows include stormwater from three small tributaries in the District (Battery Kemble Creek, Foundry Branch and Dalecarlia Tributary).
- Lateral flow from overland runoff (from DC, MD, and VA) - Flows that drain directly to the River. A variation of the rational equation is used to generate these flows.
- Potomac River tributaries – these consist of five medium streams with drainage areas greater than 10 square miles (Cameron Run, Four Mile Run, and Pimmit Run in Virginia; and Henson Creek and Oxon Run in Maryland), plus Rock Creek and Anacostia River. Flows and loads from the five medium streams are assigned to Virginia or Maryland, depending on the location of the waterbody, and flows and loads from Rock Creek and Anacostia River are assigned to the respective waterbody.
- Blue Plains and Virginia's wastewater treatment plants- flows and loads are assigned based on discharge monitoring reports and future projections calculated by MWCOG using the Regional Wastewater Flow Forecast Model

The LTCP study identified the pipe outfalls on the Potomac and its tributaries in the District and calculated the contributing drainage area for each outfall (sewersheds). The sewershed contributions from the three small tributaries for the Potomac River in the District (Battery Kemble Creek, Foundry Branch and Dalecarlia Tributary) were also calculated in the LTCP study.

Loads for each input flow are calculated by multiplying the runoff values for each specific input flow by EMCs for that input flow. The DEM was then used to determined allowable loads that would allow the mainstem to meet water quality standards. These allowable loads were then allocated to each individual source/input flow. Rock Creek and the Anacostia River were given their own allocations, as were Maryland and Virginia. Similar to other mainstem studies, all separate stormwater loads were aggregated together and are assigned as one MS4 WLA. Also similarly to the Rock Creek mainstem models, the Potomac Bacteria model includes direct drainage areas, which are defined as those areas that contribute direct runoff to either the mainstem or its small tributaries.

Specific MS4 drainage areas are not available from the Bacteria TMDL document. Therefore, a breakdown of the different sub-drainage areas used for the mainstem Potomac River is not provided here. This information is most likely available in the LTCP study documents.

Tributary TMDL Models

There are eight tributary TMDL studies in the District, of which five use the DC Small Tributaries (DCST) model to calculate loads. The five TMDLs that use the DCST model cover multiple tributaries of a mainstem and therefore establish TMDLs on multiple tributary waterbodies. Table 5 shows the list of tributary TMDLs and the model used on each one to establish pollutant loads.

Table 5: Tributary TMDLs

Tributary TMDL	TMDL Model
Hickey Run PCB, Oil and Grease, Chlordane - 1998	Monitoring data used (no modeling)
Anacostia and Tributaries Bacteria - 2003	DC Small Tributaries Model
Anacostia and Tributaries Metals and Organics – 2003	DC Small Tributaries Model
Fort Davis BOD - 2003	Monitoring data used (no modeling)
Watts Branch TSS 2003	SWMM (inflows) and HEC-6 (erosion)
Potomac and Tributaries Bacteria - 2004	DC Small Tributaries Model
Potomac and Tributaries Metals and Organics – 2004	DC Small Tributaries Model
Rock Creek Tributary Metals - 2004	DC Small Tributaries Model

The DCST model is simpler compared to mainstem TMDL models, in part because it does not account for in-stream processes. The input loads are considered fully mixed in the stream and are used directly to calculate TMDL allocations. However, the model used for the Watts Branch TSS TMDL does have added complexity relative to the DCST model because it includes stream bank erosion among the sources of total TSS load in the stream. There are also two key differences between tributary models and mainstem models that pertain to input flow and load establishment in TMDLs. These are:

- Tributary models only establish the flow from the tributary drainage area, as that is the only source of pollutant loads that needs to be identified. This load is split between WLA and LA based on the sewered and unsewered areas within the drainage area. In contrast, mainstems have varied sources of input, such as upstream flow, major tributary flows, and sub-drainage area flows.

- Tributary models are concerned only with the daylighted portion of a tributary and therefore delineate the drainage area only up to the last daylighted point of a tributary stream. Any downstream piped sections are not considered as part of the tributary drainage area. Therefore, for those tributaries that have significant piped sections, tributary drainage areas do not match the sub-drainage area mapped for that same tributary in the mainstem model because mainstem sub-drainage areas were delineated up to the pipe outfall on the mainstem. This issue primarily impacts the Anacostia tidal watershed, in which has many of the tributaries are piped before they flow into the river.

The Fort Davis BOD and the Hickey Run PCB, Oil and Grease, and Chlordane TMDLs do not use modeling to establish flows or allocations. The Fort Davis TMDL used monitoring data to establish that the stream is no longer impaired for BOD and therefore that a TMDL was no longer required. The Hickey Run TMDL uses monitoring data to set a TMDL allocation for each pollutant. For oil and grease it is set at that level which will not cause a sheen, and for PCB and chlordane, no discharges are allowed into the stream. Therefore, no models are developed for these TMDLs. The DCST model and the Watts Branch TMDL model for TSS used for the remaining tributary TMDLs are described in more detail below.

DC Small Tributaries Model

The DC Small Tributaries Model was used to model the 23 tributaries of the mainstem waterbodies in the District (i.e., the Anacostia and Potomac Rivers and Rock Creek). The tributaries modeled in the DCST are summarized in Table 6. The DCST is composed of three sub-models: an organic sub-model for chlordane, dieldrin, heptachlor epoxide, DDT, PAHs, PCBs; an inorganic chemicals sub-model for zinc, lead, copper, arsenic; and a fecal coliform bacteria sub-model. Therefore, all tributary TMDLs for these pollutants use the DCST model with the exception of the Hickey Run TMDL for chlordane, which predates the DCST study.

Table 6: Tributaries in DCST Model

Tributary	Receiving Water	MS4/ CSO Component?	Drainage Area - acres
Fort Davis	Anacostia River	MS4	72
Fort Chaplin	Anacostia River	MS4	204
Fort Dupont	Anacostia River	MS4	474
Fort Stanton	Anacostia River	MS4	125
Hickey Run	Anacostia River	MS4	1081
Nash Run	Anacostia River	MS4	465
Popes Branch	Anacostia River	MS4	232
Texas Avenue Tributary	Anacostia River	MS4	176
Watts Branch	Anacostia River	MS4	2470
Battery Kemble/Fletcher's Run	Potomac River	MS4	239
Dalecarlia Tributary	Potomac River	MS4	1111
Foundry Branch	Potomac River	MS4	168
Broad Branch	Rock Creek	MS4	1129
Dumbarton Oaks	Rock Creek	MS4	168

Table 6: Tributaries in DCST Model			
Tributary	**Receiving Water**	**MS4/ CSO Component?**	**Drainage Area - acres**
Fenwick Branch	Rock Creek	MS4	203
Klingle Valley	Rock Creek	MS4	354
Luzon Creek	Rock Creek	MS4	648
Melvin Hazen Valley Creek	Rock Creek	MS4	184
Normanstone Creek	Rock Creek	MS4	249
Piney Branch	Rock Creek	MS4 and CSO	61 (MS4 only)
Pinehurst Branch	Rock Creek	MS4	443
Portal Branch	Rock Creek	MS4	73
Soapstone Creek	Rock Creek	MS4	520

The DCST model is a simple mass balance model run on MS ACCESS that predicts daily concentrations of the modeled pollutants, while accounting for both surface runoff and base flow. Estimates of base flow and storm flow volumes discharging into each tributary were made using the Watts Branch HSPF model. The 1988 to 1990 precipitation period was used to generate daily flows for use in the development of TMDLs. As described in Section 2.2.1 in the paragraph discussing the Watts Branch HSPF model, a land use analysis was done for each of the tributary sub-watersheds to classify land uses in each tributary according to the three categories in the Watts Branch HSPF model. District land use data circa 2000 provided by MWCOG was used, along with delineations performed by ICPRB based on Quad map topographic information, sewer outfalls and associated drainage areas provided by LimnoTech and best engineering judgment. For those streams that outfall to a mainstem waterbody via a pipe, the DCST model delineated the drainage area of the tributary upstream of the last conduit before the tributary enters the MS4 system.

The DCST model also includes estimated EMC values for storm flows and base flows that are based on multiple sets of monitoring data (some from within the District and some from outside the District). Using the daily flow values and the EMC values, the model calculated pollutant loads and allocations for each pollutant.

Watts Branch TSS Model

The Watts Branch model was used to develop the TSS TMDL for Watts Branch. The model uses a drainage area of 2259 acres for Watts Branch, of which 47% is in the District. Stormwater runoff from the Watts Branch drainage area is modeled at seven local tributaries and inflow points using SWMM. The drainage areas and inflow amounts are based on topographic maps, storm drain maps, and 2002 land use/ land cover data. The model simulation period was for the water years 1993 and 1997 (October to September). The model also uses USACE’s HEC-6 to model the in-stream bed and bank erosion, which are additional sources of TSS. The model assigns loads and allocations to the MS4 system in Watts Branch.

Other Waterbodies

There are four waterbodies that fall into the “other waterbody” category. Table 7 shows the different TMDLs issued for these waterbodies and the modeling approach used in the development of the TMDLs.

Table 7: Other Waterbodies TMDLs		
TMDL	**In-stream Model**	**Drainage Area Runoff Estimation**
Tidal Basin and Ship Channel Bacteria (2004)	Environmental Fluid Dynamics Model (EFDC)	Using precipitation, infiltration loss percentage, and drainage area
Tidal Basin and Ship Channel Organics (2004)	Environmental Fluid Dynamics Model (EFDC)	Using precipitation, infiltration loss percentage, and drainage area
Ship Channel pH (2004)	No numerical modeling	Monitoring data used to estimate loads
Kingman Lake Bacteria (2003)	No numerical modeling	Based on flow to TAM/WASP segments 15-19 of the Anacostia River
Kingman Lake Organics and Metals (2003)	No numerical modeling	Based on flow to TAM/WASP segments 15-19 of the Anacostia River
Kingman Lake TSS, Oil and Grease, BOD (2003)	No numerical modeling	Based on a simple hydrologic model
Oxon Run Organics, Metals, and Bacteria (2004)	No numerical modeling	Watts Branch HSPF Model used in the DC Small Tributaries Model
Chesapeake and Ohio Canal Bacteria 2004	No numerical modeling	An HSPF Model is used with two land use categories: forested and urban lands

Tidal Basin and Ship Channel TMDLs

The Tidal Basin and Ship Channel fall within the Potomac River watershed and are connected to the River. These two waterbodies have three combined TMDLs as shown in Table 7. Both the Bacteria and Organics TMDLs use the EFDC model which is a three-dimensional model capable of simulating hydrodynamics, sediment transport and water quality using a curvilinear-orthogonal grid for a waterbody. Inputs to the EFDC model include runoff from the separate storm water system, direct runoff, and, in the case of bacteria, direct deposition from waterfowl. Drainage area runoff is estimated using the precipitation amounts during 1988 to 1990 and multiplying by the infiltration loss percentage and the drainage area. Neither the total drainage area nor the infiltration loss percentage used is available from the TMDL documentation. Table 8 below shows the land use categories in the Tidal Basin and Ship Channel drainage areas.

Table 8: Drainage Area Descriptions		
Category	Tidal Basin	Ship Channel
Land use	27% commercial/government 43% parklands/grass area 30% Basin itself	53% commercial/government/residential 22% parklands/grass area 25% Channel itself
MS4 area	150 acres drained via 6 storm pipe outfalls	445 acres drained via 9 storm pipe outfalls

In both the Bacteria and Organics TMDLs, the calculated runoff volumes are multiplied by EMC values to establish annual loads. Based on the MS4 and direct drainage areas, the calculated loads are divided into separate storm loads and direct deposit loads, and the model is then used to assign MS4 WLAs for the pollutants.

The pH TMDL for the Ship Channel does not include numerical modeling and is based on monitoring data. Monitoring data for Chlorophyll A and a developed relationship between Chlorophyll A and pH is used to determine the pH load in the Channel. The pH value in the Channel was found to not exceed the established Water Quality Criterion, and so no further action was required to allocate loads to different sources.

Kingman Lake TMDLs

Kingman Lake falls within the Anacostia River watershed and is included as a separate segment of the River in the Anacostia River TAM/WASP models. In the TAM/WASP Version 2.3 model, the Anacostia River was segmented into different portions and Kingman Lake was modeled as a parallel segment to the mainstem segments. The model also established the sub drainage areas (called sub-sheds) that contribute to the Kingman Lake segment. All three TMDLs for Kingman Lake (shown in Table 8) use the drainage areas calculated in the TAM/WASP model for Kingman Lake. The drainage area of Kingman Lake is reported as 368 acres, of which 50% is parkland/golf course, 25% is RFK stadium/parking lot, and 25% is residential. However, the TMDL documentation does not provide information on which sub-drainage areas (sub-sheds) of the TAM/WASP model are used in the Kingman Lake drainage area.

Both the Bacteria and the Organics and Metals TMDLs use the Watts Branch HSPF model to calculate runoff from the Kingman Lake drainage area. Using EMC values established for the Anacostia minor tributaries, the TMDLs calculate average annual loads based on runoff. The model is then used to assign MS4 WLAs for the pollutants.

The TSS, Oil and Grease, and BOD TMDL uses the percent imperviousness of each of the three land use categories (residential, park/grass, stadium) and multiplies the percent imperviousness value by the area of each land use and a one-inch rainfall to establish a runoff value. EMC values are based on monitoring data, except for oil and grease, which uses a Water Quality Criterion. Using the EMC values and runoff, loads are established for Kingman Lake. Load analysis indicated that allocations to specific sources were not required for either pollutant.

Oxon Run TMDL

Oxon Run is a tributary of the Potomac River. It originates in Maryland and flows into the District briefly before entering Maryland again prior to its confluence with the Potomac. Only 26% of the 12.4 sq. mile Oxon Run watershed falls within the District. Oxon Run has one TMDL: Organics, Metals and Bacteria TMDL (2004). The DCST model described earlier is used to model the pollutant loads and concentrations for the District's portion of Oxon Run. The hydrologic modeling component uses the Watts Branch HSPF model with land use classified as forest land, pervious urban land, and impervious land. The simulation period for the Oxon Run TMDL is from 1988 to 1990. Based on GIS data for the District, 85% of the District's Oxon Run watershed is located in areas covered by MS4 storm sewers. The TMDL assigns MS4 WLAs to Oxon Run for organics, metals and bacteria.

Oxon Run has also been included in two mainstem Potomac TMDLs (the Potomac River mainstem bacteria TMDL and the Potomac and Anacostia PCB TMDL). It was treated differently in the two mainstem Potomac TMDLs, with one TMDL (the Potomac River mainstem Bacteria TMDL) assigning all of Oxon Run's loads to Maryland and the other (the Potomac and Anacostia PCB TMDL) assigning a combined load for Oxon Run to the District and Maryland.

Chesapeake and Ohio Canal TMDLs

The segment of the Chesapeake and Ohio Canal (C&O Canal) within the District receives most of its water from the main stem Potomac River via intakes, but it also receives water from upstream flows in Maryland, stormwater discharge, and direct runoff from its bank areas. The District portion of the C&O Canal begins at its mouth at Rock Creek and extends 5 miles to the Maryland State line. Within the District, the C&O Canal has only one TMDL: the C&O Bacteria TMDL in 2004. Based on District sewershed GIS data, an estimated 426 acres of area discharges to the Canal via the MS4 pipe system. Runoff volumes are generated using an HSPF model that estimates wet weather flows for two land uses: forested and urban lands. Loads are calculated using EMC values from the DCST model and the HSPF runoff values. Average annual loads are based on a five year simulation period from 1995 to 1999. The TMDL assigns MS4 WLAs to the C&O Canal for bacteria.

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Attachment 2: Review of Publically Available Calculator Tools to Estimate Pollutant Loads

As described in the section 3.2, a broad suite of publically available calculators were reviewed to assess their applicability for use in the IP Modeling Tool. Each model was reviewed in order to answer the following questions:

- What is its intended use?
- Does it include a graphical user interface?
- What method is used to calculate runoff?
- What sources of pollution are included?
- What types of pollutants are included?
- What method is used to calculate pollutant load?
- What types of BMPs are included?
- What method is used to calculate BMP load reductions?

Table 1 shows the results of the review. As can be seen from the table, many of the calculator tools do not include the full suite of pollutants for which there is a TMDL, and many do not have the full suite of BMPs that are currently used by DDOE. Many of the calculators also do not track BMP volume reduction, which is a valuable metric that DDOE would like to have integrated in the IP Modeling Tool.

The review demonstrated that the publically available or calculator tools would not fulfill the requirements of the IP Modeling Tool without significant revisions or edits. It was therefore decided to not use an existing calculator, but instead build a custom built calculator tool that will satisfy all the requirements of the IP Modeling Tool as outlined in section 3.

Table 1: Review of Publically Available Calculator Tools		
Model	**Developer**	**Intended use**
STEPL	TetraTech/EPA	To calculate nutrient and sediment loads and reduction in loads as result of BMPs
WTM	Center for Watershed Protection	Calculates annual pollutant loads and runoff volumes, accounts for benefits of a full suite of stormwater treatment practices and programs
VA Runoff Reduction Method	Center for Watershed Protection	Calculates pollutant load and BMPs necessary to reach goal
National Stormwater Calculator	EPA	Computes small site hydrology, estimates stormwater runoff generated under different development and control scenarios over a long time record.
Green Values SW Management Calculator	CNT	Designed to give approximation of hydrologic benefits of LID practices and financial costs of practices
Pollutant Load Reduction Model	NHC/others	Evaluating and comparing pollutant load for storm water quality improvement projects. Geared toward Lake Tahoe.
GRTS	DC Gov	Determine pollutant load reduction from BMPs in rock creek watershed
PLOAD	EPA	Estimate point and non-point source loads in small urban or rural watersheds
LTHIA	Purdue	Used to quantify the impact of land use change on water quantity and quality
SBPAT	Geosyntec	Facilitate prioritization, and selection of BMP project opportunities in urban watersheds and quantify benefits, costs, uncertainties, and potential risks associated with stormwater quality projects
WMOST	EPA	Screening tool for water resources managers and planners to screen potential water management options in watershed or jurisdiction for cost-effectiveness as well and environmental and economic sustainability.

Table 1: Review of Publically Available Calculator Tools (continued)			
Model	**GUI**	**Runoff method used**	**Sources of pollution**
STEPL	Yes, spatial component	NRCS Curve Number Method and Universal Soil Loss Equation (USLE)	Urban, agriculture, livestock, septics, gully and stream erosion
WTM	No	Simple method	Urban and non-urban land, stream channel contribution, septics, SSOs, CSOs, illicit connections, channel erosion, livestock, marinas, road sanding
VA Runoff Reduction Method	No	Simple method	Forest open space, managed turf, impervious cover
National Stormwater Calculator	Yes, spatial component	SWMM 4.0 Engine - Green-Ampt	Doesn't calculate pollutant loads from land uses
Green Values SW Management Calculator	Yes, web based.	Curve number for runoff volume, Rational formula for peak discharge	Doesn't calculate pollutant loads from land uses
Pollutant Load Reduction Model	Yes	SWMM 5 Engine - Green-Ampt	Pollutant loads from land uses and roads
GRTS	No	Simple method	Urban areas in Rock Creek watershed
PLOAD	Yes, via BASINS	SWMM is linked to Basins, uses SWMM algorithms	Various land uses
LTHIA	Yes, spatial component	NRCS Curve Number	Various land uses
SBPAT	Yes, spatial component	EPA-SWMM engine	Various land uses
WMOST	No	None. Requires user to enter runoff	None, does not simulate pollutants

Table 1: Review of Publically Available Calculator Tools (continued)		
Model	**Pollutants Included**	**Load Calculation Method**
STEPL	Nitrogen, phosphorus, BOD, sediment, septic	EMC for various land uses
WTM	Nitrogen, phosphorus, sediments, fecal coliform	EMC for various land uses
VA Runoff Reduction Method	Nitrogen and phosphorus	EMC (no land use differentiation)
National Stormwater Calculator	No pollutants	None
Green Values SW Management Calculator	No pollutants	None
Pollutant Load Reduction Model	TSS, FSP, TP, SRP, TN, DIN	EMC for various land uses
GRTS	Chlordane, DDD, DDE, DDT, Dieldrin, HeptachlorEpoxide, PAH, TPCB	EMC (no land use differentiation)
PLOAD	TSS, TDS, BOD, COD, nitrogen, phosphorus, metals, bacteria	EMC for various land uses
LTHIA	N, P, SS, Lead, Copper, Zinc, Cadmium, Chromium, Nickel, BOD, COD, Fecal Coliform, Fecal Strep	EMC for various land uses
SBPAT	trash, nutrients, metals, bacteria, and sediment	EMC for various land uses
WMOST	N/A	None

Table 1: Review of Publically Available Calculator Tools (continued)		
Model	**Type and approximate number of BMPs included**	**BMP load reduction method**
STEPL	Agricultural, urban, and non-structural BMPs. Land Management Practices. Over 20 BMPs available.	BMP efficiencies are used. Percent reduction method.
WTM	Agricultural, urban, and non-structural BMPs. Land Management Practices. Over 20 BMPs available.	BMP efficiencies are used. Percent reduction method.
VA Runoff Reduction Method	Urban and non-structural BMPs. Over 15 BMPs available.	BMP efficiencies are used. Percent reduction method.
National Stormwater Calculator	Disconnection, rain harvesting, rain gardens, green roofs, street planters, infiltration basins, porous pavement	SWMM BMP reduction method. Each BMP has its own parameters which detail the amount of runoff captured as result of design parameters.
Green Values SW Management Calculator	Urban BMPs. Over 10 BMPs available.	Hydrologic benefits are calculated by changes in runoff coefficient and curve numbers
Pollutant Load Reduction Model	Urban and non-structural BMPs. Over 10 BMPs available	SWMM BMP reduction method. Percent reduction method.
GRTS	Urban and non-structural BMPs. Land management practices. Over 15 BMPs available.	BMP efficiencies are used. Percent reduction method.
PLOAD	No BMPs	N/A
LTHIA	Urban and non-structural BMPs. Over 10 BMPs available	Hydrologic benefits are calculated by changes in curve numbers
SBPAT	Urban and non-structural BMPs. Includes over 10 BMPs.	SWMM BMP reduction method with customized Monte Carlo Simulation model. Volume based reduction method used.
WMOST	Non-structural BMPs. Over 5 BMPs available	N/A

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Attachment 3: Comparison of the Modified Version of the Simple Method to USGS Gage Data and Models Used in DC TMDL Development

Introduction

The Modified Version of the Simple Method is recommended for use by many states and it is widely applied across the region and nationally to support storm water management planning. Although calibration and validation of the Modified Version of the Simple Method is not required or often undertaken, a comparative assessment was undertaken to independently test its ability to reproduce gaged stormwater at the watershed level. This was accomplished by applying the Modified Version of the Simple Method to observed discharge measured by USGS gages in the Washington, DC area. Modeled runoff volumes were also compared to those calculated during the development of various TMDLs that used more complex models such as HSPF and the LTCP model.

Approach

The following gages were used to compare to the Modified Version of the Simple Method. A map with these gages is shown in Figure A3-1:

- USGS 01651800 Watts Branch
- USGS 01651770 Hickey Run at National Arboretum
- USGS 01652500 Four Mile Run at Alexandria, VA
- USGS 01650800 Sligo Creek near Takoma Park, MD

These four gages represent watersheds that are the closest in nature to the Districts MS4 area. Only the Hickey Run gage measures flow that is entirely generated in the District's MS4 area. The Watts Branch gage is located in the MS4 area but measures flow that is generated in both the District and Maryland (Prince George's County). The other two gages are entirely out of the District and measure flow from areas that are much more suburban in nature than the District's MS4 area.

In addition, the following models were also used for further comparison:

- Runoff results from the LTCP model (which uses DHI's MOUSE to simulate runoff)
- Runoff results from the DC Small Tributary Model (which uses HSPF to simulate runoff)

The methodology and results for the comparison for each set of data is provided in the next two sections.

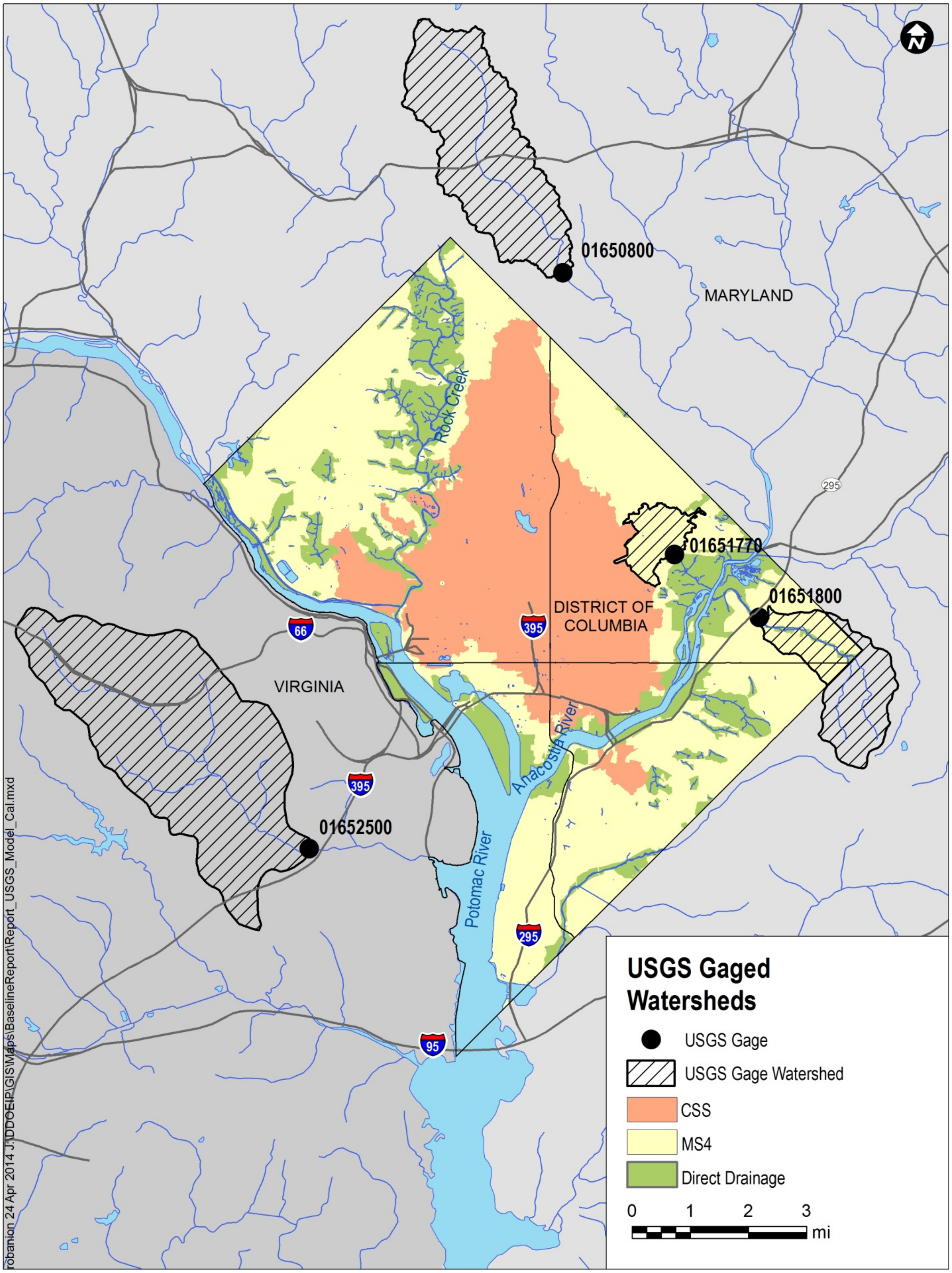

Figure 1: Location of USGS gages used for comparison of runoff volumes

Comparison to USGS Gaged Flow Data

Introduction

Flow from the USGS gages represents both baseflow (dry-weather flow) and stormflows. In order to compare the runoff volume predicted by the Modified Version of the Simple Method to the flows measured by the gages, the gaged flow must first be separated into its respective baseflow and stormflow components. The stormflows must then be summed on an annual basis to calculate a yearly runoff volume that can be compared to the runoff volume predicted by the Modified Version of the Simple Method. The runoff volume predicted by the Modified Version of the Simple Method were calculated based on the drainage area of each gage, the drainage area characteristics (landcover and soils) that will define the runoff coefficient, and annual precipitation data from Ronald Reagan National Airport (DCA).

Calculation of Runoff Volume Using the USGS Gage Data

USGS gage daily flow data was downloaded directly from the USGS website. A hydrograph separation was then performed on each flow data set to separate the baseflow and stormflow. The stormflow is equivalent to the stormwater runoff from the Modified Version of the Simple Method. The USGS HYSEP (Sloto, 1996) computer program was used to perform the hydrograph separation and HYSEP's local-minimum method separation technique was used to define the baseflow. The local minimum method checks flow data on a daily time step to determine if it is the lowest discharge in one half the interval minus 1 day before and after the day being considered. The base flow values for each day between local minimums are estimated by linear interpolation. A schematic of the low minimum method is shown in Figure 2.

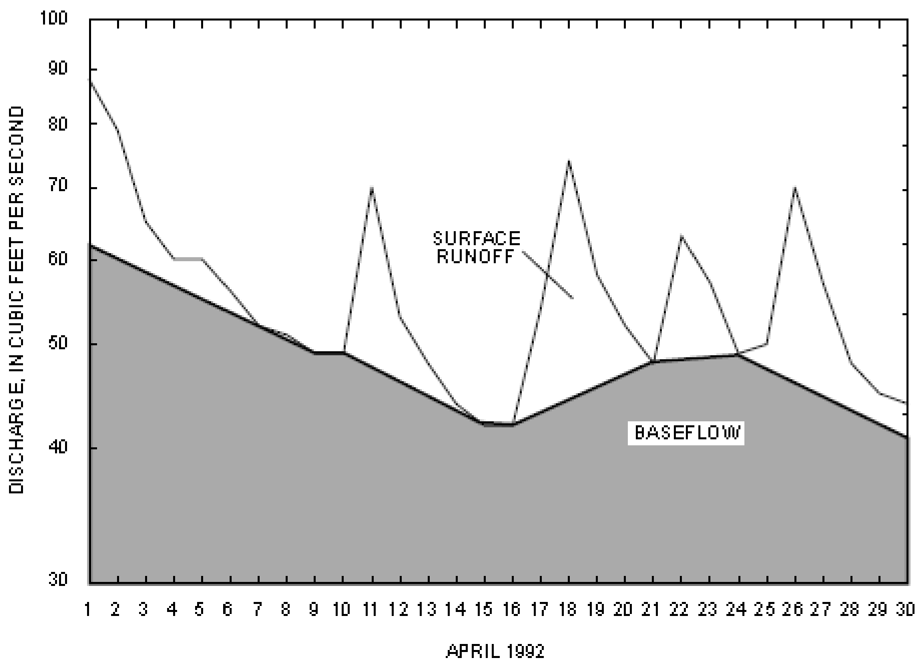

Figure 2: USGS HYSEP Local Minimum Method (USGS 1996)

The only input to HYSEP is the gage's mean daily discharge. The program outputs a base flow value for each day; the stormflow is determined by simply subtracting the baseflow from the mean daily discharge. The stormflows were then converted to daily runoff volumes and summed by year to calculate an annual runoff volume.

Calculation of Runoff Volumes using the Modified Version of the Simple Method

The runoff volume predicted by the Modified Version of the Simple Method was calculated based on the drainage area of each gage, the drainage area characteristics (landcover and soils) that define the runoff coefficient, and annual precipitation data from DCA Airport. The gage's drainage area was determined using topography and, when possible, the stormwater conduit network. The drainage area landcover in the District was determined using the DC OCTO GIS layers as described in Section 3.5.c. The drainage area landcovers for Maryland and Virginia were determined using the National Land Cover Database 2006 (NLCD 2006). Precipitation depths were obtained from official rainfall records observed at DCA) by the National Weather Service, and recorded by the National Climate Data Center (NCDC, 2014).

Results of comparison with USGS gages

Hickey Run Comparison

The Hickey Run gage is a relatively new gage. It has data only from October 2012 through December 2013. Since this gage has a limited amount of data, stormwater volumes were calculated on a monthly basis rather than an annual basis. Note that the stormwater volumes for December 2013 were not included in the analysis because of incomplete flow records for that month. The Modified Version of the Simple Method was applied for the same months to determine the predicted monthly stormwater volumes. Table 1 and Figure 3 show the results of the comparison. The results show that, on average, the Modified Version of the Simple Method over predicts the stormwater volume by 8 percent compared to the gaged storm flows.

Table 1: Comparison of Hickey Run Gaged and Simple Method Runoff Volumes

Month -Year	Total Gaged Volume	Gaged Stormwater Volume	Precipitation	Modeled Stormwater Volume	Difference between gaged and modeled
	acre-ft	acre-ft	inches	acre-ft	%
Oct-12	220	207.6	5.81	170	-17.92%
Nov-12	30	12.1	0.60	18	45.46%
Dec-12	123	103.5	3.01	88	-14.66%
Jan-13	82	64.8	2.54	74	14.97%
Feb-13	57	29.7	1.67	49	64.64%
Mar-13	142	119.7	2.80	82	-31.30%
Apr-13	42	25.6	2.76	81	216.75%
May-13	35	20.9	2.82	83	294.79%
Jun-13	364	336.5	9.97	292	-13.10%
Jul-13	56	29.6	4.43	130	337.79%
Aug-13	116	99.8	1.35	39	-60.43%
Sep-13	36	23.7	1.22	36	51.39%
Oct-13	196	175.4	6.25	183	4.55%
Nov-13	77	62.6	2.92	86	36.94%
TOTAL	**1,575**	**1,311**	**48.15**	**1,412**	**7.69%**

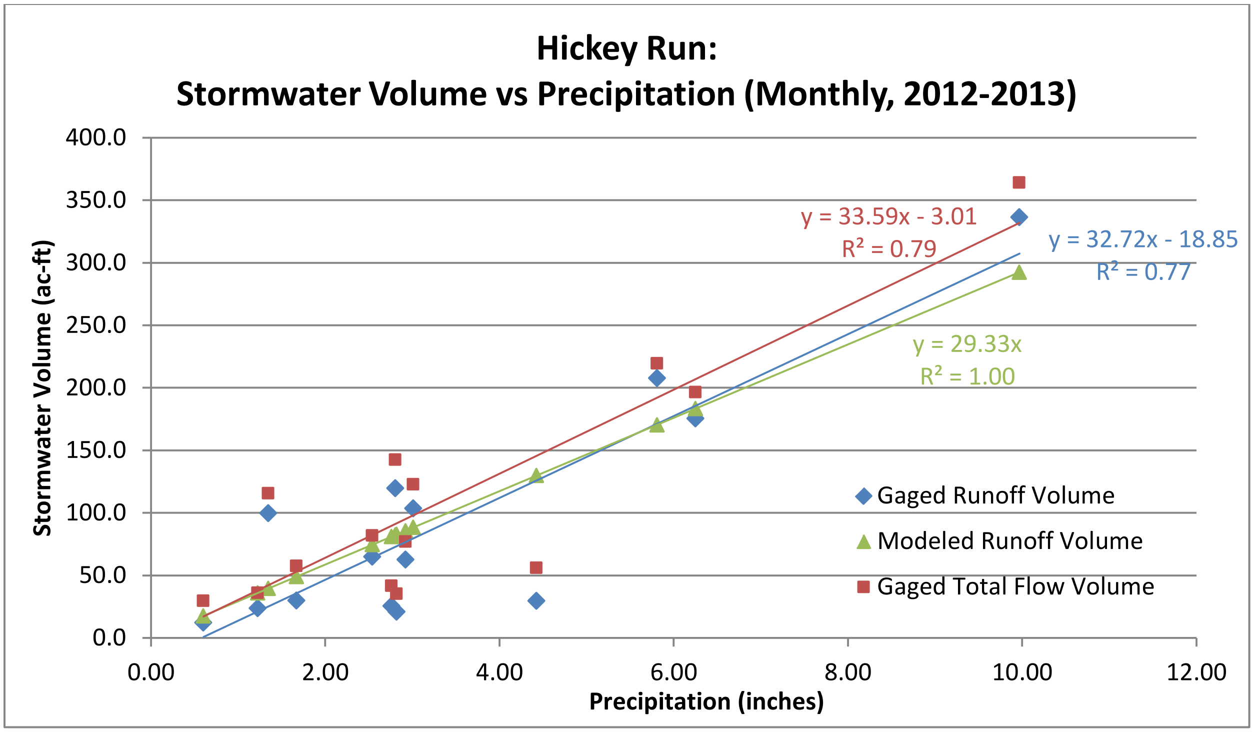

Figure 3: Comparison of Hickey Run Gaged and Simple Method Runoff Volumes

Watts Branch Comparison

The Watts Branch gaged stormwater volumes were calculated for the years 1993 through 2013. The Modified Version of the Simple Method was also applied for those same years to determine the predicted stormwater volumes. Table 2 and Figure 4 show the results of the comparison. The results show that, on average, the Modified Version of the Simple Method over predicts the stormwater volume by 18 percent compared to the gaged storm flows.

Table 2: Comparison of Watts Branch Gaged and Simple Method Runoff Volumes

Year	TOTAL Gaged Volume	Gaged Stormwater Volume	Precipitation	Modeled Stormwater Volume	Difference between gaged and modeled
	acre-ft	acre-ft	inches	acre-ft	%
1993	3,438	2,075	41.41	2,492	20.10%
1994	3,673	2,060	37.57	2,261	9.77%
1995	2,862	1,887	39.81	2,396	26.98%
1996	4,392	2,629	51.00	3,070	16.75%
1997	2,706	1,533	33.82	2,036	32.77%
1998	3,408	2,064	35.94	2,163	4.81%
1999	3,113	2,007	40.19	2,419	20.51%
2000	2,761	1,637	40.63	2,446	49.36%
2001	2,536	1,529	29.95	1,803	17.89%
2002	1,977	1,404	34.30	2,064	47.03%

Table 2: Comparison of Watts Branch Gaged and Simple Method Runoff Volumes					
Year	TOTAL Gaged Volume	Gaged Stormwater Volume	Precipitation	Modeled Stormwater Volume	Difference between gaged and modeled
	acre-ft	acre-ft	inches	acre-ft	%
2003	5,537	3,546	60.75	3,656	3.09%
2004	3,860	2,205	42.43	2,554	15.81%
2005	3,460	2,239	44.35	2,669	19.20%
2006	3,401	2,342	47.71	2,872	22.64%
2007	3,164	2,113	32.89	1,980	-6.33%
2008	4,212	2,916	46.45	2,796	-4.13%
2009	3,567	2,361	46.83	2,819	19.39%
2010	3,514	1,713	34.76	2,092	22.15%
2011	4,320	2,813	46.85	2,820	0.24%
2012	2,294	1,265	32.41	1,951	54.21%
2013	3,187	1,649	44.26	2,664	61.51%
TOTAL	**71,381**	**43,988**	**864.31**	**52,020**	**18.26%**

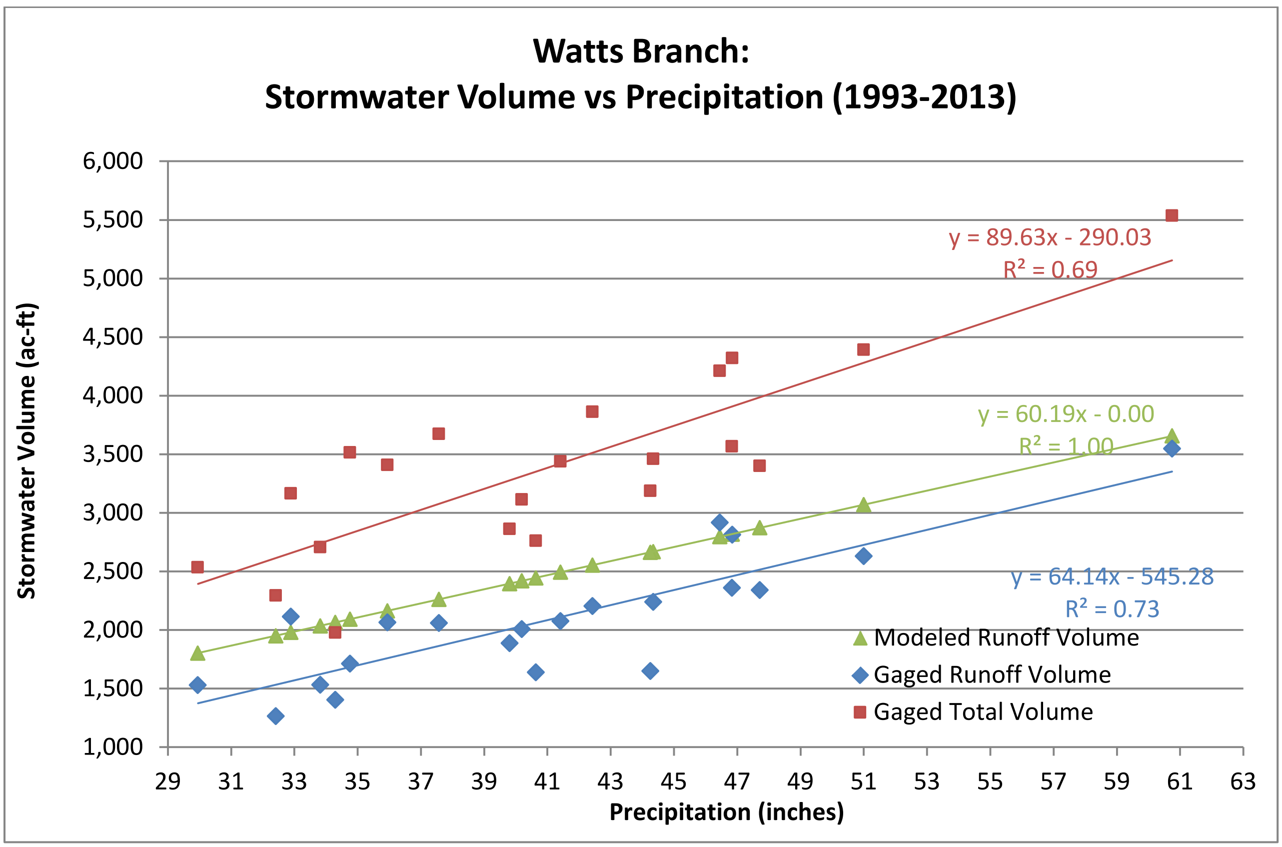

Figure 4: Comparison of Watts Branch Gaged and Simple Method Runoff Volumes

Sligo Creek Comparison

The Sligo Creek gaged stormwater volumes were calculated for the years 2009 through 2013. The Modified Version of the Simple Method was also applied for those same years to determine the predicted stormwater volumes. Table 3 and Figure 5 show the results of the comparison. The results show that, on average, the Modified Version of the Simple Method over predicts the stormwater volume by 23 percent compared to the gaged storm flows.

Table 3: Comparison of Sligo Creek Gaged and Simple Method Runoff Volumes

Year	Total Gaged Volume	Gaged Stormwater Volume	Precipitation	Modeled Stormwater Volume	Difference between gaged and modeled
	acre-ft	acre-ft	inches	acre-ft	%
2009	6,727	4,304	46.83	5,512	28.07%
2010	6,145	3,684	34.76	4,092	11.07%
2011	6,282	4,360	46.85	5,514	26.46%
2012	4,977	3,397	32.41	3,815	12.32%
2013	5,763	3,954	44.26	5,210	31.74%
TOTAL	**29,895**	**19,699**		**24,142**	**22.55%**

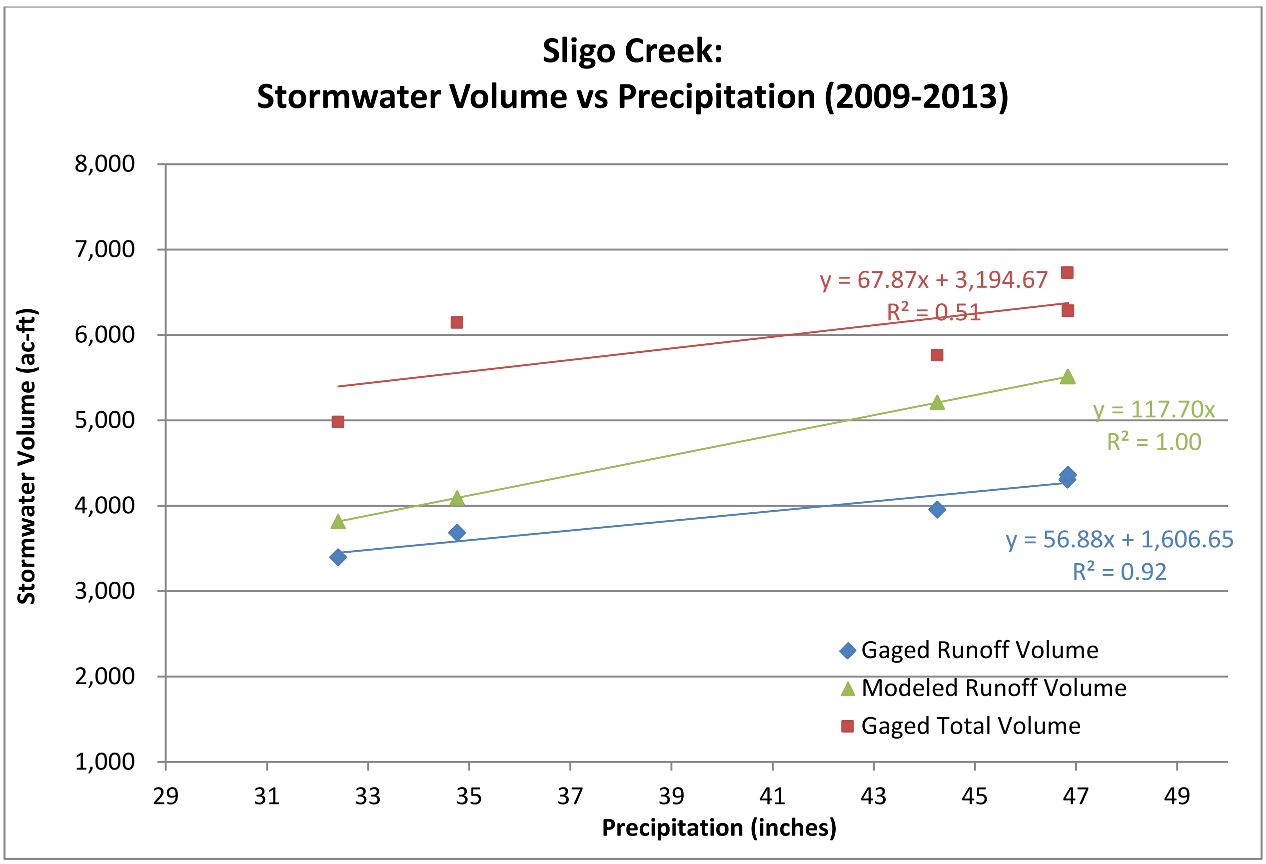

Figure 5: Comparison of Sligo Creek Gaged and Simple Method Runoff Volumes

Four Mile Run Comparison

The Four Mile Run gaged stormwater volumes were calculated for the years 1999 through 2013. The Modified Version of the Simple Method was also applied for those same years to determine the predicted stormwater volumes. Table 4 and Figure 6 show the results of the comparison. The results show that, on average, the Modified Version of the Simple Method under predicts the stormwater volume by 9 percent compared to the gaged storm flows.

Table 4: Comparison of Four Mile Run Gaged and Simple Method Runoff Volumes

Year	Total Gaged Volume	Gaged Stormwater Volume	Precipitation	Modeled Stormwater Volume	Difference between gaged and modeled
	acre-ft	acre-ft	inches	acre-ft	%
1999	18,700	14,234	40.19	11,332	-20.39%
2000	17,660	13,171	40.63	11,457	-13.01%
2001	13,809	10,050	29.95	8,445	-15.97%
2002	13,268	9,509	34.30	9,672	1.71%
2003	29,568	21,313	60.75	17,128	-19.63%
2004	16,207	10,863	42.43	11,963	10.13%
2005	20,748	15,248	44.35	12,505	-17.99%
2006	21,940	16,358	47.71	13,454	-17.75%
2007	13,883	7,900	32.89	9,274	17.39%
2008	19,886	13,221	46.45	13,098	-0.93%
2009	19,736	13,149	46.83	13,204	0.42%
2010	16,218	10,125	34.76	9,801	-3.19%
2011	22,290	16,876	46.85	13,209	-21.73%
2012	13,610	9,870	32.41	9,139	-7.41%
2013	16,437	12,339	44.26	12,480	1.14%
TOTAL	**273,960**	**194,226**	**625**	**176,160**	**-9.30%**

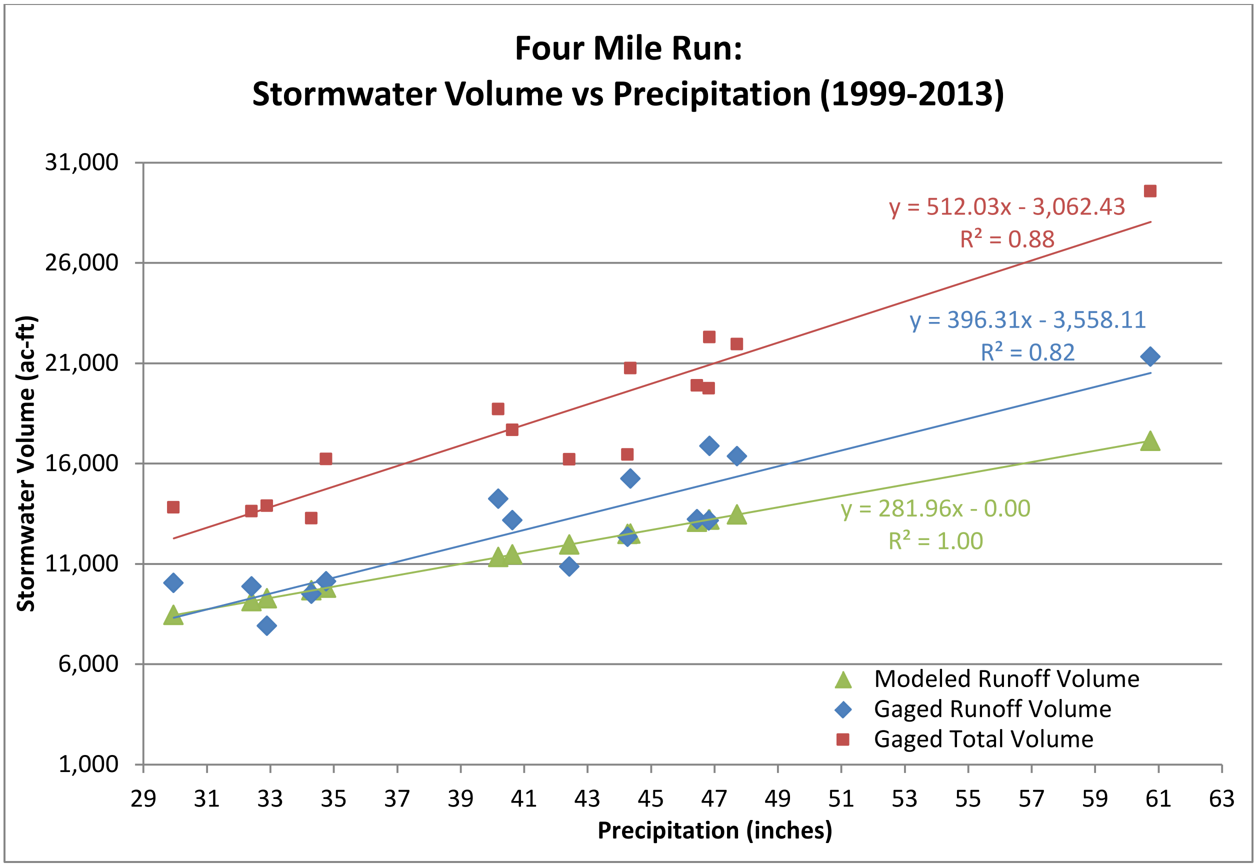

Figure 6: Comparison of Four Mile Run Gaged and Simple Method Runoff Volumes

Methodology for Comparison to Hydrology Models

Introduction

A variety of models were used to develop the DC TMDLs, as explained in Section 3.1. Of all those models, runoff output data was readily available only from the LTCP model and the DC Small Tributary Model. Therefore, the runoff output from those two models was used to compare with runoff volumes predicted by the Modified Version of the Simple Method.

Determination of Runoff Volume using TMDL Models

Modeled flows from the LTCP Model and the DCSTM Model were obtained from the model runoff output files. Several representative subsheds were selected from each model to use in the comparison. The modeled flow time series were summed on a yearly basis to obtain annual runoff volumes.

Calculation of Runoff Volumes using the Modified Version of the Simple Method

The runoff volume predicted by the Modified Version of the Simple Method was calculated using the same characterization (area, landcover, soils, Rv, etc.) of the drainage areas as was used in the LTCP and DCSTM models, including the annual precipitation.

Results of comparison with Other Models

Table 5 compares the calculated runoff volumes from the DCSTM and Modified Version of the Simple Method. The results show that, on average, the Modified Version of the Simple Method over predicts the stormwater volume by 26% to 82%. It is interesting to note that the modeled runoff volumes from the impervious areas are much more aligned (difference of only 16%) than from the pervious area (differences are more than 200%). This indicates that the DCSTM assumes that less runoff is generated by the pervious areas than what is calculated by the Modified Version of the Simple Method.

Table 5: Results of Comparison Between the DCSTM model and the Modified Version of the Simple Method

	Battery Kemble Creek	Broad Branch	Hickey Run	Luzon Creek	Piney Branch	Soapstone Creek	Watts Branch
Runoff Volume from Simple Method	212	1,211	1,504	833	44	738	2,880
Impervious Area	121	820	1,195	634	19	592	2,208
Pervious Area	91	391	310	199	25	146	657
Forested Area	0	0	0	0	0	0	14
Runoff Volume from DCSTM	134	831	1,128	610	24	557	2,292
Impervious Area	105	706	1,029	546	16	510	1,903
Pervious Area	29	125	99	63	8	47	209
Forested Area	0	0	0	0	0	0	16
% Difference	59%	46%	33%	37%	82%	33%	26%
Impervious Area	16%	16%	16%	16%	16%	16%	16%
Pervious Area	214%	214%	214%	214%	214%	214%	214%
Forested Area	-	-	-	-	-	-	-12%

Table 6 compares the calculated runoff volumes from the LTCP Model and Modified Version of the Simple Method. The results show that, on average, the Modified Version of the Simple Method matches the stormwater volumes from the LTCP model very well. This indicates that the Modified Version of the Simple Method uses assumptions to characterize runoff generation in the District that are similar to the assumptions used in the LTCP Model.

Table 6: Results of Comparison Between the DCSTM model and the Modified Version of the Simple Method

	CSO 005-c	CSO 019-ad8	CSO 020-e	CSO 024-c	CSO 049-a-WWF
Runoff Volume From Simple Method	53	31	210	188	1,368
Runoff Volume From LTCP Model	54	35	224	186	1,334
% difference	-2%	-9%	-7%	1%	3%

Discussion of Results

The results of the comparison of the Modified Version of the Simple Method to the USGS gage flow data and to the TMDL models show that:

- The Modified Version of the Simple Method, on average, overestimates the runoff volumes compared to wet-weather flows measured by in-stream gages. In this sense, the Modified Version of the Simple Method provides a conservative estimate of the total runoff volume.
- In general, the Modified Version of the Simple Method can replicate runoff volumes better when the contributing drainage area is smaller and easier to characterize. This is demonstrated by the results from the gaged data at Hickey Run and the modeled data from the LTCP model. This is

consistent with the known limitations of the Modified Version of the Simple Method, as explained in section 3.7.

It should be noted that additional review will be undertaken of the calibration procedure used to develop the runoff flows for the DCSTM, in order to better understand the differences in runoff generation, particularly from the pervious cover areas.

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Appendix B
Technical Memorandum

Sewershed and Watershed Delineations

Table of Contents

1 Introduction 1

2 Purpose 1

3 Technical Approach 1

4 Results and Discussion 22

References 24

Consolidated TMDL Implementation Plan – Comprehensive Baseline Analysis

May 08, 2015

DISTRICT DEPARTMENT OF THE ENVIRONMENT

List of Tables

Table 1: MS4, Direct Drainage, and CSS Areas of Mainstem Segments 4
Table 2: MS4, Direct Drainage, and CSS Areas of Tributary and Sewershed Segments 4
Table 3: MS4, Direct Drainage, and CSS Areas of Chesapeake Bay Segments 10
Table 4: Decision Matrix for Assigning Polygons for WLAs and LAs for Small Tributaries 18
Table 5: Decision Matrix for Assigning Polygons for WLAs and LAs for Mainstems 19
Table 6: Comparison of Watershed Areas Between Original and Updated Watershed and Sewershed Delineations Geodatabase 20
Table 7: Review and Resolutions of Major Discrepancies in Watershed Area Between Small Tributary and Geodatabase 21

List of Figures

Figure 1: Illustration of delineation for open and closed channels and direct drainage 3
Figure 2: Mainstem Segment Delineation 11
Figure 3: Subwatershed Delineation 12
Figure 4: Chesapeake Bay Segment Delineation 13
Figure 5: TMDL area assignment rollup. 15

1 Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in the District's Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) permit (U. S. EPA 2011 and U. S. EPA 2012). The IP will define and organize a multi-year process centered on reducing pollutant loads originating within the District MS4. The level of pollutant control will be based on past TMDL studies performed to protect impaired water bodies in the District. The IP will include a summary of the regulatory compliance strategy to satisfy TMDL-related permit requirements, a summary of data and methods used to develop the IP, specific prioritized recommendations for stormwater control measures, a schedule for implementation and attainment of Waste Load Allocations (WLAs), and a method for tracking progress. Substantial public involvement will be sought in plan development.

This Technical Memorandum on *Sewershed and Watershed Delineations* is one in a series of technical memoranda that provide detailed information on research, analysis, programs and procedures that support development of the Consolidated TMDL IP.

2 Purpose

The delineation of watersheds and sewersheds is critical to identifying where MS4 WLAs and nonpoint source LAs apply on the ground. By identifying the spatial extent of each TMDL watershed and sewershed, it is possible to calculate the current pollutant loads being generated, plan for the implementation of BMPs in specific locations, track the load reduction from BMP implementation, and evaluate load reduction to track progress towards meeting applicable MS4 WLAs and LAs.

The methods for delineating MS4 and nonpoint source direct drainage areas, assigning WLAs and LAs to GIS polygons based on those delineations, and performing QA/QC on the delineations and assignments, are discussed under **Technical Approach** below. The **Results and Discussion** section presents the results of the delineations and assignment of WLAs and LAs and the ramifications of these results on load calculations, load reduction tracking, and development and implementation of the Consolidated TMDL IP.

3 Technical Approach

3.1 Initial Delineation of MS4 and Mainstem Direct Drainage Areas

DDOE performed an initial delineation of watersheds and subsheds (including both subwatersheds and subsewersheds) that were divided into distinct categories. District GIS data was the primary source of information for the manual delineation of subsheds using 2-foot contour lines. Manual delineation – instead of a DEM-based automated delineation – was chosen in order to account for the complexities of delineation in an urban environment. The other significant source that was consulted was a sewer infrastructure geodatabase owned and maintained by DC Water, which included networks of sanitary sewer, combined sewer system (CSS), and MS4 pipes as well as and CSS and MS4 outfalls.

The categories of watersheds and sewersheds delineated by DDOE included:

- **TMDL Subsheds:** Subsheds representing drainage areas to each TMDL waterbody. These subsheds were delineated based on topography and include both MS4 and direct-drainage overland flow components.

- **Direct Drain Overland:** Areas that have no contributions from the MS4 or CSS service areas. Flow from these areas terminates directly into a mainstem water body, and are not part of a TMDL subshed. This data set also includes overland flow along the DC-Maryland border that drains into Maryland, and areas with indeterminate (MS4 or overland) drainage sources.
- **Direct Drain Sewersheds:** Subsheds that represent MS4 area delineations, by MS4 outfall, that drain directly to a mainstem water body, and are not part of a TMDL subshed.
- **CSS Subsheds:** Subsheds representing drainage areas of the CSS that were delineated based on topography and the DC Water sewers geodatabase.
- **All Merge:** An amalgamation of TMDL subsheds, direct drain overland, direct drain sewersheds, and CSS subsheds layers.

All categories were represented by two different data sets, one with water bodies included and one representing land area only. MS4-related delineation included any area with flow that was ultimately served by MS4 infrastructure, even if there was an overland-flow component upstream of the MS4 portion.

3.2 Additional Delineation of Small Tributaries - Open and Closed Channels and Direct Drainage

As described above, the initial delineation separated the District into TMDL subwatersheds, direct drainage areas flowing to main stem waterbodies, and CSS service areas. Parallel to this initial delineation effort, drainage areas used in the original TMDL modeling were researched. Comparison of the initial delineation to the subsheds used in the modeling revealed that the initial delineation required further refinement. In order to model the watersheds appropriately, the delineation needed to differentiate between open and closed channel (i.e., piped) streams. It also needed to separate direct drainage from sewered flow at the subwatershed scale.

According to the TMDL documentation for organics and metals in the Anacostia River and tributaries, the assessment at the subwatershed level (e.g., Texas Avenue Tributary, Hickey Run, etc.) included areas that drain to the tributaries and excluded downstream areas that drain to a closed pipe system with an outfall on the Anacostia River (Figure 1). To delineate the closed channel and open channel areas, a combination of aerial imagery, topography, pipe networks, and stream lines were used. Each subwatershed was reviewed to identify the furthest downstream point where a stream is day lighted. The final inlet to the piped system was then used as a pour point for delineation purposes.

Next, it was necessary to distinguish between the direct drainage and sewered areas of the open channel stream segments. To accomplish this task, MS4 catchment areas were intersected with the TMDL subwatershed level. The direct drainage to an open channel stream was then hand delineated (See Figure 1 for an example).

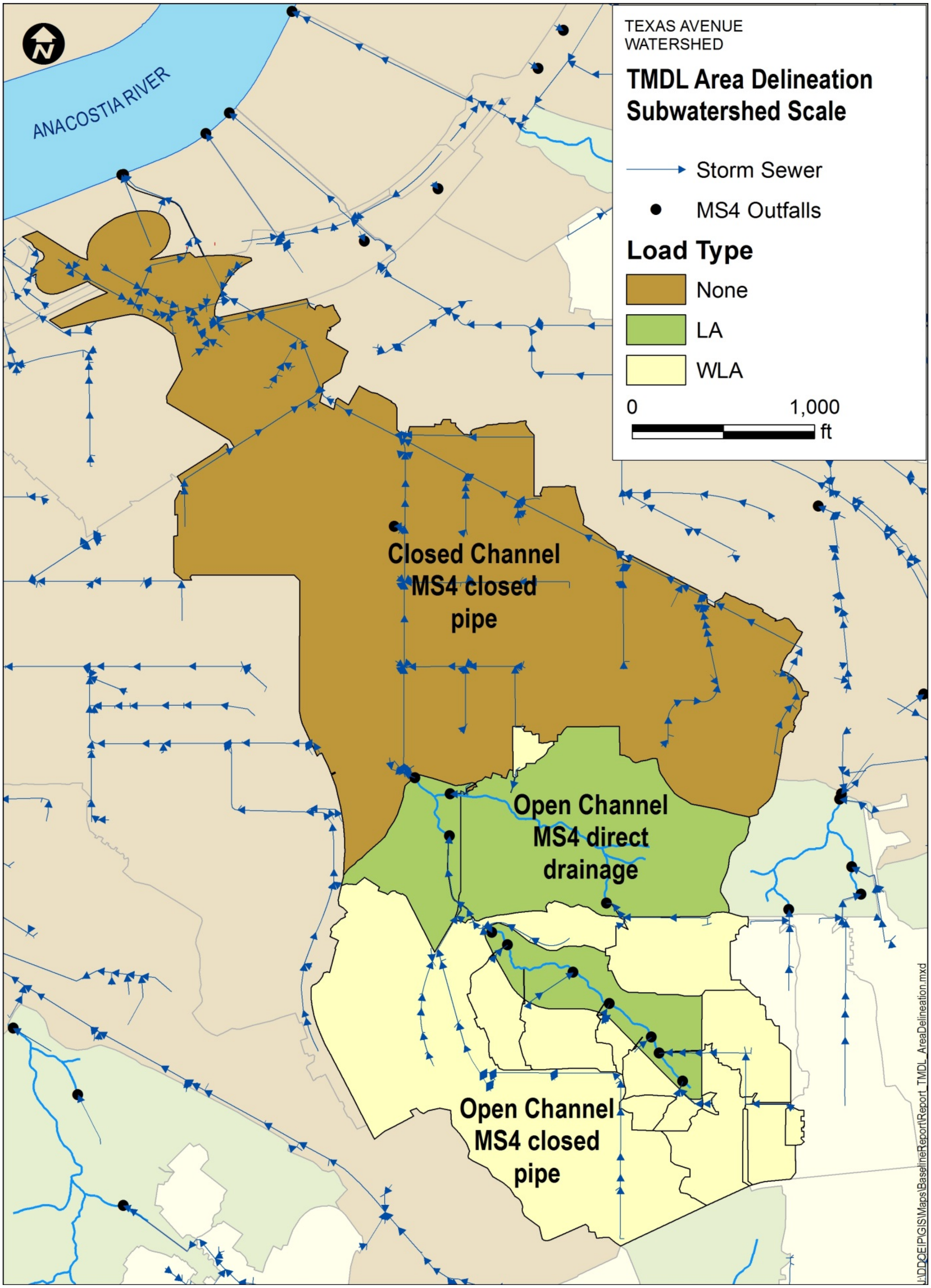

Figure 1: Illustration of delineation for open and closed channels and direct drainage

The additional delineation lead to the development of 727 features in the watershed delineation feature class. Each feature represented the finest level of detail needed for all of the TMDLs being consolidated.

Tables 1 through 3 and Figures 2 through 4 show the mainstem subsheds, the tributary and sewershed subsheds, and the Chesapeake Bay subsheds, respectively, as delineated by this process. The tables include summaries of the areas of the MS4 system, the direct drainage, and the CSS area in each subshed. Table 1 for the tributary and sewershed subsheds also shows the MS4 portion and the direct drainage of the open channel areas, as well as the closed channel parts of the MS4 system.

Table 1: MS4, Direct Drainage, and CSS Areas of Mainstem Segments

Mainstem Segment	MS4 Area (acres)	Direct Drainage Area (acres)	CSS Area (acres)	Grand Total (acres)
Anacostia Lower[1]	1567.5	631.8		2199.3
Anacostia Upper	7112.7	2195.3		9308.0
Potomac Lower	3561.4	348.0		3909.3
Potomac Middle	783.4	679.0		1462.3
Potomac Upper	2692.2	931.2		3623.4
Rock Creek Lower	1010.2	688.5		1698.7
Rock Creek Upper	3022.6	1756.5		4779.1
CSS			12218.1	12218.1
Grand Total	**19750.0**	**7230.2**	**12218.1**	**39198.3**

Table 2: MS4, Direct Drainage, and CSS Areas of Tributary and Sewershed Segments

Main-stem Segment	Subshed	MS4 Area - Closed Channel (acres)	MS4 Area – Open Channel (acres)	Open Channel Direct Drainage Area (acres)	Mainstem Direct Drainage Area (acres)	CSS Area (acres)	Grand Total (acres)
Anacostia Lower	695 SE	6.9					6.9
	Buzzard Point SW	78.5					78.5
	Fairlawn SE	26.1					26.1
	Fort Stanton Tributary	156.2	29.5	92.1			277.8
	Historic Anacostia SE	29.0					29.0
	Nationals Park SE	25.2					25.2

[1] Note that an additional mainstem segment was created for the entire Anacostia in October of 2014. The Anacostia mainstem segment is the equivalent of the sum of the upper and lower Anacostia mainstem segments. A segment for the entire Anacostia was created in order to perform the load calculations for newly published E. coli TMDL. Only one E. coli WLA value was provided for the entire Anacostia MS4 area, as opposed to the two fecal coliform WLA values that were previously provided for the upper and lower Anacostia MS4 areas.

Table 2: MS4, Direct Drainage, and CSS Areas of Tributary and Sewershed Segments							
Main-stem Segment	Subshed	MS4 Area - Closed Channel (acres)	MS4 Area – Open Channel (acres)	Open Channel Direct Drainage Area (acres)	Mainstem Direct Drainage Area (acres)	CSS Area (acres)	Grand Total (acres)
	Navy Yard	24.4					24.4
	Naylor	131.0					131.0
	Suitland-Stickfoot	1060.8		16.3			1077.0
	Mainstem Direct Drainage				523.4		523.4
Anacostia Lower (Total)		**1567.5**	**29.5**	**108.4**	**523.4**		**2199.3**
Anacostia Upper	Benning-ecap	898.7					898.7
	DC Jail SE	19.0					19.0
	Fairlawn SE	10.7					10.7
	Fort Chaplin Tributary	140.3	132.2	20.5			293.0
	Fort Davis Tributary	130.3	59.7	44.1			234.1
	Fort Dupont Tributary		49.8	382.1			431.9
	Fort Lincoln NE	222.9					222.9
	Hickey Run		825.6	268.6			1094.2
	Kingman Lake		295.6	295.5			591.2
	Lower Beaverdam Creek		1.9	28.8			30.6
	Nash Run		296.7	12.3			309.0
	Northwest Branch		1976.4	11.7			1988.1
	Pope Branch	43.6	171.9	64.9			280.5
	Ridge	127.5					127.5
	Sligo Creek	240.6					240.6
	Texas Avenue Tributary	130.7	74.2	44.4			249.3
	To MD - Anacostia	238.6					238.6

Table 2: MS4, Direct Drainage, and CSS Areas of Tributary and Sewershed Segments							
Main-stem Segment	Subshed	MS4 Area - Closed Channel (acres)	MS4 Area – Open Channel (acres)	Open Channel Direct Drainage Area (acres)	Mainstem Direct Drainage Area (acres)	CSS Area (acres)	Grand Total (acres)
	US National Arboretum at New York Ave NE	6.6					6.6
	Watts Branch		1019.2	231.1			1250.3
	Mainstem Direct Drainage				791.3		791.3
Anacostia Upper (Total)		**7112.7**	**4903.2**	**1404.0**	**791.3**		**9308.0**
Potomac Lower	295 at Overlook Ave SW	102.8					102.8
	295 SW	37.7					37.7
	Blue Plains	26.2					26.2
	Oxon Cove	60.6					60.6
	Oxon Run		1808.9	345.9			2154.7
	Shepherd Parkway SE	321.5					321.5
	Mainstem Direct Drainage				2.1		2.1
	DC Water-Bolling	1203.5					1203.5
Potomac Lower (Total)		**3561.4**	**1808.9**	**345.9**	**2.1**		**3909.3**
Potomac Middle	East Potomac Park	19.0					19.0
	George-town at 30th Street	0.9					0.9
	George-town at Water Street	4.9					4.9
	Kennedy Center	30.8					30.8
	Lincoln Memorial	41.3					41.3

Table 2: MS4, Direct Drainage, and CSS Areas of Tributary and Sewershed Segments

Main-stem Segment	Subshed	MS4 Area - Closed Channel (acres)	MS4 Area – Open Channel (acres)	Open Channel Direct Drainage Area (acres)	Mainstem Direct Drainage Area (acres)	CSS Area (acres)	Grand Total (acres)
	Tidal Basin		247.0	54.5			301.4
	Washington Ship Channel		439.6	176.2			615.8
	Mainstem Direct Drainage				448.3		448.3
Potomac Middle (Total)		**783.4**	**686.6**	**230.7**	**448.3**		**1462.3**
Potomac Upper	Arizona Ave NW	157.4					157.4
	Battery Kemble Creek		92.0	139.6			231.6
	C&O Canal		490.0	97.2			587.2
	Dalecarlia Tributary		977.8	114.0			1091.8
	Foundry Branch	595.1	217.1	322.0			1134.2
	To Little Falls	162.9					162.9
	Mainstem Direct Drainage				258.5		258.5
Potomac Upper (Total)		**2692.2**	**1776.9**	**672.7**	**258.5**		**3623.4**
Rock Creek Lower	Adams Morgan at Belmont Road NW	4.8					4.8
	Cleveland Park NW	247.9					247.9
	Dumbarton Oaks		12.1	123.9			136.1
	Dupont Circle NW	3.3					3.3
	Foggy Bottom NW	9.8					9.8
	Georgetown at Q Street NW	2.0					2.0

Table 2: MS4, Direct Drainage, and CSS Areas of Tributary and Sewershed Segments

Main-stem Segment	Subshed	MS4 Area - Closed Channel (acres)	MS4 Area – Open Channel (acres)	Open Channel Direct Drainage Area (acres)	Mainstem Direct Drainage Area (acres)	CSS Area (acres)	Grand Total (acres)
	Kalorama NW	15.5					15.5
	Klingle Road NW	7.1					7.1
	Klingle Valley Run		125.5	46.3			171.7
	Mass Ave Heights NW	34.1					34.1
	Melvin Hazen Valley Branch		109.0	65.3			174.3
	Mt. Pleasant NW	9.3					9.3
	Norman-stone Creek		165.6	51.3			216.8
	Piney Branch		44.7	55.1			99.6
	Tilden St NW	61.1					61.1
	US Naval Observatory NW	48.9					48.9
	Woodley Park at Beach Dr NW	15.8					15.8
	Woodley Park NW	93.9					93.9
	Mainstem Direct Drainage				346.6		346.6
Rock Creek Lower (Total)		**1010.2**	**456.8**	**341.8**	**346.6**		**1698.7**
Rock Creek Upper	16th Street Heights	8.5					8.5
	Beach Drive NW in Rock Creek Park	16.8					16.8
	Bingham Run		85.7	80.4			166.2

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Table 2: MS4, Direct Drainage, and CSS Areas of Tributary and Sewershed Segments							
Main-stem Segment	**Subshed**	**MS4 Area - Closed Channel (acres)**	**MS4 Area – Open Channel (acres)**	**Open Channel Direct Drainage Area (acres)**	**Mainstem Direct Drainage Area (acres)**	**CSS Area (acres)**	**Grand Total (acres)**
	Blagden Run		193.7	10.2			203.9
	Broad Branch		899.9	244.7			1144.6
	Colonial Village	44.5					44.5
	Crestwood NW	12.5					12.5
	Fenwick Branch		161.7	57.5			219.1
	Luzon Branch		590.6	52.9			643.4
	Military Road NW	87.8					87.8
	Milkhouse Run		25.4	40.6			66.1
	Pinehurst Branch		246.0	200.6			446.6
	Portal Branch		62.0	8.8			70.8
	Shepherd Park NW	99.9					99.9
	Soapstone Creek		410.8	103.6			514.4
	Walter Reed Army Medical Center	37.6					37.6
	Western Ave Near 32nd Street	39.3					39.3
	Mainstem Direct Drainage				957.1		957.1
Rock Creek Upper (Total)		**3022.6**	**2675.7**	**799.4**	**957.1**		**4779.1**
CSS						**12218.1**	**12218.1**
Grand Total		**19750.0**		**3902.8**	**3327.4**	**12218.1**	**39198.3**

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Table 3: MS4, Direct Drainage, and CSS Areas of Chesapeake Bay Segments				
Chesapeake Bay Segment	**MS4 Area (acres)**	**Direct Drainage Area (acres)**	**CSS Area (acres)**	**Grand Total (acres)**
ANATF_DC	6893.2	2952.0		9845.2
ANATF_MD	2522.2	105.8		2628.0
POTTF_DC	9200.8	4021.9		13222.7
POTTF_MD	1133.8	150.5		1284.4
CSS			12218.1	12218.1
Grand Total	**19750.0**	**7230.2**	**12218.1**	**39198.3**

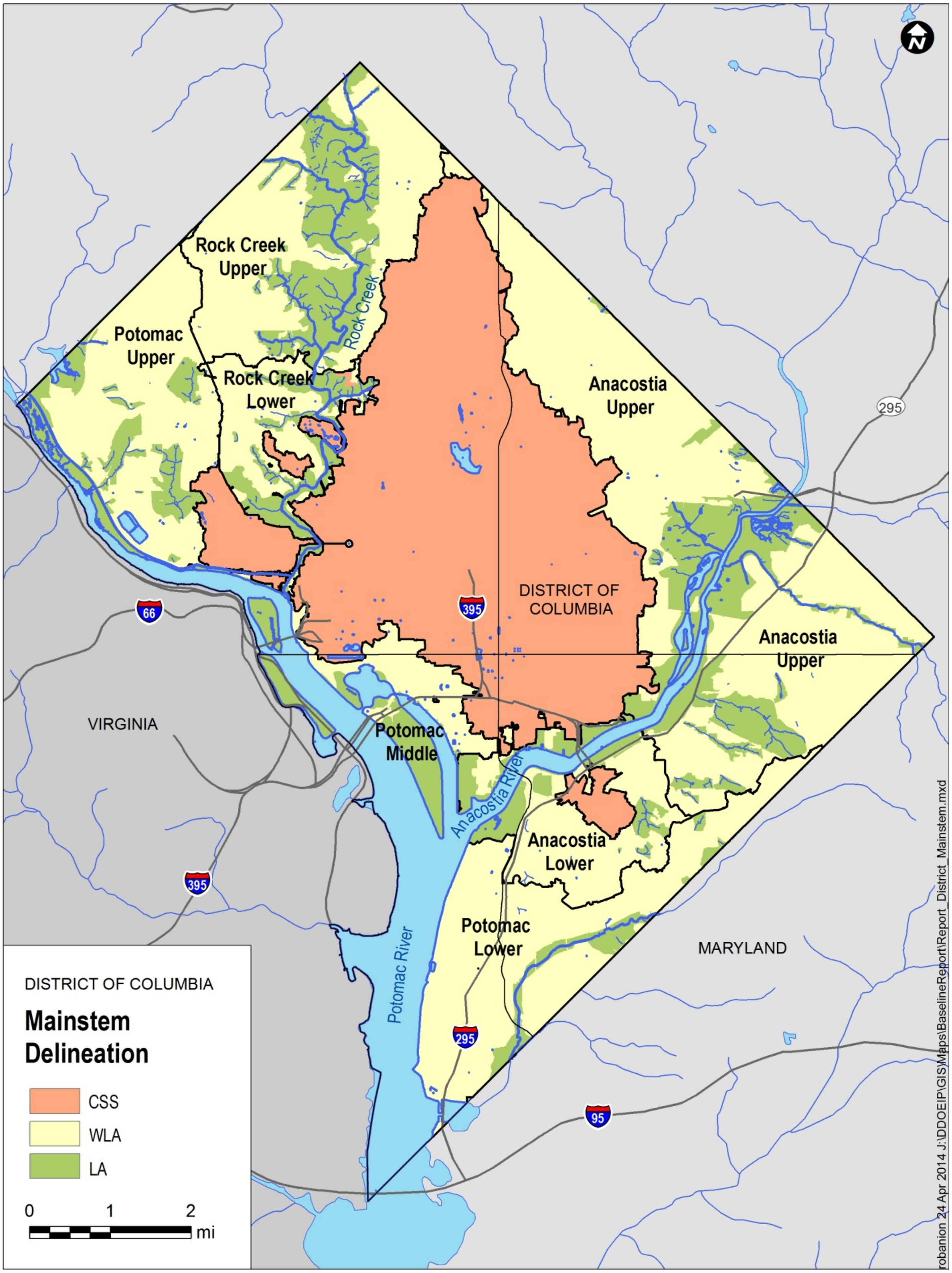

Figure 2: Mainstem Segment Delineation

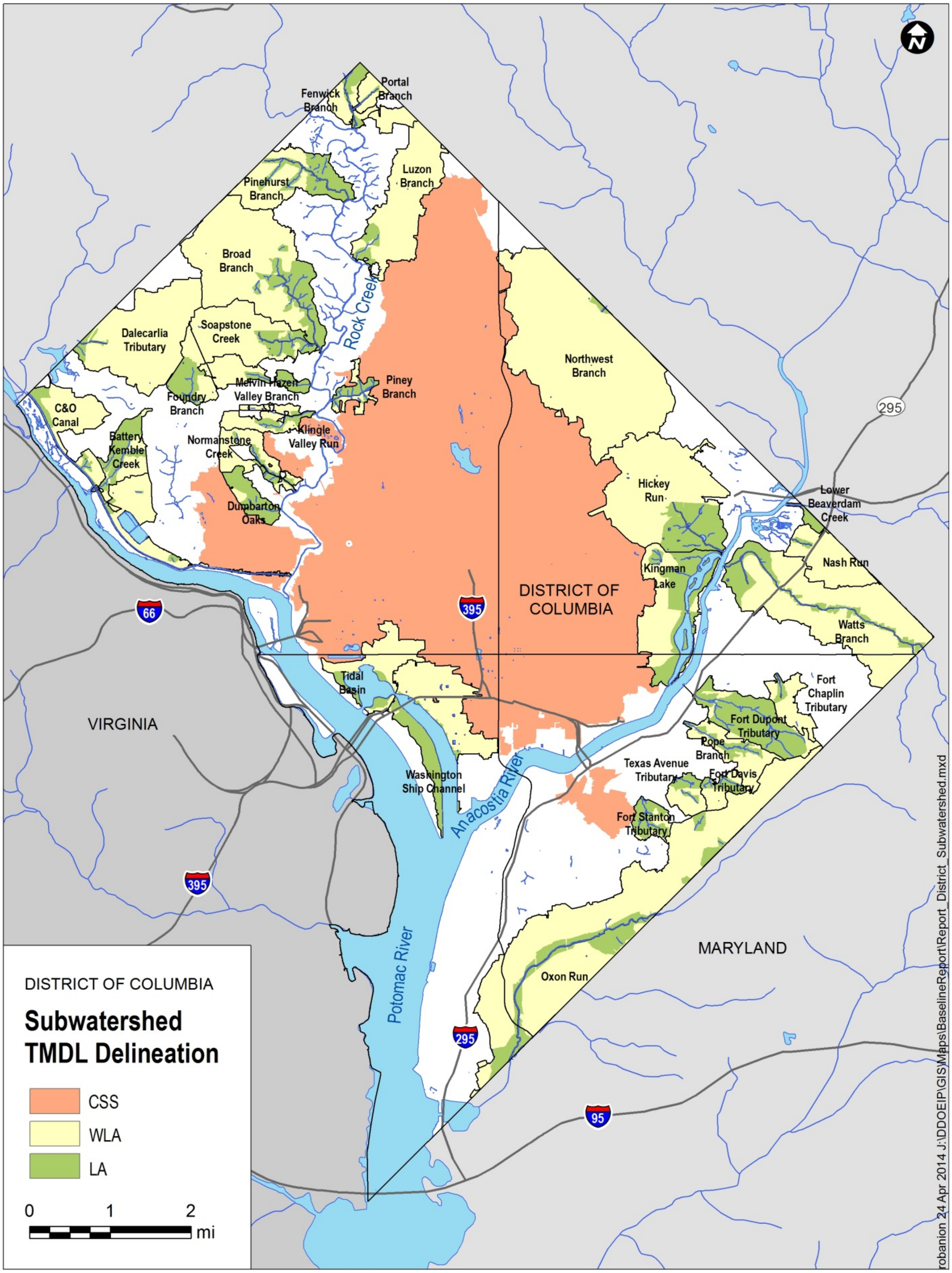

Figure 3: Subwatershed Delineation

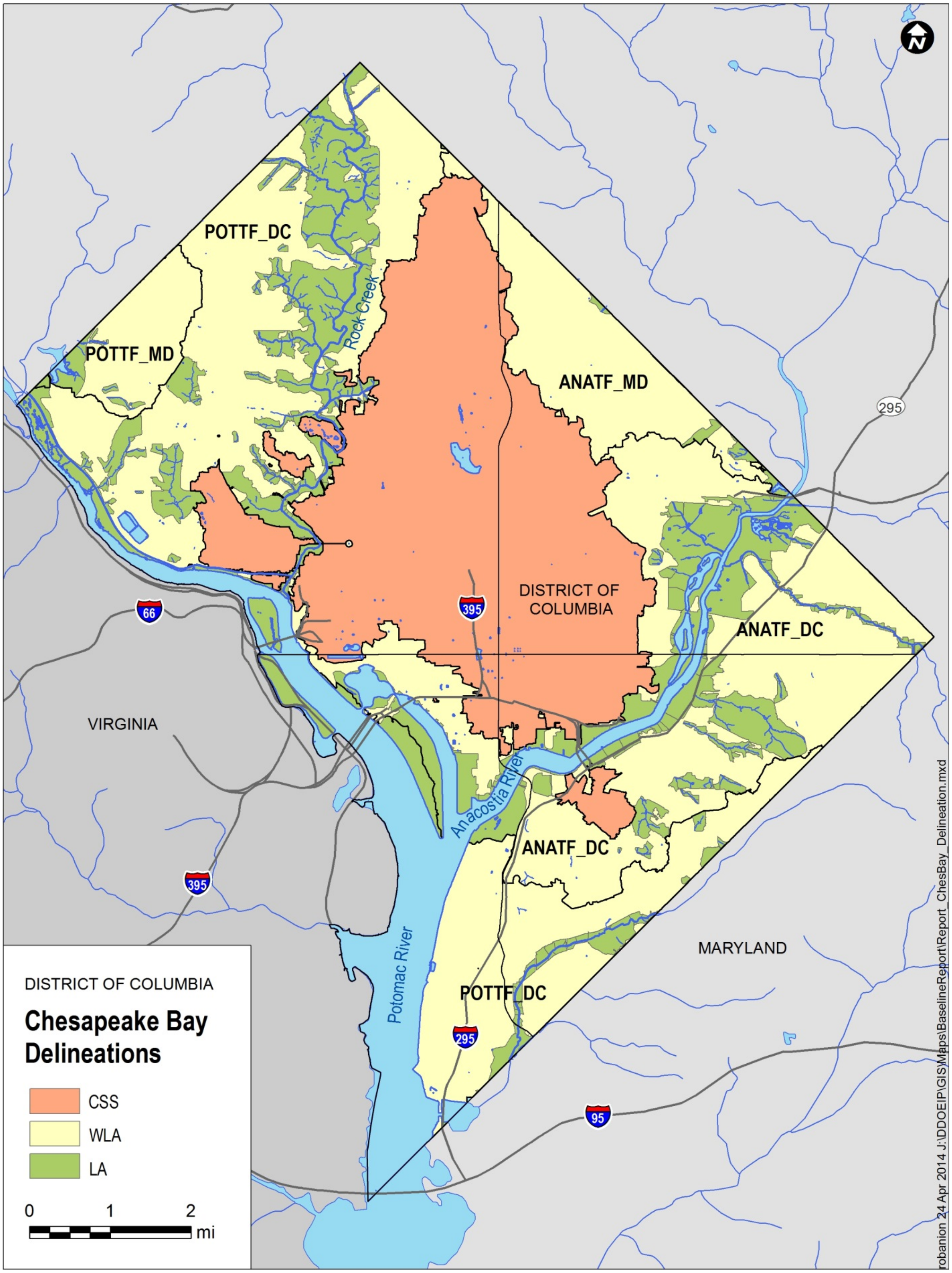

Figure 4: Chesapeake Bay Segment Delineation

3.3 **Assigning WLAs and LAs to GIS Polygons**

After finalizing the delineation, all MS4 WLAs and nonpoint source LAs were assigned to GIS polygons that represented where these WLAs and LAs actually applied on the ground. A hierarchical categorization of the GIS polygons was developed in order to make these assignments. This hierarchical categorization of GIS polygons was necessary because of the different scales at which the District's TMDLs assign WLAs and LAs. These "scales" included:

- Small tributaries and other minor waterbodies like Kingman Lake, the Washington Ship Channel and the C&O Canal
- Large mainstems that contain small tributary areas
- Chesapeake Bay TMDL segment-shed level, which represented a more "jurisdictional" approach rather than a strict watershed approach (i.e., polygons were assigned based on a combination of political and watershed boundaries rather than on solely watershed boundaries)

Thus, polygons representing tributary-scale areas needed to be "rolled up" and included as part of mainstem-scale areas. For example, the polygons representing the Anacostia small tributaries (e.g., Texas Avenue Tributary, Hickey Run, Fort Davis, Fort Chaplin, etc.) needed to be included when developing the polygons for the Anacostia (Figure 5).

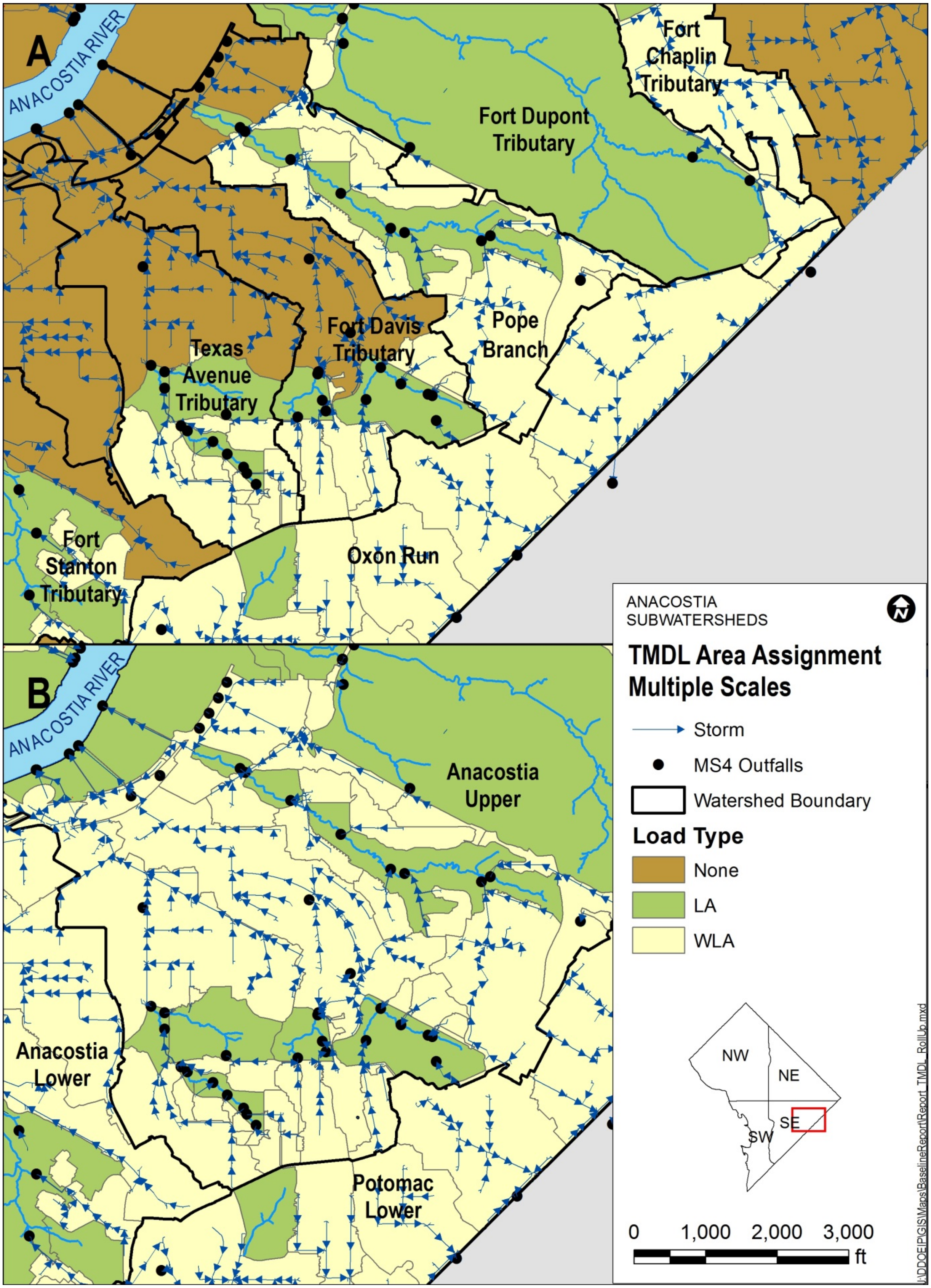

Figure 5: TMDL area assignment rollup. Map A is the subwatershed scale. Map B is the mainstem scale.

As described in the previous section, separate polygons were created for the open channel portion of tributary MS4 subsheds, the entirety (open and closed channel) of tributary MS4 subsheds, tributary direct drainage subsheds, mainstem MS4 subsheds, and mainstem direct drainage subsheds. MS4 WLAs and nonpoint source LAs were then assigned to various combinations of GIS polygons to represent where the various “scales” of MS4 WLAs and nonpoint source LAs applied on the ground. The finest scale TMDLs (TMDLs for small tributaries and other minor waterbodies) could be assigned to individual polygons (e.g., the Klingle Valley WLAs could be assigned to the Klingle Valley open channel MS4 polygon and the Klingle Valley LAs could be assigned to the Klingle Valley direct drainage polygon); but the larger scale TMDLs (e.g., TMDLs for the Upper and Lower Anacostia) needed to be assigned to a large polygon constructed from multiple smaller polygons consisting of tributary MS4 subsheds, tributary direct drainage subsheds, mainstem MS4 subsheds, and mainstem direct drainage subsheds in that watershed. In order to develop the correct larger polygon from multiple smaller polygons, a hierarchical categorization of polygons was utilized.

The hierarchical classification designed to assign the WLAs and LAs consisted of five “Watershed” and two “Sewer Type” classifications. These are described below:

WatershedL1

These are the three major basins in the District (Anacostia, Potomac, and Rock Creek). Every polygon was assigned to one of these three major basins.

WatershedL2

This classification consists of subdivisions of the three major basins in the District. The classification includes Upper and Lower Anacostia, (entire) Anacostia, Upper and Lower Rock Creek, and Upper, Middle and Lower Potomac. Every polygon in the District was assigned to one of these Watershed L2 classifications. This was the scale to which the District’s mainstem TMDLs were assigned.

WatershedL3

This is the primary classification level for individual polygons, and it consists of MS4 sewersheds, small tributaries, and other delineated areas. There are 82 distinct classifications at this level.

WatershedL4

A fourth watershed level was necessary to address TMDLs in the Watts Branch subwatershed. In several TMDLs the watershed was broken into Upper and Lower components. However, other TMDLs assigned MS4 WLAs to Watts Branch as a whole at the Watershed L3 classification level. The WatershedL4 classification level allows for TMDLs to be assigned at both scales.

WatershedL5

The WatershedL5 level is used for further sub-classification of small waterbody (WatershedL3) polygons as being open channel or closed pipe. This allows the assignment of WLAs for small tributaries, because the DC Small Tributaries model (DCST) assigns WLAs to only the open channel areas of the small tributaries.

SewerTypeL1

Every polygon was classified as either “MS4,” “CSS,” or “None (direct drainage).” This classification was used to determine if the polygon should be assigned a WLA or an LA. Polygons classified as “MS4” were assigned MS4 WLAs; polygons classified as “None (direct drainage)” were assigned nonpoint source LAs; and polygons classified as “CSS” were not considered for further analysis because they represented combined sewer areas, which are not covered under DDOE’s MS4 NPDES permit, and thus are not part of the Consolidated TMDL IP requirement.

SewerTypeL2

The SewerTypeL2 level is a further sub-classification of the polygons in the MS4. This classification assigns polygons in the MS4 area as either "MS4 direct drainage" or "MS4 closed pipe." This allows WatershedL5 areas to be assigned to WatershedL3 (mainstem) allocations. Areas with a WatershedL5 designation of "MS4 closed pipe" are assigned to WatershedL3 mainstem WLAs and areas with a WatershedL5 designation of "MS4 direct drainage" are assigned to WatershedL3 (mainstem) LAs.

These various classifications were used in a series of GIS queries to assign WLAs and LAs from the individual TMDLs to the GIS polygons. The GIS queries functioned as a type of "logical matrix" whereby individual conditions were set among the various classification categories to assign WLAs and LAs to various combinations of individual polygons (and thereby to mainstem and tributary waterbodies) according to the various rules under which the original TMDLs were done. Because the polygons were established at the scale of the smallest waterbody for which there are TMDLs (the WatershedL3 tributary/small waterbody scale), WLAs and LAs from individual TMDLs may be assigned to one or more polygons depending on the scale of the original TMDL (i.e., loads from the small tributary TMDLs would be assigned to less total polygons than would the loads from a mainstem waterbody TMDL). For example, the WLA for a mainstem TMDL would be assigned to all of the polygons representing the tributaries to that mainstem, whereas the WLA for a tributary TMDL would only be assigned to the one polygon that represents the MS4 area of that tributary. GIS can then be used to track progress in reducing loads, because load reductions achieved by BMPs implemented in any of the polygons which are assigned as part of a WLA or a LA can be applied to the WLA or LA.

Small Tributary Load Assignments

As described above, the WatershedL3 level is the classification level for tributary and other waterbody TMDLs. For each of the polygons with a WatershedL3 classification corresponding to one of the tributary or other waterbody TMDLs (e.g., Klingle Valley, Hickey Run, Foundry Branch, etc.), MS4 WLAs and LAs are assigned according to the following logic. First, all of the WatershedL3 tributary or other waterbody polygons are assigned as MS4 area under the SewerTypeL1 classification because all of these tributaries and other waterbodies are at least partially served by the MS4 system. Next, the WatershedL5 classification is reviewed. If the WatershedL5 classification is "Open," that means that the polygon is an open channel section of the waterbody, which is the area used for small tributaries modeled by the DCST. Subsequently, if the SewerTypeL2 classification for this open channel section of the waterbody is "MS4 closed pipe," that means that the open channel area is served by the MS4 system, and thus that the polygon should be assigned to the WLA for that TMDL. In contrast, if the SewerTypeL2 classification for this open channel section of the waterbody is "Direct Drainage," that means that the open channel area is not served by the MS4 system (i.e., it is overland flow direct drainage into the tributary), and thus that the polygon should be assigned to the LA for that TMDL. In contrast to polygons with WatershedL5 classifications of "Open," if the WatershedL5 classification of a polygon is "Closed," that means that the polygon represents a section of the waterbody that is completely piped (e.g., no open channel). By definition, the DCST, which defines all small tributary WLAs, does not include closed channel areas as part of the WLA. Therefore, this area is not included anywhere in the small tributary allocations.

This decision matrix is shown in Table 4 below:

Table 4: Decision Matrix for Assigning Polygons for WLAs and LAs for Small Tributaries				
WatershedL3	**SewerTypeL1**	**WatershedL5**	**SewertypeL2**	**Result**
All Sheds	MS4	Open	MS4 closed pipe	WLA
All Sheds	MS4	Open	Direct Drainage	LA
All Sheds	MS4	Closed	MS4 closed pipe	Null

Watts Branch Load Assignments

For several TMDLs (Anacostia and Tributaries Metals and Organics [2003]; Anacostia and Tributaries Bacteria [2003] and Watts Branch TSS [2003]), Watts Branch was broken into Upper and Lower components and different loads were assigned to Upper and Lower Watts Branch. Since the entire Watts Branch subwatershed was also assigned loads in other TMDLs, Watts Branch as a whole was classified at the WatershedL3 level. Therefore, in order to accommodate loads for Upper and Lower Watts Branch, these classifications were assigned to Watts Branch at the WatershedL4 level. Once that was accomplished, the load assignments for Upper and Lower Watts Branch were assigned following the same logic as described above for small tributaries.

Mainstem Load Assignments

As described above, the WatershedL2 level is the classification level for mainstem waterbody TMDLs. For each unique WatershedL2 value (Upper and Lower Anacostia, (entire) Anacostia, Upper and Lower Rock Creek, and Upper, Middle and Lower Potomac), the combination of SewerTypeL1, WatershedL5, and SewerTypeL2 are queried. SewerTypeL1 data can be “MS4,” “CSS,” or “None (direct drainage).” If SewerType L1 is “None (direct drainage),” the polygon is not served by the MS4 system, and is assigned to the LA of the mainstem TMDL. If the SewerTypeL1 classification is “MS4”, the polygon is in the MS4 area, and the data from the remainder of the query is used to help assign the load. If the WatershedL5 data shows that the area is “Closed” and the SewerTypeL2 indicates “MS4 closed pipe,” that means that the polygon represents a section of the waterbody that is served by a completely piped MS4 system (e.g., the MS4 system does not first flow into an open channel tributary and then into the mainstem). Therefore, this area is assigned to the WLA for the mainstem. In contrast, if the WatershedL5 data indicates that the area is an open channel (“Open”), additional information from the SewerTypeL2 classification is required. If the SewerTypeL2 data shows that the areas is served by “MS4 closed pipe,” then it is assigned to the WLA. If the SewerTypeL2 field shows that the area is MS4 direct drainage (i.e., it is direct overland flow to the waterbody), it is assigned to the LA. This is also how the assignments of these areas were made for the original Rock Creek and Potomac TMDLs. However, due to the differences in the way that the Potomac, Anacostia, and Rock Creek were modeled in the original TMDLs, this area was not included at all for the original Anacostia mainstem TMDLs (see Attachment 1 [*DC TMDL Modeling Approach for Mainstems and Tributaries*] to Appendix A, *Technical Memorandum: Model Selection and Justification*, for a discussion of the modeling of mainstem waterbodies and how this impacted the assignment of WLAs and LAs).

The logic behind these queries is shown in Table 5 below:

Table 5: Decision Matrix for Assigning Polygons for WLAs and LAs for Mainstems				
WatershedL2	**SewerTypeL1**	**WatershedL5**	**SewerTypeL2**	**Result**
All Sheds	None (direct drainage)	N/A	N/A	LA
All Sheds	MS4	Closed	MS4 closed pipe	WLA
All Sheds	MS4	Open	MS4 direct drainage	LA
All Sheds	MS4	Open	MS4 closed pipe	WLA

3.4 QA/QC of Delineations and Assignment of WLAs and LAs

After initial delineations and assignments of WLAs and LAs to specific GIS polygons were completed, a series of QA/QC steps were taken to ensure that the delineations were both accurate relative to current information on the extent of the MS4 system, but that they were also able to reflect the sewer and watersheds as they were originally delineated in the TMDL studies. QA/QC included tabulation of areas from the original TMDLs (either through evaluation of model input files on sewer/watershed areas or tables of these areas in TMDL-related documents) and comparison of these areas to areas of the updated delineations from the geodatabase. QA/QC also included visual comparison of the watershed and sewershed boundaries between maps from the TMDL documents, GIS files from the original TMDL modeling, and current delineations. In several cases, discrepancies were found between the sewershed and watershed delineations completed for the original TMDLs and the delineations based on updated data. These discrepancies were resolved through further research into the original TMDL data, review of topography and other outside mapping data, and engineering judgment. Corrections to delineations were made where necessary. In general, delineations were made to conform to the most current data on MS4 drainage areas. By utilizing the most updated information on MS4 areas, the modeling will reflect current loads from MS4 areas and load reductions from implementation of BMPs that can help meet MS4 WLAs. However, in some cases (particularly in cases where it was unclear whether TMDLs were supposed to apply to an entire watershed or only parts of a watershed), delineations and/or polygon assignments were changed to reflect what was in the original TMDL. In all cases where changes were made to delineations, notes were made in the geodatabase to identify the changes. Keeping notes on the changes will help allow for flexibility in how the watershed and sewershed data can be used. For example, if there is a need to compare loads modeled with the IP modeling tool to loads from the original TMDLs, delineations can be changed to reflect the delineations in the original TMDL studies.

Another QA/QC check involved the comparison of areas from the current geodatabase with areas in the original TMDLs (see Table 6). In general, areas agreed within ± 20 percent, which was deemed to be acceptable for this type of exercise with multiple delineations. However, several subsheds, including seven (7) small tributaries and the ANATF-MD Chesapeake Bay segment shed, had discrepancies of more than 20 percent. These are summarized in Table 6 below, along with a discussion of how the discrepancies were resolved.

Table 6: Comparison of Watershed Areas Between Original and Updated Watershed and Sewershed Delineations Geodatabase

WATERBODY	Area (acre)								
	MS4			Direct Drainage			All (MS4 + DD)		
	IPMT	TMDL	% Diff	IPMT	TMDL	% Diff	IPMT	TMDL	%Diff.
Anacostia Lower	1,567	Not found	-	632	110	476.44%	2,199	Not found	-
Anacostia Upper	7,112	Not found	-	2,195	215	922.68%	9,308	Not found	-
ANATF_DC	6,893	Not found	-	2,952	Not found	-	9,845	11,096	-11.27%
ANATF_MD	2,522	Not found	-	106	Not found	-	2,628	1,888	39.16%
Battery Kemble Creek	92	Not found	-	140	Not found	-	232	239	-3.03%
Broad Branch	900	Not found	-	245	Not found	-	1,145	1,129	1.37%
C&O Canal	490	426	15.03%	97	Not found	-	587	Not found	-
Dalecarlia Tributary	977	Not found	-	114	Not found	-	1,091	1,111	-1.83%
Dumbarton Oaks	12	Not found	-	124	Not found	-	136	168	-18.96%
Fenwick Branch	162	Not found	-	57	Not found	-	219	203	7.68%
Fort Chaplin Tributary	132	Not found	-	21	Not found	-	153	204	-24.98%
Fort Davis Tributary	60	Not found	-	44	Not found	-	104	72	44.84%
Fort Dupont Tributary	50	Not found	-	382	Not found	-	432	474	-8.94%
Fort Stanton Tributary	29	Not found	-	92	Not found	-	122	125	-2.50%
Foundry Branch	90	Not found	-	106	Not found	-	196	168	17.11%
Hickey Run	826	Not found	-	269	Not found	-	1,094	1,081	1.25%
Kingman Lake	296	Not found	-	296	Not found	-	591	Not found	-
Klingle Valley Run	125	Not found	-	46	Not found	-	172	354	-51.46%
Lower Beaverdam Creek	2	Not found	-	29	Not found	-	31	Not found	-
Luzon Branch	590	Not found	-	53	Not found	-	643	648	-0.78%
Melvin Hazen Valley Branch	109	Not found	-	65	Not found	-	174	184	-5.32%
Nash Run	297	Not found	-	12	Not found	-	309	286	8.02%
Normanstone Creek	166	Not found	-	51	Not found	-	217	249	-13.01%
Northwest Branch	1,976	Not found	-	12	Not found	-	1,988	Not found	-
Oxon Run	1,800	Not found	-	344	Not found	-	2,144	Not found	-
Pinehurst Branch	246	Not found	-	201	Not found	-	446	443	0.83%
Piney Branch	45	Not found	-	55	Not found	-	100	61	62.13%
Pope Branch	172	Not found	-	65	Not found	-	237	232	2.25%
Portal Branch	62	Not found	-	9	Not found	-	71	73	-2.98%
Potomac Lower	3,552	Not found	-	346	Not found	-	3,898	Not found	-
Potomac Middle	783	Not found	-	679	Not found	-	1,462	Not found	-
Potomac Upper	2,692	Not found	-	931	Not found	-	3,622	Not found	-
POTTF_DC	9,190	Not found	-	4,019	Not found	-	13,210	12,396	6.56%
POTTF_MD	1,133	Not found	-	150	Not found	-	1,283	1,311	-2.12%
Rock Creek Lower	1,010	826	22.32%	688	2,707	-9.70%	1,699	6,131	5.64%
Rock Creek Upper	3,022	2,598	16.32%	1,756			4,778		
Soapstone Creek	411	Not found	-	104	Not found	-	514	520	-1.09%
Texas Avenue Tributary	74	Not found	-	44	Not found	-	119	176	-32.54%
Tidal Basin	247	Not found	-	54	Not found	-	301	Not found	-

Table 6: Comparison of Watershed Areas Between Original and Updated Watershed and Sewershed Delineations Geodatabase

WATERBODY	Area (acre)								
	MS4			Direct Drainage			All (MS4 + DD)		
	IPMT	TMDL	% Diff	IPMT	TMDL	% Diff	IPMT	TMDL	%Diff.
Washington Ship Channel	440	Not found	-	176	Not found	-	616	Not found	-
Watts Branch	1,019	Not found	-	231	Not found	-	1,250	1,161	7.69%
Watts Branch - Lower	261	Not found	-	145	Not found	-	406	Not found	-
Watts Branch - Upper	758	Not found	-	86	Not found	-	844	Not found	-

Table 7: Review and Resolutions of Major Discrepancies in Watershed Area Between Small Tributary and Geodatabase

TMDL Watershed	Calculated Area (from Geodatabase) (acres)	Reference Area (from Input Files to DCST or Other Sources) (acres)	Percent Difference (%)	Discussion
Dalecarlia Tributary	270	1,111	-75.73	The reference area and GIS shapefiles for this watershed indicate that the DCST used the "Mill Creek" watershed, in addition to the Dalecarlia Tributary drainage area, to calculate loads for the Dalecarlia Tributary. Therefore, the current database was modified to include the Mill Creek drainage area within the Dalecarlia Tributary watershed.
Fort Chaplin Tributary	153	204	-24.98	The DCST included area that was "closed pipe" (and therefore should not have been included in the watershed area). The current geodatabase correctly excludes this area from the Fort Chaplin TMDLs.
Fort Davis Tributary	104	72	44.84	The DCST assigned a portion of the Fort Davis Tributary watershed to Texas Avenue, accounting for the discrepancy in areas. The current delineation correctly assigns this area to the Fort Davis Tributary.
Foundry Branch	539	168	221.65	DCST assigns MS4 WLA only to the upper part of the Foundry Branch watershed. Therefore, the delineation in the current database was modified to include only the upper part of the watershed for Foundry Branch TMDLs.

Table 7: Review and Resolutions of Major Discrepancies in Watershed Area Between Small Tributary and Geodatabase				
TMDL Watershed	**Calculated Area (from Geodatabase) (acres)**	**Reference Area (from Input Files to DCST or Other Sources) (acres)**	**Percent Difference (%)**	**Discussion**
Klingle Valley Run	172	354	-51.46	The DCST included several areas that actually discharge directly to Upper Rock Creek (and not into the Klingle Valley Tributary) in the Klingle Valley shapefile. Therefore, the DCST was incorrect and there is no need to change the delineations.
Piney Branch	114	61	85.63	Updated delineation of this watershed had assigned some area as MS4 that was potentially in the CSS. Additional review concluded that this area should be re-classified from MS4 to CSS area, thereby resolving the discrepancy.
Texas Avenue Tributary	119	176	-32.54	See note for Fort Davis Tributary
ANATF_MD	2,628	1,888	39.16	Chesapeake Bay Program incorrectly assigned a large area of Northeast DC (~740 acres) to ANATF_DC that should have been assigned to ANATF_MD. This error was corrected in the updated delineation. No reciprocal error flag occurred in ANATF_DC because ANATF_DC is a much larger area, and so this discrepancy was less than 20% of the total ANATF_DC area

4 Results and Discussion

The delineation of TMDL watersheds and sewersheds using the most current data on the MS4 system, including the sewer geodatabase, resulted in several changes to watersheds and sewersheds relative to those used to develop the original TMDLs. Some of these changes were due to an updated understanding of the sewer system and of where flows discharge (for example, see the discussions of Fort Davis, Klingle Valley Run, Piney Branch and Texas Avenue in Table 7 above). In other cases, errors in the original assignment of areas to watersheds and sewersheds were corrected (for example, see discussion of Fort Chaplin in Table 7 above). Finally, in several cases, the logic for assigning WLAs and LAs to specific polygons was modified to accommodate the way that WLAs and LAs were assigned in the original TMDLs (for example, see the discussion of Dalecarlia and Foundry Branch in Table 7 above).

As described in the **Purpose** section above, the delineation of watersheds and sewersheds is critical to identifying where MS4 WLAs and nonpoint source LAs apply on the ground. Because of the complexity of the original TMDL modeling, different TMDL studies used different logic for determining the areas to which that TMDL's MS4 WLAs, and nonpoint source LAs apply. The differences in modeling and consequent identification of MS4 and nonpoint source areas included in the TMDLs are particularly important with respect to mainstems versus small tributaries and other waterbodies. Therefore, understanding the delineation and extent of watersheds and sewersheds from the original TMDLs is of critical importance. It is also important to understand the most updated information on the MS4 sewersheds, because the current MS4 delineations do not always match up exactly with the delineations used in the original TMDLs. One reason for this is that the writers of the original TMDLs did not have access to the sewers geodatabase that has subsequently been developed to help track the MS4 and CSS areas in the District. The sewers geodatabase has been critical in the development of updated MS4 and unsewered areas delineations.

One ramification of the differences between the watershed and sewershed delineations in the original TMDLs and the updated watershed and sewershed delineations is that loads calculated from these updated areas will not match the loads calculated for the original TMDLs. Because load is a function of runoff, which in turn is dependent on the contributing drainage area, changes in area inherently impact loads. However, any changes in loads due to changes in land areas delineated for the TMDLs reflect the actual current conditions in that watershed/sewershed using the most updated data. This greatly increases confidence in the IP and its ability to affect changes in the watersheds and sewersheds that will lead to meeting applicable MS4s and improving water quality in District waterbodies. Any changes that are made to the sewersheds and watersheds relative to what was used in the original TMDLs will be documented and tracked so that comparisons can be made to the original data. For example, if boundaries of a specific sewershed have been updated from the original TMDL boundaries, these original boundaries will be documented so that current loads based on the updated load calculation methodology (See Appendix A, *Model Selection, Justification and Validation*, for a discussion of the load calculation methodology used in the IP) can be calculated for the old sewershed boundaries, and compared to the original TMDL loads to determine the similarity of the loads. This can serve as a method for validating the load calculation methodology.

In conclusion, the updated watershed and sewershed delineations and the assignment of WLAs and LAs to appropriate GIS polygons will be instrumental in the development of a defensible Consolidated TMDL IP that is based on the most up-to-date understanding of MS4 areas, but also considers the intent of the original TMDLs.

References

U.S. EPA. 2011. *Authorization to Discharge under the National Pollutant Discharge Elimination System Municipal Separate Storm Sewer System Permit.* NPDES Permit No. DC0000221.

U.S. EPA. 2012. *Authorization to Discharge under the National Pollutant Discharge Elimination System Municipal Separate Storm Sewer System Permit.* NPDES Permit No. DC0000221. Modification #1.

Appendix C

Technical Memorandum

Stream Erosion Methodology

Table of Contents

1 Introduction 1

2 Purpose 1

3 Technical Approach 1

4 Results and Discussion 8

References 9

Attachments 11

DISTRICT DEPARTMENT OF THE ENVIRONMENT

List of Tables

Table 1: Measured Rate of In-stream Erosion in District Streams 3
Table 2: WTM In-Stream Erosion Relationships 4
Table 3: Comparison of In-Stream Erosion Load Calculation Methods for Hickey Run 6
Table 4: Proposed Scaling Factors 6
Table 5: Comparison of in-stream erosion loads 7

List of Figures

Figure 1: Empirical equation established by MDE to correlate percent watershed impervious and percent stream bank erosion 5
Figure 2: SBE (as a percent of total TSS load) as a Function of Imperviousness and Stream Degradation Potential 7

1 Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in the District's Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) permit (U. S. EPA 2011 and U. S. EPA 2012). The IP will define and organize a multi-year process centered on reducing pollutant loads originating within the District MS4. The level of pollutant control will be based on past TMDL studies performed to protect impaired water bodies in the District. The IP will include a summary of the regulatory compliance strategy to satisfy TMDL-related permit requirements, a summary of data and methods used to develop the IP, specific prioritized recommendations for stormwater control measures, a schedule for implementation and attainment of Waste Load Allocations (WLAs), and a method for tracking progress. Substantial public involvement will be sought in plan development.

This Technical Memorandum on the methodology for estimating pollutant loads associated with in-stream erosion is one in a series of technical memoranda that provide detailed information on research, analysis, programs and procedures that support development of the Consolidated TMDL IP.

2 Purpose

There are two primary generators of pollutant loads applicable to the District's MS4 area: runoff loads associated with the build-up and wash-off of pollutants from the surrounding watershed, and in-stream loads associated with erosion of native bed and bank material and accumulated legacy sediments. Runoff loads are discussed further in separate technical memoranda. In-stream erosion loads are the topic of this Technical Memorandum.

The purpose of this Technical Memorandum is to document the selection of the method used to calculate in-stream erosion loads. The **Technical Approach** employed includes:

- A review of accounting for and calculating in-stream erosion loads in District TMDL development.
- A literature review of in-stream erosion load calculation methods.
- An evaluation of in-stream erosion load calculation methods and the selection of a method to apply in the IP Modeling Tool.
- A review of applicable sediment delivery ratios.

The **Results** section of this Technical Memorandum presents the selected in-stream erosion load calculation method and provides commentary on the rationale for the method's selection and use in the IP.

3 Technical Approach

3.1 Review of In-Stream Erosion in the District TMDLs

An evaluation of documentation from the various District TMDLs was conducted to determine if and how in-stream erosion was calculated in the development of each TMDL, and whether the in-stream erosion load is considered a point source or a non-point source. This evaluation was used to determine whether and how in-stream erosion should be accounted for in the baseline pollutant load modeling required to support development of the Consolidated TMDL IP. A full review of how in-stream erosion is handled in each of the TMDLs is presented in Attachment A.

There are five TSS TMDLs for the District, and each addresses in-stream erosion to some extent. These include:

1. 2002 TMDL for TSS for the Upper and Lower Anacostia – This TMDL implicitly accounts for in-stream erosion by applying a high TSS EMC value for "open channel" tributaries (i.e., tributaries that do not have piped sections – which include Watts Branch, Popes Branch, Fort Dupont, and Nash Run) that are thought to have significant in-stream erosion. This high TSS EMC represents TSS contributions from in-stream erosion as well as from land-based sources. All stormwater loads, including loads from in-stream erosion, are considered a non-point source and are accounted for under the Load Allocation (LA).
2. 2003 TMDL for Total Suspended Solids in Watts Branch – This TMDL back-calculates the individual TSS contribution from land sources and in-stream erosion using the total Watts Branch TSS load estimated in the 2002 Anacostia TMDL. The contribution of TSS from in-stream erosion was estimated to be 52 tons/yr. The loads from in-stream erosion are considered a non-point source and are accounted for under the LA.
3. 2007 TMDL of Sediment/Total Suspended Solids for the Anacostia River Basin – This TMDL calculates in-stream erosion explicitly, but only for Watts Branch within the District (in-stream erosion is calculated for other water bodies in Maryland). The contribution of TSS from in-stream erosion in Watts Branch was estimated to be 67 tons/yr. The TMDL does not calculate in-stream erosion for other DC tributaries. The Watts Branch in-stream erosion load is considered a point source and is accounted for under the MS4 WLA.
4. 2010 Chesapeake Bay TSS TMDL – The Bay TMDL documentation implies that in-stream erosion is implicitly accounted for through model calibration. The documentation also implies that loads from in-stream erosion are considered a point source and are accounted for under the MS4 WLA.

The inconsistency in accounting for in-stream erosion in the TMDLs is partly due to the fact that EPA, over time, has evolved a policy of specifying that in-stream sediment loads in urban areas are to be assigned to the MS4. This evolving policy in turn affected where it is accounted for in the TMDL IP baseline load modeling. Several factors ultimately informed the decision to include in-stream erosion in the MS4 baseline load modeling for addressing the Chesapeake Bay TMDL, and in the direct drainage baseline modeling for local TMDLs. These factors include the following:

- The Chesapeake Bay Program (CBP) gives credit towards MS4 WLAs for stream restoration. A significant component of the credit accounting for stream restoration relates to the control of in-stream erosion (CWP/CSN 2014). This implies that the CBP links in-stream erosion at least in part to MS4 flows. Therefore, in-stream erosion will be included as part of the MS4 baseline load when accounting for the loads for the Chesapeake Bay TMDL.
- The local TMDLs are inconsistent in allocating the loads from in-stream erosion to the MS4 or direct drainage areas. In addition, the local TMDLs do not calculate in-stream erosion for all DC tributaries even though all tributaries are known to have varying degrees of in-stream erosion. Because of these inconsistencies, in-stream erosion will be included as part of the direct drainage baseline load, until a future time when the TMDLs can revisit the issue of in-stream erosion.

3.2 Review of In-Stream Erosion Load Calculation Method

The mechanisms of in-stream erosion are complex and often very location-specific. Stream erosion is dependent upon a number of variables, including extent and composition of development within the stream drainage area, channel geomorphology and geometry, presence and orientation of piped drainage, number of outfalls, and condition of riparian vegetation. In addition, eroded soils can be deposited at downstream "sinks" within the stream, and are not necessarily exported to the larger-order streams further downstream. Therefore, it is important to recognize that the gross in-stream erosion is not the same as the net export of sediment. While in-stream erosion occurs naturally in unaltered watersheds, it is primarily driven by changes in land use (e.g., increases in unmanaged impervious cover, alteration of, or decreases in, riparian vegetation). From a review of literature, a number of approaches were identified for estimating the rate of sediment load from in-stream erosion, and the portion of the in-stream erosion that contributes to the downstream sediment yield. These are explained in the following subsections.

3.2.a Direct Measurement

The most reliable method of determining gross in-stream erosion loads is through direct measurement. This could include estimation of lateral erosion rates from temporally varied aerial photos or strategically placed bank pins coupled with field measurement of bank heights. Direct measurement of in-stream erosion is not widely available for District water bodies and requires considerable field effort over many years. The U.S. Fish and Wildlife Service has conducted studies to estimate in-stream erosion in Hickey Run, Watts Branch, and Oxon Run. In addition, DDOE conducted measurements of in-stream erosion in Nash Run. A summary of the measured rates of erosion are presented in Table 1.

Table 1: Measured Rate of In-stream Erosion in District Streams

Name of Study	Stream	Rate of Erosion (tons/yr)	Measurement Method
2005 U.S. Fish and Wildlife Service. Hickey Run, Washington DC, Watershed and Stream Assessment	Hickey Run	1,031	Bank pins
2002 U.S. Fish and Wildlife Service. Watts Branch, Washington DC, Watershed and Stream Assessment	Watts Branch	705	Bank pins
2003 U.S. Fish and Wildlife Service. Oxon Run, Washington DC, Watershed and Stream Assessment	Oxon Run	1,032	Bank pins
2013 DDOE Nash Run Restoration Final Design Report	Nash Run	33.5	Bank pins

Note that the rate of erosion in Watts Branch is more than 10 times higher than the estimated rate of erosion shown in the 2007 Anacostia Sediment TMDL (705 tons/yr vs 67 tons/yr). This is likely due to the fact that the direct measurements provide an estimate of gross rates of erosion and the TMDL provides an estimate of the net rate of erosion. Because direct measurements of stream bank erosion don't exist for every tributary in the MS4, this method of estimating sediment load contribution from soil bank erosion (SBE) is not readily applicable to integrate into the IP Modeling Tool.

3.2.b Theoretical Calculation Methods

Theoretical calculation methods exist to prediction bank erosion rates from a variety of dependent variables. These methods require detailed information on the stream characteristics in order to calculate the sediment load due to in-stream erosion. Two examples of these methods include the Bank Assessment for Non-point source Consequences of Sediment (BANCS) Method and the Penn State Mapshed Method. Both of these methods are described in detail in Attachment 2. Most of the information needed to apply these two methods, such as a Bank Erosion Hazard Index (BEHI) assessment or Near Bank Stress (NBS) rating, is not available for many of the streams in the District. Therefore these methods are not readily applicable to estimate the sediment load contribution from SBE.

3.2.c Empirical Methods

Two studies were identified that used empirical data to develop an equation to estimate the sediment contribution from in-stream erosion. The first method was develop by the Center for Watershed Protection (CWP) and applied in the Watershed Treatment Model (WTM). The following description is mainly taken from the WTM model documentation (Caraco, 2013). The WTM is a simple spreadsheet planning model developed by CWP to evaluate pollutant loads from a wide range of sources. The WTM utilizes a simplified relationship, which is based on an analysis of ten years' worth of data from streams in southern California (Trimble 1997) to establish a simplified relationship between general watershed and stream condition and total watershed sediment loading and in-stream erosion, using the percentages identified in Table 2.

Table 2: WTM In-Stream Erosion Relationships

Stream Degradation Rating	In-Stream Erosion as a Fraction of Total Watershed Sediment Loads (CE%)
High	67%
Medium	50%
Low	25%
No degradation	0%

In the WTM, the sediment load from in-stream (channel) erosion (LCE) is a fraction of the total watershed load. Thus the equation is as follows:

$$LCE = LOS/(100/CE\%-1)$$

where:

LCE = Sediment load from in-stream (channel) erosion (lb/year)

LOS = Sediment load from other urban sources (lb/year)

CE (%) = In-stream (channel) erosion as a percent of the total urban watershed load

WTM documentation does not provide any guidance on approaches for rating the condition of the stream channels other than to say that the ratings should be based on "stream channel surveys or observations."

The second method was developed by the Maryland Department of Environment (MDE) and has been applied in numerous Maryland TMDL applications. The following description is taken primarily from the 2009 "TMDL of Sediment in the Gwynns Falls Watershed, Baltimore City and Baltimore County, MD" (MDE, 2009). This TMDL uses an equation to estimate stream bank erosion based on impervious area in a watershed. The method is described as follows:

Using CBP P5 urban sediment EOF target values, MDE developed a formula for estimating the percent of erosional sediment resultant from streambank erosion (i.e., that portion of the total urban sediment load attributed to stream bank erosion) based on the amount of impervious land within a watershed. The equation uses the urban sediment loading factors to estimate the proportion of the urban sediment load from stream bank erosion. The assumption is that as impervious surfaces increase, the upland sources decrease, flow increases, and the change in sediment load results from increased streambank erosion. While this formula only represents an empirical approximation, it is consistent with results from the Anacostia River Sediment TMDL and recognizes that stream bank erosion can be a significant portion of the total sediment load. (MDE, 2009)

The equation developed by MDE is represented graphically by Figure 1 below (MDE, 2009).

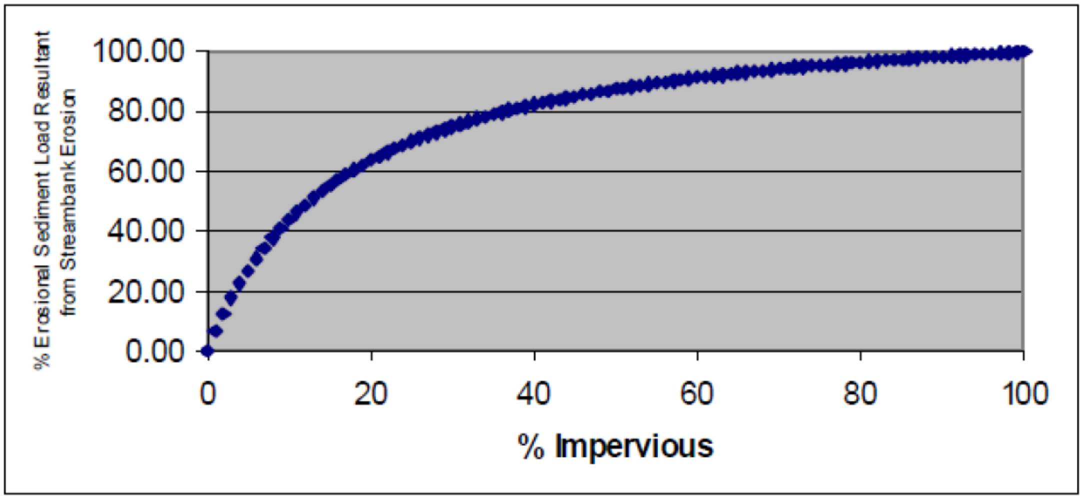

Figure 1: Empirical equation established by MDE to correlate percent watershed impervious and percent stream bank erosion

The MDE empirical method is not entirely consistent with the application of the Simple Method. The Simple Method assumes that the sediment load from land-based sources increase as the percent impervious increases. The MDE method assumes that as the percent impervious increases, the land-based sources become less prominent and the in-stream erosion becomes the dominant source of overall watershed sediment load. This inconsistency and how to address it is further explained in section 3.3.

3.2.d Application of the Sediment Delivery Ratio

As noted in the Introduction, eroded soils can be deposited at downstream "sinks" within the stream, and are not necessarily exported to the larger-order streams further downstream. It is important, therefore, to recognize that the gross in-stream erosion is not the same as the net export of sediment. In-stream soil erosion represents the amount of soil that is eroded from the banks and beds of stream. Only a fraction of the eroded soil contributes to the sediment yield, while the rest is deposited in downstream water channels. The amount that contributes to the sediment yield can be quantified using a sediment delivery ratio (SDR), expressed as a fraction of gross erosion that is delivered to a particular point in the drainage system. The Chesapeake Bay Model uses an SDR to estimate the amount of sediment that is delivered to the Bay from upstream sources. This value is 0.181 for non-coastal plain streams and 0.061 for coastal plain streams (CWP/CSN, 2014), and is based on the ratio of the Edge of Field (EoF) load to the Edge of Stream (EoS) load. The 2007 Anacostia TMDL also uses an SDR to estimate the amount of sediment that is delivered to the Anacostia from upstream sources. The TMDL provides different SDRs for different drainage areas of the Anacostia Watershed. An SDR of 0.23 represents the sediment yield delivered from the Anacostia tributaries to the Anacostia mainstem. Additionally, an SDR of 0.77 was used to represent the sediment yield within Watts Branch.

3.3 **Evaluation and Selection of In-Stream Erosion Load Calculation Method for Inclusion in the IP Modeling Tool**

A comparison of each of the results from each of the methods discussed in Section 3.2 is presented for Hickey Run in Table 3 below. For Hickey Run, the BANCS method yields similar gross in-stream erosion loads as the direct measurement method. This is due in part because it relates actual stream bank conditions and stresses to erosion rates and because it is calibrated to a District dataset that includes Hickey Run. The Mapshed, CWP and MDE methods estimate less in-stream erosion and rely on more generalized relationships with watershed conditions that were developed in other parts of the country (namely Pennsylvania and California). While it may be more reliable, the drawback with the BANCS method is that it is requires detailed data that is not currently available for many of the streams in the District.

Table 3: Comparison of In-Stream Erosion Load Calculation Methods for Hickey Run		
Method	**In-Stream Erosion (tons/year)**	**Source**
Measured (2005)	1,031	See USFWS, 2005, p. 46
BANCS prediction	1,349	See CWP and CSN, 2014, p. B-10 and B-11
MapShed prediction	90	Application of equations shown in Attachment 2
WTM prediction	167	Application of percentages shown in Table 1
MDE prediction	655	Application of curve shown in Figure 1

Because of the current lack of data that would allow a detailed assessment of each stream's rate of in-stream erosion, a more simplified method is needed to estimate the in-stream erosion. The two simplified methods identified previously include the CWP and MDE methods.

The MDE method was applied to Watts Branch in the District to determine if it could reproduce the same loads as those estimated in the 2007 Anacostia TMDL. The DC portion of Watts Branch is approximately 39% impervious, which means approximately 79% of the total load is attributable to in-stream erosion. The land-based sources of TSS for Watts Branch are currently estimated at 168 tons/yr, so the in-stream erosion loads would be approximately 636 tons/yr (79% of the 804 lb total TSS load). This is much larger than the 67 tons/yr estimated in the 2007 Anacostia TMDL, and slightly lower than the 705 tons/yr estimated by FWS.

Since it is not known why there is such a large discrepancy between the loads measured in Watts Branch and the loads estimated by the TMDL for Watts Branch, it is difficult to determine if the MDE method could be applied to District streams with confidence. However, since the TMDL is the driving force behind the creation of the IP Modeling Tool, it was decided that the method for estimating the load from in-stream erosion should be more biased to the SBE loads identified in the TMDL. To align the MDE method with the Simple Method (see discussion in section 3.2.c) it was decided to scale the MDE curve to represent various different "stream degradation potential" ratings. In other words, the curve developed by MDE represents a "worst case" scenario of in-stream erosion that could be applied to streams that have a great probability of stream degradation. Using the CWP method for estimating in-stream erosion based on the stream degradation potential, and assuming that the percent of SBE are applicable to watersheds with a median percent imperviousness for the District from Figure 1, the following scaling factors were developed based on stream degradation potential:

Table 4: Proposed Scaling Factors		
Median Percent Impervious in the MS4	35	Scaling Factor Applied to MDE curve
SBE as a percent of total watershed load based on MDE curve	78	
SBE as a percent of total watershed load based on CWP stream rating of "high degradation potential"	67	67/78 = 0.86
SBE as a percent of total watershed load based on CWP stream rating of "medium degradation potential"	50	50/78 = 0.64
SBE as a percent of total watershed load based on CWP stream rating of "low degradation potential"	25	25/78 = 0.32

These scaling factors were then applied to each ordinate on the MDE curve to produce three additional curves that represent the three different stream degradation potentials, as shown in Figure 2.

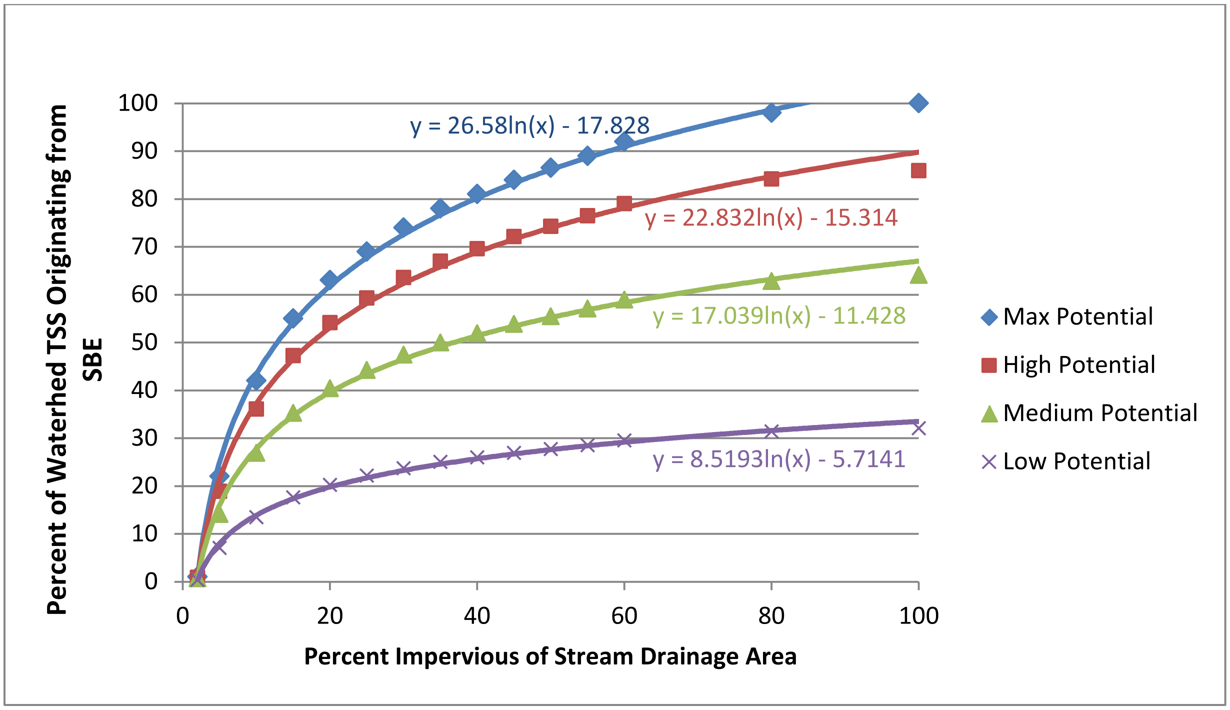

Figure 2: SBE (as a percent of total TSS load) as a Function of Imperviousness and Stream Degradation Potential

In order to more closely align the estimates of in-stream erosion loads with the values published in the TMDL, all streams in the District were assigned a "medium degradation potential." As additional field verification of the streams is completed in the future, the stream degradation potential can be adjusted to better reflect actual conditions. Table 5 below shows the in-stream erosion loads for several DC streams that were calculated using the medium degradation potential curve, and compares it to the load estimated by either the TMDL or by field monitoring.

Table 5: Comparison of in-stream erosion loads

Stream Name	SBE calculated with the medium degradation potential curve	SBE estimated by field monitoring	SBE estimated by the TMDL
Watts Branch	172	705	67
Nash Run	58	33.5	0
Hickey Run	162	1,031	0
Oxon Run	178	1,032	No sediment TMDL

In addition, it is recommended that a SDR of 0.181 and 0.061 is applied to estimate the amount of in-stream erosion that is delivered to the Bay for non-coastal plain and coastal plain streams respectively, that a SDR of 0.23 is applied to estimate the amount of in-stream erosion that is delivered to the mainstem rivers of the District, and that a SDR of 0.77 is applied to estimate the amount of in-stream erosion to Watts Branch. No SDR is used to quantify the sediment yield within each smaller-ordered, minor, tributary. The Sediment Delivery Ratio is only applied to in-stream sediment loads but not to the land-based sediment loads. It is assumed that the TSS EMCs selected to represent the land-based sediment loads implicitly account for any deposition that occurs within the watershed and MS4 pipe system.

In-stream erosion contributes to the overall sediment, nitrogen, and phosphorus loads. To translate sediment loading to nitrogen and phosphorus loading, the following CBP -approved conversion rates were used for the District (CWP/CSN, 2014):

- 1.05 pounds P/ton sediment
- 2.28 pounds N/ton sediment

4 Results and Discussion

As noted in Section 3, in-stream erosion can be estimated using different methods. The resultant TSS load using these methods does not agree with the estimated TSS load from in-stream erosion that are documented in the TSS TMDLs. In addition, the TSS TMDLs are not always in agreement on whether in-stream erosion should be a point source or a non-point source. This has implications on the accounting of loads for meeting WLAs or LAs. Because of the conflicting information on in-stream erosion, several recommendations are made, including:

- When calculating sediment loads and sediment load reductions for meeting the Chesapeake Bay TMDL, in-stream erosion will be included as part of the MS4 load.
- When calculating sediment loads and sediment load reductions for meeting the local TMDLs, in-stream erosion will be included as part of the direct drainage load.
- Calculate the in-stream erosion sediment load using the empirical equation developed by MDE that correlates in-stream erosion to imperviousness, but scale the equation to allow for an assessment of the stream degradation potential developed by CWP.
- Apply a sediment delivery ratio to estimate the sediment yield from upland in-stream erosion sources to the mainstem rivers and the Chesapeake Bay.

In conclusion, the method to account for and calculate in-stream erosion is limited due to a lack of data and conflicting information. As additional data on in-stream erosion is collected and more clarity on accounting for in-stream erosion is provided by the regulatory agencies, it may be possible to establish better methodologies to account for and calculate the loads from in-stream erosion. Until such time though, it is recommended that the accounting and calculation methods set forth in this document will be utilized in the IP Modeling Tool.

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TABLE OF CONTENTS

Attachment 1: Review of In-Stream Erosion Calculations in the District TMDLs A1-12

Table 1: Existing Loads (from page 21 of 2003 TMDL report).. .... A1-1
Table 2: Existing Loads for Watts Branch.. A1-2
Table 3: Existing Loads for Main Stem Anacostia, in DC.. A1-3

Attachment 2: Theoretical Calculation Methods for Estimating In-Stream Erosion Rates................ ...A2-1

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Attachment 1: Review of In-Stream Erosion Calculations in the District TMDLs

2002 Anacostia TSS TMDL

This TMDL does not mention streambank erosion specifically. All stormwater is considered a nonpoint source and is counted towards the LA. The Anacostia TMDL modeled the sediment loads in Watts Branch, Popes Branch, Fort Dupont, and Nash Run using a TSS EMC of 227mg/L. This EMC is based on in-stream monitoring at Popes Branch and implicitly includes the contribution of both in-stream erosion and land-based stormwater loads. Data from this TMDL was used in the subsequent Watts Branch TSS TMDL (see below), and the total TSS load for Watts Branch implicitly includes streambank erosion. No EMC specific to Watts Branch was available at the time that this TMDL was developed. Note that loads in this TMDL are typically expressed on a seasonal rather than an annual basis, so this must be kept in mind when comparing the TMDL loads to annual loads.

Total WB TSS existing load = 212 tons/season or 363 tons/yr.

2003 Watts Branch TSS TMDL

The Watts Branch TSS TMDL is based on the sediment loads calculated in the 2002 Anacostia TSS TMDL. The Watts Branch TMDL further broke out the TSS loads of Watts Branch between Maryland and the District, between the upper and lower sections of Watts Branch in the District, and between stormwater, streambank erosion, and baseflow loads. All stormwater and streambank erosion is considered a nonpoint source and is counted towards the LA. The portion of TSS load from stream bank erosion was broken out of the total Watts Branch TSS load based on a regression curve that relates peak flows and sediment discharge, and an estimate of the number of peak flows per year. The methodology and assumptions used to back-calculate the stream bank erosion are not explained in detail.

Table 1: Existing Loads (from page 21 of 2003 TMDL report)

	Watts Branch (all)	Watts Branch DC	Watts Branch MD
	Tons/yr	Tons/yr	Tons/yr
Streambank erosion	250	117	132
Stormwater	111	52	59
Baseflow	4	2	2
TOTAL	363	171	192

Note there are some rounding errors in the TMDL report

Note that a study by USFWS estimates streambank erosion in Watts Branch to be 1500 tons/yr or 6 times higher than the TMDL. However, the USFWS study only looks at gross streambank erosion; it doesn't provide an assessment of how much of the eroded soils is deposited downstream. In other words, not all of the eroded sediment is ultimately exported. Some of the eroded sediment is deposited in downstream areas, known as aggrading stream sections. A good example of this is the lower section of Watts Branch, which is known to be a sediment sink.

The load allocations for Watts Branch assume a 54% reduction in stormwater load and a 90% reduction in streambank erosion load. Annual LA for the District section of Watts Branch= 38 tons/yr.

Note that loads in this TMDL are typically expressed on a seasonal rather than an annual basis, so caution must be used when comparing the TMDL loads to annual loads.

2007 Anacostia TSS TMDL

The TMDL points out that streambank erosion is the biggest source of TSS pollution. It is listed under nonpoint sources, BUT it is allocated as part of the WLA.

From section 4.3.1 of the TMDL:

Loads for Watts Branch were obtained directly from HSPF output [Note: This load explicitly includes loads from streambank erosion. Lower Beaverdam Creek loads were also obtained from HSPF output but no stream bank erosion is assumed to occur in the District portion of Lower Beaverdam Creek]. Loads from the remaining portion of the watershed, the "tidal drainage area," were computed using daily Watts Branch loads per land use type per unit area, with streambank erosion assumed to be negligible for all tributaries (except for Watts Branch and Lower Beaverdam Creek).

This explanation is slightly contradictory from the explanation provided in Section 4.5 of the TMDL:

"Because it results primarily from the altered hydrology associated with urban impervious surfaces connected directly to storm sewer systems, the estimated streambank erosion load is included in the MS4-WLA. Loads from forest and agricultural lands were calculated based on standard loading factors, loads from developed land were calculated based on the monitoring data from MS4 permits, and point source discharges were calculated from required monitoring. Streambank erosion was determined by subtracting these loads from the monitored total load. [Note: This is interpreted to mean that streambank erosion was their "fudge factor." All sources that could be estimated (MS4, CSO) were added), and this load was compared to the monitored TSS loads, and the difference is assumed to be the load from streambank erosion]. Thus, the estimated streambank erosion load includes legacy sediment, current erosion and background loads. At this time, these components cannot be determined separately. As data generated by assessments of stream restoration projects and other monitoring efforts produce more refined estimates of streambank loads in the future, MDE may determine to calculate the TMDL or reallocate loads within the TMDL."

Streambank erosion for Watts Branch up to the USGS gage (segment 150 in HSPF), was determined to be 187 tons/year. Note that a study by USFWS estimates streambank erosion in Watts Branch to be 1500 tons/yr or 8 times higher than the TMDL. However, the USFWS study only looks at gross streambank erosion; it doesn't provide an assessment of how much of the eroded soils is deposited downstream. In other words, not all of the eroded sediment is ultimately exported. Some of the eroded sediment is deposited in downstream areas, known as aggrading stream sections. A good example of this is the lower section of Watts Branch, which is known to be a sediment sink.

Table 2: Existing Loads for Watts Branch

	Watts Branch (up to the USGS gauge)	Watts Branch DC	Watts Branch MD
	Tons/yr	Tons/yr	Tons/yr
Streambank erosion	186	67	119
Urban Loads	255	138	117
Forest Loads	5	0	5
TOTAL	**446**	**205**	**241**

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Table 3: Existing Loads for Main Stem Anacostia, in DC			
	DC Streambank Erosion	DC Urban Loads	DC Total
	Tons/yr	Tons/yr	Tons/yr
Northwest Branch, DC	0	175	175
Lower Beaverdam Creek, DC	0	4	4
Watts Branch, DC	67	138	205
Tidal Anacostia, DC	0	1,210	1,210
TOTAL	**67**	**1,527**	**1,594**

2010 Chesapeake Bay TSS TMDL

- Stream erosion is explicitly accounted for in large rivers (>100cfs)
    - Mean flow of the Potomac is ~10,800 cfs, so erosion was explicitly accounted for (but not reported as a separate load in the baseline loads or in the WLA/LA)
    - Mean flow of the Anacostia is 138 cfs, so erosion was explicitly accounted for (but also not reported as a separate load)
- Stream erosion is implicitly accounted for all smaller rivers (Rock Creek, Watts Branch, etc.) since the model is calibrated to in-stream TSS data. This means SBE is reflected in the loading rates.
- Stream erosion is likely included in both the existing loads reported for the MS4 WLA and for the Direct Drainage LA.
- Stream restoration credits can be applied toward the MS4-WLA.

Additional References:

From the TMDL report (p. 4-42) ...

"Because sediment monitoring stations in the watershed collect all the sediment loads passing the station, including both land erosion and bank erosion sources, the stream bank load is accounted for, ultimately, both in the Chesapeake Bay watershed monitoring network and in the Bay Watershed Model, at least as part of the total combination of sediment from land and riverine sources. In the same way, streambank loads are also accounted for in tracking sediment load reductions from stream restoration actions and through reductions of nitrogen, phosphorus, and sediment tracked in the jurisdictions' WIPs."

EPA responses to comments on the Bay TMDL regarding erosion include:

"Within the watershed, legacy sediments and other erosion from the river system are inherently included in the calculation of sediment loads from the watershed in the Phase 5.3 Watershed Model. In simulated rivers (generally greater than 100 cubic feet per second) erosion and scour are explicitly simulated. Based on the recommendation of the Chesapeake Bay Program's Sediment Work Group, the watershed jurisdictions can get nutrient and sediment credit in their implementation plans for performing in-stream erosion control practices. Tidal resuspension of sediment is also simulated in the Chesapeake Bay Water Quality and Sediment Transport Model and there are a series of management practices the jurisdictions have taken and can continue to take to reduce sediment resuspension in tidal waters. As underwater bay grass beds continue to expand in the Bay, as they are projected to do under the TMDL nutrient and sediment reductions, more sediment will be bound by the grass beds and kept from resuspension."

"Within the watershed, erosion from the river systems is included in the calculation of sediment loads from the watershed in the Phase 5.3 Chesapeake Bay Watershed Model. In simulated rivers which are generally greater than 100 cubic feet per second, erosion and scour are explicitly simulated and calibrated to about 130 sediment monitoring stations throughout the watershed. Based on the recommendation of the Chesapeake Bay Program's Sediment Work Group, jurisdictions can get nutrient and sediment credit in their implementation plans for performing in-stream erosion control practices."

"So-called 'legacy' sediments and other erosion from the river system are inherently included in the calculation of sediment loads from the watershed in the watershed model. Based on the recommendation of the Chesapeake Bay Program's Sediment Work Group, jurisdictions can get nutrient and sediment credit in their implementation plans for performing in-stream erosion control practices. The sediment work group is well aware of the research on legacy sediment.

As discussed in the Chesapeake Bay Program Sediment workgroup, the total flux of sediment generally decreases from sources on the landscape to a point downstream in a river of 4th or 5th order. In other words, the stream network is net sink of sediment. Of course, there are localized areas where this is not the case. Stream erosion is implicitly considered in the simulation in that there would be a lot more reduction of edge-of-stream sediment if there were no stream erosion. In simulated rivers (generally greater than 100 cubic feet per second) erosion and scour are explicitly simulated, however, "legacy" issues are generally on streams smaller than this, however.

In addition, "legacy" sediment issue can be addressed in the states' Watershed Implementation Plans which receive nutrient and sediment credit for stream erosion control practices."

Attachment 2: Theoretical Calculation Methods for Estimating In-Stream Erosion Rates

Bank Assessment for Non-point source Consequences of Sediment (BANCS) Method

The first approach evaluated for prediction of in-stream erosion rates is the Bank Assessment for Non-point source Consequences of Sediment (BANCS) method. This method employs two separate risk rating tools for estimating bank erodibility: the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS). The method was developed by Rosgen (2001) and is utilized in the U.S. Environmental Protection Agency's (EPA) on-line tool: Watershed Assessment of River Stability & Sediment Supply (WARSSS) (http://water.epa.gov/scitech/datait/tools/warsss/). The BANCS method is also employed in the CBP-approved approach for determining stream restoration pollutant reduction credit. The credit accounting approach is outlined in *Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects* (CWP/CSN 2014).

The BANCS method involves evaluating stream bank characteristics using the BEHI tool and stream flow and channel geomorphological characteristics using the NBS tool. The BEHI tool utilizes the following parameters to develop a qualitative rating of bank erosion risk for a particular stream reach:

- Bank height/maximum bankfull height
- Root depth/bank height
- Weighted root density
- Bank angle
- Surface protection

The NBS tool presents a number of parameters for estimating near bank stress risk ratings. At least one of these parameters, listed below, is needed to develop the NBS rating. If more than one parameter is used, they can serve to verify the rating or to provide an average rating.

- Ratio of radius of curvature to bankfull width
- Ratio of pool slope to average water surface slope
- Ratio of pool slope to riffle slope
- Ratio of near-bank maximum depth to bankfull mean depth
- Ratio of near-bank shear stress to bankfull shear stress
- Velocity profiles or velocity gradient

The ratings derived from the BEHI and NBS tools are used in tandem with a plot that relates field measured annual lateral erosion rates with field derived BEHI and NBS ratings. Such a plot has been developed for the Hickey Run stream in the District by the USFWS. This District plot is included in the previously mentioned stream restoration credit accounting approach (CWP/CSN 2013). From this plot, an annual rate of lateral bank erosion can be determined. This rate is then multiplied by the bank height and the length of bank in a similar condition to yield an estimate of annual sediment loading, as follows (CWP/CSN 2013):

$$S = \Sigma(cAR)/2000$$

where:

S = sediment load (ton/year) for reach or stream

c = bulk density of soil (lbs/ft^3), assumed to be 125 lbs/ft^3

R = lateral bank erosion rate (ft/year), calculated from BANCS method

A = eroding bank area (ft^2)

The stream restoration credit accounting approach (CWP/CSN 2013) includes a conversion rate to translate sediment loading to nitrogen and phosphorus loadings, as follows:

- 1.05 pounds P/ton sediment
- 2.28 pounds N/ton sediment

Penn State MapShed Method

Researchers at Penn State have developed a watershed modeling tool called MapShed. This tool is a GIS-enabled, enhanced version of the Generalized Watershed Loading Function (GWLF) watershed model originally developed at Cornell University (Haith and Shoemaker 1987). A pre-cursor to MapShed was called AVGWLF, which was also developed by Penn State (Evans et al 2002).

In addition to numerous other simulated watershed functions, MapShed provides the ability to calculate the in-stream erosion contribution to overall pollutant loading.

This protocol is based on an approach described by numerous researchers in the field of geomorphology in which monthly streambank erosion is estimated by first calculating a watershed-specific lateral erosion rate using some form of the equation:

$$LER = a * q^{0.6}$$

where:

LER = lateral bank erosion rate (m/month)

a = an empirically-derived constant related to the mass of soil eroded from streambanks

q = monthly stream flow (m^3/s)

Evans et al. (2003) determined that the value for the “a” constant was empirically found to range from about 10^{-5} to 10^{-4} for watersheds in Pennsylvania. This constant was statistically related to five watershed parameters, including animal density, curve number, soil erodibility, mean watershed slope, and percent of developed land in the watershed, as follows:

$$a = (0.00147 * PD) + (0.000143 * AD) - (0.000001 * CN) + (0.000425 * KF) + (0.000001 * MS) - 0.000016$$

where:

PD = Percent developed land in the watershed

AD = Animal density of the watershed in animal equivalent units (AEUs)

CN = Average curve number value of the watershed

KF = Average soil “k” factor value for the watershed, and

MS = Mean topographic slope (%) of the watershed

It should be noted that the LER is calculated as a monthly erosion rate. Annual rates can be computed by using either average monthly stream flow values multiplied by 12 or by summing monthly stream flow values calculated for each month of the year.

As with the BANCS method, once an annual lateral erosion rate is determined, it is multiplied by the bank height and the length of bank to yield an estimate of annual sediment loading, as follows:

$$S = \Sigma(c*A*LER)/2000$$

where:

S = sediment load (ton/year) for reach or stream

c = bulk density of soil (lbs/ft^3), assumed to be 125 lbs/ft^3

LER = lateral bank erosion rate (ft/year), calculated from MapShed method

A = eroding bank area (ft^2)

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Appendix D
Technical Memorandum

Selection of Event Mean Concentrations (EMCs)

Table of Contents

1 INTRODUCTION 1
2 PURPOSE 1
3 TECHNICAL APPROACH 2
4 RESULTS AND DISCUSSION 24
REFERENCES 29
ATTACHMENTS 30

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Consolidated TMDL Implementation Plan – Comprehensive Baseline Analysis
May 08, 2015

List of Tables

Table 1: Summary of EMCs Used in District TMDLs 6
Table 2: EMC Data by Pollutant and Land Use Category 11
Table 3: Stormwater Outfall Monitoring Locations, 2000-2012 (Source: EDC 2006) 18
Table 4: Parameters Analyzed Outfall Discharge Monitoring Samples, 2000-2011 (Source: Apex Companies 2012) 20
Table 5: Analytical Methods and Hold Times for MS4 Monitoring 2004-2011 (Source: EDC 2006)......... 20
Table 6: Required Interim Monitoring Stations (Source Table 5, MS4 Permit)... 21
Table 7: Parameters Analyzed in Outfall Discharge Monitoring Samples, 2012-2013 (Source: Apex 2012) 21
Table 8: Wet Weather MS4 Sampling Analytical Methods and Hold Times (Source: Apex 2012) 21
Table 9: Parameters to be Monitored for Outfall Discharge as Part of Revised Program, 2015 (Source: MS4 Permit, Table 4) 22
Table 10: Summary Statistics for Wet Weather MS4 Monitoring Data, City-Wide 2001-2013.................... 23
Table 11: Summary Statistics for Wet Weather MS4 Outfall Monitoring Data by Watershed, 2001-2013..23
Table 12: Summary of ANOVA Analysis.. 26
Table 13: Recommended EMCs 27

List of Figures

Figure 1: Land Use Based TSS EMCs 12
Figure 2: Figure Land Use Based TN EMCs.. 12
Figure 3: Land Use Based TP EMCs 13
Figure 4: Land Use Based Fecal Coliform EMCs 13
Figure 5: Land Use Based BOD EMCs... 14
Figure 6: Land Use Based Oil and Grease EMCs 14
Figure 7: Land Use Based Copper EMCs.. 15
Figure 8: Land Use Based Lead EMCs 15
Figure 9: Land Use Based Zinc EMCs 16
Figure 10: Land Use Based Arsenic and Mercury EMCs 16
Figure 11: Urban Use Toxics EMCs.. 17
Figure 12: MS4 Monitoring Station 2000-2013 19

1 Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in the District's Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) permit (U. S. EPA 2011 and U. S. EPA 2012). The IP will define and organize a multi-year process centered on reducing pollutant loads originating within the District MS4. The level of pollutant control will be based on past TMDL studies performed to protect impaired water bodies in the District. The IP will include a summary of the regulatory compliance strategy to satisfy TMDL-related permit requirements, a summary of data and methods used to develop the IP, specific prioritized recommendations for stormwater control measures, a schedule for implementation and attainment of Waste Load Allocations (WLAs), and a method for tracking progress. Substantial public involvement will be sought in plan development.

This Technical Memorandum on the selection of event mean concentrations (EMCs) is one in a series of technical memoranda that provide detailed information on research, analysis, programs and procedures that support development of the Consolidated TMDL IP.

2 Purpose

EMCs are an essential component of most storm water pollutant load estimation procedures. In practice, EMCs are considered to be the flow proportional concentration of a given pollutant parameter during storm events. That is, the total mass discharged divided by the total runoff volume. The multiplication of observed or model simulated runoff (flow) by an EMC for a particular pollutant generates a pollutant load.

The selection and application of EMCs was instrumental in the development of TMDLs in the District. EMCs were used to estimate pollutant loads for conventional pollutants (e.g., TSS, nutrients, and bacteria) as well as metals and other toxic substances. In some instances the EMCs were applied to runoff at stormwater outfalls to develop MS4 stormwater loads. In other instances the EMCs were applied to runoff in watersheds to develop watershed loads. In addition, substantially dissimilar EMCs were often used to characterize the same pollutant in different TMDL studies.

The requirement to develop a Consolidated TMDL IP for the District provides an opportunity, if defensible, to identify and apply a consistent set of EMCs to support modeling of pollutant load estimations and pollutant reduction with BMPs and other non-structural control practices. In addition, comparisons of land use-based EMC values compiled from the scientific literature and MS4 outfall monitoring-derived EMCs to the EMCs used in the original TMDLs allows the evaluation of the feasibility of using updated EMCs in place of the EMCs used in the original TMDLs. Utilization of land use-based EMCs would confer the advantage of allowing different land uses to generate different loads, and this would help with targeting BMP practices to the land use types with the highest loads. Conversely, using EMCs derived from current MS4 outfall monitoring data would ensure that the EMCs used in the IP Modeling Tool were reflective of current pollutant concentrations in the District. This would contrast with the EMCs used in the original TMDLs, which are based on older data, and some of which was not collected within the District.

The purpose of this Technical Memorandum is to document the process that was used to develop a set of EMCs that can be applied on a city-wide basis across the District. The **Technical Approach** employed includes:

- A review of the EMCs used to develop TMDLs in the District.
- A review of EMCs reported in literature for various land use classes.

- An evaluation of District MS4 outfall monitoring data to develop DC-specific EMCs.

The **Results and Discussion** section of this Technical Memorandum presents the EMCs selected with commentary on the rationale for their selection and use of the EMCs in the IP.

3 Technical Approach

3.1 Review of EMCs used to develop the DC TMDLs

Most of the TMDLs done for the District used EMCs in conjunction with flow data to calculate loads for different wet weather flow types (i.e., stormwater and CSOs). EMCs used in District TMDLs were typically developed from local monitoring data, although in a few cases, other data (such as data from Maryland and/or literature values) were used. Several different sets of EMCs developed at different times for different purposes were used in the TMDLs. For example, some TMDLs used monitoring data specifically conducted for use in that TMDL, while others used historical MS4 outfall monitoring data, and still others used EMCs developed for the DC Water CSO Long Term Control Plan.

Because the EMCs were based on sampling from an entire watershed and they were applied to all flows from the entire watershed, these EMCs are referred to as "watershed-based EMCs." This contrasts with land use-based EMCs, which are derived for specific land use types.

Discussions of the EMCs developed for each pollutant type are presented below. A table summarizing the various EMCs used for the different TMDLs follows the discussions.

3.1.a Bacteria

Bacteria EMCs used in District TMDLs came from either the LTCP studies or MS4 monitoring data. The EMCs developed from the MS4 monitoring data was used in the DC Small Tributaries Model. The DC Small Tributaries Model was used for the Anacostia Tributaries, Oxon Run, C&O Canal, and Potomac tributaries bacteria TMDLs. Page 10 of the *DCST Model Report* (DC DOH, July 2003) states that "The average storm water concentration estimate for fecal coliform bacteria was obtained from District MS4 monitoring data (Nicoline Shelterbrandt [sic], private communication)." The bacteria EMCs developed by the LTCP studies to characterize separate storm sewer areas were used for the Anacostia, Potomac, and Rock Creek mainstem bacteria TMDLs, as well as for the Kingman Lake, Washington Ship Channel and Tidal Basin bacteria TMDLs. This EMC was developed through an analytical review of Nationwide Urban Runoff Program EMC data (U.S. EPA, 1983), and through the collection of stormwater samples taken at 6 sites by DDOE, and the collection of stormwater samples taken at 2 sites by DC Water. The original sample results are presented in *Study Memorandum LTCP 5-8 (Final), CSS and SSWS Event Mean Concentrations* (DC Water, October 2001), Table F-2.

Beginning in January 1, 2008, the District bacteriological WQS changed from fecal coliform to E. coli. The current Class A water standards are a geometric mean of 126 MPN. The District-specific bacteria translator was used to convert fecal coliform EMCs directly to E. coli EMCs (LimnoTech 2011) and 2012)[1]. This separate effort to develop a statistically valid bacteria translator involved extensive comparison of paired fecal coliform and E.Coli samples and development of a regression equation for translation of bacteria concentrations. No further analysis of District E. coli data is contained in this Technical Memorandum.

[1] Documentation related to development of the translator is in LimnoTech's 2011 Memorandum, Final Memo Summarizing DC Bacteria Data and Recommending a DC Bacteria Translator (Task 2) and LimnoTech's 2012 Memorandum, Update on Development of DC Bacteria Translators.

Paired Metals

The DC Small Tributaries Model was used for all of the metals TMDLs except the Rock Creek mainstem Metals TMDL. Table 2b in the DCST summarizes baseflow and stormflow EMCs for the Inorganic Chemicals Sub-Model. Copper, lead and zinc storm flow EMCs were calculated by averaging the DC WASA LTCP separate sewer system EMCs (DC WASA, 2002) with means of the recent DC MS4 monitoring results. This is explained in more detail in Section 2.2.4, *Other Tributaries and Separate Storm Sewer Loads* and Table 2-4 in *TAM/WASP Toxics Screening Level Model for the Tidal Portions of the Anacostia River, Final Report* (Behm, et. al., April, 2003). The original sample results for the LTCP EMCs are presented in *Study Memorandum LTCP 5-8 (Final), CSS and SSWS Event Mean Concentrations* (DC Water, October 2001), Table F-1 and consist of four composite samples from Suitland Parkway taken over four storms from September 1999 to February 200, plus four composites taken over the same four storms at Hickey Run, plus two additional grab samples from the November 1999 storm taken at Hickey Run. In contrast to the EMCs for copper, lead and zinc, the EMC for arsenic was based solely on MS4 monitoring data.

For the Rock Creek mainstem Metals TMDL EMCs, were based on sampling data performed by LimnoTech at five locations on Rock Creek over two storms in 2003 and sampling performed by DC Department of Health (DOH) at three locations over three storms in 1994 and 1995 (DC DOH, February 2004.

3.1.b Organics

The DC Small Tributaries Model was used for all of the organics TMDLs except the Potomac and Anacostia Tidal PCB TMDL. Table 2a in the DCST summarizes baseflow and stormflow EMCs for the Organic Chemicals Sub-Model. EMCs for chlordane, heptachlor epoxide and PAHs were calculated from data from the Northeast and Northwest Branches in Maryland because stormwater monitoring data for the tidal portion of the Anacostia River were not available and DC MS4 results for these contaminants are all non-detect (Behm, et.al., April, 2003, p. 143 for chlordane and heptachlor epoxide; p. 125 for PAHs). For chlordane, the original values for baseflow (which was calculated as the average of six baseflow samples collected in instream in 1995-1996 at the USGS gages on the Northeast and Northwest Branches) and stormflow (which was calculated as the average of four composite stormflow samples collected in instream in 1995-1996 at the USGS gages on the Northeast and Northwest Branches) were multiplied by 1.0 each to develop the individual baseflow and stormflow EMCs (Behm, et.al., April, 2003, Table 3-15; note that the sampling results summarized in the table do not support the EMC that is supposedly derived from them) (note that the load adjustment factors were used for each parameter to better calibrate modeled data to observed data; in the case of chlordane, that load adjustment factor was 1.0). For heptachlor epoxide, the original baseflow and stormflow values were multiplied by a load adjustment factor of 0.7 to develop the individual baseflow and stormflow EMCs (Behm, et.al., April, 2003, Table 3-22). The calibrated model incorporates this load reduction factor of 0.7 for heptachlor epoxide because bed sediment concentrations for heptachlor epoxide were over-estimated in the original model run (Behm, et.al., April, 2003, p. 144).

For the PAHs, the original values for baseflow and stormflow were multiplied by 1.5 to develop the individual baseflow and stormflow EMCs (Behm, et.al., April, 2003, Table 3-15). This 1.5 multiplier was used in the final calibrated model as a load adjustment factor to provide a better fit to bed sediment data (Behm, et.al., April, 2003, p. 127).

Dieldrin, DDD, DDE, and DDT EMCs were calculated from District MS4 monitoring data. For dieldrin, tidal sub-basin tributaries and separate storm sewer system EMCs were estimated at 0.00029 ug/L, based on MS4 monitoring data (Nicoline Shelterbrandt, private communication) of 20 samples with 18 non-detects, where non-detects were estimated as half the detection limit (Behm, et.al., April, 2003, p. 155).

The baseflow EMC for dieldrin for the tidal sub-basin tributaries and separate storm sewer systems was estimated as the average of the Northeast and Northwest Branch base flows. For DDD, DDE, and DDT, tidal sub-basin EMCs, including separate storm sewer system, and CSO are based on data from the District's MS4 storm water monitoring program, with an average minimum detection limit of 3E-04 ug/L (Nicoline Shelterbrandt, private communication) (Behm, et.al., April, 2003, p. 163). For DDD, the original sampling data value was multiplied by 20; for DDE, the original sampling data value was multiplied by 15; and for DDT, the original sampling data value was multiplied by 20. These adjustments were made for both baseflow and storm data.

For PCBs, tidal sub-basin tributaries storm flow, separate storm sewer system, and CSO Total PCB EMCs are based on data from the District's MS4 monitoring (Nicoline Shelterbrandt, private communication), where non-detects for each classification (PCB1, PCB2, and PCB3) were estimated to be 0.00025 ug/L, which is approximately half the reported minimum detection limit (Behm, et.al., April, 2003, p. 102). The baseflow EMC for each classification for the tidal sub-basin tributaries and separate storm sewer systems was estimated as the average of the Northeast and Northwest Branch base flows. For each PCB classification in the model, the original sampling data value was multiplied by 3 in order to better calibrate against observed monitoring data. These adjustments were made for both baseflow and storm data.

For the Potomac and Anacostia Tidal PCB TMDL, ICPRB looked at TSS vs. PCB regression relationships to set PCB concentrations, so no PCB EMCs were used.

3.1.c Nutrients

COG supplied the data and the methodology to calculate representative concentrations of nitrogen, phosphorus, and BOD5 for loads from the smaller tributaries, storm sewers, and the direct drainage to the tidal Anacostia River for the Anacostia Nutrients and BOD TMDL (2001). The methodology used storm flow composite samples collected from earlier studies of small urban watersheds in the District of Columbia. Representative storm flow concentrations were developed for closed systems (storm sewers) and open systems (watersheds with primarily free-flowing tributaries). For the direct drainage to the tidal Anacostia River, a weighted average of close and open system concentrations was calculated, depending on land use. Commercial, industrial, and high and medium density residential land uses were assigned close-system concentrations; the remaining land uses were assigned open-system concentrations. Representative stormwater TN and TP concentrations were then calculated for each modeling segment, as an average, weighted by land use, of the concentrations associated with the direct drainage and subwatersheds discharging to that model segment. Concentrations ranged from 2.34 to 3.9 mg/L for TN and 0.36 to 0.77 mg/L for TP. Only storm flow loads are calculated for the smaller tributaries, storm sewers and direct drainage. No attempt was made to estimate loads in base flow or groundwater discharge to the tidal Anacostia (Mandel and Schultz, 2000).

For the Anacostia Nutrients and BOD TMDL (2008), EMCs were calculated from monitoring data. For segments of the drainage area in Maryland, EMCs were calculated by land use type, but in the District, monitoring stations represented a mix of land use types, so EMCs were not calculated by land use type. EMCs were calculated for TKN (2.6 mg/L), Nitrate (1.1 mg/L), and TP (0.5 mg/L). The TN EMC can be calculated as the sum of the TKN and Nitrate EMCs: 2.6 mg/L TKN + 1.1 mg/L Nitrate = 3.7 mg/L TN (Mandel, et. al., 2008, p. 5).

Baseflow EMCs are provided in Table 2.6.3 and were also based on previous sampling data.

The Chesapeake Bay TMDL did not use EMCs for Total Nitrogen and Total Phosphorus because MS4 land areas are modeled by the Bay Watershed Model, which primarily uses loading rates (e.g.: pounds of pollutants per acre of land use). However, Chapter 10, pp. 15-16 of the Bay Watershed Model documentation (U.S. EPA 2010) discusses development of stormwater loads. Research had shown little variation in TN and TP between land uses in the Chesapeake Bay region. Therefore, the Phase 5.3 model used the same values to be reflective of both high and low density residential areas. For calculation of the developed land expected load, the overall median concentrations of 2.0 mg/L TN and 0.27 mg/L TP are used.

3.1.d TSS/Sediment

The Anacostia TSS TMDL (2002) used TSS storm concentrations of 227 mg/L to represent open-channel systems, including Nash Run, Fort Dupont, and Pope Branch. The storm concentration was based on previous COG sampling of Pope Branch. This TMDL uses storm concentrations of 94 mg/L to represent closed-channel systems, including Fort Chaplin, Fort Davis, Fort Stanton, Hickey Run, and Texas Avenue Tributary. Baseflow EMCs were either 0 or 2 mg/L depending on the specific sub-shed (Schultz, October 2001, revised April 2003, Table 2-5). Because no storm flow monitoring data for TSS is available for Watts Branch, a storm TSS concentration of 227 mg/L was used, based on the MWCOG Pope Branch open channel result. A non-storm TSS concentration of 6 mg/L for the Watts Branch was estimated from available DC DOH routine monitoring data for station TWB01 (time period 4/20/82 to 12/9/97) by computing the median value of the non-storm data (where the criteria for non-storm conditions was no precipitation recorded at National Airport on the day of and the day preceding the sampling event) (Schultz, October 2001, revised April 2003, p. 22). Output from the Prince Georges County HSPF model of Lower Beaverdam Creek was used to generate daily TSS loads from Lower Beaverdam Creek (Schultz, October 2001, revised April 2003, p. 22).

The Anacostia Sediment and TSS TMDL (2007) does not provide clear information as to the storm and baseflow EMCs used in the modeling. Therefore, it is assumed that the same storm and baseflow EMCs used in the 2002 Anacostia TSS TMDL were used in this TMDL.

The Watts Branch TSS TMDL (2003) does not identify overall stormflow EMCs, but it is assumed that the storm TSS concentration of 227 mg/L was used from the previous Anacostia TSS TMDL (2002) to calculate the total load, but a storm EMC of 60 mg/L was used after the stream erosion component was broken out of the equation (Watts Branch TSS TMDL, 2003, p. 20).

The Kingman Lake TSS, Oil & Grease, and BOD TMDL (2003) used data from three samples from the storm sewer collecting runoff from a residential area tributary to Kingman Lake to calculate EMCs. The location was selected to be representative of the commercial, industrial, residential, and recreational land use activities. Samples were collected over three storms (12/17/01; 4/9/02; and 4/18/02) and averaged to develop the EMCs. The EMC for TSS was 34.67 mg/L. The TMDL also shows a separate TSS EMC of 5.66 mg/L for grassed areas (p. 7).

The Chesapeake Bay TMDL did not use EMCs for TSS because MS4 land areas are modeled by the Bay Watershed Model, which primarily uses loading rates (e.g.: pounds of pollutants per acre of land use). The Bay Watershed Model Version 5.3 uses edge-of-field erosion rates for different land use types to establish loads from different land use types. This is documented in Chapter 9 of the Bay Watershed Model documentation (U.S. EPA, 2010). As a point of comparison, Maryland has used a TSS EMC of 80 mg/L in the past when addressing its allocations under the Chesapeake Bay TMDL (MDE, 2009).

3.1.e Other

COG supplied the data and the methodology to calculate representative concentrations of nitrogen, phosphorus, and BOD5 for loads from the smaller tributaries, storm sewers, and the direct drainage to the tidal Anacostia River for the Anacostia Nutrients and BOD TMDL (2001). According to Mandel and Schultz (2000), the methodology used storm flow composite samples collected from earlier studies of small urban watersheds in the District of Columbia. Representative storm flow concentrations were developed for closed systems (storm sewers) and open systems (watersheds with primarily free-flowing tributaries). For the direct drainage to the tidal Anacostia River, a weighted average of close and open system concentrations was calculated, depending on land use. Commercial, industrial, and high and medium density residential land uses were assigned close-system concentrations; the remaining land uses were assigned open-system concentrations. Representative storm-water BOD5 concentrations were then calculated for each modeling segment, as an average, weighted by land use, of the concentrations associated with the direct drainage and subwatersheds discharging to that model segment. However, while the document indicates that these BOD concentrations are to be found in Table 4.2-8 of Mandel and Schultz (2000), this table does not contain BOD information, so the actual EMCs are not documented. No attempt was made to estimate loads in base flow or groundwater discharge to the tidal Anacostia.

For the Anacostia Nutrients and BOD TMDL (2008), EMCs were calculated from monitoring data. For segments of the drainage area in Maryland, EMCs were calculated by land use type, but in the District, monitoring stations represented a mix of land use types, so EMCs were not calculated by land use type. The BOD EMC was calculated 42.9 mg/L (Mandel, et. al., 2008, p. 5). The baseflow EMC for BOD as provided in Table 2.6.3 is 1.2 mg/L. This EMC was also based on previous sampling data.

The Kingman Lake TSS, Oil & Grease, and BOD TMDL (2003) used data from three samples from the storm sewer collecting runoff from a residential area tributary to Kingman Lake to calculate EMCs. The location was selected to be representative of the commercial, industrial, residential, and recreational land use activities. Samples were collected over three storms (12/17/01; 4/9/02; and 4/18/02) and averaged to develop the EMCs. The EMC for BOD was 27 mg/L. The EMC for oil and grease was set at the method detection limit of 5 mg/L. No samples were actually measured over the method detection limit. The TMDL also shows a separate BOD EMC of 4.41 mg/L for grassed areas (p. 7).

No EMCs were used to model loads for the Anacostia Oil & Grease TMDL (2003), the Fort Davis BOD TMDL (2003) or the Hickey Run PCB, Oil and Grease, and Chlordane TMDL (1998).

Table 1: Summary of EMCs Used in District TMDLs

Pollutant	Units	Baseflow EMC	Stormflow EMC	TMDLs
Bacteria				
Fecal coliform bacteria	Number/100 mL	280	17,300	DC Small Tribs Model: Anacostia Tributaries; Oxon Run; C&O Canal; and Potomac Tributaries
Fecal coliform bacteria	Number/100 mL	N/A	28,265	CSO LTCP Approach: Anacostia, Potomac, and Rock Creek mainstems, as well as Kingman Lake, Washington Ship Channel and Tidal Basin
Metals				
Arsenic	ug/L (dissolved + particulate)	0.2	1.4	All of the metals TMDLs except the Rock Creek Mainstem Metals
Copper	ug/L (dissolved + particulate)	3.5	57	All of the metals TMDLs except the Rock Creek Mainstem Metals
Copper	ug/L	N/A	78	Rock Creek Mainstem Metals
Lead	ug/L (dissolved + particulate)	0.6	29	All of the metals TMDLs except the Rock Creek Mainstem Metals
Lead	ug/L	N/A	36	Rock Creek Mainstem Metals
Mercury	ug/L	N/A	0.19	Rock Creek Mainstem Metals

Table 1: Summary of EMCs Used in District TMDLs				
Pollutant	**Units**	**Baseflow EMC**	**Stormflow EMC**	**TMDLs**
Zinc	ug/L (dissolved + particulate)	7.5	173	All of the metals TMDLs except the Rock Creek Mainstem Metals
Zinc	ug/L	N/A	183	Rock Creek Mainstem Metals
Organics				
Chlordane	ug/L	0.000963	0.00983	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
Heptachlor epoxide	ug/L	0.000641	0.000957	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
PAH1	ug/L	0.0825	0.6585	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
PAH2	ug/L	0.219	4.1595	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
PAH3	ug/L	0.1065	2.682	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
Dieldrin	ug/L	0.000641	0.00029	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
DDD	ug/L	0.00462	0.003	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
DDE	ug/L	0.00393	0.0133	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
DDT	ug/L	0.01226	0.0342	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
DDT (Watts Branch)	ug/L	0.00061	0.00171	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
Total PCBs	ug/L	0.0115	0.0806	DC Small Tributaries Model: all organics TMDLs except Potomac and Anacostia Tidal PCB TMDL
Nutrients				
TN (winter)	mg/L	1.918	3.7	Anacostia Nutrients and BOD TMDL
TN (spring)	mg/L	1.418	3.7	Anacostia Nutrients and BOD TMDL
TN (summer)	mg/L	1.018	3.7	Anacostia Nutrients and BOD TMDL
TN (fall)	mg/L	1.318	3.7	Anacostia Nutrients and BOD TMDL

Table 1: Summary of EMCs Used in District TMDLs				
Pollutant	**Units**	**Baseflow EMC**	**Stormflow EMC**	**TMDLs**
TKN	mg/L	0.418	2.6	Anacostia Nutrients and BOD TMDL
NH4	mg/L	0.018	No Data	Anacostia Nutrients and BOD TMDL
NO3 (winter)	mg/L	1.5	1.1	Anacostia Nutrients and BOD TMDL
NO3 (spring)	mg/L	1.0	1.1	Anacostia Nutrients and BOD TMDL
NO3 (summer)	mg/L	0.6	1.1	Anacostia Nutrients and BOD TMDL
NO3 (fall)	mg/L	0.9	1.1	Anacostia Nutrients and BOD TMDL
Organic N	mg/L	0.4	No Data	Anacostia Nutrients and BOD TMDL
TP	mg/L	0.055	No Data	Anacostia Nutrients and BOD TMDL
Sediment				
TSS	mg/L	0 or 2	227	Anacostia TSS TMDL open channel tributaries
TSS	mg/L	0 or 2	94	Anacostia TSS TMDL closed channel sewersheds
TSS	mg/L	6	227	Anacostia TSS TMDL, Watts Branch
TSS	mg/L	No Data	227	Watts Branch TSS TMDL
TSS	mg/L	No Data	60 (after instream erosion was factored out)	Watts Branch TSS TMDL
TSS	mg/L	No Data	167 (instream erosion)	Watts Branch TSS TMDL
TSS	mg/L	No Data	34.67 (representative of the commercial, industrial, residential, and recreational land use activities)	Kingman Lake TSS, Oil & Grease, and BOD TMDL
TSS	mg/L	No Data	5.66 (grassed areas)	Kingman Lake TSS, Oil & Grease, and BOD TMDL

3.2 Review of Land Use-Based EMCs Reported in Literature

Different land use types have been shown to have significant variability in pollutant loads (Stein 2008). Many research institutions have conducted pollutant sampling of different land uses in order to establish land use-based EMCs (see Attachment 1). This research, along with the knowledge that the District of Columbia Office of the Chief Technology Officer (DC OCTO) has developed a very detailed GIS layer of land use and land cover (LULC) for the District, could provide a means to calculate pollutant loads for the MS4 area. This approach would be beneficial since it would identify areas in the city with higher pollutant load potential, which would in turn allow for targeted BMP implementation. A literature review was therefore undertaken to compile land use based EMC values for all of the pollutants which have a TMDL in the MS4 area. The following sections describe the methodology used to compile and analyze the EMCs reported in literature, as well as the results of the literature review.

3.2.a Methodology

The literature review was focused around the 23 pollutants for which DC has TMDLs. In addition, only land uses that are most predominant in the DC MS4 area (e.g.: residential, institutional), or land uses that potentially contribute a large proportion of a certain pollutant (e.g.: golf course, industrial) were targeted for the literature review. For non-conventional pollutants, such as organics, there was little information on EMCs by land use type, and published values were often lumped under the category "urban" land use, so urban was added to the list of land use categories to be researched. The full list of land uses is shown below.

- Commercial
- Forest
- Golf Course
- Highway
- Industrial
- Institutional
- Mixed Use
- Open
- Residential
- Residential, Low Density
- Residential, Medium Density
- Residential, High Density
- Residential, Multifamily
- Roadway
- Urban

The search method for the EMCs comprised of looking at keywords (e.g. EMC, event mean concentration, etc.). The sources of the literature consisted of peer-reviewed research papers and technical reports that were published by federal, state, or local agencies, or through scientific journals. The review was geographically comprehensive and includes data from international, national, and regional sources. Regional values included published data specific to DC, Virginia, and Maryland. Much of the regional data originates from local technical reports, watershed implementation plans (WIPs), and TMDL reports. To the extent possible, we attempted to find the original report and source data. An annotated bibliography is provided in Attachment 1. Both mean and median EMC values were compiled for further analysis.

3.2.b Results

For conventional pollutants, such as TSS, nutrients, and some metals, a significant amount of EMC data was found for all or most land use types. For some of the metals and all of the organics and toxics, very little EMC data was found by land use type. Table 2 provides a general overview of EMC data that was found for each pollutant and land use category.

After compiling the data into a spreadsheet, a statistical analysis of the data was undertaken to determine the min, Q1, median, Q3, and max values. The amount of data that was found for each land use and pollutant combination varied drastically. At least 10 data points per pollutant and land use combination were deemed necessary to conduct a meaningful statistical analysis. If there were not enough data points per land use and pollutant category, then similar land uses were lumped together into broader general land use category. For example, forest and open land uses were combined in some instances. After the compilation, nine land use categories were formed, including:

- Commercial
- Highway/Roadway
- Industrial
- Open/Forest
- Residential (total)
- Residential, Low Density
- Residential, Medium Density
- Residential, High Density
- Urban

The results of the statistical analysis are plotted using box and whisker plots and presented in Figures 1 through 11.

Table 2: EMC Data by Pollutant and Land Use Category

	TSS	TN	TP	BOD	FC	As	Cu	Pb	Hg	Zn	O&G	Chlordane	DDD	DDE	DDT	Dieldrin	Heptachlor Epoxide	PAH1	PAH2	PAH3	ΣPAH	TPCB
Commercial	x	x	x	x	x	x	x	x	x	x	x										x	
Forest	x	x	x	x	x		x	x		x												
Golf Course	x		x																			
Highway	x	x	x	x	x	x	x	x	x	x											x	
Industrial	x	x	x	x	x	x	x	x	x	x	x										x	
Institutional	x	x	x	x	x		x	x		x												
Mixed-Use	x	x	x	x			x	x		x												
Open	x	x	x	x	x		x	x		x											x	
Residential	x	x	x	x	x		x	x	x	x	x											
Residential, LD	x	x	x	x	x	x	x	x		x	x										x	
Residential, MD	x	x	x	x																		
Residential, HD	x	x	x	x	x		x	x		x	x										x	
Residential, Multifamily	x	x	x	x	x		x	x		x												
Roadway	x	x	x	x	x		x	x		x												
Urban	x		x	x	x	x	x	x	x	x	x	x	x	x	x		x				x	

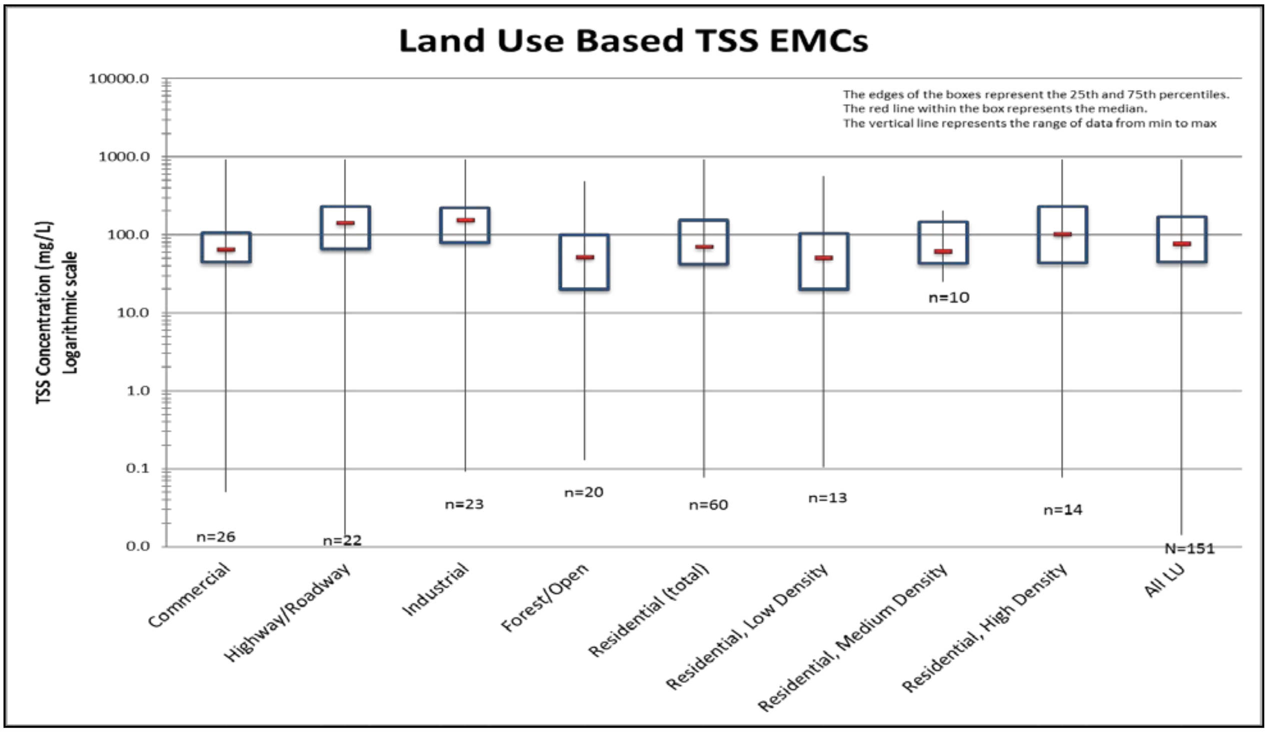

Figure 1: Land Use Based TSS EMCs

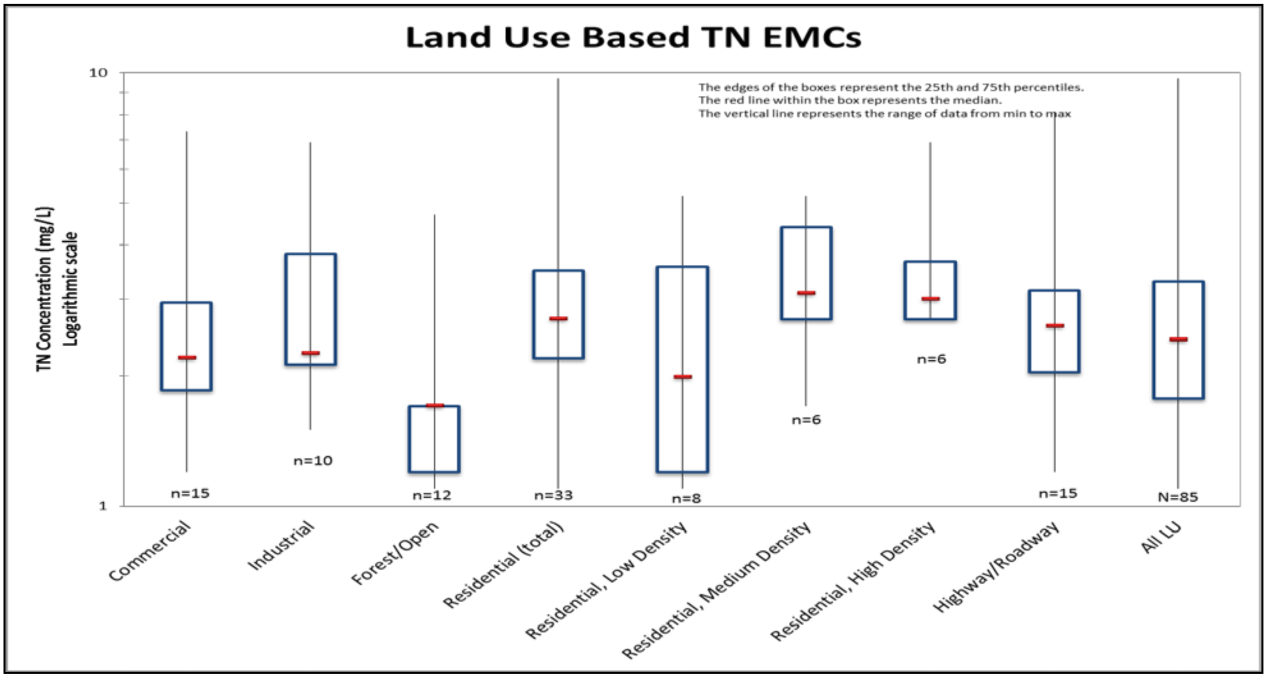

Figure 2: Figure Land Use Based TN EMCs

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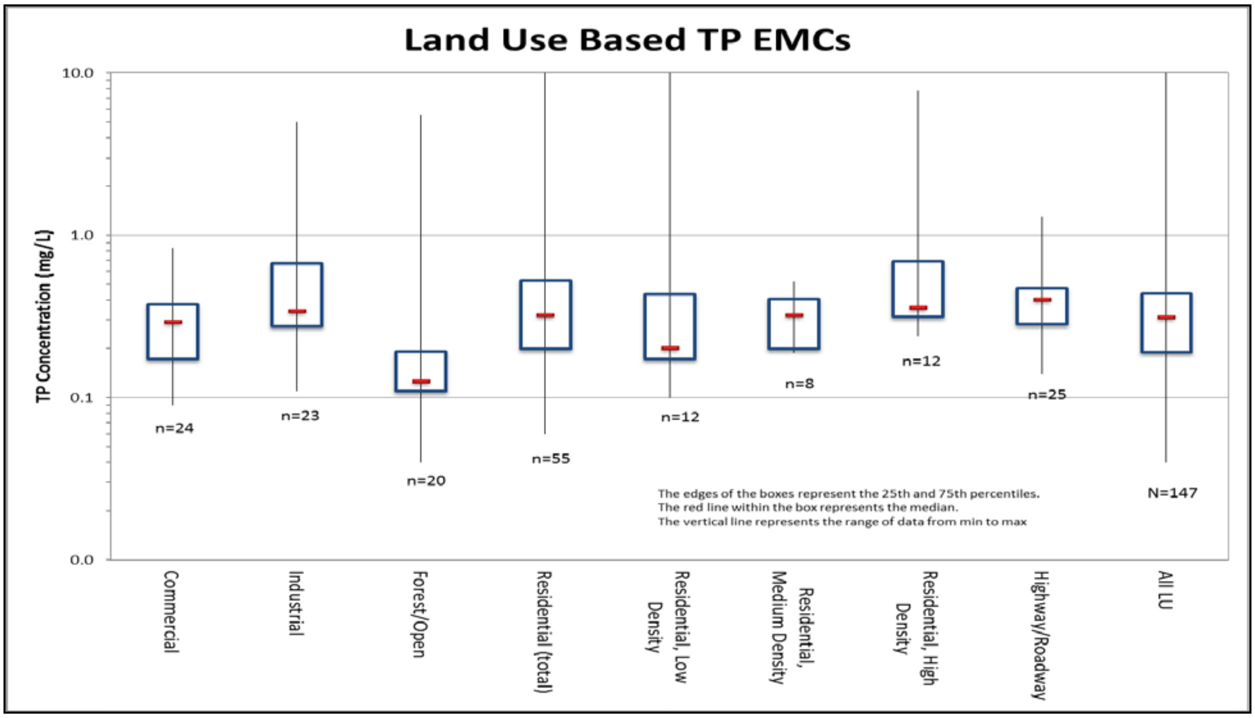

Figure 3: Land Use Based TP EMCs

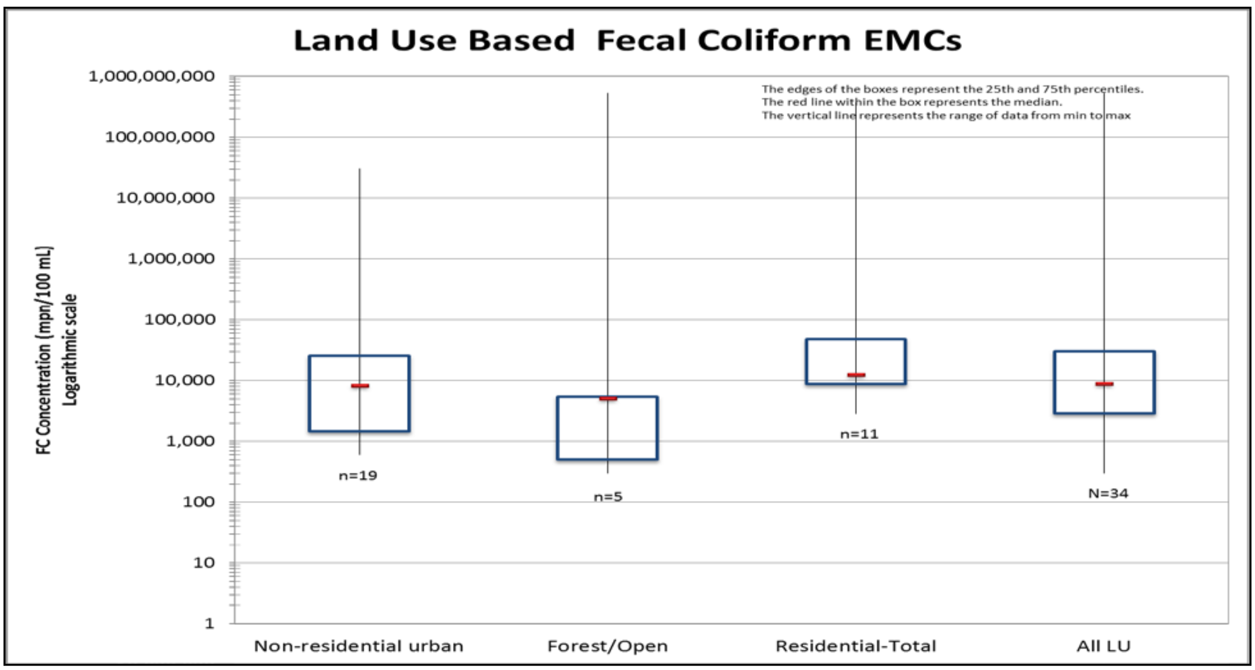

Figure 4: Land Use Based Fecal Coliform EMCs

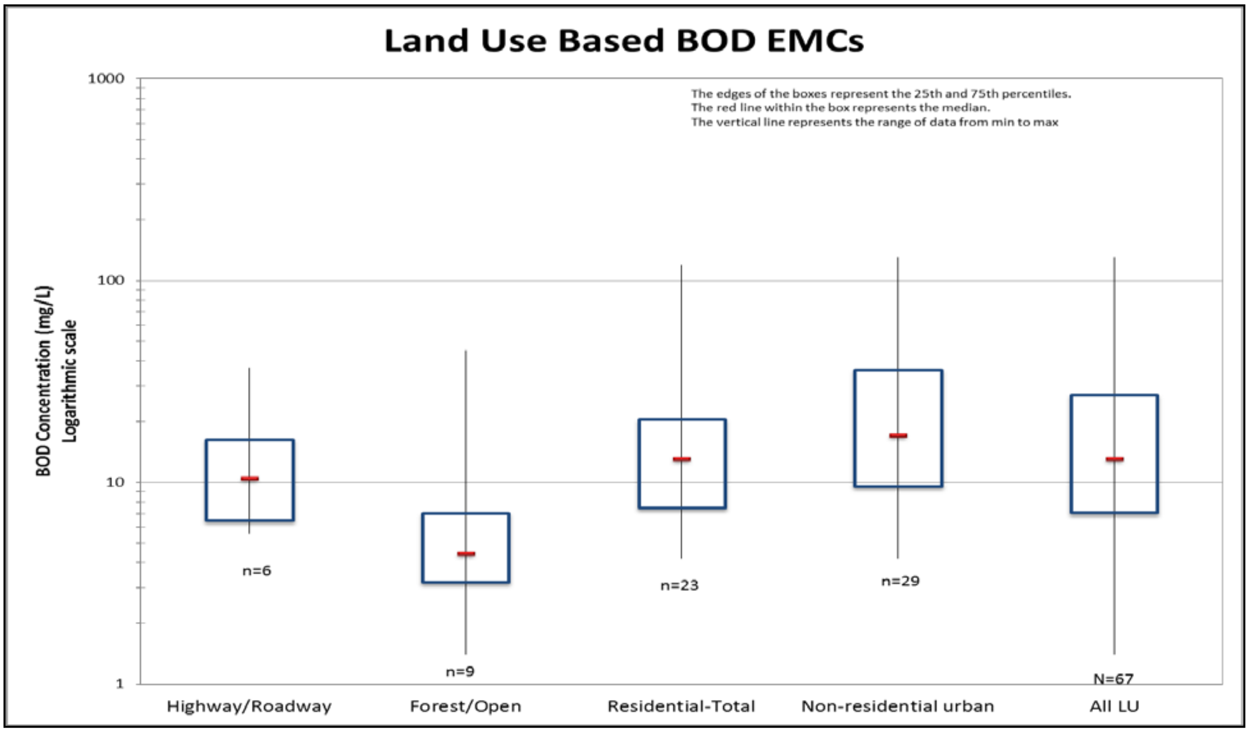

Figure 5: Land Use Based BOD EMCs

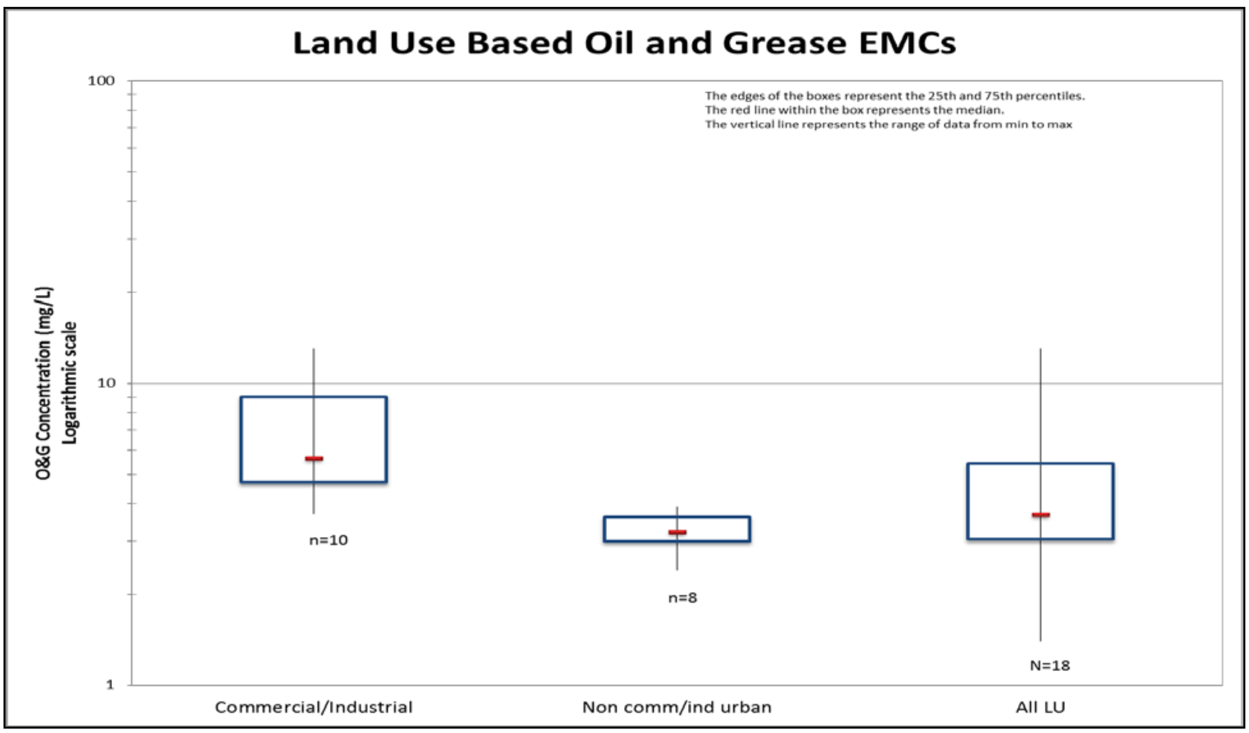

Figure 6: Land Use Based Oil and Grease EMCs

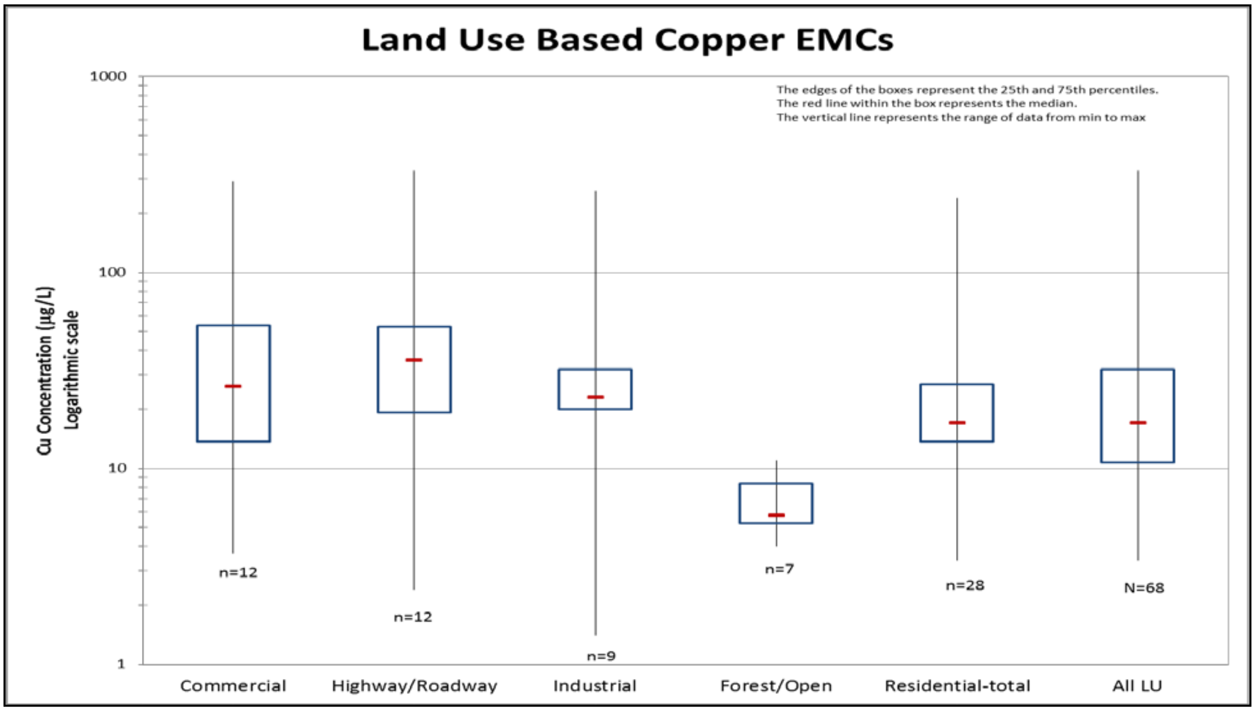

Figure 7: Land Use Based Copper EMCs

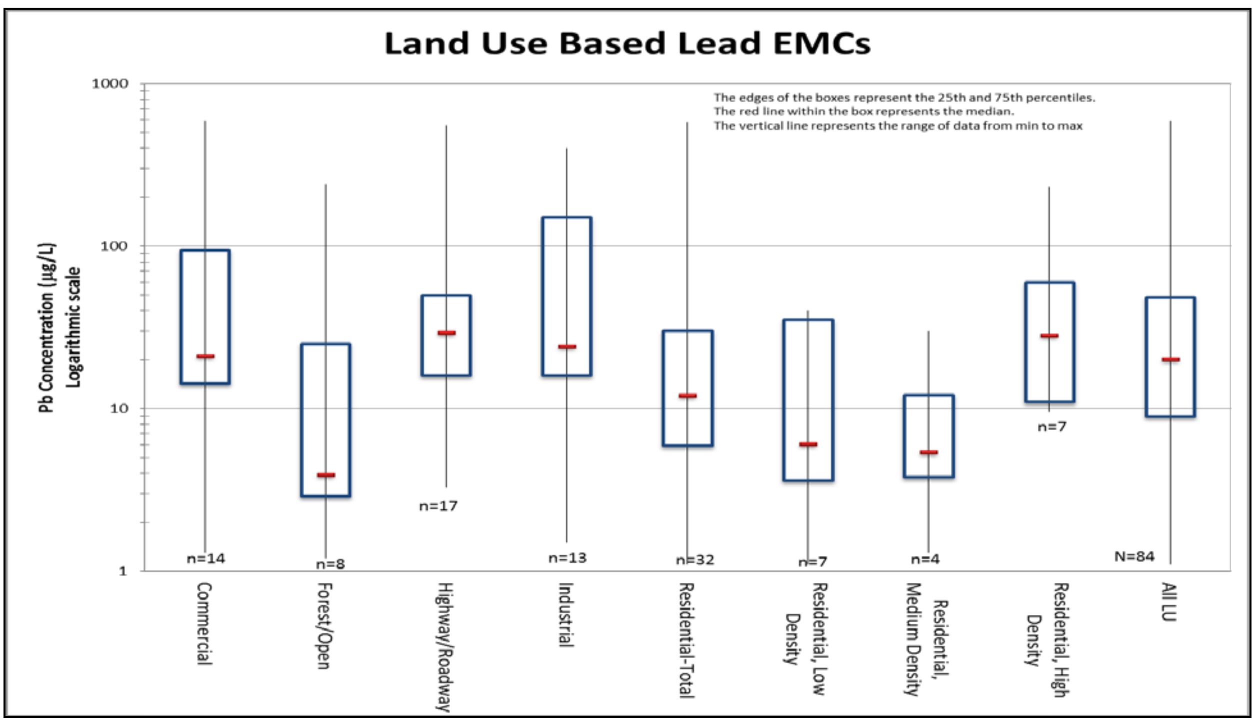

Figure 8: Land Use Based Lead EMCs

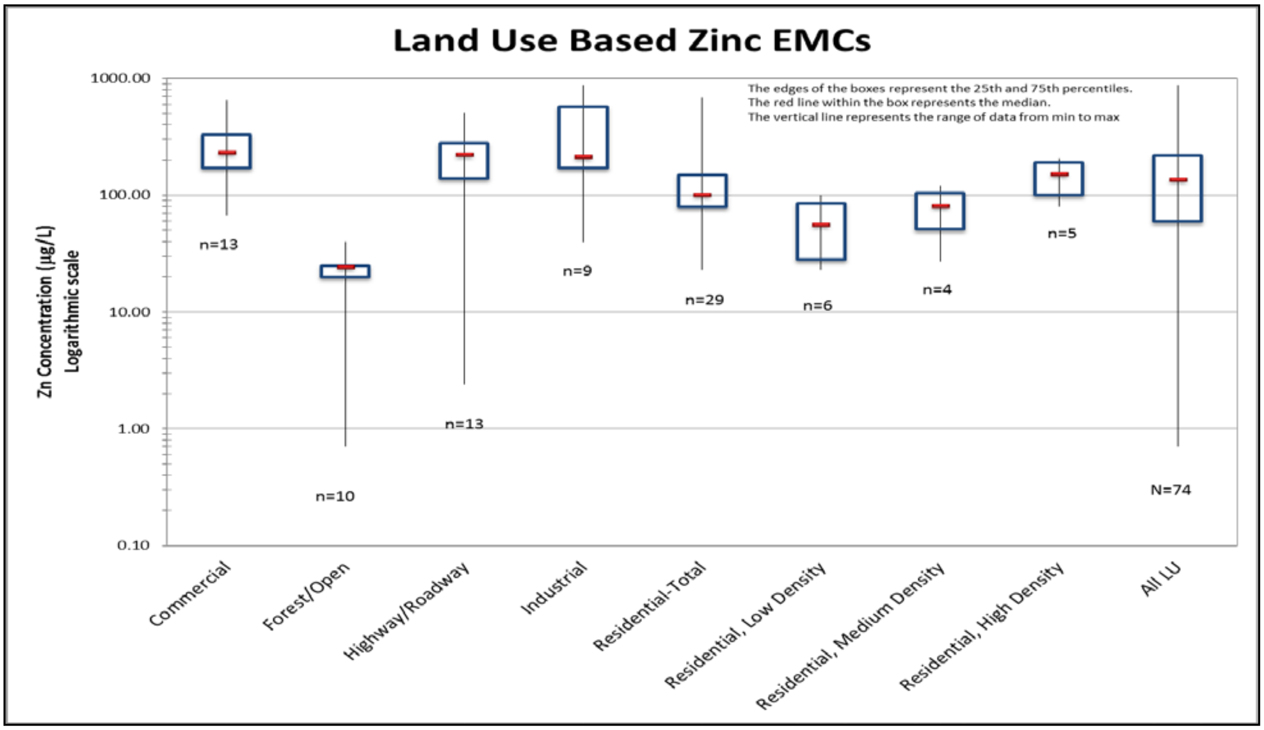

Figure 9: Land Use Based Zinc EMCs

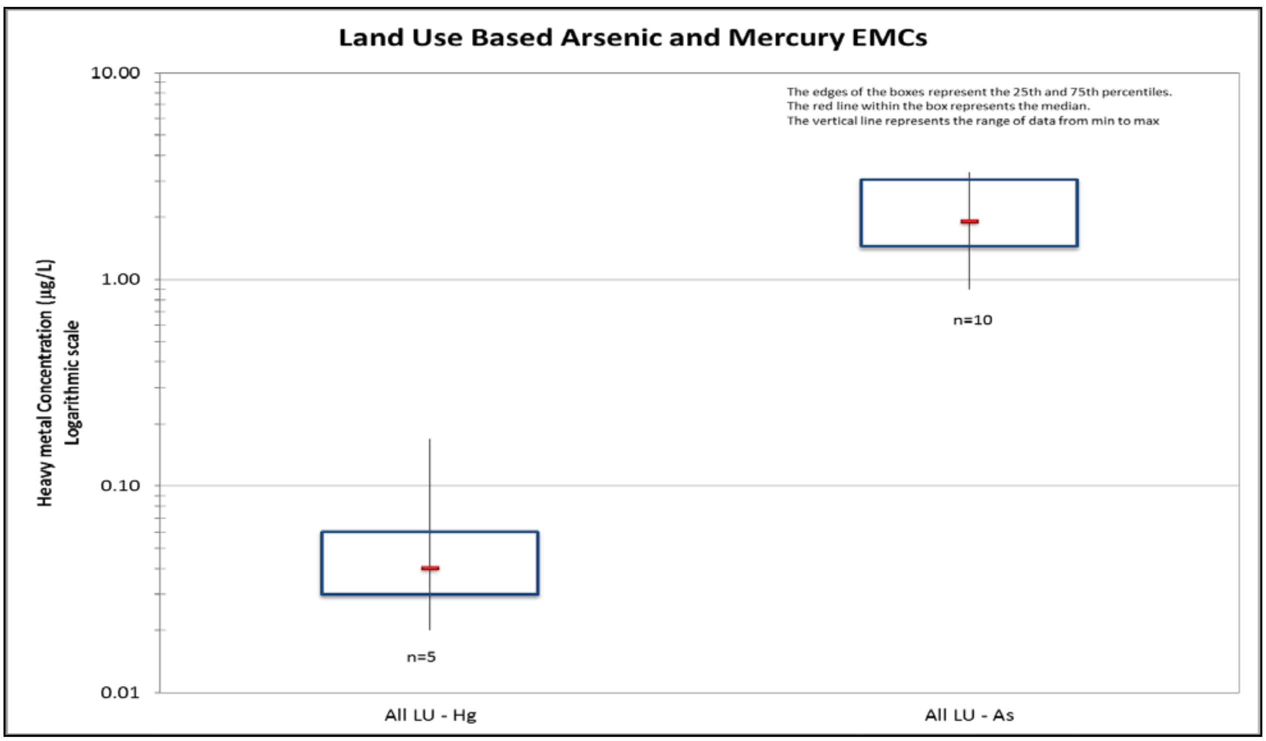

Figure 10: Land Use Based Arsenic and Mercury EMCs

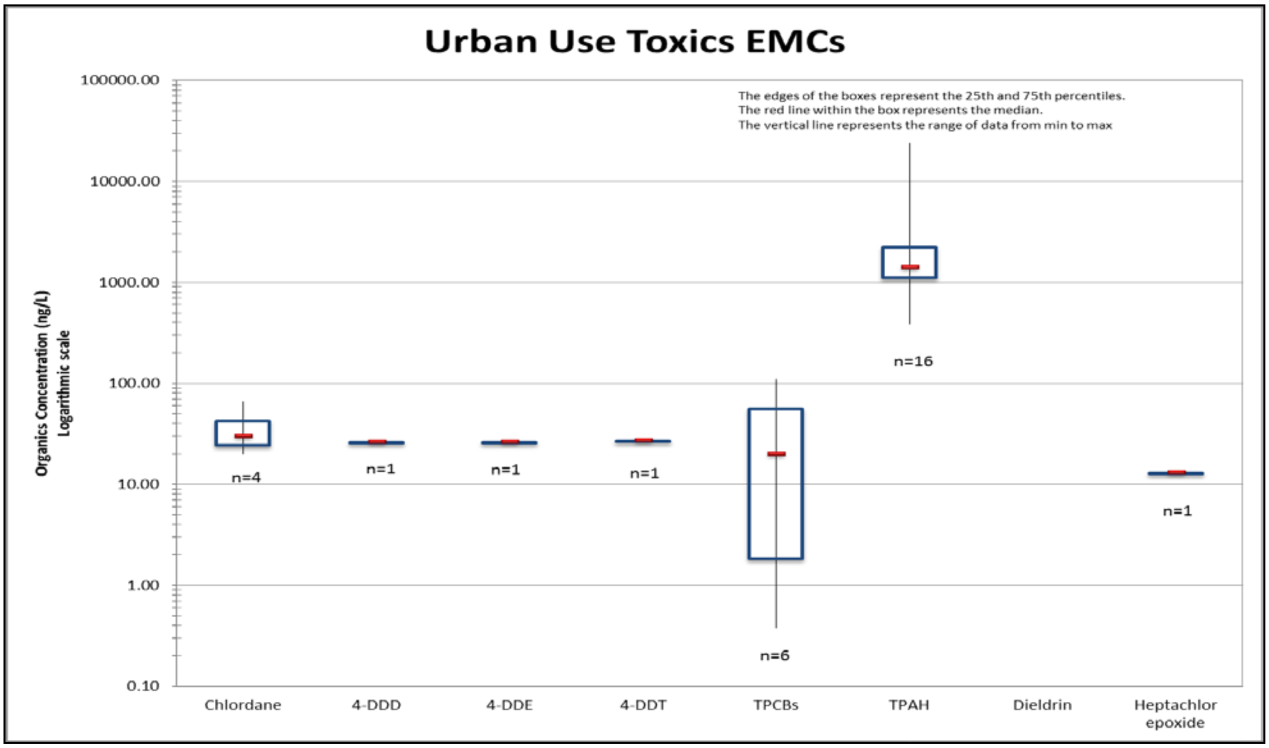

Figure 11: Urban Use Toxics EMCs

3.3 Evaluation of District MS4 Outfall Monitoring Data to Develop EMCs

3.3.a MS4 Monitoring Background

The District has been implementing wet weather monitoring programs in association with its municipal separate storm sewer (MS4) permit since 2000 when its first permit was issued. Within each watershed, DDOE has selected outfalls that are representative of the MS4. The outfall monitoring stations used since 2000 are shown in Table 3 and Figures 1-12 below. The District's 2004 MS4 permit established a rotating schedule for monitoring wet weather discharges to the Anacostia River, Rock Creek, and the Potomac River. Monitoring each year occurs only in one of the watersheds so that each watershed is monitored once every three years. Three wet events are sampled at all locations for the designated watershed each year. Storm events are chosen given the following criteria: at least 0.1 inch of precipitation, 72 hours since the last storm, and one month since the last collection at a specific site. From 2000 through 2011, samples were collected by grab method, except for those that could be analyzed in the field. From 2012 and on, time-composite samples were collected, except for those that could be analyzed in the field.

Table 3: Stormwater Outfall Monitoring Locations, 2000-2012 (Source: EDC 2006)
A. Anacostia River Sub Watershed Monitoring Sites
1. Stickfoot Sewer (Suitland Parkway)-2400 block of Martin Luther King, Jr. Ave., SE, near Metro bus entrance.
2. O St. Storm Water Pump Station - 125 O St., 125 O SE-just outside front gate at O St. Pump Station
3. Anacostia High School/Anacostia Recreation Center - corner of 17th St. and Minnesota Ave. SE
4. Gallatin & 14th St., NE-across from the intersection of 14th St. and Gallatin St. in a large outfall
5. Varnum and 19th Place,NE-2100 Block of Varnum St.
6. Nash Run-intersection of Anacostia Drive and Polk St., NE
7. East Capitol St.-200 Block of Oklahoma Ave., NE
8. Ft. Lincoln-Newtown BMP-in the brush along the side of New York Ave. West (coming into city) after the bridge
9. Hickey run-33rd and V Streets, NE
B. Rock Creek Subwatershed Monitoring Sites
1. Walter Reed (Fort Stevens Drive)
2. Military Road and Beach Drive
3. Soapstone Creek (Connecticut Avenue and Albemarle Street)
4. Melvin Hazen Valley Branch (Melvin Hazen Park and Quebec Street)
5. Klingle Valley Creek (Devonshire Place and 30th Street)
6. Normanstone Creek (Normanstone Drive and Normanstone Parkway)
7. Portal Dr. and 16^{th} St.
8. Broad Branch
9. Oregon and Pinehurst
C. Potomac River Subwatershed Monitoring Sites
1. Battery Kemble Creek-49th and Hawthorne Streets, NW
2. Foundary Branch-at Van Ness and Upton Streets, NW in the park
3. Dalecarlia Tributary-Van Ness Street and Dalecarlia Parkway
4. Oxon Run-Mississippi Avenue and 15th Street, SE
5. Tidal Basin-17th Street and Constitution Avenue, NW
6. Washington Ship Channel-Washington Marina parking lot, SW
7. C and O Canal-Potomac Avenue and Foxhall Road, NW
8. Archbold Parkway

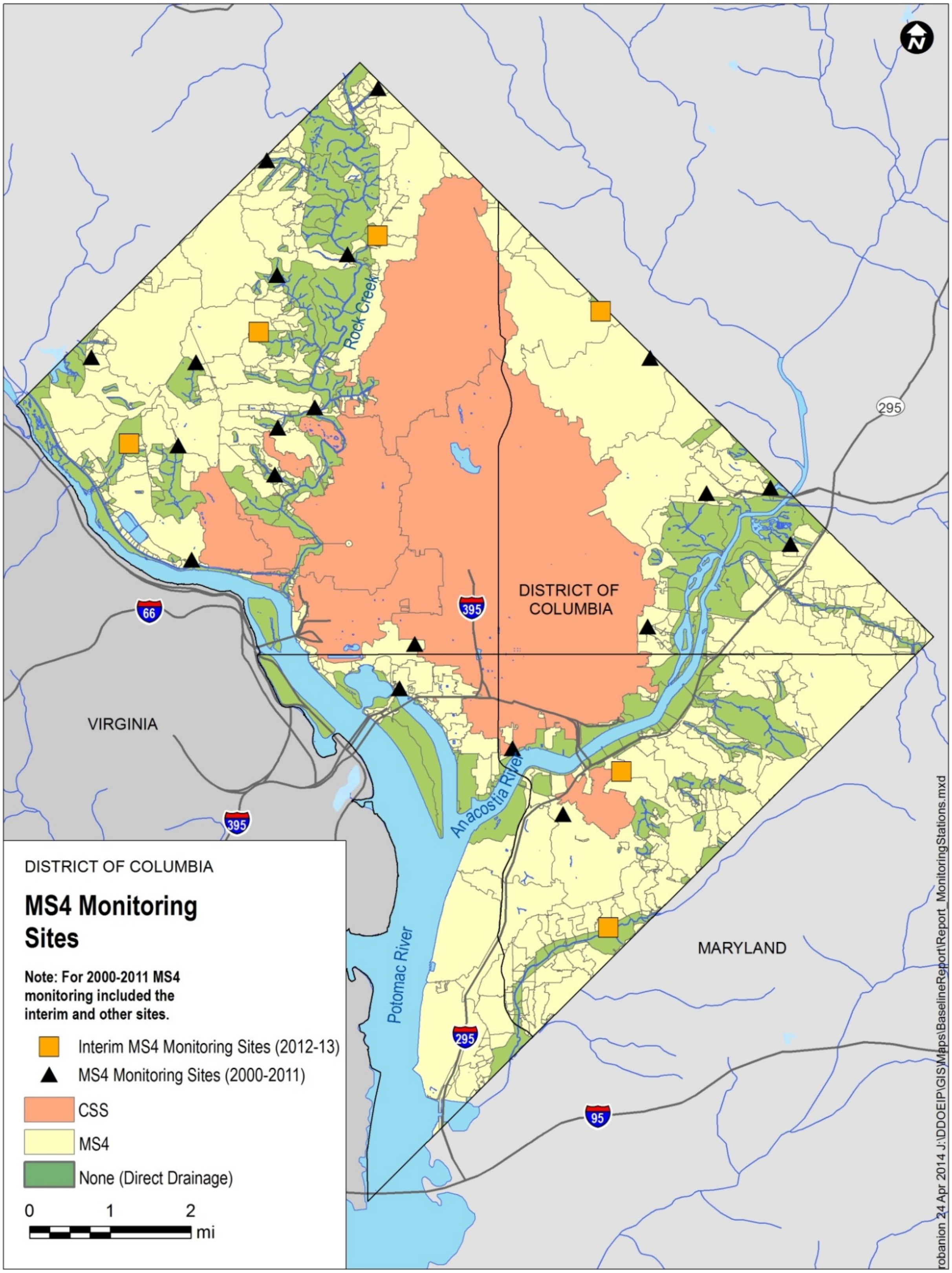

Figure 12: MS4 Monitoring Station 2000-2013

Table 4 shows the list of parameters that were analyzed from 2000 through 2011. Analytical methods and hold times are provided in Table 5.

Table 4: Parameters Analyzed Outfall Discharge Monitoring Samples, 2000-2011 (Source: Apex Companies 2012)		
Grab Samples		**Field Analysis**
• VOCs	• SVOCs	• Residual Chlorine
• Cyanide	• Pesticides and PCBs	• Dissolved Oxygen
• Total Phenols	• Metals	• pH
• Oil & Grease	• Nutrients	• Temperature
• Fecal Coliform	• BOD5, Chlorophyll a	• Flow
• Fecal Streptococcus	• TSS, TDS, Hardness, TOC	
• E-Coli	• Dioxin	

Table 5: Analytical Methods and Hold Times for MS4 Monitoring 2004-2011 (Source: EDC 2006)		
Parameters	**Analytical Method**	**Hold Times**
BOD5	EPA 405.1	
Chlorophyll a	Chlorophyll-a	
COD	EPA 410.4	
Dioxin	EPA 8280	
Dissolved Oxygen, pH, Temperature, Flow, Hardness	Field	
Dissolved phosphorus	SM 18 4500 P B + E	
Fecal Coliform	SM 18 9221 E	
Fecal streptococcus	SM 18 9230 B	
Mercury	EPA 245.1	
Metals, Cyanide and Phenols	EPA 200.8	
Nitrite plus nitrate	EPA 353.2	
Oil & Grease	EPA 1664 A	
Pesticides and PCBs	EPA 608	
Residual Chlorine		
SVOCs	EPA 625	
TKN, or total ammonia plus organic nitrogen	EPA 351.3	
Total dissolved solid	EPA 160.1	
Total phosphorus	EPA 160.1	7 days
TSS	EPA 160.2	7 days
VOCs	EPA 624	14 days

Starting in 2012, the wet weather discharge monitoring was implemented in a slightly revised format (the interim program) based on the revised MS4 permit (finalized in 2012). For the interim program, the sampling protocols changed to include time-composited samples for certain parameters (see Table 7 or which parameters are collected by each method) and the number of stations monitored was reduced to 2 per watershed (to be monitored each year) for efficiency's sake while a new monitoring program is being developed (Tables 6 and-7). Composite samples are taken every 15 minutes from the outfall discharge by automatic samplers equipped with 2.5 gallon glass jars supplied by the analytical laboratory. Grab samples are taken by field staff downstream of the outfall with laboratory-provided collection containers appropriate to the parameter being analyzed. Samples are preserved and packaged according to laboratory instructions and delivered to the lab within approximately 90 minutes of collection. Analytical methods are provided in Table 8.

Table 6: Required Interim Monitoring Stations (Source Table 5, MS4 Permit)
A. Anacostia River Sub Watershed Monitoring Sites
1. Gallatin Street & 14th Street N.E. across from the intersection of 14th St. and Gallatin St. in an outfall (MS-2)
2. Anacostia High School/Anacostia Recreation Center – Corner of 17th St and Minnesota Ave SE
B. Rock Creek Subwatershed Monitoring Sites
1. Walter Reed -- Fort Stevens Drive -- 16th Street and Fort Stevens Road, N.W. at an outfall (MS-6)
2. Soapstone Creek -- Connecticut Avenue and Albemarle Street N.W. at an outfall (MS-5)
C. Potomac River Subwatershed Monitoring Sites
1. Battery Kemble Creek-49th and Hawthorne Streets, N.W. at an outfall (MS-4)
2. Oxon Run-Mississippi Avenue and 15th Street, S.E. into Oxon Run via an outfall (MS-1)

Table 7: Parameters Analyzed in Outfall Discharge Monitoring Samples, 2012-2013 (Source: Apex 2012)

GRAB SAMPLES	COMPOSITE SAMPLES	FIELD ANALYSIS
VOCs	SVOCs	Residual Chlorine
Cyanide	Pesticides/PCBs	Dissolved Oxygen
Coliform	Metals (As, Cu, Cr, Cd, Ni, Pb, Zn)	pH
E. coli, Fecal Coliform, Fecal Streptococcus	Nutrients	Temperature
Oil and Grease	BOD5, Chlorophyll a, COD	Flow
Total Phenols	TSS, TDS, Hardness, TOC	
	Dioxin	

Table 8: Wet Weather MS4 Sampling Analytical Methods and Hold Times (Source: Apex 2012)

Parameters *(to be Analyzed in Wet Weather Samples)*	Method	Holding Times
E. coli	SM (20) 9221E	6 hours
Total nitrogen	SM (20) 4500-NO3 E + SM 4500orgN	28 days
Total phosphorus	EPA 365.1	28 days
Total Suspended Solids	SM (2) 2540D	7 days

Table 8: Wet Weather MS4 Sampling Analytical Methods and Hold Times (Source: Apex 2012)		
Parameters (*to be Analyzed in Wet Weather Samples)*	**Method**	**Holding Times**
Cadmium	EPA 200.7	180 days
Copper	EPA 200.7	180 days
Lead	EPA 200.7	180 days
Zinc	EPA 200.7	180 days
pH	SM (20) 4500 H B	15 minutes
Fecal coliform	SM (20) 9221 E	6 hours
Dissolved Oxygen	SM (20) 4500 O-G	1 day
Hardness	SM (20) 2340 C	28 days
Chlorophyll a	SM 10200H	2 day s
Temperature	Field	Instant

Section 5.1 of DDOE's revised MS4 permit (first issued in 2011 and modified in 2012) includes the requirement to design a revised monitoring program. The permit requires a small set of parameters to be monitored (Table 9). The monitoring sites and protocols are currently in development (to be completed in 2015).

Table 9: Parameters to be Monitored for Outfall Discharge as Part of Revised Program, 2015 (Source: MS4 Permit, Table 4)		
E. coli	Lead	Total Suspended Solids
Total nitrogen	Zinc	Arsenic
Total phosphorus	Trash	Copper

3.3.b Methodology

Data from various documents and spreadsheets provided by DDOE was consolidated into a database of all available MS4 monitoring data 2001-13. The following quality control actions were taken with the data before analysis. First, all dry weather data and fecal coliform samples qualified with ">" were removed. When units of the minimum detection limit (MDL) and the result did not match, both units were checked the original sources and corrected. Those samples marked as non-detects ("ND") or below quantification limit ("BQL") were estimated to be one half the detection limit for analysis. The interquartile range (IQR) was established as the difference between the upper (Q3) and lower (Q1) values for each parameter, where

$$IQR = Q3 - Q1$$

Using the Interquartile Rule for the determination of outliers, outliers were identified as data values that are greater than Q3 + (3.0 * IQR). This analysis was applied o data sets that had sufficient data (i.e., data sets that did not contain large numbers of non-detects [NDs]), including conventional pollutants and all metals except mercury, most metals to identify outliers.

3.3.c Results

Available wet weather data for the years 2001-2013 were analyzed for minimum, maximum, average, median, number of samples and number of non-detects (NDs) on a city-wide (Table 10) and watershed basis (Table 11). The following parameters had such a large number of NDs that they are excluded from this analysis due to lack of meaningful data: mercury, PAHs, PCBs, chlordane, dieldrin, DDT isomers, and heptachlor epoxide.

Table 10: Summary Statistics for Wet Weather MS4 Monitoring Data, City-Wide 2001-2013

	TSS	TN	TP	Fecal Coliform	BOD	Oil and Grease	Arsenic	Copper	Lead	Zinc
Units	mg/l	mg/l	mg/l	MPN/ 100ml	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	0.50	0.003	0.03	8.00	1.00	1.25	0.00013	0.00050	0.00012	0.00075
Max	290	11	1.2	92,000	120	13	0.01	0.23	0.07	0.34
Average	58.94	3.32	0.38	13,639	28.34	3.72	0.002	0.05	0.02	0.11
Median	42.5	3.1	0.33	4,600	18.5	2.5	0.001	0.04	0.012	0.0985
n	190	194	198	115	184	149	158	203	191	216
# NDs	5	18	0	1	13	103	109	7	11	7

Table 11: Summary Statistics for Wet Weather MS4 Outfall Monitoring Data by Watershed, 2001-2013

	TSS	TN	TP	Fecal Coliform	BOD	Oil and Grease	Arsenic	Copper	Lead	Zinc
Units	mg/l	mg/l	mg/l	MPN/ 100ml	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Anacostia River Watershed										
Min	8	0.0025	0.025	33	1	1.25	0.000302	0.0005	0.00012	0.0055
Max	290	9.1	1.2	90,000	110	11	0.0048	0.19	0.067	0.29
Average	73.33	3.39	0.42	12,512	35.93	3.65	0.002	0.04	0.02	0.12
Median	60	3.344	0.39	4,600	24.5	2.5	0.001	0.032	0.013	0.12
n	73	80	81	44	50	53	68	84	83	89
# NDs	0	8	0	0	1	38	45	3	2	0
Rock Creek Watershed										
Min	1	0.5	0.076	22	1	2.5	0.001	0.001	0.001	0.01
Max	210	11	1.05	90,000	100	12	0.0054	0.13	0.072	0.294
Average	59.50	3.24	0.33	16,295	23.67	4.15	0.00	0.05	0.02	0.10
Median	52	3.265	0.32	6,500	16.5	2.5	0.001	0.043	0.013	0.089
n	53	50	54	42	48	48	50	60	57	60
# NDs	2	4	0	1	9	30	38	1	3	4

Table 11: Summary Statistics for Wet Weather MS4 Outfall Monitoring Data by Watershed, 2001-2013										
	TSS	**TN**	**TP**	**Fecal Coliform**	**BOD**	**Oil and Grease**	**Arsenic**	**Copper**	**Lead**	**Zinc**
Units	**mg/l**	**mg/l**	**mg/l**	**MPN/ 100ml**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Potomac River Watershed										
Min	0.5	0.0025	0.039	8	1	1.25	0.000125	0.00075	0.000115	0.00075
Max	220	9.7	1.06	92,000	120	13	0.004	0.234	0.062	0.344
Average	42.06	3.28	0.37	11,503	28.08	3.35	0.00	0.07	0.01	0.10
Median	33	2.8	0.3	3,000	16.5	2.5	0.001	0.05	0.011	0.083
n	64	64	63	29	40	48	40	59	51	67
# NDs	3	6	0	0	3	35	26	3	6	3

4 Results and Discussion

The review of EMCs in the previous section illustrates the complexity of EMC assignment. In particular,

- There are extremely broad differences in the EMCs used to establish TMDLs in the District, but these reasons for these differences may have as much to do with the data and sources used to develop the original EMCs as with actual differences in waterbody EMCs for different pollutants.
- The national and regional body of literature on EMCs is rich but highly variable with regard to land use classes, and relating these studies to local circumstances in the District is not straightforward.
- District MS4 outfall monitoring data offer some promise because the data are local and recent, and because the number of wet weather observations is fairly large for most of the parameters of interest.

Based upon this review it was determined that further analyses were needed before specific EMCs could be recommended. One analysis addressed the appropriateness of using land use-based EMCs in the District (Analysis 1). The second analysis addressed the adequacy of the District MS4 outfall monitoring data to support the derivation of EMCs (Analysis 2). A third analysis (an offshoot of Analysis 2) was undertaken to assess development of watershed based EMCs with District MS4 outfall monitoring data (Analysis 3).

The details of these three analyses are described in the following sub-sections. Conclusions and recommended EMCs are discussed and presented at the end of the section.

4.1 Analysis 1, Evaluation of Land Use-Based EMCs

The first analysis was to determine if the land use based EMCs from the literature could be used to predict the monitored EMCs. In other words, are the land use based EMCs from the literature, which are based on nationwide data, appropriate to characterize the site specific conditions of the District? If the analysis is favorable, then the land use-based EMC values could be used with a high degree of confidence to represent local pollutant load conditions.

To do this analysis, a subset of the monitored data was used and average EMCs were calculated for each pollutant of concern. The subset of District outfall monitoring data selected included the EMC data provided by the 2009 Stormwater Management Plan (DDOE, 2009), and the EMC data provided by the *Study Memorandum LTCP 5-8 (Final), CSS and SSWS Event Mean Concentrations* (DC Water, October 2001). The reason this subset of data was selected is because it was, at the time of the analysis, readily available in a useable format, and provided a good selection of monitoring sites across the MS4 area. A total of 16 sites were included in this subset of data, and each site was sampled during 3 to 5 storms over the course of a year. The drainage area of each site was delineated and the land use types within the drainage areas were defined using the 2005 DC OCTO existing land use GIS layer (DC OCTO, 2005). Then the land use based EMCs were applied and an overall area-weighted land use based EMC was calculated for each site. This calculated value was subsequently compared to the monitored value. The full table of comparison for each pollutant is available in Attachment 2. The results of this analysis showed that:

1. Not enough land use based EMC data exists in the literature for the organics and some of the metals to make land use based EMC predictions.
2. The calculated EMC values using the average values per land use type identified from the literature were, in most cases, lower than the monitored value. As a consequence, the average literature values were increased for each land use type by anywhere from 10% to 400% in order to produce a larger area-weighted land use based EMC value that was more aligned with the monitored value. Note that, even after increasing the average value of the individual land use based EMCs, the increased values were still within the observed ranges reported by the literature for each land use type.
3. Even after adjusting the average land use based values, it was practically impossible to match the monitored values in all locations. Only when comparing the calculated and monitored average and median EMC values for all the sites combined did the calculated values more closely match the monitored values. But on a site by site basis, the calculated EMCs would sometimes over-predict, and at other times under-predict the monitored values. No obvious trends in the data were observed on a site by site basis.
4. The monitored EMCs seem to be dependent on more than just land use, as watersheds with similar land use types do not always have similar EMC values. This is apparent in the results table shown in Attachment 2. Other factors that may affect EMC values include rain intensity, anthropogenic activities such as construction, the sampling protocol used, and other watershed characteristics such as slope.
5. The variability in the predictions did not provide the level of confidence needed to move forward with using the land use based EMC values.

4.2 **Analysis 2, Updated EMCs from MS4 Monitoring Data**

The second analysis that was undertaken was to determine if sufficient monitored EMC data exists to calculate EMC values for all of the TMDL pollutants. An additional line of inquiry was to compare the average monitored EMCs to the EMCs used to develop the TMDLs. The full table of comparison is available in Attachment 3. The results of this analysis showed that:

1. Sufficient monitoring data exists only for sediment, nitrogen, phosphorus, BOD, bacteria, oil and grease, arsenic, copper, lead, and zinc. For all other pollutants, many non-detects were found in the data, and this precluded any sort of meaningful interpretation of the monitoring data.
2. The EMCs for pollutants with sufficient data show that they are generally within the same range as the EMCs used to develop the TMDLs, but are typically slightly lower than the mainstem EMCs and slightly higher than the tributary and Chesapeake Bay EMCs.

4.3 Analysis 3, Evaluation of Watershed EMCs

Statistical analysis was undertaken to determine whether city-wide or watershed specific EMCs should be used for further modeling. The MS4 outfall monitoring data was grouped according to monitoring station location in either the Anacostia, Potomac or Rock Creek watershed. Standard EMC summary statistics and median values were calculated for each watershed. Analysis of variance (ANOVA) was used to examine differences in data collected in the three different watersheds. ANOVA is a standard statistical method used to test differences between two or more means (in this case EMCs) (See Attachment 4 for a summary of the ANOVA analysis). The relevant statistics and results are summarized in Table 12. These results show that a significant difference in EMCs at the watershed level was determined for four parameters: BOD, Oil & Grease, TSS and Zinc. Significance differences at the 0.05 level or lower mean that there is >95% confidence that the watershed EMCs are truly different and that this difference is not due to chance. No significant difference was found at the watershed level for the other parameters.

Table 12: Summary of ANOVA Analysis

Parameter	Transformation[1]	F-Statistic	Pr (>F)	Result
Arsenic	N/A	N/A	N/A	No Difference
Biological Oxygen Demand	Log	3.426	0.03463	Significant Difference at the 0.05 Level
Copper	Log	1.895	0.1530	No Difference
Fecal Coliform	Log	1.259	0.2878	No Difference
Lead	N/A	N/A	N/A	No Difference
Nitrogen	0.5454	0.036	0.9641	No Difference
Oil & Grease	-0.5858	4.379	0.0142	Significant Difference at the 0.05 Level
Phosphorus	0.3434	1.681	0.1889	No Difference
Total Suspended Solids	Log	6.315	0.0022	Significant Difference at the 0.01 Level
Zinc	0.4646	3.804	0.0238	Significant Difference at the 0.05 Level

[1] Numbers (ex. λ=0.5454) indicate a power transformation identified through a Box-Cox transformation analysis. N/A indicates that no suitable transformation for normality was identified and best professional judgment was used for difference analysis.

4.4 Conclusion

The results of the three analyses demonstrated that:

- Literature-derived land use-based EMCs cannot consistently predict EMCs from the monitoring data.
- District MS4 outfall monitoring data offered promise as a way to establish EMCs for conventional pollutants and metals. The average concentration of the pooled MS4 outfall monitoring data compared very well with the EMCs used in District TMDL studies.
- The District MS4 outfall monitoring data can be used to develop EMCs for TSS, nutrients, and some metals. For all other pollutants, insufficient monitoring data exists to develop EMCs.

- For some parameters for which updated EMCs can be developed from MS4 monitoring data, the monitoring data is sufficient to develop EMCs at the watershed/basin level (i.e., Anacostia, Rock Creek, and Potomac watersheds). For other parameters, updated EMCs can only be calculated at the District scale.

4.5 **Recommended EMCs**

An updated set of EMCs is recommended following a detailed review and analysis of:

- EMCs used to develop TMDLs in the District;
- EMCs reported in literature for various land use classes; and
- District MS4 outfall monitoring data.

The recommendation for organic compounds, arsenic and mercury is to use the original EMCs applied to develop TMDLs in the District. The recommendation for conventional pollutants and the other metals is to use average EMCs derived from the MS4 outfall monitoring data, with watershed-based EMCs for BOD, Oil & Grease, TSS and Zinc.

A summary of the recommended EMCs to be applied in the IP Modeling Tool is presented in Table 13.

Table 13: Recommended EMCs

Pollutant	Units	EMC Value	Source of EMC
TN	mg/l	3.32	From monitoring data
TP	mg/l	0.38	From monitoring data
TSS (Anacostia)	mg/l	73	From monitoring data
TSS (Rock Creek)	mg/l	60	From monitoring data
TSS (Potomac)	mg/l	42	From monitoring data
FC	MPN/100ml	13,639	From monitoring data
E. coli	MPN/100ml	5,474	From DC bacteria translator
BOD (Anacostia)	mg/l	35.93	From monitoring data
BOD (Rock Creek)	mg/l	23.67	From monitoring data
BOD (Potomac)	mg/l	28.08	From monitoring data
Oil&Grease (Anacostia)	mg/l	3.65	From monitoring data
Oil&Grease (Rock Creek)	mg/l	4.15	From monitoring data
Oil&Grease (Potomac)	mg/l	3.35	From monitoring data
Arsenic	ug/l	1.54	From monitoring data
Copper	ug/l	52.88	From monitoring data
Lead	ug/l	15.94	From monitoring data
Mercury	ug/l	0.19	From TMDL
Zinc (Anacostia)	ug/l	120.92	From monitoring data
Zinc (Rock Creek)	ug/l	101.73	From monitoring data
Zinc (Potomac)	ug/l	100.90	From monitoring data

Table 13: Recommended EMCs			
Pollutant	**Units**	**EMC Value**	**Source of EMC**
Chlordane	ug/l	0.00983	From TMDL
DDD	ug/l	0.003	From TMDL
DDE	ug/l	0.0133	From TMDL
DDT	ug/l	0.0342	From TMDL
Dieldrin	ug/l	0.00029	From TMDL
Heptachlor Epoxide	ug/l	0.000957	From TMDL
PAH1	ug/l	0.6585	From TMDL
PAH2	ug/l	4.1595	From TMDL
PAH3	ug/l	2.682	From TMDL
TPCB	ug/l	0.0806	From TMDL

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Attachments

TABLE OF CONTENTS

ATTACHMENT 1: ANNOTATED BIBLIOGRAPHY A1-32

ATTACHMENT 2: RESULTS ANALYSIS 1, EVALUATION OF LAND USE-BASED EMCS A2-1

Figure 1: Location of Sampling Sites Used in Analysis 1 ..... A2-2
Table 1: TSS EMC Comparison Between Reported and Calculated Values Calculated Values A2-3
Table 2: TN EMC Comparison Between Reported and Calculated Values A2-4
Table 3: TP EMC Comparison Between Reported and Calculated Values A2-5
Table 4: Fecal Coliform EMC Comparison Between Reported and Calculated Values A2-6
Table 5: BOD EMC Comparison Between Reported and Calculated Values A2-7
Table 6: Oil and Grease EMC Comparison Between Reported and Calculated Values A2-8
Table 7: Copper EMC Comparison Between Reported and Calculated Values A2-9
Table 8: Lead EMC Comparison Between Reported and Calculated Values A2-10
Table 9: Zinc EMC Comparison Between Reported and Calculated Values A2-11

ATTACHMENT 3: RESULTS OF ANALYSIS 2, UPDATED EMCS FROM MS4 MONITORING DATA . A3-1

Table 1: Statistical Analysis of MS4 monitoring Data for conventional pollutants and some metals A3-2
Table 2: Statistical Analysis of MS4 monitoring Data for organics, toxics, and some metals A3-3

ATTACHMENT 4: ANALYSIS OF EMC DIFFERENCES A4-1

Table 1: Summary of ANOVA Analysis A4-2
Figure 1: Box and Whisker plot of Arsenic data A4-2
Figure 2: Box and Whisker plot of Lead data A4-3

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Attachment 1: Annotated Bibliography

Annotated Bibliography of the Land use Based EMC Literature Review

Currier, P., SB 1295 Stormwater Commission on Event Mean Concentration and Land Use; April 6, 2009

Summary: This brief report specifically discusses the event mean concentrations by varying land use. Data was collected from the Houston, TX area. Land uses consisted of residential, commercial, mixed urban, agricultural/pastures and herbaceous/open land. For this study, the focus is on urban areas and not rural areas. Parameters reviewed were total suspended solids (TSS), biological oxygen demand (BOD), total nitrogen (TN) and total phosphorus (TP). Fecal coliform was discussed on a national scale with another diagram showing the high fecal coliform count in urban areas. EMC values were calculated for the different land uses and were ranked in order from lowest to highest concentration. For TSS, the highest concentration rank was in the industrial land use and the lowest was in the water/wetland land use area. For TP, the highest concentration was in the medium density residential area and the lowest concentration was the water/wetland land use area. Total nitrogen had the highest concentration in agricultural/pasture and zinc had the highest concentrations in the industrial land use.

Flint, K., Water Quality Characteristics of Highway Stormwater Run-off from an Ultra-Urban Area, Thesis, University of Maryland-College Park, 2004

Summary: This is a thesis paper on water quality characterization of urban highway stormwater run-off. In the literature review, event mean concentrations were cited from several different sources in Sweden, North Carolina, and Texas. Conventional pollutants were documented such as TSS. Nitrate nitrogen, nitrite nitrogen, copper, lead, cadmium, zinc, total kjehldahl nitrogen and total phosphorus. Most of the land use area was rural, but there were some mixed used land uses that was beneficial to the project.

Lin, J., Review of Published Export Coefficient and Event Mean Concentration Data; Wetlands Regulatory Assistance Program, ERDC-TN-WRAP-04-3, September 2004

Summary: This review covers export coefficients and event mean concentration for various land use areas in different areas of the country. Export coefficients are designated for rural areas, while event mean concentrations (EMCs) are designated for urban land uses. Event mean concentrations are used to estimate pollutant loading and land use specific EMCs can help regulators determine the effects of the change of land uses on pollutant loads. Lin 2004 discusses "possible regional trends in export coefficient and EMCs". Median and mean EMCs were sited from sources from Upper Neuse River Basin, NC; Dallas/Ft. Worth, TX; Colorado Springs, CO; Los Angeles, CA; Central and South Florida and the Twin Cities Metro area, MN.

The Upper Neuse River basin data was comprised from a study done in 2002 (Line 2002). The land use EMCs were attained from six small drainage areas that were monitored in east central North Carolina. The Dallas/Ft. Worth report was developed by Baldy 1998. This report contains EMCs from data collected at 26 sites in the Dallas/Ft. Worth area. The Colorado Springs report documents mean and median land use EMC values from five locations in the city. Land uses were not specifically given to the areas that were monitored, but the percentage of land use coverage for each area. Sites identified as commercial were 61.1 % commercial, industrial sites were 79.5% industrial and residential sites were 79.4% residential. Being a large city, Los Angeles County conducts their monitoring for stormwater. The Los Angeles County Department of Public Works published annually a stormwater monitoring report. The data for this report in Los Angeles originated from the LA report from 1998-1999. Lastly, the data from Florida is a summary of land use EMCs from 40 reports that was compiled from a summary report by Harper 1998. Pollutants identified included: NO_3, NO_3+NO_2, TKN, NH_3-N, TN, TP and TSS.

Stein, E.D. Comparison of Stormwater Pollutant Loading by Land Use Type; Southern California Coastal Water Research Project, AR08-015-027 2008. ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/AnnualReports/2008AnnualReport/AR08_015_027.pdf

Summary: Stein did a comparison study on stormwater pollutant loading for different land use areas. Pollutant concentration and flows were measured over the entire storm duration from eight land use types in five Southern California watersheds. Land use types were being observed to determine patterns of pollutant loads in urban runoff and how varying land use types may affect them. The data was taken from the 2000-2001 to 2004-2005 storm seasons. There were 33 site events used for this study. Land use areas were homogeneous and comprised of: high density residential, low density residential, commercial, industry, agriculture, recreational, transportation and open space. Predicted stormwater loads are highly sensitive to land use designation and their associated EMC estimates. The greatest uncertainty to modeling efforts is inaccurate EMC data.

Environmental Assessment. USEPA.gov; water.epa.gov/scitech/.../2006_10_31_guide_stormwater_usw_b.pdf

Summary: This summary gives an overview of the effect of urban runoff on water quality when there is a change in perviousness due to urbanization. This report discusses the physical, chemical and biological effects of polluted urban run-off. Many studies of storm water runoff were conducted after the Water Quality Act of 1965. EPA's National Urban Runoff Program of 1983 was one of many programs that examined the effect of urban runoff on waterways. NURP was created to examine the characteristics of urban runoff to determine if there are differences between urban land uses. The program also examined whether urban runoff is a significant contributor to water quality problems nationwide and the performance characteristics and effectiveness of Best Management Practices (BMPs) to control pollution loads from urban runoff. Samples were taken from 28 NURP projects that included 81 specific sites and more than 2,300 separate storm events.

NURP focused on the following ten constituents:

- Total Suspended Solids (TSS)
- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Phosphorus (TP)
- Soluble Phosphorus (SP)
- Total Kjehldahl Nitrogen (TKN)
- Nitrate + Nitrite (N)
- Total Copper (Cu)
- Total Lead (Pb)
- Total Zinc (Zn)

NURP also examined coliform bacteria and priority pollutants at a subset of sites. Median event mean concentrations (EMCs) for the ten general NURP pollutants for various urban land use categories are presented in this report (Table 4-1).

McKee, P.J. and H.C. McWreath, Computed and Estimated Pollutant Loads, West Fork Trinity River; Water-Resources Investigations Report 01–4253, U.S. GEOLOGICAL SURVEY, Fort Worth, Texas, 1997, Trinity River Authority, Austin, TX 2001

Summary: This report shows the EMC values for: total suspended solids (TSS) labeled as suspended solids in the table; total nitrogen (TN); ammonia and organic nitrogen (NH3 + org N-TKN); dissolved phosphorus (P^{3-}); total phosphorus (TP); biochemical oxygen demand (BOD); total recoverable copper (Cu); total recoverable lead (Pb); total recoverable zinc (Zn) and total recoverable diazinon. These values are median values and the table also shows the number of samples that were taken to find the median values.

Kieser & Associates, LLC; Urban Build-Out and Stormwater BMP Analysis in the Paw Paw River Watershed; Southwest Michigan Planning Commission, Benton Harbor, MI April 2008

Summary: This report addresses land uses, the reclassification of some of the land uses, future maps based on land uses and the analysis of BMPs for those areas. GIS and computer models were used to estimate the impact of stormwater BMPs. EMCs were estimated for each land use. Imperviousness was observed for each land use. They ranged from 0% to 90% imperviousness.

CDM, Temescal Canyon Park Stormwater Best Management Practices Project Pollutant Loading and Reductions; City of Los Angeles August 2009

Summary: This summary involves a pollutant loading model developed to estimate expected pollutant loads and concentrations from stormwater runoff within the Temescal Canyon watershed tributary to evaluate the underground cistern Best Management Practice (BMP). The pollutant loading model is based on four main equations that determine the runoff coefficient, the annual runoff, the annual pollutant loadings, and the resulting average annual pollutant concentrations adapted from the Simple Method. The model is used for estimating changes in runoff volumes, pollutant loads, and resulting pollutant concentrations that may occur as a result of property development or redevelopment. Concentrations observed total suspended solids (TSS), total phosphorus (Total P), dissolved phosphorus, total nitrogen (Total N), organic nitrogen, ammonia-nitrogen, nitrate + nitrite as nitrogen, total copper (Cu), dissolved Cu, total lead (Pb), dissolved Pb, zinc (Zn), dissolved Zn, and fecal coliform. EMCs from different land uses were used in the model.

Pitt, R., A. Maestre and R. Morquecho; Research Progress Report, Findings from the National Stormwater Quality Database (NSQD)

Summary: The University of Alabama and the Center for Watershed Protection have collected and evaluated stormwater data from a representative number of National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) stormwater permit holders. As of September 2003, data from 3,770 separate storm events from 66 agencies and municipalities from 17 states were collected and entered into NSQD. Data for individual storms, their geographic location and land use were documented. Median EMCs for individual land uses were recorded.

BETA Group, Inc.; Technical Memorandum Watershed Based Plan for the Chicopee Basin; Massachusetts Department of Environmental Protection September 2006

Summary: The Chicopee Basin, located in Central Massachusetts, covers several tributaries and the drainage area in the watershed is approximately 723 square miles. There are several documents that give data on pollutant loads in the basin:

- Chicopee River Watershed 1998 Water Quality Assessment Report
- Total Maximum Daily Load for Phosphorus for Selected Chicopee Basin Lakes
- Total Maximum Daily Load for Phosphorus for Quaboag Pond and Quacumquasit Pond
- EOEA Chicopee River Watershed Assessment Report 2003
- EOEA Chicopee River 5-Year Watershed Action Plan 2005-2010
- 2003 Chicopee Nonpoint Source Action Strategy
- Massachusetts Year 2004 Integrated List of Waters

The Watershed Management Model (WMM) was be used to offset any existing gap in the data from the other documents. The WMM estimates annual pollutant loads within each simulated sub watershed based on rainfall, overall pervious and impervious runoff coefficients within each sub watershed, land use-based pollutant event mean concentrations (EMCs), percent imperviousness for each land use category, and the sub watershed delivery ratios.

Ha, S.J., Predictive Modeling of Stormwater Runoff Quantity and Quality for a large Urban Watershed; a PhD Dissertation, University of California, Los Angeles

Abstract: In this research a predictive model for stormwater runoff volume was implemented in an ArcGIS platform based on the Rational Method and Browne's empirical relation for soil characteristics. Characterization of pollutant load contributions of land use types to total loads of the upper Ballona Creek watershed was achieved through zeroth-order regularization and L- BFGS-B optimization techniques. Relative form was used in the objective function to compensate for strong contributions of high magnitude variables. Model predictions showed reasonable agreement with total Zn, TKN, and TSS loadings measured at the mass emission site for the upper Ballona Creek watershed. Two additional categories, highways and local roads, which have not been routinely used as land use categories, were separately studied. Best Management Practices (BMP) strategies were evaluated a typical storm event, which exceeded total zinc TMDL by over 70%. The model was used to compare optimized BMP applications to the simplest application, which would treat all areas equally. Approximately 44 % removal efficiency with treatment of the entire runoff would be needed to meet the TMDL.

Wang, S., Pollutant concentrations and pollution loads in stormwater runoff from different land uses in Chongqing, Journal of Environmental Sciences 2013, 25(3) 502–510

Abstract: To investigate the distribution of pollutant concentrations and pollution loads in stormwater runoff in Chongqing, six typical land use types were selected and studied from August 2009 to September 2011. Statistical analysis on the distribution of pollutant concentrations in all water samples shows that pollutant concentrations fluctuate greatly in rainfall-runoff, and the concentrations of the same pollutant also vary greatly in different rainfall events. In addition, it indicates that the event mean concentrations (EMCs) of total suspended solids (TSS) and chemical oxygen demand (COD) from urban traffic roads (UTR) are significantly higher than those from residential roads (RR), commercial areas (CA), concrete roofs (CR), tile roofs (TRoof), and campus catchment areas (CCA); and the EMCs of total phosphorus (TP) and NH_3-N from UTR and CA are 2.35–5 and 3 times of the class-III standard values specified in the Environmental Quality Standards for Surface Water (GB 3838-2002). The EMCs of Fe, Pb and Cd are also much higher than the class-III standard values. The analysis of pollution load producing coefficients (PLPC) reveals that the main pollution source of TSS, COD and TP is UTR.

Lee, J.H. and Ki Woong Bang, Characterization of Urban Stormwater Runoff, Wat. Res. Vol. 34, No. 6, pp. 1773±1780, 2000

Abstract: The purpose of this study is to investigate the characteristics of pollutants overflow on storm events, relationships between pollutant load and runoff, and the first flush effect in urban areas. Nine watersheds in the cities of Taejon and Chongju, Korea were selected for sampling and study with different characteristics during the period from June 1995 to November 1997. Runoff and quality parameters such as BOD_5, COD, SS, TKN, NO_3-N, PO_4-P, TP, Pb, Fe, and n-Hexane extracts were analyzed for the development of relationships between runoff and water quality. From the hydrograph and pollutograph analysis, the peak of pollutant concentration preceded that of the flow rate in an area smaller than 100ha in which impervious area occupied more than 80%. The peak of pollutant concentration, however, was followed by that of flow rate in the watershed in an area larger than 100 ha in that the impervious area was less than 50%. In the storm event, the relative magnitude of the pollutants unit loading rate was in the following order; high density residential > low density residential > industrial > undeveloped watershed.

Yoon, S.W., Monitoring of non-point source pollutants load from a mixed forest land use; Journal of Environmental Sciences 2010, 22(6) 801–805

Abstract: The aim of this study was to determine the unit load of NPS (non-point source) pollutants including organic variables such as BOD (biochemical oxygen demand), COD (chemical oxygen demand) and DOC (dissolved organic carbon), nitrogen and phosphorus constituents, and suspended solids (SS) and their event mean concentration (EMC) of runoff flows from a water-shed of mixed forest land use by

DISTRICT DEPARTMENT OF THE ENVIRONMENT

intensive field experiments. The EMCs of individual runoff event were estimated for each water quality constituent based on the flow rate and concentration data of runoff discharge. Affecting parameters on the EMCs were investigated by statistical analysis of the field data. As a result, significant correlations with precipitation, rainfall intensity, and total runoff flows were found in most constituents.

Event Mean Concentrations (EMCs) and Export Coefficients Appendix IV; www.water.epa.gov/scitech/datait/models/basin/upload/2002_05_10_BASINS; PLOAD version 3.0

Summary: The PLOAD model is a GIS based model designed to calculate pollutant loads from non-point sources for watersheds. The GIS model requires certain data sets to calculate pollutant loads such as GIS land use data, GIS watershed data, pollutant loading rate data tables, and impervious terrain factor data tables. Event mean concentrations and export coefficients from different parts of the US were obtained from literature. The EMCs values were obtained for different land uses from the Mid-Atlantic; Coastal Texas; Atlanta, GA; Florida, Washington State, North Carolina and Milwaukee, Wisconsin. Pollutants examined included: TSS, TDS, BOD, COD, phosphorus, nitrogen, nitrate plus nitrite, TKN, Ammonia, fecal coliform, lead and zinc.

Urban Stormwater Runoff Loadings; Chesapeake Bay Basin Toxics Loading and Release Inventory; Chesapeake Bay Program; May 1999

Summary: The Chesapeake Bay Basin Toxics Loading and Release Inventory is designed to identify sources of pollutants and develop source reduction and pollution prevention goals for the Chesapeake Bay. Reducing chemical loads will require looking at point sources and non-point sources. One of the ways to reduce loads is to incorporate the Clean Water Act's TMDL program that "complements and enhances traditional approaches of controlling chemical concentrations exiting pipes by addresses the ambient concentration of contaminants from all sources." Event mean concentrations are used to estimate pollutant loads in urban areas. Descriptive statistics and EMCs for inorganic and organic pollutants were documented:

- ***Oil and grease***
- Cyanide
- Total phenol
- Chloroform
- ***Benzo(a)anthracene***
- ***Benzo(a)pyrene***
- 3,4-benzofluoranthene
- Benzo(k)fluoranthene
- Bis(2-chloroethoxy)methane
- 1,4-dichlorobenzene
- ***Fluoranthene***
- ***Fluorene***
- ***Phenanthrene***
- ***Pyrene***
- Antimony
- ***Arsenic***
- Beryllium
- Cadmium
- Chromium
- ***Copper***
- ***Lead***
- ***Mercury***
- Nickel
- Selenium
- Silver
- Thallium
- ***Zinc***

CSN Technical Bulletin No. 9 Stormwater Nutrient Accounting; Local Stormwater Load Reduction in the Chesapeake Bay Watershed version 1.0, Review Draft; August 15, 2011

Summary: This technical bulletin has incorporated several sections on nutrients in the Chesapeake Bay as a result of stormwater. It summarizes the impact of eutrophication on waterbodies, the TMDLs and the WIPs implemented to reduce nutrient loads, sources of nutrients in urban stormwater, models used to estimate loads and pollutant removals by BMPs. Table 6 of this report lists event mean concentrations for total nitrogen and total phosphorus for different urban land uses such as highways, streets, parking lots, rooftops and general urban land cover.

Impacts of Impervious cover on Aquatic Systems; Watershed Protection Research Monograph No. 1; Center for Watershed Protection, March 2003

Summary: This research monograph explores the impacts of urbanization on small streams and receiving waters. These impacts are categorized as changes in hydrologic, physical, water quality or biological indicators. Impervious cover has been identified as a significant factor as an indicator of stream quality. The Impervious Cover Model (ICM) is designed to predict stream quality indication by the imperviousness of the area. Chapter four discusses the water quality impacts of impervious cover. The information in this chapter contains urban stormwater data from national and regional data for nine categories of pollutants. EMC data included sediments, nutrients, metals, hydrocarbons, bacteria, organic carbon and pesticides. There was data for EMCs according to land use areas: commercial (parking lot, rooftop), street (high, medium, low), residential (rooftop, driveway, lawn).

Pitt, R., A. Maestre and R. Morquecho; Evaluation of NPDES Phase I Municipal Stormwater Monitoring Data, Center for Watershed Protection 2001

Summary: The University of Alabama and the Center for Watershed Protection collected data from various NPDES permit across the United States. This NPDES database provides detailed descriptions of the test areas and sampling conditions are also being collected, including aerial photographs and topographic maps for many locations, which we are collecting from public sources. The land use information used is as supplied by the communities submitting the data, although aerial photographs and maps are also used to clarify any questions. Most of the sites have homogeneous land uses, although many are mixed. Constituents analyzed included typical conventional pollutants (TSS, TDS, COD, BOD_5, oil and grease, fecal coliforms, fecal strep, pH, Cl, TKN, NO_3, TP, and PO_4), plus many heavy metals (including total forms of arsenic, chromium, copper, lead, mercury, and zinc, plus others), and numerous listed organic toxicants (including PAHs, pesticides, and PCBs). Our database includes information for about 125 different stormwater quality constituents, although the database is mostly populated with data from 44 of the commonly analyzed pollutants.

Chesapeake Stormwater Network Biohabitats, Montgomery County Implementation Guidance Memo; Montgomery County DEP, April 2010

Summary: The Montgomery County IP Guidance Document provides a schedule for the watershed analyses to be conducted over the next year and through the permit cycle. Watershed Implementation Plans (WIPs) are prepared for the County that has to meet certain parts of the MS4 permit requirements, including watershed restoration; EPA approved TMDLs and trash and litter management for the Potomac. These measures have to be cost effective and gain regulatory approval. Part three of the memorandum discusses the estimation of pollutant load reductions. The WTM (Watershed Treatment Model) will be used to estimate pollutant loads for the watershed. Where there are TMDLs, modeling information from the TMDL will be used for calibration of the WTM model, including event mean concentrations and total load allocations. For each major watershed in the County, one of the outcomes for the pollutant load analysis will be to assign EMCs and runoff volume coefficients for each land use/cover type for computation of an annual pollutant from primary sources. Pollutants include nitrogen (lbs/yr), phosphorus (lbs/yr), sediment (lbs/yr) and fecal coliform (billion/yr). In Appendix B, the table (1) presents recommended event mean concentrations for urban land uses in Montgomery County based on literature from Pitt (2008).

NPDES 18th Annual Update (MD0068322/00-DP-3318); Howard County Department of Public Works June 2013

Summary: National Pollutant Discharge Elimination System permits have to be renewed at least every five years. Howard County with a population of just over 290,000, is one of five medium and five large jurisdictions in Maryland that is regulated by a NPDES permit. The large NPDES MS4 permits serve populations greater than 250,000, which includes Howard County. The conditions of the permit condition are to identify sources of pollutants in stormwater runoff and linked to specific water quality impacts on a watershed basis. Based on this information, watershed restoration plans are developed to improve water quality. Howard County's municipal NPDES management program effectiveness is evaluated through chemical, biological and physical assessments through monitoring and sampling analysis. For chemical monitoring, eight storm events are monitored per year at each monitoring location with at least two [storm events] occurring per quarter. At least three samples representative of each storm event shall be evaluated and EMCs are calculated for:

- BOD
- TKN
- Nitrate + nitrite
- TSS
- TPH
- F.Coli/E.Coli
- Pb
- Cu
- Zn
- TP
- Oil and grease

EMC information is included in the annual report under Section C.

Anne Arundel County NPDES Annual Report; Anne Arundel County Department of Public Works; Sept 2 2013

Summary: The annual report for the NPDES MS4 permit was designed to detail the activities in Anne Arundel County from November 2011 through September 2012 that demonstrates compliance with the MS4 permit. It details the stormwater management program, the implementation status and proposed revisions. The report also summarizes the monitoring programs employed by Anne Arundel County, including data collection and analysis. As part of the County's watershed studies, Event Mean Concentration (EMC) data for the Anne Arundel County urban land covers were compiled for various studied pollutants. The EMC data are weighted mean values derived from statistical assessment of pollutant concentrations measured for multiple storm events. The data are currently utilized for assessing pollutant loadings using the EPA Simple Method. During the 2011 Phase II Watershed Implementation Plan (WIP) development, the County reconciled its EMCs for various land covers with those used in the Chesapeake Bay Program's (CBP) Watershed Model (Version 5.3). Table 7 identifies the adjustments made to reconcile the concentrations with those used in the Bay Program's Watershed Model. Beginning with the 2011 assessment for the Patapsco Tidal and Bodkin Creek watersheds, EMCs based on the CBP Watershed Model have been used to characterize pollutant loading and develop watershed restoration projects.

Patapsco Tidal and Bodkin Creek Watershed Assessment Comprehensive Summary Report; Anne Arundel County, Department of Public Works, Bureau of Engineering Watershed Ecosystem and Restoration Services Division Watershed Assessment and Planning Program, in association with LimnoTech and Versar; August 2012

Summary: The Anne Arundel County, Maryland, Watershed Assessment and Planning Program initiated a comprehensive assessment of the Patapsco Tidal and Bodkin Creek Watersheds in the spring of 2010. The main purpose of the assessment was to characterize current stream and upland conditions in the watershed to support and prioritize watershed management and planning activities. The scope of the Patapsco Tidal and Bodkin Creek Watersheds study encompassed collection of field and stream assessment data and supporting Geographic Information System (GIS) data, followed by analysis and modeling using the County's customized watershed assessment and modeling tools. The WTM was just one of the models used to forecast results from data being collected. Pollutant loads are the product of the annual runoff, the drainage area and the event mean concentrations for each land use category. EMC values according to each land use are listed in Table 3.3 of the WTM. These values were either found in literature of calculated from export coefficients used by the Chesapeake Bay Program.

Watershed Management Plan; Dept. of Environmental Services, Environmental Planning Office; Virginia Dept. of Environmental Quality; Arlington County, Arlington, VA; January 2001

Summary: With a grant from the Virginia Dept. of Environmental Quality, Arlington County developed a watershed management to address growing issues of stormwater flows and pollution in the heavily urban and impervious area. For Arlington County, the Watershed Management program analyzes existing water sources and runoff management practices; sets management goals for subwatersheds based current stream conditions, current land uses and future land use changes; provides management recommendations for subwatersheds and provides an implementation plan. One of the conditions of Arlington's MS4 permit and section one of the watershed management plan is for DES collects samples from four storm sewer outfalls in the County. Each outfall drains a land use and the data is beneficial to determine pollutant loads in different land uses. From laboratory analysis, event mean concentrations are calculated for each pollutant.

A User's Guide to Watershed Planning in Maryland: A Maryland DNR Guide; Center for Watershed Protection for Maryland Department of Natural Resources; December 2005. www.dnr.maryland.gov

Summary: This guide gives an overview of how to create a watershed plan that meets federal funding, regulatory programs such as TMDLs the Chesapeake Bay 2000 Agreement and address current land issues. Watersheds and sub-watersheds are geographical scales used to develop these plans. Watershed planning steps include: developing watershed goals; classifying and screening priority subwatersheds; identifying watershed planning opportunities; conducting detailed assessments; assemble recommendations into a plan; determining if watershed plan meets goals; developing methods to implement the plan and implementing and measuring improvements over time. The Watershed Treatment Model (WTM) estimates pollutant loads for watersheds. EMCs of sediment, phosphorus and nitrogen for various land uses are provided in the WTM as defaults, but CBP Watershed Model data should be substituted when available. EMCs for nutrients and sediment for three urban land uses are in Table 4.14 of the Maryland DNR Guide.

Howell, N.L, Lakshmanan, D., Rifai, H.S., and Koenig, L.; PCB dry and wet weather concentration and load comparisons in Houston-area urban channels; Science of the Total Environment 409 (2011) 1867-1888

Abstract: All 209 PCB congeners are quantified in water in both dry and wet weather urban flows in Houston, Texas, USA. Total water PCBs ranged from 0.82 to 9.4 ng/L in wet weather and 0.46 to 9.0

ng/L in dry. Wet weather loads were 8.2 times higher (by median) than dry weather with some increases of over 100-fold. The majority of the PCB load was in the dissolved fraction in dry weather while it was in the suspended fraction in wet weather. Dissolved PCB loads were correlated with rain intensity and highly developed land area, and a multiple linear regression (MLR) equation was developed to quantify these correlations. PCA generated five PCB components with nearly all positive loadings. The PCB 11 component was statistically higher in wet versus dry weather when no other component showed such clear distinctions.

Smullen, J., Ksyniak, D., Blair, D., and J. Wetherington; A Watershed Runoff Loading Methodology for Polychlorinated Biphenyls; CDM, Philadelphia Water Dept; Dupont Company; 2005

Abstract: For the initial stage of the Delaware Estuary TMDL for Polychlorinated Biphenyls (PCBs), estimates were needed for watershed runoff loads of PCBs delivered to the Delaware River and Bay from tributaries for which no monitoring data were available. For these tidewater tributary basins, an alternative approach was developed to estimate Polychlorinated Biphenyl (PCB) loads using data available from existing international stormwater databases and from some locally collected stream discharge water quality databases. The approach is based on studies conducted both in the region and elsewhere in the United States, and is used to estimate average daily PCB loadings for comparisons with other pollutant sources in the total maximum daily load assessments. To estimate yields of PCBs from urban areas in the basins, event mean concentrations of PCBs in urban runoff were derived through the retrieval and careful review of over 200 references that yielded 12 investigations with EMC results for PCBs.

The literature search for PCB EMCs yielded no information suitable for estimating loads from rural areas. To provide estimates for PCB contributions from rural areas, a simple USEPA indirect loading methodology was employed. For this application, the atmospheric deposition rates were taken from the published and unpublished works of researchers at Rutgers University, who have conducted atmospheric deposition monitoring in the Delaware Estuary drainage (Van Ry, et al., 2002)

Schiff, K., Watershed Monitoring and Modeling in Switzer, Chollas and Paleta Creek Watersheds; Southern California Coastal Water Research Project in conjunction with Tetra Tech; May 15, 2007. www.sccwrp.org

Summary: San Diego Bay was listed in California's impaired waterbodies due to contaminated sediments and impaired benthic communities. Chollas Creek (North and South forks), Switzer Creek, and Paleta Creek are three of the creek mouth areas listed as impaired, therefore having TMDLs allocated to them. The purpose of this study is to help gather technical information for the TMDL. Pollutants of potential concern are copper, polynuclear aromatic hydrocarbons (total PAHs), polychlorinated biphenyls (total PCBs), and chlordane. This study tackled two primary data gaps: 1) estimates of pollutant loading to San Diego Bay from each of the three watersheds; and 2) estimate relative pollutant contributions from various land uses within each watershed.

Watershed Model Development for the LA/LB Harbors: October 2010

Summary: This report describes the model used to estimate metals and organic pollutant loads from the Los Angeles River, the San Gabriel River, and other near shore watershed areas. These models, in addition to the Dominguez Channel model, were used to determine the pollutant loadings to Dominguez Channel and Greater Los Angeles and Long Beach Harbor Waters. Pollutants of interest include metals such as copper, lead, and zinc, and several organic pollutants (PAHs, DDT, PCBs, and chlordane). Separate approaches were used to represent dry- and wet-weather conditions. The wet weather analyses are based on an eleven-year simulation using the LSPC watershed model. Stormwater total PAH concentrations for each model subwatershed were predicted using weighted averages of land use EMCs based on area and runoff potential of each land use in each subwatershed. For DDT, PCBs, and chlordane, a different approach was required because no detectable levels of these pollutants were found in the mass emissions monitoring stations (DDT was only detected in stations associated with agricultural runoff). Sediment concentrations from Bight 03 monitoring data were applied to predicted sediment loads to estimate loads of these pollutants.

Bannerman, R.T., Legg, A.D., and S.R. Greb; Quality of Wisconsin Stormwater, 1989-94; U.S. Geological Survey Open-File Report 96-458, Wisconsin Department of Natural Resources, Madison, WI 1996

Abstract: Water-quality data were compiled from four urban stormwater monitoring projects conducted in Wisconsin between 1989 and 1994. These projects included monitoring in both storm-sewer pipes and urban streams. A total of 147 constituents were analyzed for in stormwater sampled from 10 storm-sewer pipes and four urban streams. Land uses represented by the storm-sewer watersheds included residential, commercial, industrial, and mixed. For about one-half the constituents, at least 10 percent of the event mean concentrations exceeded the laboratory's minimum reporting limit. Detection frequencies were greater than 75 percent for many of the heavy metals and polycyclic aromatic hydrocarbons in both the storm sewer and stream samples, whereas detection frequencies were about 20 percent or greater for many of the pesticides in both types of samples. Stormwater concentrations for conventional constituents, such as suspended solids, chloride, total phosphorus, and fecal coliform bacteria were greater than minimum reporting limits almost 100 percent of the time. Concentrations of many of the constituents were high enough to say that stormwater in the storm sewers and urban streams might be contributing to the degradation of the streams.

Attachment 2: Results Analysis 1, Evaluation of Land Use-Based EMCs

The following sets of tables show the results from Analysis 1. Evaluation of Land Use-Based EMCs, as explained in Section 4. This analysis was conducted to determine if the land use based EMCs from the literature could be used to predict the monitored EMCs. In other words, are the land use based EMCs from the literature, which are based on nationwide data, appropriate to characterize the site specific conditions of the District?

To do this analysis, a subset of the monitored data was used and average EMCs were calculated for each pollutant of concern. The subset of monitored data selected included the EMC data provided by the 2009 Stormwater Management Plan (DDOE, 2009), and the EMC data provided by the *Study Memorandum LTCP 5-8 (Final), CSS and SSWS Event Mean Concentrations* (DC Water, October 2001). The reason this subset of data was selected is because it was, at the time of the analysis, readily available in a useable format, and provided a good selection of monitoring sites across the MS4 area. A total of 16 sites were included in this subset of data, and each site was sampled during 3 to 5 storms over the course of a year. A map of the sites is provided in Figure 1. The drainage area of each site was delineated and the land use types within the drainage areas were defined using the 2005 DC OCTO existing land use GIS layer (DC OCTO, 2005). Then the land use based EMCs were applied and an overall area-weighted land use based EMC was calculated for each site. This calculated value was subsequently compared to the monitored value. The full table of comparison for each pollutant is presented below.

The results of this analysis showed that:

1. The amount of land use based EMC data that exists in the literature for the organics and some of the metals not sufficient to make land use based EMC predictions.
2. The calculated EMC values using the average values per land use type, identified from the literature, were in most cases lower than the monitored value. As a consequence, the average literature values were increased for each land use type by anywhere from 10% to 400% in order to produce a larger area-weighted land use based EMC value that was more aligned with the monitored value. Note that, even after increasing the average value of the individual land use based EMCs, the increased values were still within the observed ranges reported by the literature for each land use type.
3. Even after adjusting the average land use based values, it was practically impossible to match the monitored values in all locations. Only when comparing the calculated and monitored average and median EMC values for all the sites combined did the calculated values more closely match the monitored values. But on a site by site basis, the calculated EMCs would sometimes over-predict, and at other times under-predict the monitored values. No obvious trends in the data were observed on a site by site basis.

It should be noted that Analysis 1 will be further refined to include all data from all sites and time periods. The refined analysis will be included in the Comprehensive Baseline Report.

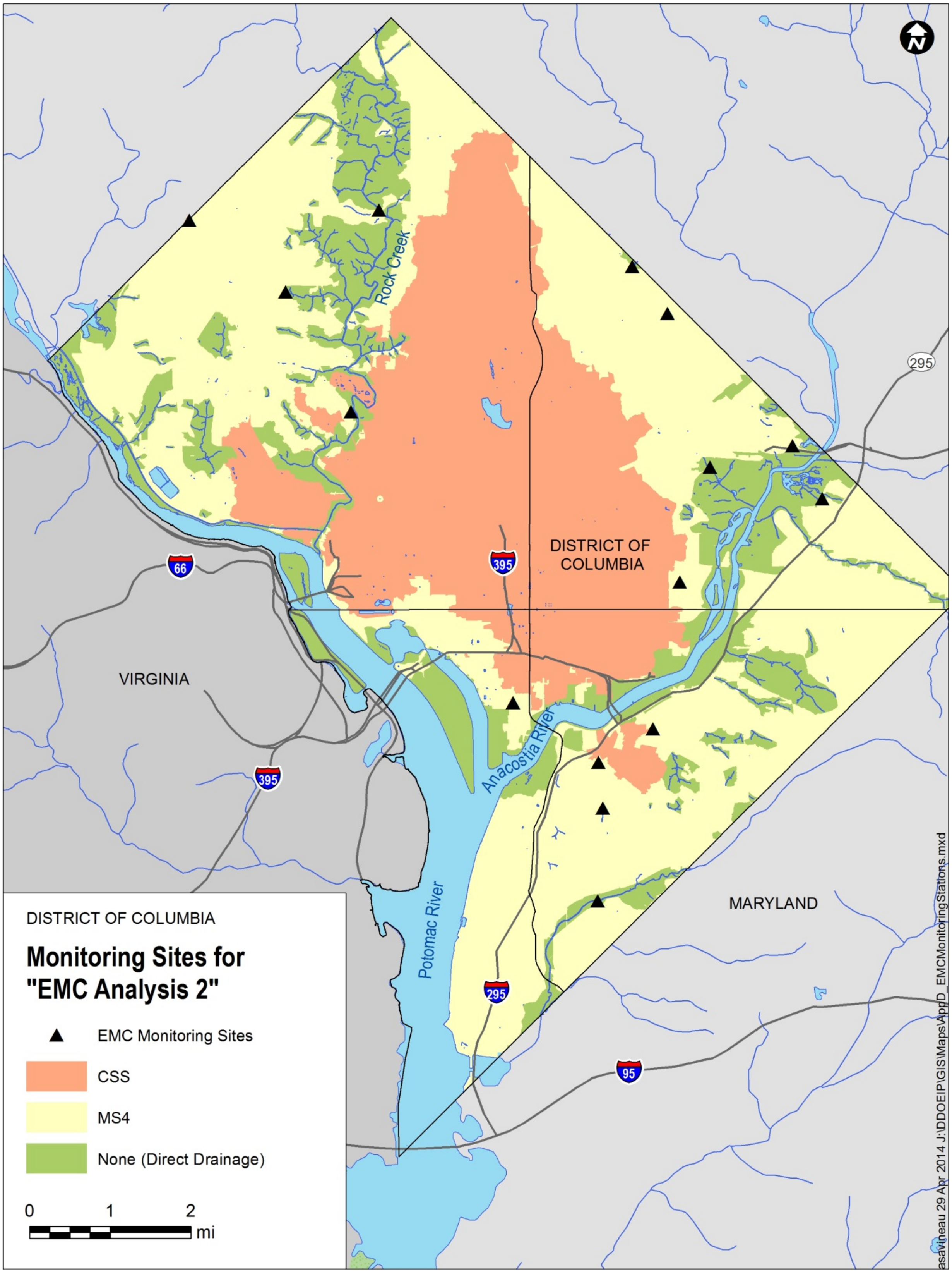

Figure 1: Location of Sampling Sites Used in Analysis 1

Table 1: TSS EMC Comparison Between Reported and Calculated Values Calculated Values					
Catchment	**Range of Reported EMCs (mg/L)**	**Average of Reported EMCs (mg/L)**	**Calculated LU-Based EMC (mg/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	4.0	4.7	17.3%	Low/med residential, parks, commercial
East Capitol	Not In Report	6.7	5.9	-11.4%	Low/med residential
Fort Lincoln	Not In Report	5.4	2.8	-47.4%	Parks, mixed use
Gallatin	Not In Report	3.0	4.5	47.1%	Low/med residential, institutional
Nash Run	Not In Report	4.1	4.9	19.9%	Low/med residential, parks
O Street	Not In Report	3.2	3.4	4.7%	Mixed, commercial
Stickfoot	Not In Report	6.7	6.0	-10.9%	Low/med residential
Varnum	Not In Report	3.6	4.8	33.4%	Low/med residential, institutional, mixed
Oxon Run	3.1 - 7.21	5.0	5.5	8.7%	Low/med residential, institutional
Rock Creek, Military	3.22 - 6.47	4.5	2.6	-42.7%	Parks, institutional
Hickey	6.74 - 8.32	7.6	5.9	-22.1%	Industrial, low-/med residential
Rock Creek, Cathedral	1.07 - 8.58	4.4	5.5	25.4%	Low/med residential, med/high residential
Soapstone	2.22 - 8.49	5.5	3.1	-44.1%	Institutional, federal, commercial
Potomac Trib	4.01 - 5.23	4.8	4.9	2.5%	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	2.2 - 3.05	2.5	4.4	71.9%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	1.37 - 3.08	2.4	5.1	112.4%	Low/med residential, industrial
	Average	4.6	4.6	0.6%	
	Median	4.4	4.8	9.1%	
	Maximum	7.6	6.0	-21.4%	
	Minimum	2.4	2.6	7.3%	

Table 2: TN EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (mg/L)**	**Average of Reported EMCs (mg/L)**	**Calculated LU-Based EMC (mg/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	4.0	4.7	17.3%	Low/med residential, parks, commercial
East Capitol	Not In Report	6.7	5.9	-11.4%	Low/med residential
Fort Lincoln	Not In Report	5.4	2.8	-47.4%	Parks, mixed use
Gallatin	Not In Report	3.0	4.5	47.1%	Low/med residential, institutional
Nash Run	Not In Report	4.1	4.9	19.9%	Low/med residential, parks
O Street	Not In Report	3.2	3.4	4.7%	Mixed, commercial
Stickfoot	Not In Report	6.7	6.0	-10.9%	Low/med residential
Varnum	Not In Report	3.6	4.8	33.4%	Low/med residential, institutional, mixed
Oxon Run (MS1)	3.1 - 7.21	5.0	5.5	8.7%	Low/med residential, institutional
Rock Creek, Military (MS2)	3.22 - 6.47	4.5	2.6	-42.7%	Parks, institutional
Hickey (MS3)	6.74 - 8.32	7.6	5.9	-22.1%	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	1.07 - 8.58	4.4	5.5	25.4%	Low/med residential, med/high residential
Soapstone (MS5)	2.22 - 8.49	5.5	3.1	-44.1%	Institutional, federal, commercial
Potomac Trib (MS6)	4.01 - 5.23	4.8	4.9	2.5%	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	2.2 - 3.05	2.5	4.4	71.9%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	1.37 - 3.08	2.4	5.1	112.4%	Low/med residential, industrial
	Average	4.6	4.6	0.6%	
	Median	4.4	4.8	9.1%	
	Maximum	7.6	6.0	-21.4%	
	Minimum	2.4	2.6	7.3%	

Table 3: TP EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (mg/L)**	**Average of Reported EMCs (mg/L)**	**Calculated LU-Based EMC (mg/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	0.3	0.4	17.7%	Low/med residential, parks, commercial
East Capitol	Not In Report	0.7	0.5	-29.9%	Low/med residential
Fort Lincoln	Not In Report	0.5	0.2	-67.7%	Parks, mixed use
Gallatin	Not In Report	0.3	0.4	15.4%	Low/med residential, institutional
Nash Run	Not In Report	0.4	0.4	7.9%	Low/med residential, parks
O Street	Not In Report	0.2	0.3	29.9%	Mixed, commercial
Stickfoot	Not In Report	0.8	0.5	-29.4%	Low/med residential
Varnum	Not In Report	0.1	0.4	199.9%	Low/med residential, institutional, mixed
Oxon Run (MS1)	0.03 - 130.0	65.0	0.5	-99.3%	Low/med residential, institutional
Rock Creek, Military (MS2)	0.01 - 0.08	0.0	0.1	175.3%	Parks, institutional
Hickey (MS3)	0.01 - 0.05	0.0	0.4	1620.2%	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	0.03 - 0.05	0.0	0.5	1065.6%	Low/med residential, med/high residential
Soapstone (MS5)	0.03 - 0.05	0.0	0.3	676.1%	Institutional, federal, commercial
Potomac Trib (MS6)	0.06 - 0.25	0.1	0.4	249.7%	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	0.28 - 1.5	0.6	0.4	-40.3%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	0.2 - .56	0.4	0.4	0.4%	Low/med residential, industrial
	Average	0.4	0.4	-5.3%	
	Median	0.4	0.4	6.7%	
	Maximum	0.8	0.5	-29.4%	
	Minimum	0.1	0.1	2.4%	

Table 4: Fecal Coliform EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (MPN/100mL)**	**Average of Reported EMCs (MPN/100mL)**	**Calculated LU-Based EMC (MPN/100mL)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	8890.8	20264.7	127.9%	Low/med residential, parks, commercial
East Capitol	Not In Report	8897.3	22810.0	156.4%	Low/med residential
Fort Lincoln	Not In Report	105046.4	16000.0	-84.8%	Parks, mixed use
Gallatin	Not In Report	19815.9	19216.4	-3.0%	Low/med residential, institutional
Nash Run	Not In Report	104937.5	20894.9	-80.1%	Low/med residential, parks
O Street	Not In Report	210.0	16015.3	7526.3%	Mixed, commercial
Stickfoot	Not In Report	20187.1	22994.8	13.9%	Low/med residential
Varnum	Not In Report	930.0	20020.0	2052.7%	Low/med residential, institutional, mixed
Oxon Run (MS1)	Not Sampled	Not Sampled	21759.0	N/A	Low/med residential, institutional
Rock Creek, Military (MS2)	Not Sampled	Not Sampled	16000.0	N/A	Parks, institutional
Hickey (MS3)	Not Sampled	Not Sampled	18352.6	N/A	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	Not Sampled	Not Sampled	22445.9	N/A	Low/med residential, med/high residential
Soapstone (MS5)	Not Sampled	Not Sampled	16276.6	N/A	Institutional, federal, commercial
Potomac Trib (MS6)	Not Sampled	Not Sampled	20120.3	N/A	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	100-13,000	36546.0	19416.8	-46.9%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	100-90,000	19985.0	19846.6	-0.7%	Low/med residential, industrial
	Average	32544.6	19747.9	-39.3%	
	Median	19900.5	19933.3	0.2%	
	Maximum	105046.4	22994.8	-78.1%	
	Minimum	210.0	16000.0	7519.0%	

Table 5: BOD EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (mg/L)**	**Average of Reported EMCs (mg/L)**	**Calculated LU-Based EMC (mg/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	39.5	34.6	-12.4%	Low/med residential, parks, commercial
East Capitol	Not In Report	94.5	34.9	-63.1%	Low/med residential
Fort Lincoln	Not In Report	20.4	36.6	79.5%	Parks, mixed use
Gallatin	Not In Report	31.9	37.7	18.2%	Low/med residential, institutional
Nash Run	Not In Report	45.8	33.5	-26.9%	Low/med residential, parks
O Street	Not In Report	36.0	47.0	30.5%	Mixed, commercial
Stickfoot	Not In Report	43.9	35.0	-20.2%	Low/med residential
Varnum	Not In Report	17.0	37.9	122.7%	Low/med residential, institutional, mixed
Oxon Run (MS1)	Not Sampled	Not Sampled	35.7	N/A	Low/med residential, institutional
Rock Creek, Military (MS2)	Not Sampled	Not Sampled	31.5	N/A	Parks, institutional
Hickey (MS3)	Not Sampled	Not Sampled	52.1	N/A	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	Not Sampled	Not Sampled	37.9	N/A	Low/med residential, med/high residential
Soapstone (MS5)	Not Sampled	Not Sampled	40.2	N/A	Institutional, federal, commercial
Potomac Trib (MS6)	Not Sampled	Not Sampled	39.4	N/A	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	6.0 - 28.0	15.8	35.8	127.2%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	5.0 - 37.0	23.0	40.6	76.3%	Low/med residential, industrial
	Average	36.8	37.3	1.6%	
	Median	33.9	36.2	6.6%	
	Maximum	94.5	47.0	-50.3%	
	Minimum	15.8	33.5	112.7%	

Table 6: Oil and Grease EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (mg/L)**	**Average of Reported EMCs (mg/L)**	**Calculated LU-Based EMC (mg/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	Not In Report	13.2	N/A	Low/med residential, parks, commercial
East Capitol	Not In Report	13.3	12.9	-3.0%	Low/med residential
Fort Lincoln	Not In Report	109.8	11.6	-89.4%	Parks, mixed use
Gallatin	Not In Report	Not In Report	13.8	N/A	Low/med residential, institutional
Nash Run	Not In Report	37.8	12.1	-68.0%	Low/med residential, parks
O Street	Not In Report	7.6	16.2	113.1%	Mixed, commercial
Stickfoot	Not In Report	Not In Report	13.0	N/A	Low/med residential
Varnum	Not In Report	7.3	14.0	92.3%	Low/med residential, institutional, mixed
Oxon Run (MS1)	Not Sampled	Not Sampled	13.5	N/A	Low/med residential, institutional
Rock Creek, Military (MS2)	Not Sampled	Not Sampled	10.9	N/A	Parks, institutional
Hickey (MS3)	Not Sampled	Not Sampled	17.6	N/A	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	Not Sampled	Not Sampled	13.1	N/A	Low/med residential, med/high residential
Soapstone (MS5)	Not Sampled	Not Sampled	16.9	N/A	Institutional, federal, commercial
Potomac Trib (MS6)	Not Sampled	Not Sampled	14.2	N/A	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	Not Sampled	Not Sampled	13.3	N/A	Low/med residential, institutional, parks
Hickey Run (DCWASA)	Not Sampled	Not Sampled	15.0	N/A	Low/med residential, industrial
	Average	35.2	13.8	-60.6%	
	Median	13.3	13.4	0.7%	
	Maximum	109.8	17.6	-83.9%	
	Minimum	7.3	10.9	49.2%	

Table 7: Copper EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (µG/L)**	**Average of reported EMCs (µG/L)**	**Calculated LU-based EMC (µG/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	125.0	52.8	-57.8%	Low/med residential, parks, commercial
East Capitol	Not In Report	96.0	40.0	-58.3%	Low/med residential
Fort Lincoln	Not In Report	82.1	59.7	-27.4%	Parks, mixed use
Gallatin	Not In Report	31.2	65.0	108.4%	Low/med residential, institutional
Nash Run	Not In Report	36.8	40.0	8.7%	Low/med residential, parks
O Street	Not In Report	25.0	106.7	326.8%	Mixed, commercial
Stickfoot	Not In Report	35.0	40.1	14.5%	Low/med residential
Varnum	Not In Report	73.0	64.1	-12.2%	Low/med residential, institutional, mixed
Oxon Run (MS1)	15.1 - 50.2	32.7	50.1	53.3%	Low/med residential, institutional
Rock Creek, Military (MS2)	44.2 - 73.2	58.0	48.9	-15.7%	Parks, institutional
Hickey (MS3)	26.1 - 144.0	68.6	114.4	66.8%	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	12.4 - 186.0	84.1	50.9	-39.4%	Low/med residential, med/high residential
Soapstone (MS5)	55.3 - 201.0	105.8	106.1	0.3%	Institutional, federal, commercial
Potomac Trib (MS6)	45.5 - 76.1	63.0	66.1	4.8%	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	0.0 - .0	45.5	58.8	29.1%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	60.78 - 60.78	73.0	75.8	3.8%	Low/med residential, industrial
	Average	64.7	65.0	0.4%	
	Median	65.8	59.2	-10.0%	
	Maximum	125.0	114.4	-8.4%	
	Minimum	25.0	40.0	60.0%	

Table 8: Lead EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (µG/L)**	**Average of reported EMCs (µG/L)**	**Calculated LU-based EMC (µG/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	46.0	24.9	-45.9%	Low/med residential, parks, commercial
East Capitol	Not In Report	88.0	21.8	-75.2%	Low/med residential
Fort Lincoln	Not In Report	16.8	18.3	9.0%	Parks, mixed use
Gallatin	Not In Report	25.0	27.5	10.0%	Low/med residential, institutional
Nash Run	Not In Report	21.4	19.9	-7.0%	Low/med residential, parks
O Street	Not In Report	17.0	33.0	93.9%	Mixed, commercial
Stickfoot	Not In Report	39.0	22.0	-43.5%	Low/med residential
Varnum	Not In Report	9.0	27.6	206.2%	Low/med residential, institutional, mixed
Oxon Run (MS1)	20.0 - 22.9	17.9	25.0	39.5%	Low/med residential, institutional
Rock Creek, Military (MS2)	30.9 - 33.2	19.2	18.7	-2.8%	Parks, institutional
Hickey (MS3)	34.7 - 64.6	27.1	51.4	89.3%	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	15.4 - 18.8	34.8	27.3	-21.5%	Low/med residential, med/high residential
Soapstone (MS5)	0.0 - 0.0	47.0	43.6	-7.2%	Institutional, federal, commercial
Potomac Trib (MS6)	0.0 - 0.0	20.9	26.6	26.9%	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	59.25 - 59.25	17.8	25.9	45.7%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	35.11 - 35.11	49.0	34.6	-29.3%	Low/med residential, industrial
	Average	31.0	28.0	-9.7%	
	Median	23.2	26.2	13.0%	
	Maximum	88.0	51.4	-41.6%	
	Minimum	9.0	18.3	103.1%	

Table 9: Zinc EMC Comparison Between Reported and Calculated Values					
Catchment	**Range of Reported EMCs (µG/L)**	**Average of reported EMCs (µG/L)**	**Calculated LU-based EMC (µG/L)**	**Percent Difference**	**LU Description**
Anacostia High	Not In Report	101.0	180.7	78.9%	Low/med residential, parks, commercial
East Capitol	Not In Report	396.0	136.4	-65.5%	Low/med residential
Fort Lincoln	Not In Report	146.5	225.4	53.9%	Parks, mixed use
Gallatin	Not In Report	131.3	205.5	56.5%	Low/med residential, institutional
Nash Run	Not In Report	111.9	140.2	25.3%	Low/med residential, parks
O Street	Not In Report	143.0	385.3	169.4%	Mixed, commercial
Stickfoot	Not In Report	261.0	136.2	-47.8%	Low/med residential
Varnum	Not In Report	187.0	197.7	5.7%	Low/med residential, institutional, mixed
Oxon Run (MS1)	27.13 - 176.0	147.1	158.2	7.5%	Low/med residential, institutional
Rock Creek, Military (MS2)	34.8 - 183.0	193.0	164.8	-14.6%	Parks, institutional
Hickey (MS3)	47.0 - 139.0	270.1	347.8	28.8%	Industrial, low-/med residential
Rock Creek, Cathedral (MS4)	20.93 - 309.0	218.7	165.9	-24.1%	Low/med residential, med/high residential
Soapstone (MS5)	27.84 - 27.84	213.3	296.9	39.2%	Institutional, federal, commercial
Potomac Trib (MS6)	0.0 - 0.0	263.3	223.2	-15.2%	Low/med residential, mixed use
Suitland Pkwy (DCWASA)	33.38 - 33.38	120.0	179.7	49.8%	Low/med residential, institutional, parks
Hickey Run (DCWASA)	202.22 - 202.22	268.0	239.7	-10.6%	Low/med residential, industrial
	Average	198.2	211.5	6.7%	
	Median	190.0	189.2	-0.4%	
	Maximum	396.0	385.3	-2.7%	
	Minimum	101.0	136.2	34.9%	

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Attachment 3: Results of Analysis 2, Updated EMCs from MS4 Monitoring Data

The following two tables show the results from Analysis 2, Updated EMCs from MS4 Monitoring Data, as explained in section 4. This analysis was undertaken to determine if sufficient monitored EMC data exists to calculate EMC values for all of the TMDL pollutants. An additional line of inquiry was to compare the average monitored EMCs to the EMCs used to develop the TMDLs.

A statistical analysis was undertaken of the monitored data to calculate the average and median values of the EMCs, on a city-wide basis (i.e.: all sites aggregated). The statistical analysis was only possible for sediment, nitrogen, phosphorus, BOD, bacteria, oil and grease, copper, lead, and zinc. The statistical results for these pollutants are shown in Table 1. For all other pollutants, many non-detects were found in the data, and this precluded any sort of meaningful statistical analysis of the monitoring data (Table 2).

The results of this analysis showed that:

1. Sufficient monitoring data exists only for sediment, nitrogen, phosphorus, BOD, bacteria, oil and grease, copper, lead, and zinc. For all other pollutants, many non-detects (over 2/3) were found in the data, and this precluded any sort of meaningful interpretation of the monitoring data.
2. The EMCs for pollutants with sufficient data show that they are generally within the same range as the EMCs used to develop the TMDLs, but are typically slightly lower than the mainstem EMCs and slightly higher than the tributary and Chesapeake Bay EMCs.

It should be noted that additional statistical analysis are currently being undertaken on the District MS4 monitoring program results to determine if further refinement of the EMCs on a watershed or waterbody level is possible. The additional analysis will be included in the Comprehensive Baseline Report.

Table 1: Statistical Analysis of MS4 monitoring Data for conventional pollutants and some metals

	TSS	TN	TP	Fecal Coliform Bacteria	BOD	Oil and Grease	Copper	Lead	Zinc
Units	mg/l	mg/l	mg/l	MPN/100ml	mg/l	mg/l	mg/l	mg/l	mg/l
City Wide Statistical Results of reported EMCs									
Min	0.50	0.0025	0.03	8.00	1.00	1.25	0.00050	0.00012	0.00075
Max	1100	22.00	2.60	500,000	200.00	116.00	0.68	0.31	0.89
Average	81.25	3.7	0.41	22,963	29.3	5.2	0.065	0.025	0.118
Median	44	3.2	0.35	5,000	19.0	2.5	0.042	0.013	0.103
n	198	200	203	121	185	156	212	205	220
# NDs	5	18	0	1	13	103	7	11	7
EMC values used in TMDLs									
Ranges	34.67 (Kingman) 60 (Watts Branch) 80?? (CB TMDL) 94 (Mainstem) 227 (Tribs)	3.7 (DC TMDLs) 2 (CB TMDL)	0.5 (DC TMDLs) 0.27 (CB TMDL)	28,265 (Mainstem) 17,300 (Tribs)	27 (Kingman) 42.9 (all other)	3.65 (Kingman) 10 (all other)	0.078 (RC Mainstem) 0.057 (all others)	0.036 (RC Mainstem) 0.029 (all others)	0.183 (RC Mainstem) 0.173 (all others)

Table 2: Statistical Analysis of MS4 monitoring Data for organics, toxics, and some metals												
	Arsenic	**Mercury**	**Chlordane**	**DDD**	**DDE**	**DDT**	**Dieldrin**	**Heptachlor Epoxide**	**PAH1**	**PAH2**	**PAH3**	**TPCB**
Units	**mg/l**	**mg/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**
City Wide Statistical Results of reported EMCs												
Min	TOO MANY NON-DETECTS TO DO MEANINGFUL STATISTICS											
Max												
Average												
Median												
n	162	137	134	133	134	133	135	133	136	123	137	90
# NDs	109	130	132	132	128	123	129	132	136	123	137	90
EMC values used in TMDLs												
Ranges	0.0014	0.0019 (RC Mainstem)	0.00983	0.003	0.0133	0.0342	0.00029	0.000957	0.6585	4.1595	2.682	0.0806

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Attachment 4: Analysis of EMC Differences

Memorandum

From: R. O'Banion and B. Crary

To: A. Savineau
Click here to enter text.

Date: 6/27/2014
Project: DDOEIP
CC: Click here to enter text.

SUBJECT: **EMC Watershed Difference Analysis**

Watershed EMC Analysis

Water quality sampling data were collected by DDOE from 2001 to 2013. These data were used to develop event mean concentrations (EMC) at both the city wide and watershed (Anacostia, Potomac, Rock Creek) scales. A statistical analysis was completed to determine whether the city wide or watershed specific EMCs should be used for further modeling.

Analysis of Variance

An analysis of variance (ANOVA) is a test of significance that measures between population difference and within population variance to test the null hypothesis of no difference (Qian 2010). In other words, ANOVA tests that:

H_0: $\mu_1 = \ldots \mu_k$

where H_0 is the null hypothesis

μ is the population mean

k is the number of experimental groups

If the null hypothesis is accepted, we expect the different watershed means to be similar to the citywide mean. However, if the null hypothesis is rejected, we expect the watershed means to be different from the citywide mean.

In order to appropriately apply ANOVA, it is necessary to make underlying assumptions about the data. The assumptions and relation to the data being analyzed are discussed below:

- Data are independent – All data in this analysis are independent.
- Data are normally distributed- The data in this analysis are not normally distributed. To account for this, the data have been transformed as needed (Table 1).
- Data have equal variance- As long as the sample sizes, *n*, between the groups are equal or nearly equal, ANOVA is a very robust test regardless of variance (Zar 1999). Since the sample sizes are similar, for this analysis, the data were assumed to have equal variances.

Tests of Significance

Analysis of variance was calculated on the EMC values of ten different pollutants. All analyses were run with R statistical software (R 2010). Table 1 provides all results from the analysis, including the f-statistic. Significant differences (indicated by the p-value) at the 0.05 level or lower means that there is >95% confidence that the watershed EMCs are truly different and that this difference is not due to chance.

Table 1: Summary of ANOVA Analysis							
Parameter	**Potomac Sample Size (n)**	**Rock Creek Sample Size (n)**	**Anacostia Sample Size (n)**	**Transformation**	**F-statistic**	**P-value**	**Result**
Arsenic	40	50	68	N/A	N/A	N/A	No Difference
Biological Oxygen Demand	61	48	75	Log	3.426	0.03463	Significant Difference at the 0.05 Level
Copper	59	60	84	Log	1.895	0.1530	No Difference
Fecal Coliform	29	42	44	Log	1.259	0.2878	No Difference
Lead	51	83	57	N/A	N/A	N/A	No Difference
Nitrogen	64	50	80	0.5454	0.036	0.9641	No Difference
Oil & Grease	53	48	48	-0.5858	4.379	0.0142	Significant Difference at the 0.05 Level
Phosphorus	63	54	81	0.3434	1.681	0.1889	No Difference
Total Suspended Solids	64	53	73	Log	6.315	0.0022	Significant Difference at the 0.01 Level
Zinc	67	60	89	0.4646	3.804	0.0238	Significant Difference at the 0.05 Level

A discussion of each EMC ANOVA is found below.

Arsenic

The arsenic EMC data are independent, but no appropriate transformation was identified to meet the assumption of normal distribution. Based on this, a formal ANOVA was not run. However, by looking at box and whisker plots (Figure 1), it is possible to see that the mean values are similar across the watersheds. Therefore, based on best professional judgment, a citywide EMC should be used. It is also worth noting that the arsenic data contains a large amount of non-detect values (109 out of 158 total data points). Non-detect values were estimated to be ½ the detection limit for the analysis.

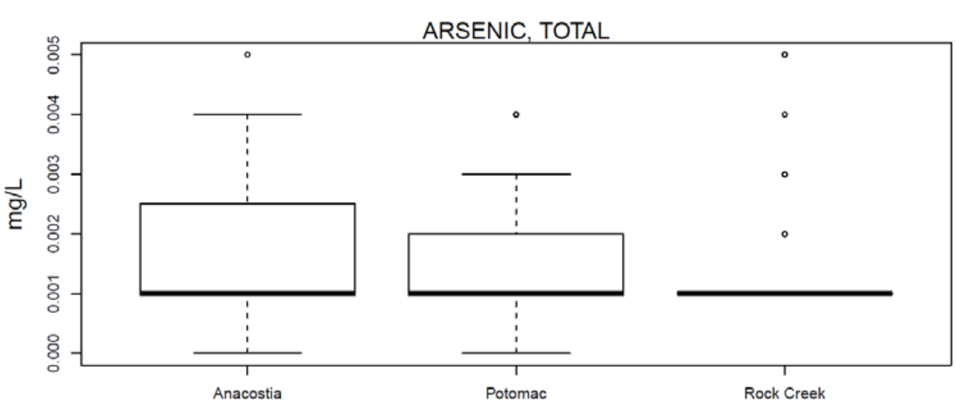

Figure 1: Box and Whisker plot of Arsenic data

Biological Oxygen Demand

The BOD EMC data were found to be log normal. The ANOVA indicated that the difference between the watershed means is significant at the 0.05 level. Therefore, the null hypothesis can be rejected. Further statistical tests should be used to identify pairwise differences. Watershed specific EMC values for BOD should be used for further modeling efforts.

Copper

The copper EMC data were found to be log normal. The ANOVA indicated that the difference between the watershed means is not significant. Therefore, the null hypothesis is accepted. Citywide copper EMCs should be used for further modeling efforts.

Fecal Coliform

The fecal coliform EMC data were found to be log normal. The ANOVA indicated that the difference between the watershed means is not significant. Therefore, the null hypothesis is accepted. Citywide fecal coliform EMCs should be used for further modeling efforts.

Lead

The lead EMC data are independent, but no appropriate transformation was identified to meet the assumption of normal distribution. Based on this, a formal ANOVA was not run. However, by looking at box and whisker plots (Figure 2), it is possible to see that the mean values are similar across the watersheds. Therefore, based on best professional judgment, a citywide EMC should be used.

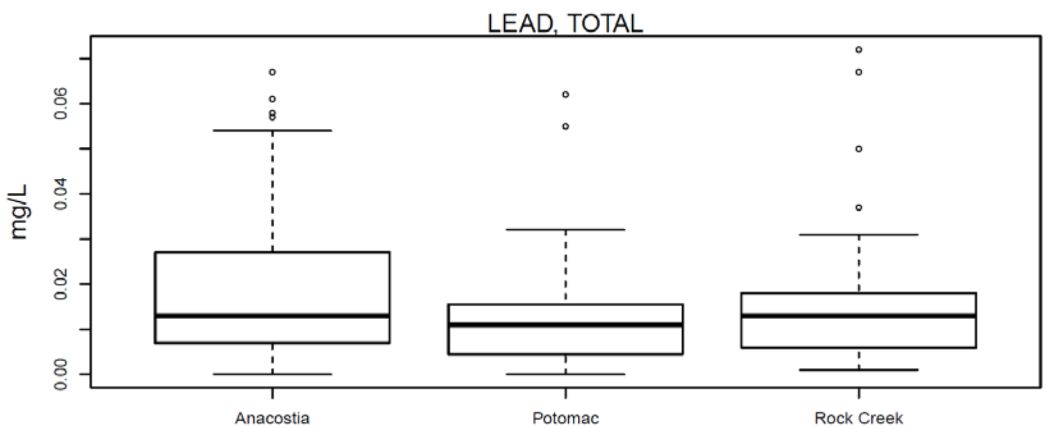

Figure 2: Box and Whisker plot of Lead data

Total Nitrogen

The total nitrogen EMC data were found to be normal with a power transformation (λ=0.5454). The ANOVA indicated that the difference between the watershed means is not significant. Therefore, the null hypothesis is accepted. Citywide total nitrogen EMCs should be used for further modeling efforts.

Oil and Grease

The oil and grease EMC data were found to be normal with a power transformation (λ=-0.5858). The ANOVA indicated that the difference between the watershed means is significant at the 0.05 level. Therefore, the null hypothesis can be rejected. Further statistical tests should be used to identify pairwise differences. It is worth noting that the Oil and Grease data contains a large amount of non-detect values (103 out of 149 total data points). Non-detect values were estimated to be ½ the detection limit for the analysis.

Total Phosphorus

The total nitrogen EMC data were found to be normal with a power transformation (λ=0.3434). The ANOVA indicated that the difference between the watershed means is not significant. Therefore, the null hypothesis is accepted. Citywide total phosphorus EMCs should be used for further modeling efforts.

Total Suspended Solids

The total suspended solids EMC data were found to be log normal. The ANOVA indicated that the difference between the watershed means is significant at the 0.01 level. Therefore, the null hypothesis can be rejected. Further statistical tests should be used to identify pairwise differences.

Zinc

The zinc EMC data were found to be normal with a power transformation (λ=0.4646).The ANOVA indicated that the difference between the watershed means is significant at the 0.05 level. Therefore, the null hypothesis can be rejected. Further statistical tests should be used to identify pairwise differences.

Tukey Honestly Significant Differences Test

The rejection of a null hypothesis with an ANOVA test does not imply that all groups are different from each other, nor does it provide information as to which and how many differences exist. Thus, it is common practice to perform subsequent statistical tests to determine which groups are significantly different from each other. If multiple pairwise t-tests are performed on a single data set, then it is more likely that an incorrect rejection of the null hypothesis occurs (Zar 1999). In other words, with an increasing number of logical tests on the same data, we are increasingly likely to falsely determine that any two groups are different.

A common solution to this issue is the Tukey Honestly Significant Differences Test. This method conducts all t-tests, but uses a significance level which represents the probability of encountering at least one Type-1 error across all pairwise comparisons (Zar 1999). The null hypothesis for each pairwise test is that the compared groups have equal means, or:

$$H_0: \mu_1 = \ldots \mu_k$$

where H_0 is the null hypothesis

μ_1 is the mean of group 1

μ_2 is the mean of group 2

Multiple Comparisons

There were four pollutants in which watershed means were found to be different than citywide means (BOD, Oil and Grease, TSS, and Zinc) using the ANOVA test. The Tukey HSD test was performed on these pollutants to determine which watershed means differed. Table 2 shows the 95% confidence interval for difference in group means and the corresponding significance value for rejecting the null hypothesis.

Table 2 Summary of Tukey HSD test

Parameter	Watershed 1	Watershed 2	Difference in mean	Lower Bound (95% CI)	Upper Bound (95% CI)	p	Result
BOD	Potomac	Rock Creek	0.3481	-0.1413	0.8374	0.2153	No difference
	Potomac	Anacostia	0.1699	-0.2674	0.6072	0.6296	No difference

Table 2 Summary of Tukey HSD test

Parameter	Watershed 1	Watershed 2	Difference in mean	Lower Bound (95% CI)	Upper Bound (95% CI)	p	Result
	Anacostia	Rock Creek	0.5180	0.0491	0.9868	0.0264	Significant Difference
Oil and Grease	Anacostia	Rock Creek	0.0462	-0.0255	0.1178	0.2819	No difference
	Potomac	Rock Creek	0.0918	0.0183	0.1652	0.0100	Significant Difference
	Potomac	Anacostia	0.0456	-0.0261	0.1172	0.2910	No difference
TSS	Rock Creek	Potomac	0.3369	-0.1211	0.7950	0.1940	No difference
	Anacostia	Potomac	0.6353	0.2129	1.0576	0.0014	Significant Difference
	Anacostia	Rock Creek	0.2984	-0.1467	0.7435	0.2552	No difference
Zinc	Rock Creek	Potomac	0.0073	-0.0374	0.0521	0.9208	No difference
	Anacostia	Potomac	0.0437	0.0030	0.0845	0.0319	Significant Difference
	Anacostia	Rock Creek	0.0364	-0.0057	0.0785	0.1046	No difference

Biological Oxygen Demand

The only statistical difference found for BOD EMC values was between the means of Anacostia and Rock Creek. The results suggest that while these two means are significantly different, the mean of Potomac is not significantly different from the mean of either Anacostia or Rock Creek. Thus the test results are ambiguous and fail to distinguish between the three EMC 'populations' in a way that is applicable to watershed loading.

Oil and Grease

The only statistical difference found for Oil and Grease EMC values was between the means of Potomac and Rock Creek. The results suggest that while these two means are significantly different, the mean of Anacostia is not significantly different from the mean of either Potomac or Rock Creek. Thus the test results are ambiguous and fail to distinguish between the three EMC 'populations' in a way that is applicable to watershed loading.

Total Suspended Solids

The only statistical difference found for TSS EMC values was between the means of Anacostia and Potomac. The results suggest that while these two means are significantly different, the mean of Rock Creek is not significantly different from the mean of either Anacostia or Potomac. Thus the test results are ambiguous and fail to distinguish between the three EMC 'populations' in a way that is applicable to watershed loading.

Zinc

The only statistical difference found for BOD EMC means was between the means of Anacostia and Rock Creek. The results suggest that while these two means are significantly different, the mean of Potomac is not significantly different from the mean of either Anacostia or Rock Creek. Thus the test results are ambiguous and fail to distinguish between the three EMC 'populations' in a way that is applicable to watershed loading.

Tukey Recommendations

The Tukey HSD test failed to identify coherent set of EMC relationships for the four pollutants that the ANOVA identified as having significant differences. This is not an uncommon result for Tukey tests, particularly because the ANOVA is a more powerful test (Zar 1999). Given the ambiguous results, it is recommended that watershed specific EMC values should be used for modeling purpose.

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Appendix E

Technical Memorandum

Review of MS4 Outfall Monitoring and Water Quality Conditions to Assess MS4 WLAs and TMDLs

Table of Contents

1 Introduction 1

2 Purpose 1

3 Technical Approach and Findings 1

References 30

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Consolidated TMDL Implementation Plan – Comprehensive Baseline Analysis

May 08, 2015

List of Tables

Table 1: Inventory of TMDL Studies 3
Table 2: Stormwater Outfall Monitoring Locations, 2000-2012 (Source: EDC 2006) 12
Table 3: Parameters Analyzed Outfall Discharge Monitoring Samples, 2000-2011. (Source: Apex Companies 2012) 15
Table 4: Analytical Methods and Hold Times for MS4 Monitoring 2004-2011 (Source: EDC 2006) 15
Table 5: Required Interim Monitoring Stations (Source Table 5, MS4 Permit) 16
Table 6: Parameters Analyzed in Outfall Discharge Monitoring Samples, 2012-2013 (Source: Apex 2012) 16
Table 7: Wet Weather MS4 Sampling Analytical Methods and Hold Times (Source: Apex 2012) 16
Table 8: Parameters to be Monitored for Outfall Discharge as Part of Revised Program, 2015 (Source: MS4 Permit, Table 4) 17

List of Figures

Figure 1: MS4 Monitoring Sites in Washington DC 14
Figure 2: Fecal Coliform, Anacostia River Watershed 19
Figure 3: TN, Anacostia River Watershed 19
Figure 4: TP, Anacostia River Watershed 20
Figure 5: TSS, Anacostia River Watershed 20
Figure 6: Fecal Coliform, Potomac River Watershed 21
Figure 7: TN, Potomac River Watershed 21
Figure 8: TP, Potomac River Watershed 22
Figure 9: TSS, Potomac River Watershed 22
Figure 10: Fecal Coliform, Rock Creek Watershed 23
Figure 11: TN, Rock Creek Watershed 23
Figure 12: TP, Rock Creek Watershed 24
Figure 13: TSS, Rock Creek Watershed 24
Figure 14: TSS, City-Wide 25
Figure 15: TP, City-Wide 25
Figure 16: TN, City-Wide 26
Figure 17: Oil & Grease, City-Wide 26
Figure 18: BOD, City-Wide 27
Figure 19: Fecal Coliform, City-Wide 27
Figure 20: Lead, City-Wide 28
Figure 21: Copper, City-Wide 28
Figure 22: Arsenic, City-Wide 29
Figure 23: Zinc, City-Wide 29

1 Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in the District's Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) permit (U. S. EPA 2011 and U. S. EPA 2012). The IP will define and organize a multi-year process centered on reducing pollutant loads originating within the District MS4. The level of pollutant control will be based on past TMDL studies performed to protect impaired water bodies in the District. The IP will include a summary of the regulatory compliance strategy to satisfy TMDL-related permit requirements, a summary of data and methods used to develop the IP, specific prioritized recommendations for stormwater control measures, a schedule for implementation and attainment of Waste Load Allocations (WLAs), and a method for tracking progress. Substantial public involvement will be sought in plan development.

This Technical Memorandum reviews District MS4 outfall monitoring data and reported water quality conditions to assess MS4 WLAs and District TMDLs is one in a series of technical memoranda that provide detailed information on research, analysis, programs and procedures that support development of the Consolidated TMDL IP.

2 Purpose

TMDLs define the maximum amount of pollutant load delivered to a water body that is protective of water quality standards. Most of the TMDLs developed for water bodies in the District contain a WLA for point sources and a LA for nonpoint sources.

The purpose of this Technical Memorandum is to address two concerns identified as being required for the Baseline Report:

- An evaluation of the development of TMDLs and the District's water quality monitoring record to determine if TMDL WLAs have been achieved.
- An analysis of pollutant load increases (or decreases) that have occurred since WLAs were first established.

Addressing these concerns provides the District with a data-based appraisal of progress (or lack thereof) in achieving WLAs and TMDLs that is parallel to the model based gap analysis described in the Baseline Report.

The technical approach employed includes:

- A review and summarization of causes and sources of water quality impairment and the status of use attainment as reported in the District's most recent 2012 Integrated Report (DDOE, 2012a).
- A trend analysis of MS4 outfall monitoring data.

3 Technical Approach and Findings

3.1 Review of the District's 2012 Integrated Report

As defined in the Executive Summary of the District's 2012 Integrated Report:

> *The District of Columbia 2012 Integrated Report provides information on the quality of the District's water. The Integrated Report combines the comprehensive biennial reporting requirements of the Clean Water Act's Section 305(b) and the Section 303(d) listing of waters for which total maximum daily loads (TMDLs) may be required.*

The 2012 Integrated Report is based on water quality data collected over the period 2007 to 2011 across 36 waterbody segments to assess whether or not water quality standards and designated uses are achieved and supported. This report provides sufficient assessment of the District's water quality monitoring record to determine if TMDLs (if not individual WLAs) have been achieved.

A major finding of the 2012 Integrated Report is that:

> *The evaluation found that the designated uses that directly relate to human use of the District's waters were generally not supported. The uses related to the quality of habitat for aquatic life were not supported. No waterbody monitored by the Water Quality Division fully supported all of its designated uses. The water quality of the District's waterbodies continues to be impaired.*

Most, if not all, of the water bodies in the District have MS4 WLAs and nonpoint source LAs for specific pollutants. Some waterbodies also have WLAs for specific pollutants from other permitted sources as well as WLAs and LAs for specific pollutants from upstream sources outside of the District. The 2012 Integrated Report assesses water quality standards and use attainment at the waterbody or waterbody segment level; it does not directly address individual WLAs or LAs. Nevertheless, the finding that no water body included in this assessment fully supported all of its uses and that the District's water bodies continue to be impaired suggests that MS4 WLAs may not have been achieved.

A summarization of TMDLs, TMDL pollutants, waterbodies and segments is cross referenced in Table 1 with the appropriate uses, causes of impairment and the status of use attainment. As discussed earlier in this section, the table shows that, in general, waterbodies for which TMDLs were completed are not supporting the uses for which the TMDLs were developed. In other cases, particularly with respect to primary contact recreation uses impaired by fecal coliform, insufficient data were collected to determine if uses were being met. This was because the sampling regime for fecal coliform was not sufficient to collect the required number of samples per month to calculate the geomean necessary to compare against the water quality standard.

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Hickey Run PCB, Oil and Grease, Chlordane – 1998	Anacostia	DCTHR01R_00	Hickey Run	Protection and Propagation of Fish, Shellfish and Wildlife	Oil and Grease	Oil and Grease	Not Supporting	No
				Protection and Propagation of Fish, Shellfish and Wildlife	Organics	PCBs, Chlordane	Not Supporting	No
Anacostia BOD – 2001	Anacostia	DCANA00E_01	Mainstem - Lower	Protection of Human Health related to Consumption of Fish and Shellfish	BOD, Nitrogen, Phosphorus	BOD, Nitrogen, Phosphorus	Not Supporting	No
		DCANA00E_02	Mainstem - Upper	Protection of Human Health related to Consumption of Fish and Shellfish	BOD, Nitrogen, Phosphorus	BOD, Nitrogen, Phosphorus	Not Supporting	No
Anacostia TSS – 2002	Anacostia	DCANA00E_01	Mainstem - Lower	Protection of Human Health related to Consumption of Fish and Shellfish	TSS	TSS	Not Supporting	No
		DCANA00E_02	Mainstem - Upper	Protection of Human Health related to Consumption of Fish and Shellfish	TSS	TSS	Not Supporting	No
		DCTFD01R_00	Fort Davis	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
Anacostia Bacteria– 2003	Anacostia	DCTFC01R_00	Fort Chaplin	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCTDU01R_00	Fort Dupont	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCTFS01R_00	Fort Stanton	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCTNA01R_00	Nash Run	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCTHR01R_00	Hickey Run	Protection and Propagation of Fish, Shellfish and Wildlife	Fecal Coliform	Fecal Coliform	Not Supporting	No
		DCTPB01R_00	Popes Branch	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Anacostia Bacteria– 2003	Anacostia	DCTTX27R_00	Texas Ave. Tributary	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCTWB00R_01	Watts Branch, Lower	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
Anacostia &Tributaries Metals and Organics - 2003	Anacostia	DCANA00E_01	Mainstem - Lower	Protection of Human Health related to Consumption of Fish and Shellfish	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Not Supporting	No
		DCANA00E_02	Mainstem - Upper	Protection of Human Health related to Consumption of Fish and Shellfish	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Not Supporting	No
		DCTFD01R_00	Fort Davis	Protection and Propagation of Fish, Shellfish and Wildlife	Metals	Arsenic, Copper, Lead, Zinc	Not Supporting	No
		DCTFC01R_00	Fort Chaplin	Protection and Propagation of Fish, Shellfish and Wildlife	Metals	Arsenic, Copper, Lead, Zinc	Not Supporting	No
		DCTDU01R_00	Fort Dupont	Protection and Propagation of Fish, Shellfish and Wildlife	Metals	Arsenic, Copper, Lead, Zinc	Insufficient Information	No
		DCTFS01R_00	Fort Stanton	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Not Supporting	No

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Anacostia &Tributaries Metals and Organics - 2003	Anacostia	DCTNA01R_00	Nash Run	Protection and Propagation of Fish, Shellfish and Wildlife	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Insufficient Information	No
		DCTHR01R_00	Hickey Run	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTPB01R_00	Popes Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Not Supporting	No
		DCTTX27R_00	Texas Ave. Tributary	Protection and Propagation of Fish, Shellfish and Wildlife	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Not Supporting	No
		DCTWB00R_01	Watts Branch, Lower	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTWB00R_02	Watts Branch, Upper	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Anacostia Oil and Grease - 2003	Anacostia	DCANA00E_01	Mainstem - Lower	Primary Contact Recreation	Oil and Grease	Oil and Grease	Not Supporting Not Supporting	No No
		DCANA00E_02	Mainstem - Upper	Primary Contact Recreation	Oil and Grease	Oil and Grease	Insufficient Information	No
Fort Davis BOD - 2003	Anacostia	DCTFD01R_00	Fort Davis	Protection and Propagation of Fish, Shellfish and Wildlife	BOD	BOD	Not Supporting	No
Watts Branch TSS - 2003	Anacostia	DCTWB00R_01	Watts Branch, Lower	Protection and Propagation of Fish, Shellfish and Wildlife	TSS	TSS	Not Supporting	No
		DCTWB00R_02	Watts Branch, Upper	Protection and Propagation of Fish, Shellfish and Wildlife	TSS	TSS	Not Supporting	No
Kingman Lake Bacteria - 2003	Anacostia	DCAKL00L_00	Kingman Lake	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
Kingman Lake Organics and Metals - 2003	Anacostia	DCAKL00L_00	Kingman Lake	Protection and Propagation of Fish, Shellfish and Wildlife	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Not Supporting	No
Kingman Lake TSS, Oil and Grease, BOD - 2003	Anacostia	DCAKL00L_00	Kingman Lake	Protection and Propagation of Fish, Shellfish and Wildlife	TSS	TSS	Not Supporting	No
				Protection and Propagation of Fish, Shellfish and Wildlife	BOD	BOD	Not Supporting	No
				Primary Contact Recreation	Oil and Grease	Oil and Grease	Insufficient Information	No

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Anacostia TSS – 2007	Anacostia	DCANA00E_01	Lower Tidal	Protection of Human Health related to Consumption of Fish and Shellfish	TSS	TSS	Not Supporting	No
		DCANA00E_02	Upper Tidal	Protection of Human Health related to Consumption of Fish and Shellfish	TSS	TSS	Not Supporting	No
		n/a	Lower Beaverdam Creek	not listed separately in IR	TSS	TSS	Not Assessed	No
		n/a	Northwest Branch	not listed separately in IR	TSS	TSS	Not Assessed	No
		DCTWB00R_01	Watts Branch, Lower	Protection and Propagation of Fish, Shellfish and Wildlife	BOD	BOD	Not Supporting	No
		DCTWB00R_02	Watts Branch, Upper	Protection and Propagation of Fish, Shellfish and Wildlife	BOD	BOD	Not Supporting	No
Anacostia Nutrients/BOD – 2008	Anacostia	DCANA00E_01	Mainstem - Lower	Protection of Human Health related to Consumption of Fish and Shellfish	BOD, Nitrogen, Phosphorus	BOD, Nitrogen, Phosphorus	Not Supporting	No
		DCANA00E_02	Mainstem - Upper	Protection of Human Health related to Consumption of Fish and Shellfish	BOD, Nitrogen, Phosphorus	BOD, Nitrogen, Phosphorus	Not Supporting	No
Anacostia Trash - 2010	Anacostia	DCANA00E_01	Mainstem - Lower	Secondary Contact Recreation and Aesthetic Enjoyment	Debris/Float -ables/Trash	Debris/Floatables/ Trash	Not Supporting	No
		DCANA00E_02	Mainstem - Upper	Secondary Contact Recreation and Aesthetic Enjoyment	Debris/Float -ables/Trash	Debris/Floatables/ Trash	Not Supporting	No

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Potomac and Anacostia Tidal PCB - 2007	Anacostia	DCANA00E_01	Mainstem - Lower	Protection of Human Health related to Consumption of Fish and Shellfish	PCBs	PCBs	Not Supporting	No
		DCANA00E_02	Mainstem - Upper	Protection of Human Health related to Consumption of Fish and Shellfish	PCBs	PCBs	Not Supporting	No
	Potomac	DCPMS00E_01	Potomac, Lower	Protection and Propagation of Fish, Shellfish and Wildlife	PCBs	PCBs	Insufficient Information	No
		DCPMS00E_02	Potomac, Middle	Protection and Propagation of Fish, Shellfish and Wildlife	PCBs	PCBs	Not Supporting	No
		DCPMS00E_03	Potomac, Upper	Protection and Propagation of Fish, Shellfish and Wildlife	PCBs	PCBs	Not Supporting	No
Potomac & Tributaries Bacteria -2004	Potomac	DCTBK01R_00	Battery Kemble	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCTDA01R_00	Dalecarlia Tributary	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCTFB02R_00	Foundry Branch	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCPMS00E_01	Potomac, Lower	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCPMS00E_02	Potomac, Middle	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
		DCPMS00E_03	Potomac, Upper	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
Potomac Tributaries Organics and Metals - 2004	Potomac	DCTBK01R_00	Battery Kemble	Protection and Propagation of Fish, Shellfish and Wildlife	Metals	Arsenic, Copper, Lead, Zinc	Not Supporting	No

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Potomac Tributaries Organics and Metals - 2004	Potomac	DCTDA01R_00	Dalecarlia Tributary	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTFB02R_00	Foundry Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Metals	Arsenic, Copper, Lead, Zinc	Not Supporting	No
Tidal Basin and Ship Channel Bacteria - 2004	Potomac	DCPTB01L_00	Tidal Basin	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Not Supporting	No
		DCPWC04E_00	Washington Ship Channel	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Not Supporting	No
Tidal Basin and Ship Channel Organics -2004	Potomac	DCPTB01L_00	Tidal Basin	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCPWC04E_00	Washington Ship Channel	Protection and Propagation of Fish, Shellfish and Wildlife	Organics (except PCBs)	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
Oxon Run Organics, Metals, and Bacteria - 2004	Potomac	DCTOR01R_00	Oxon Run	Protection and Propagation of Fish, Shellfish and Wildlife	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Not Supporting	No
		DCTOR01R_00	Oxon Run	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
Ship Channel pH - 2004	Potomac	DCPWC04E_00	Washington Ship Channel	Protection of Human Health related to Consumption of Fish and Shellfish	pH	pH	Not Supporting	No - Due to Fish Consumption Advisory

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Chesapeake and Ohio Canal Bacteria - 2004	Potomac	DCTCO01L_00	C&O Canal	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Insufficient Information	No
Rock Creek Metals -2004	Rock Creek	DCRCR00R_01	Lower Rock Creek	Protection and Propagation of Fish, Shellfish and Wildlife	Metals	Copper, Lead, Mercury, Zinc	Not Supporting	No
		DCRCR00R_02	Upper Rock Creek	Protection and Propagation of Fish, Shellfish and Wildlife	Metals	Copper, Lead, Mercury, Zinc	Not Supporting	No
Rock Creek Bacteria -2004	Rock Creek	DCRCR00R_01	Lower Rock Creek	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Not Supporting	No
		DCRCR00R_02	Upper Rock Creek	Primary Contact Recreation	Fecal Coliform	Fecal Coliform	Not Supporting	No
Rock Creek Tributary Organics and Metals – 2004	Rock Creek	DCTBR01R_00	Broad Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTDO01R_00	Dumbarton Oaks	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTFE01R_00	Fenwick Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTKV01R_00	Klingle Valley	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No

Table 1: Inventory of TMDL Studies

TMDL Study/Year TMDL Established	Waterbody	WB ID	Tributary/ Segment	Use	Causes	Pollutants Listed in TMDL	Attainment Status 2012 IR	Achievement of TMDL and WLA?
Rock Creek Tributary Organics and Metals – 2004	Rock Creek	DCTLU01R_00	Luzon Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTMH01R_00	Melvin Hazen Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTNS01R_00	Norman-stone Creek	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Insufficient Information	No
		DCTPI01R_00	Pinehurst Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No
		DCTPY01R_00	Piney Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics and Metals	Arsenic, Chlordane, Copper, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, Lead, PAH1, PAH2, PAH3, PCBs, Zinc	Insufficient Information	No
		DCTPO01R_00	Portal Branch	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Insufficient Information	No
		DCTSO01R_00	Soapstone Creek	Protection and Propagation of Fish, Shellfish and Wildlife	Organics	Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor Epoxide, PAH1, PAH2, PAH3, PCBs	Not Supporting	No

3.2 **Review and Assessment of the District's MS4 Outfall Monitoring Data**

3.2a MS4 Monitoring Background

The District has been implementing wet weather monitoring programs in association with its municipal separate storm sewer (MS4) permit since 2000 when its first permit was issued. Within each watershed, DDOE has selected outfalls that are representative of the MS4. Samples from these outfalls reflect end-of pipe runoff concentrations from MS4 sources discharging to waterbodies.

The monitoring stations used since 2000 are shown in Table 2 and Figure 1 below. The District's 2004 MS4 permit established a rotating schedule for monitoring wet weather discharges to the Anacostia River, Rock Creek, and the Potomac River. Monitoring each year occurred only in one of the watersheds so that each watershed was monitored once every three years. Three wet events were sampled at all locations for the designated watershed each year. Storm events are chosen given the following criteria: at least 0.1 inch of precipitation, 72 hours since the last storm, and one month since the last collection at a specific site. From 2000 through 2011, samples were collected by grab method, except for those that could be analyzed in the field. From 2012 and on, time-composite samples were collected, except for those that could be analyzed in the field.

Table 2: Stormwater Outfall Monitoring Locations, 2000-2012 (Source: EDC 2006)
A. Anacostia River Sub Watershed Monitoring Sites
1. Stickfoot Sewer (Suitland Parkway)-2400 block of Martin Luther King, Jr. Ave., SE, near Metro bus entrance.
2. O St. Storm Water Pump Station - 125 O St., 125 O SE-just outside front gate at O St. Pump Station
3. Anacostia High School/Anacostia Recreation Center - corner of 17th St. and Minnesota Ave. SE
4. Gallatin & 14th St., NE-across from the intersection of 14th St. and Gallatin St. in a large outfall
5. Varnum and 19th Place, NE-2100 Block of Varnum St.
6. Nash Run-intersection of Anacostia Drive and Polk St., NE.
7. East Capitol St.-200 Block of Oklahoma Ave., NE.
8. Ft. Lincoln-Newtown BMP-in the brush along the side of New York Ave. West (coming into city) after the bridge.
9. Hickey run-33rd and V Streets, NE.
B. Rock Creek Subwatershed Monitoring Sites
1. Walter Reed (Fort Stevens Drive).
2. Military Road and Beach Drive.
3. Soapstone Creek (Connecticut Avenue and Albemarle Street).
4. Melvin Hazen Valley Branch (Melvin Hazen Park and Quebec Street).
5. Klingle Valley Creek (Devonshire Place and 30th Street).
6. Normanstone Creek (Normanstone Drive and Normanstone Parkway).
7. Portal Dr. and 16th St.
8. Broad Branch.
9. Oregon and Pinehurst.
C. Potomac River Subwatershed Monitoring Sites
1. Battery Kemble Creek-49th and Hawthorne Streets, NW.
2. Foundry Branch-at Van Ness and Upton Streets, NW in the park.

Table 2: Stormwater Outfall Monitoring Locations, 2000-2012 (Source: EDC 2006)
3. Dalecarlia Tributary-Van Ness Street and Dalecarlia Parkway.
4. Oxon Run-Mississippi Avenue and 15th Street, SE.
5. Tidal Basin-17th Street and Constitution Avenue, NW.
6. Washington Ship Channel-Washington Marina parking lot, SW.
7. C and O Canal-Potomac Avenue and Foxhall Road, NW.
8. Archbold Parkway.

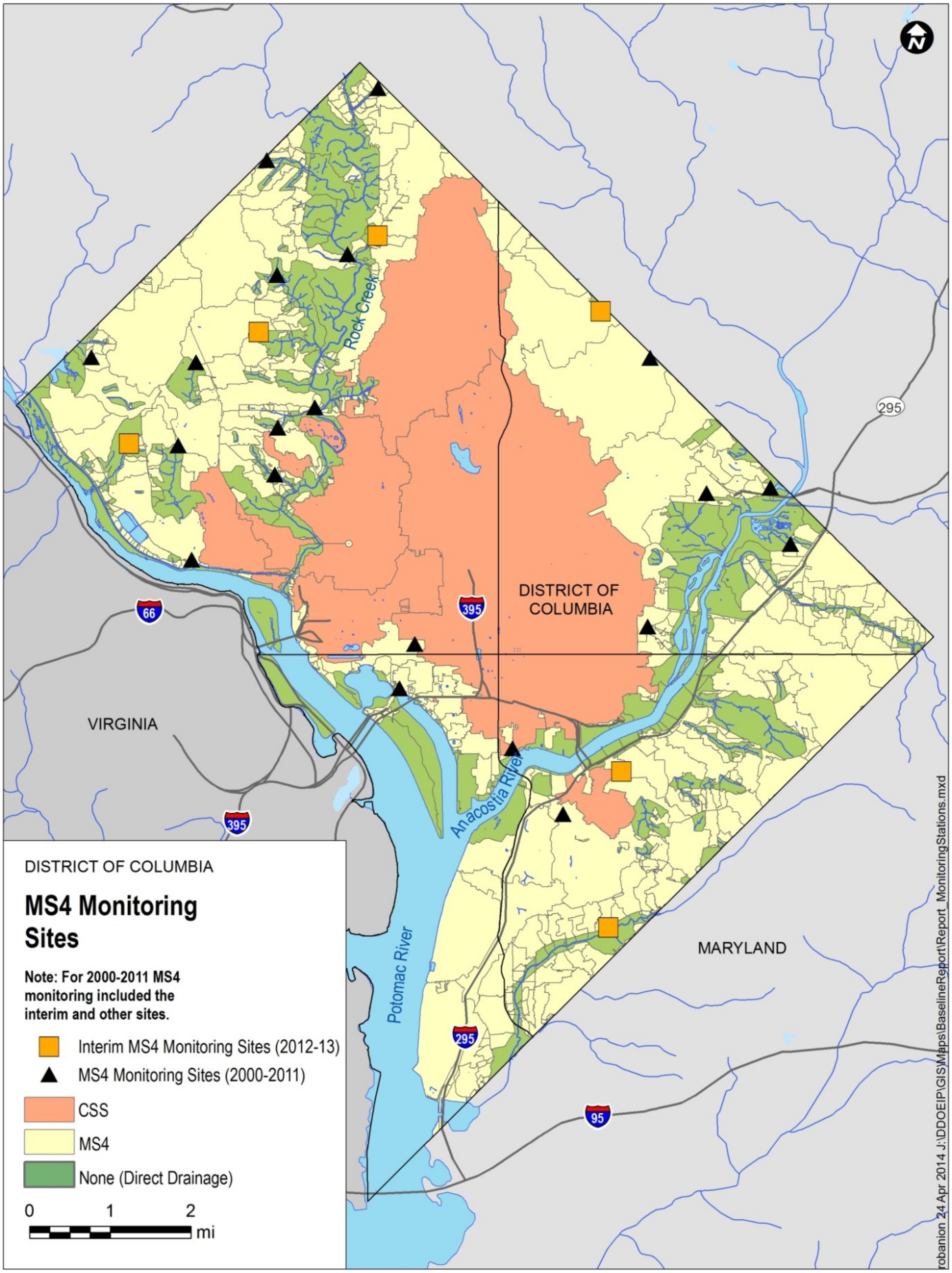

Figure 1: MS4 Monitoring Sites in Washington DC

DISTRICT DEPARTMENT OF THE ENVIRONMENT

Table 3 shows the list of parameters that were analyzed from 2000 through 2011. Analytical methods and hold times are provided in Table 4.

Table 3: Parameters Analyzed Outfall Discharge Monitoring Samples, 2000-2011. (Source: Apex Companies 2012)

Grab Samples		Field Analysis
• VOCs	• SVOCs	• Residual Chlorine
• Cyanide	• Pesticides and PCBs	• Dissolved Oxygen
• Total Phenols	• Metals	• pH
• Oil & Grease	• Nutrients	• Temperature
• Fecal Coliform	• BOD5, Chlorophyll a	• Flow
• Fecal Streptococcus	• TSS, TDS, Hardness, TOC	
• E-Coli	• Dioxin	

Table 4: Analytical Methods and Hold Times for MS4 Monitoring 2004-2011 (Source: EDC 2006)

Parameters	Analytical Method	Hold Times
BOD5	EPA 405.1	
Chlorophyll a	Chlorophyll-a	
COD	EPA 410.4	
Dioxin	EPA 8280	
Dissolved Oxygen, pH, Temperature, Flow, Hardness	Field	
Dissolved phosphorus	SM 18 4500 P B + E	
Fecal Coliform	SM 18 9221 E	
Fecal streptococcus	SM 18 9230 B	
Mercury	EPA 245.1	
Metals, Cyanide and Phenols	EPA 200.8	
Nitrite plus nitrate	EPA 353.2	
Oil & Grease	EPA 1664 A	
Pesticides and PCBs	EPA 608	
Residual Chlorine		
SVOCs	EPA 625	
TKN, or total ammonia plus organic nitrogen	EPA 351.3	
Total dissolved solid	EPA 160.1	
Total phosphorus	EPA 160.1	7 days
TSS	EPA 160.2	7 days
VOCs	EPA 624	14 days

Starting in 2012, the wet weather discharge monitoring was implemented in a slightly revised format (the interim program) based on the revised MS4 permit (finalized in 2012). Interim monitoring stations are shown in Table 5. For the interim program, the sampling protocols changed to include time-composited samples for certain parameters (see Table 6) for which parameters are collected by each method) and the number of stations monitored was reduced to two per watershed (to be monitored each year) for efficiency's sake while a new monitoring program is being developed. Composite samples are taken every 15 minutes from the outfall discharge by automatic samplers equipped with 2.5 gallon glass jars supplied by the analytical laboratory. Grab samples are taken by field staff downstream of the outfall with laboratory-provided collection containers appropriate to the parameter being analyzed. Samples are preserved and packaged according to laboratory instructions and delivered to the lab within approximately 90 minutes of collection. Analytical methods are provided in Table 7.

Table 5: Required Interim Monitoring Stations (Source Table 5, MS4 Permit)
A. Anacostia River Sub Watershed Monitoring Sites
1. Gallatin Street & 14th Street N.E. across from the intersection of 14th St. and Gallatin St. in an outfall (MS-2)
2. Anacostia High School/Anacostia Recreation Center – Corner of 17th St and Minnesota Ave SE
B. Rock Creek Subwatershed Monitoring Sites
1. Walter Reed -- Fort Stevens Drive -- 16th Street and Fort Stevens Road, N.W. at an outfall (MS-6)
2. Soapstone Creek -- Connecticut Avenue and Albemarle Street N.W. at an outfall (MS-5)
C. Potomac River Subwatershed Monitoring Sites
1. Battery Kemble Creek-49th and Hawthorne Streets, N.W. at an outfall (MS-4)
2. Oxon Run-Mississippi Avenue and 15th Street, S.E. into Oxon Run via an outfall (MS-1)

Table 6: Parameters Analyzed in Outfall Discharge Monitoring Samples, 2012-2013 (Source: Apex 2012)		
GRAB SAMPLES	**COMPOSITE SAMPLES**	**FIELD SAMPLES**
VOCs	SVOCs	Residual Chlorine
Cyanide	Pesticides/PCBs	Dissolved Oxygen
Coliform	Metals (As, Cu, Cr, Cd, Ni, Pb, Zn)	pH
E. Coli, Fecal Coliform, Fecal Streptococcus	Nutrients	Temperature
Oil and Grease	BOD5, Chlorophyll a, COD	Flow
Total Phenols	TSS, TDS, Hardness, TOC	
	Dioxin	

Table 7: Wet Weather MS4 Sampling Analytical Methods and Hold Times (Source: Apex 2012)		
Parameters	**Method**	**Holding Times**
Parameters to be Analyzed in Wet Weather Samples		
E. coli	SM (20) 9221E	6 hours
Total nitrogen	SM (20) 4500-NO3 E + SM 4500orgN	28 days

Table 7: Wet Weather MS4 Sampling Analytical Methods and Hold Times (Source: Apex 2012)		
Parameters	**Method**	**Holding Times**
Total phosphorus	EPA 365.1	28 days
Total Suspended Solids	SM (2) 2540D	7 day s
Cadmium	EPA 200.7	180 days
Copper	EPA 200.7	180 days
Lead	EPA 200.7	180 days
Zinc	EPA 200.7	180 days
pH	SM (20) 4500 H B	15 minutes
Fecal coliform	SM (20) 9221 E	6 hours
Dissolved Oxygen	SM (20) 4500 O-G	1 day
Hardness	SM (20) 2340 C	28 days
Chlorophyll a	SM 10200H	2 day s
Temperature		Instant

Section 5.1 of DDOE's revised MS4 permit (first issued in 2011 and modified in 2012) includes the requirement to design a revised monitoring program. The permit requires a small set of parameters to be monitored (Table 8). The monitoring sites and protocols are currently in development (to be completed in 2015).

Table 8: Parameters to be Monitored for Outfall Discharge as Part of Revised Program, 2015 (Source: MS4 Permit, Table 4)		
E. coli	Lead	Total Suspended Solids
Total nitrogen	Zinc	Arsenic
Total phosphorus	Trash	Copper

3.2b Methodology

Data from various documents and spreadsheets provided by DDOE was consolidated into a database of all available MS4 monitoring data 2001-13. The following quality control actions were taken with the data before analysis. First, all dry weather data and fecal coliform samples qualified with ">" were removed. When units of the minimum detection limit (MDL) and the result did not match, both units were checked the original sources and corrected. Those samples marked as non-detects ("ND") or below quantification limit ("BQL") were estimated to be one half the detection limit for analysis. The interquartile range (IQR) was established as the difference between the upper (Q3) and lower (Q1) values for each parameter, where

$$IQR = Q3 - Q1$$

Using the Interquartile Rule for the determination of outliers, outliers were identified as data values that are greater than Q3 + (3.0 * IQR). This analysis was applied to conventional pollutants and most metals to identify outliers. The following parameters had such a large number of NDs that they are excluded from further analysis due to lack of meaningful data: mercury, PAHs, PCBs, chlordane, dieldrin, DDT isomers, and heptachlor epoxide.

Trend analysis by parameter of the remaining parameters over the period 2001 to 2013 is utilized to examine whether or not there is any evidence in the data that show an increase or decrease in pollutant load since the impairments were documented (listed) and the MS4 WLAs were established. This included trend analysis by parameter at two levels:

- Pooled watershed data
- Pooled city-wide data

The number of observations at the station-specific level is not sufficient for trend analysis.

Scatter diagrams with trend lines for these two levels are provided in Figure 2 through Figure 23. The results of this analysis suggest that:

1) The results of trend analysis at the watershed level do not indicate any increasing or decreasing trends.
2) The results of trend analysis at the city-wide level show some evidence of decreasing concentration for many parameters, but the trend is not statistically significant.

In a separate analysis, DDOE reported on trend analysis in its 2011 and 2012 DC MS4 Annual Report (DDOE, 2012b). Using the MS4 outfall monitoring data, mean pollutant concentrations for the 2001-2002, 2005-2006, 2008-2009 and 2011-2112 monitoring rotations were calculated and compared for monitoring stations in the Anacostia watershed. While some differences were seen across the monitoring rotations, there was no clear sign or finding that pollutant concentrations (or pollutant loads) were increasing or decreasing.

Taken together, the two separate trend analyses do not provide any meaningful evidence that MS4 pollutant load increases (or decreases) have occurred since WLAs were first established.

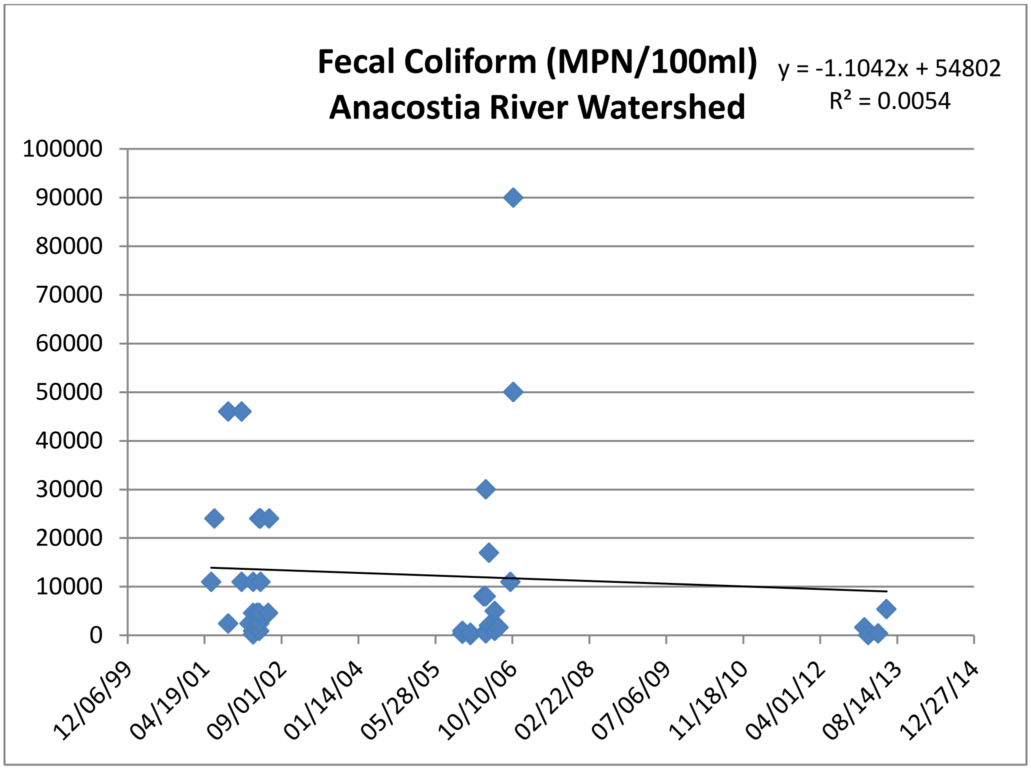

Figure 2: Fecal Coliform, Anacostia River Watershed

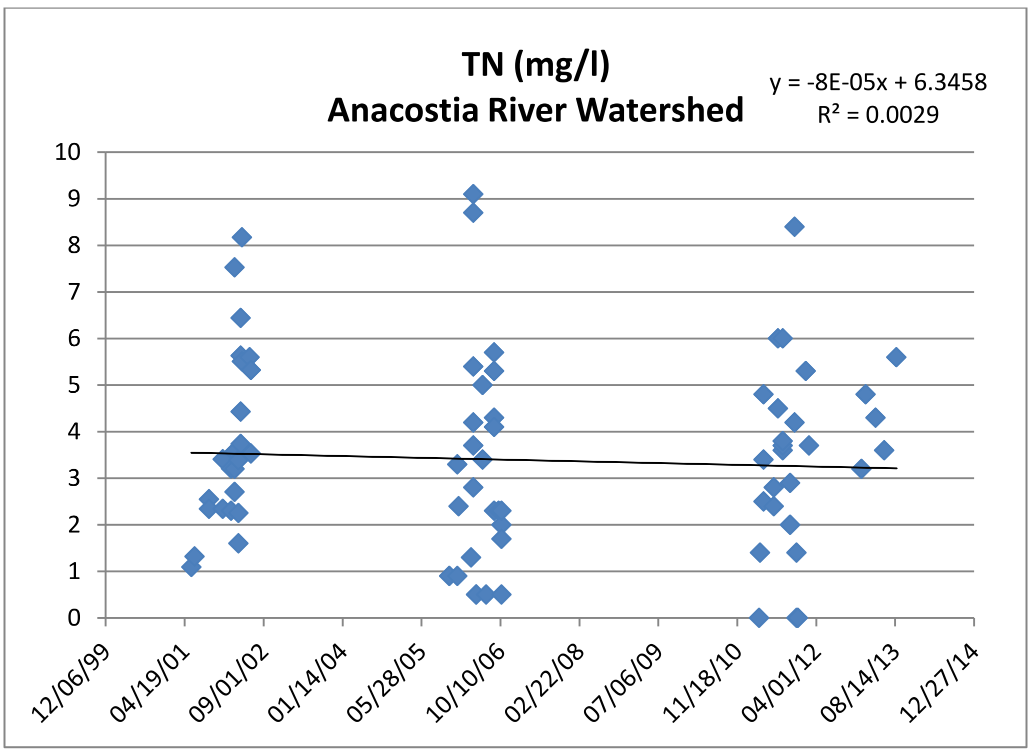

Figure 3: TN, Anacostia River Watershed

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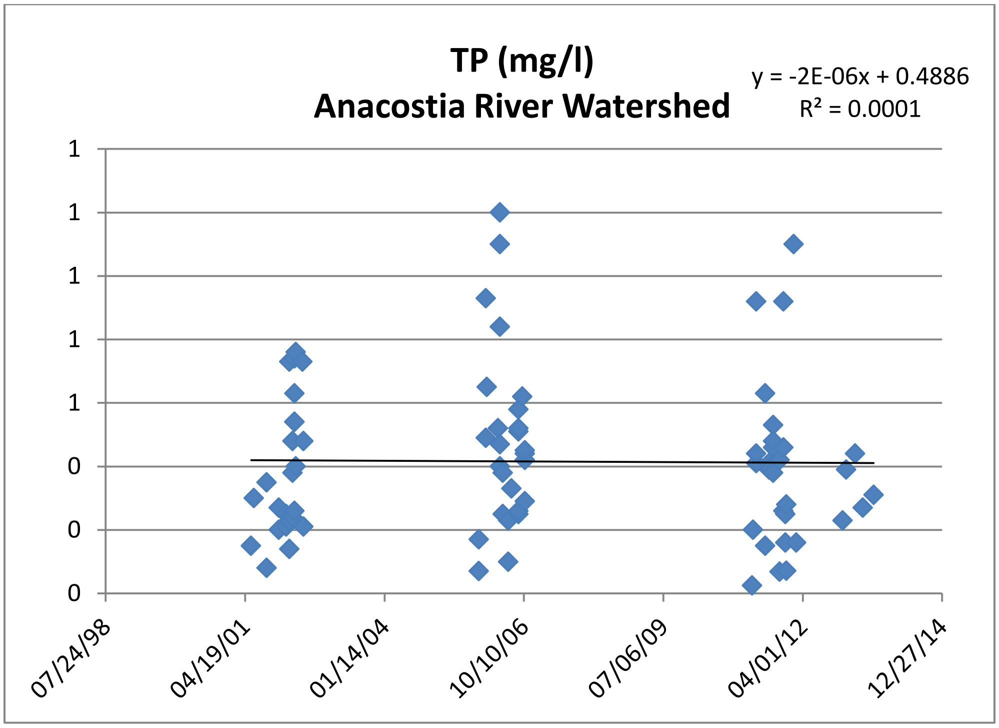

Figure 4: TP, Anacostia River Watershed

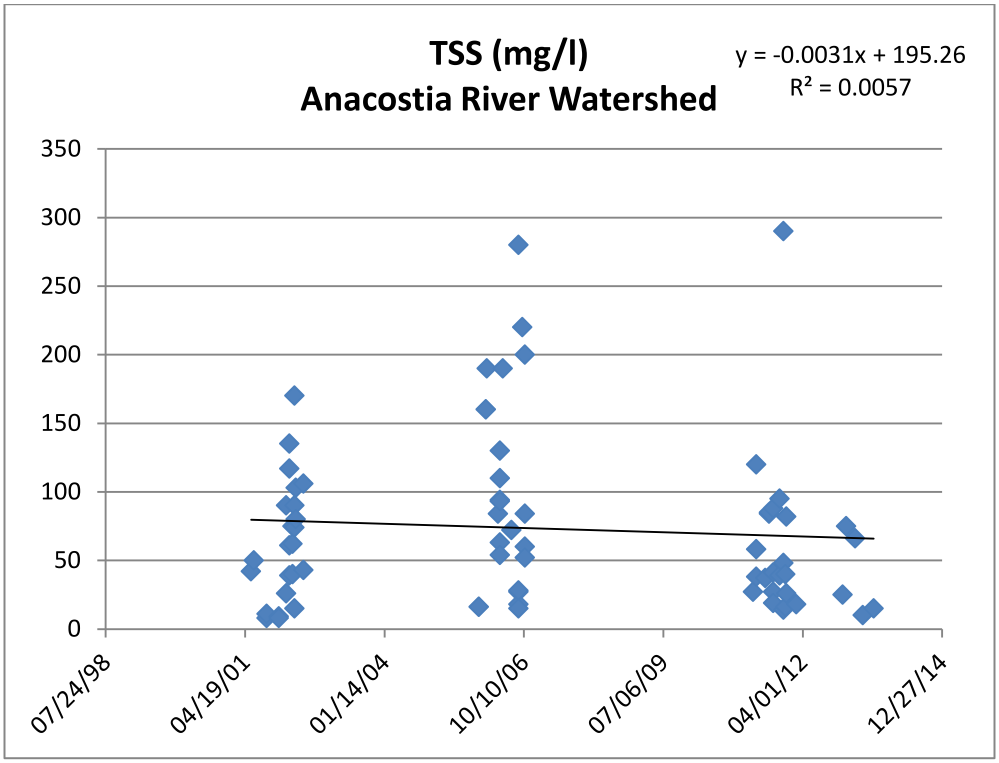

Figure 5: TSS, Anacostia River Watershed

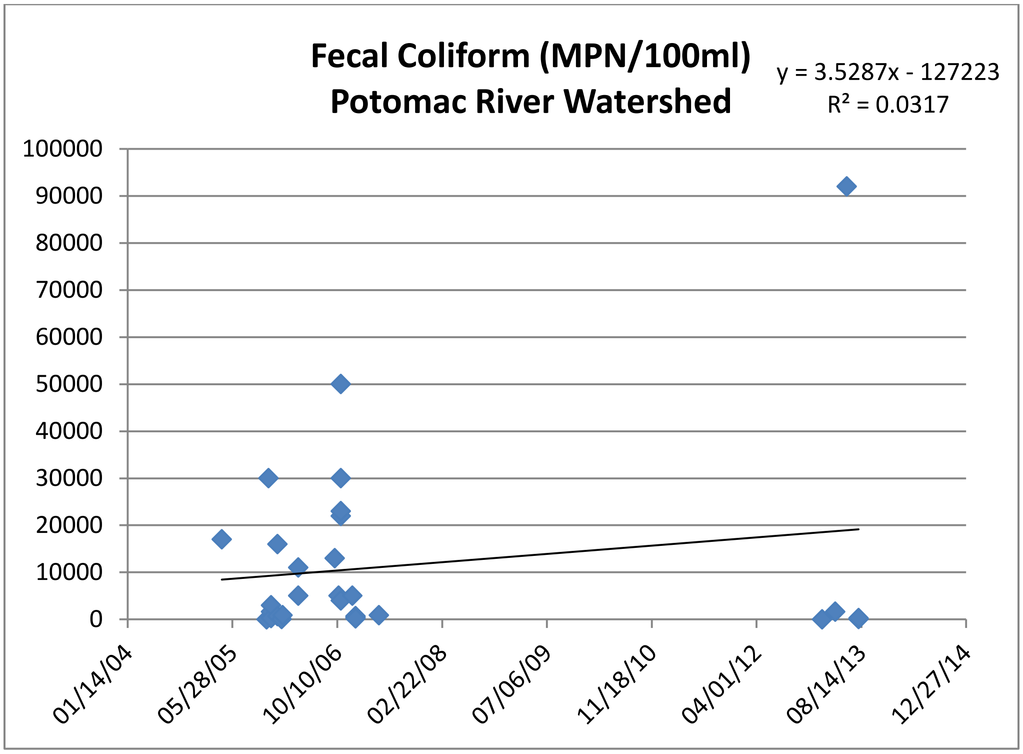

Figure 6: Fecal Coliform, Potomac River Watershed

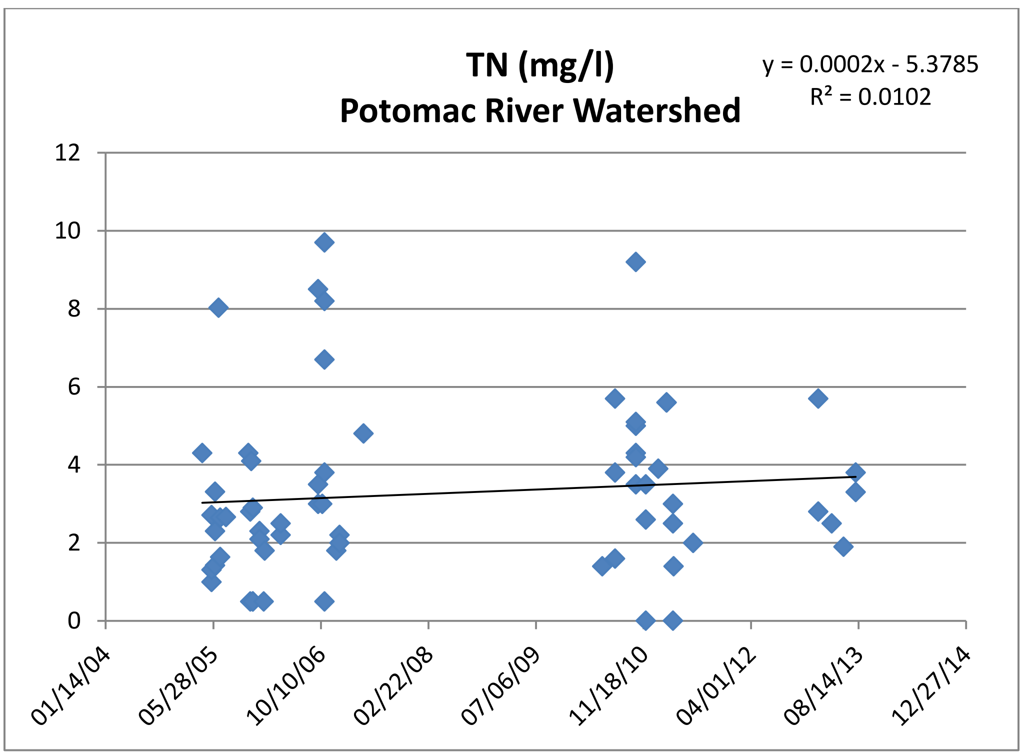

Figure 7: TN, Potomac River Watershed

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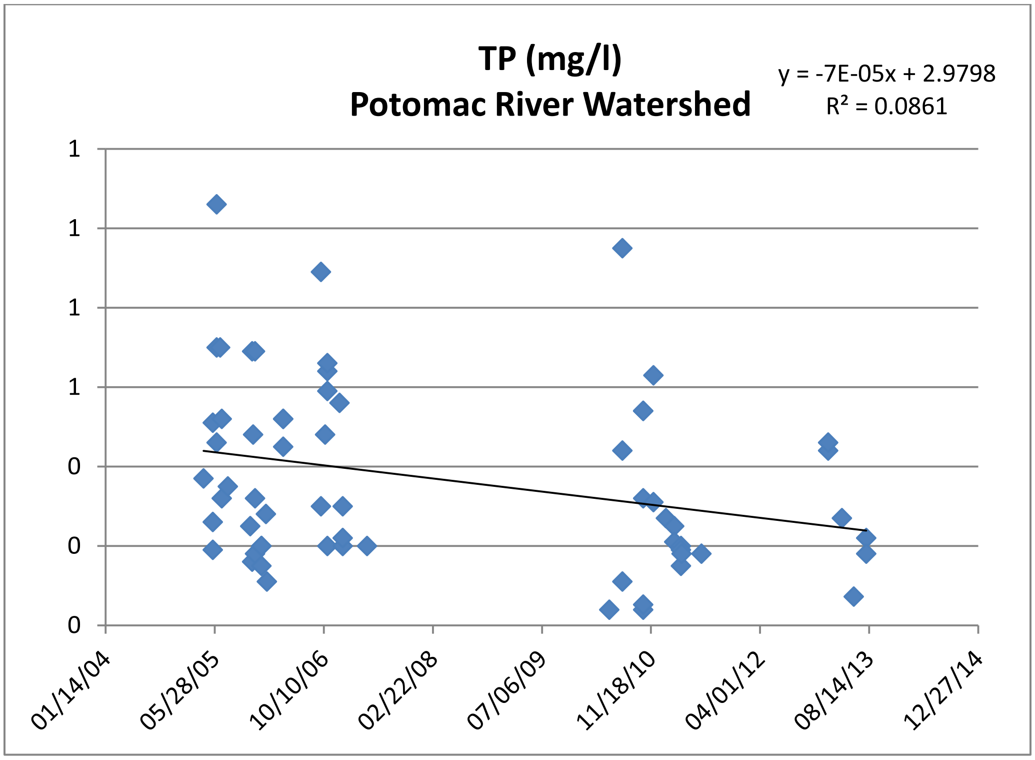

Figure 8: TP, Potomac River Watershed

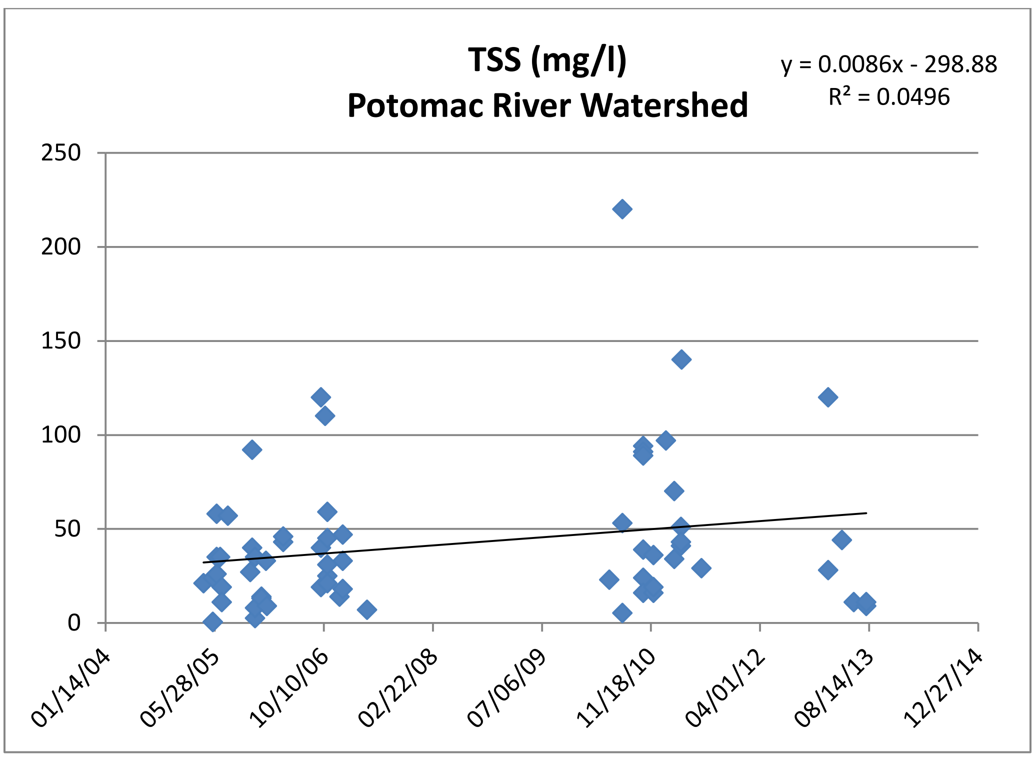

Figure 9: TSS, Potomac River Watershed

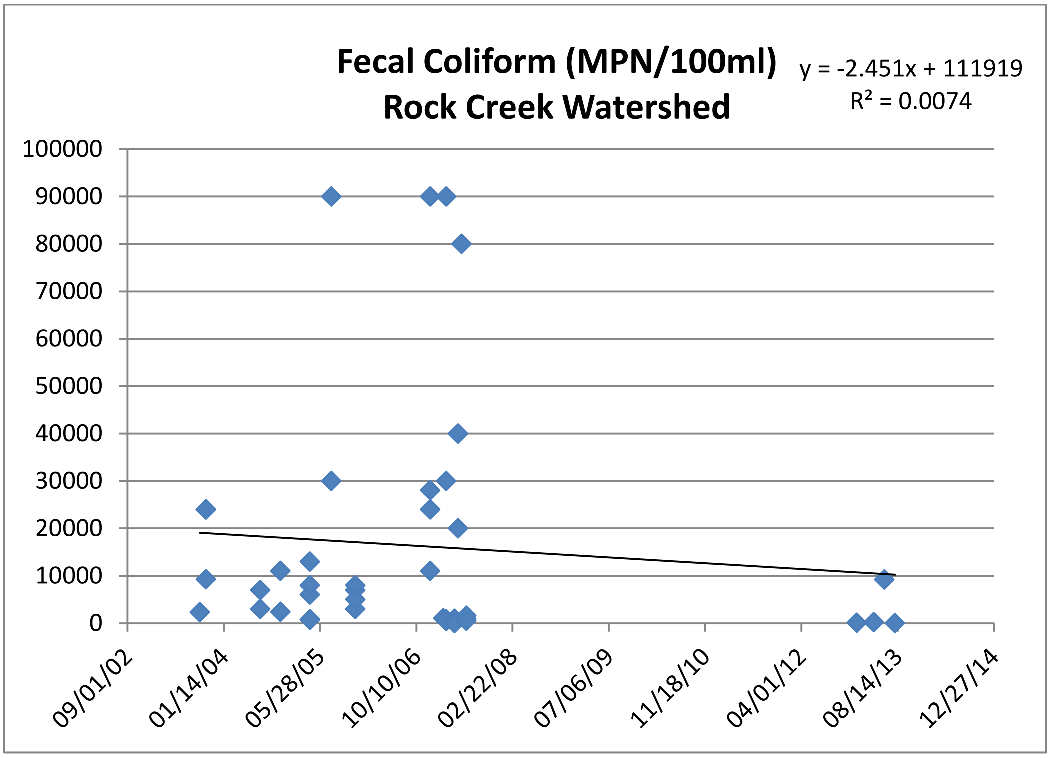

Figure 10: Fecal Coliform, Rock Creek Watershed

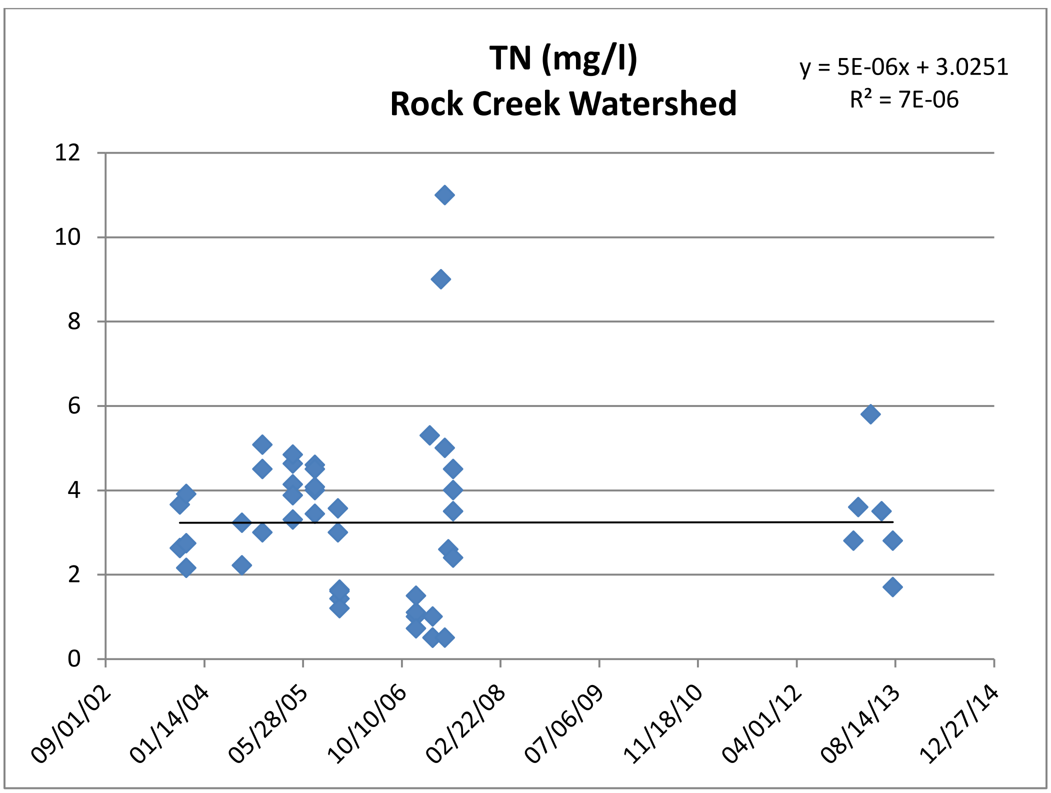

Figure 11: TN, Rock Creek Watershed

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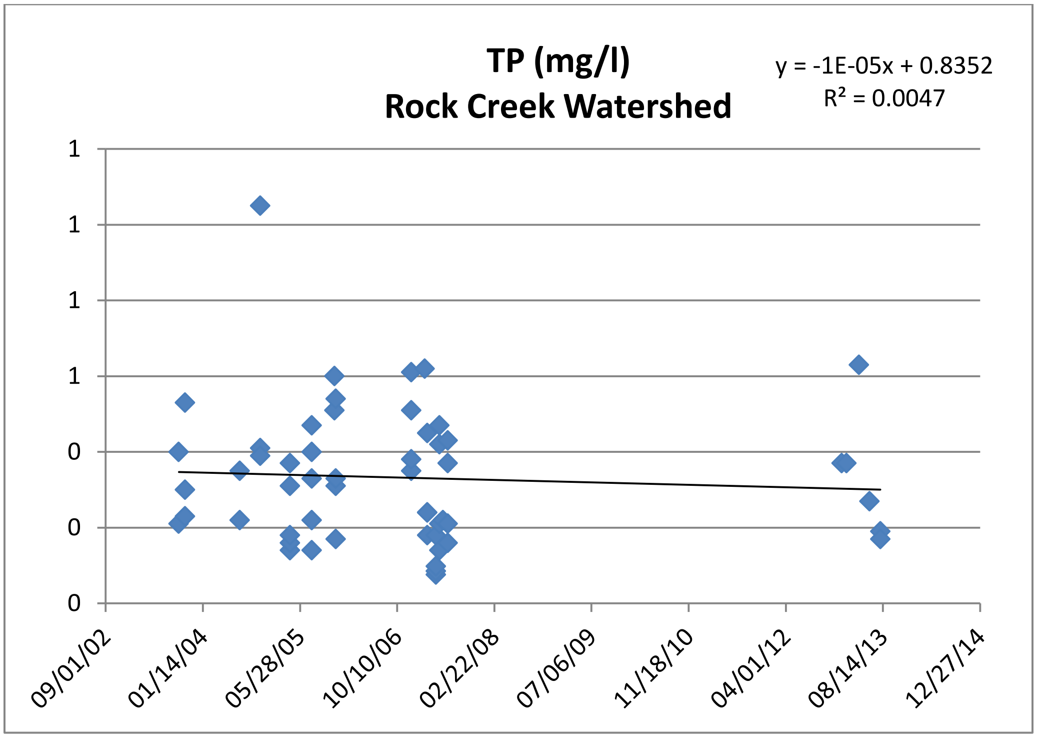

Figure 12: TP, Rock Creek Watershed

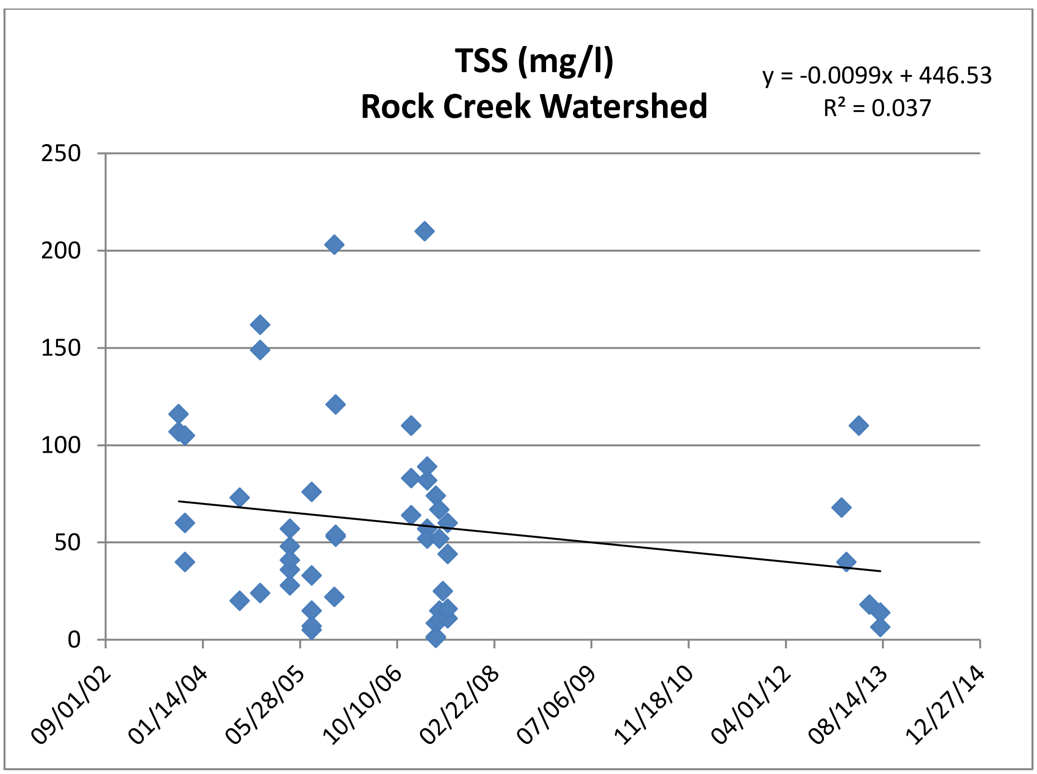

Figure 13: TSS, Rock Creek Watershed

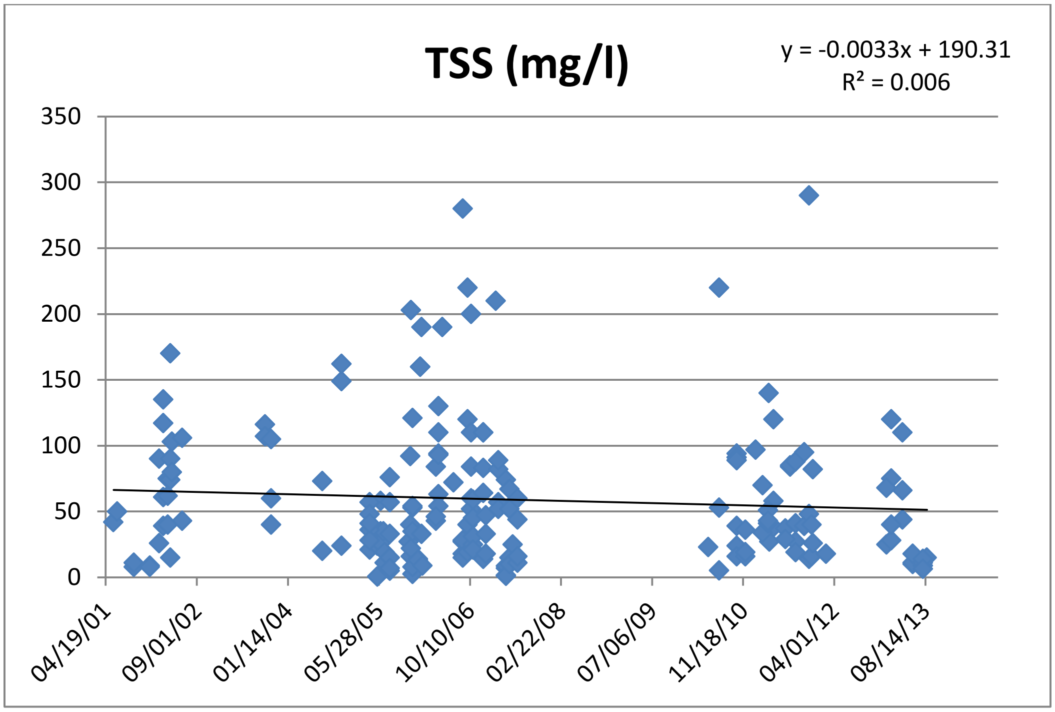

Figure 14: TSS, City-Wide

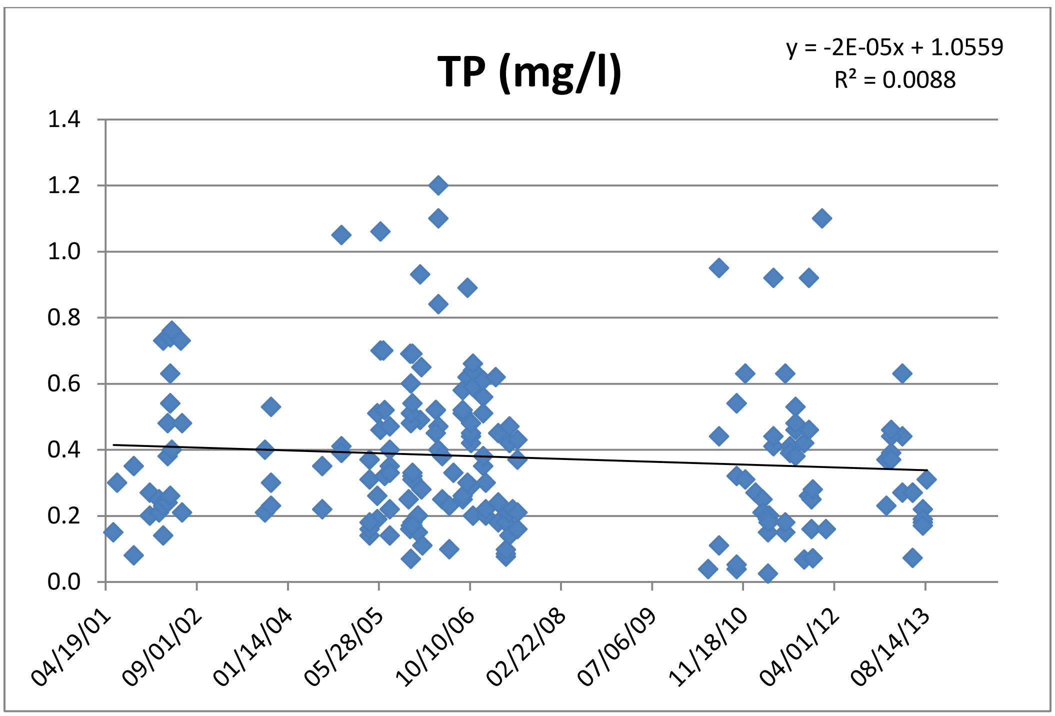

Figure 15: TP, City-Wide

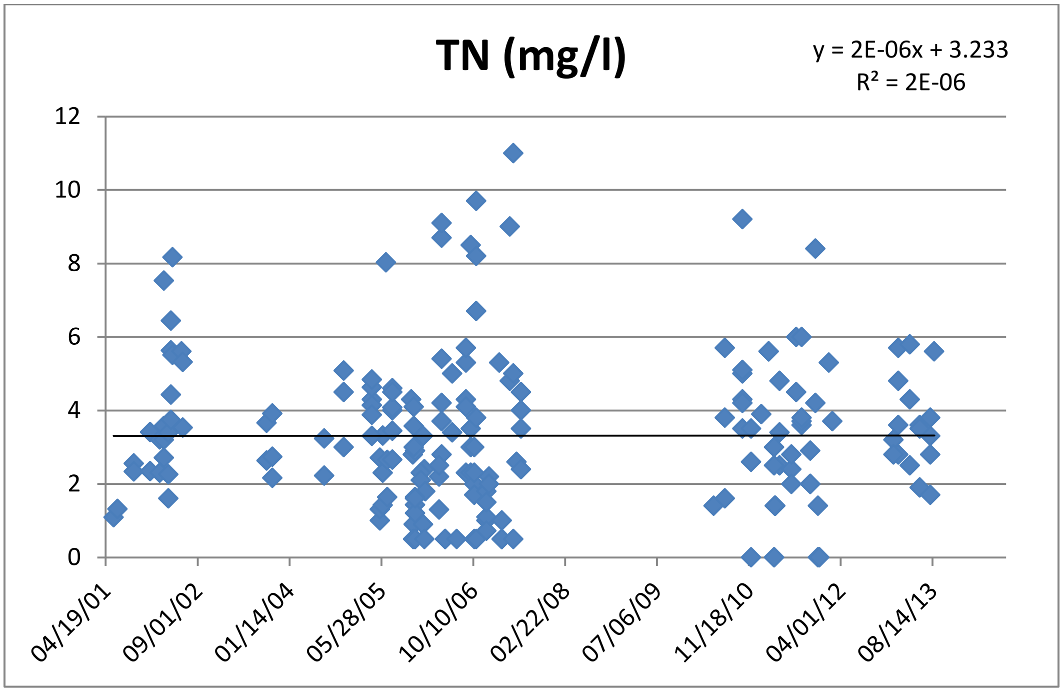

Figure 16: TN, City-Wide

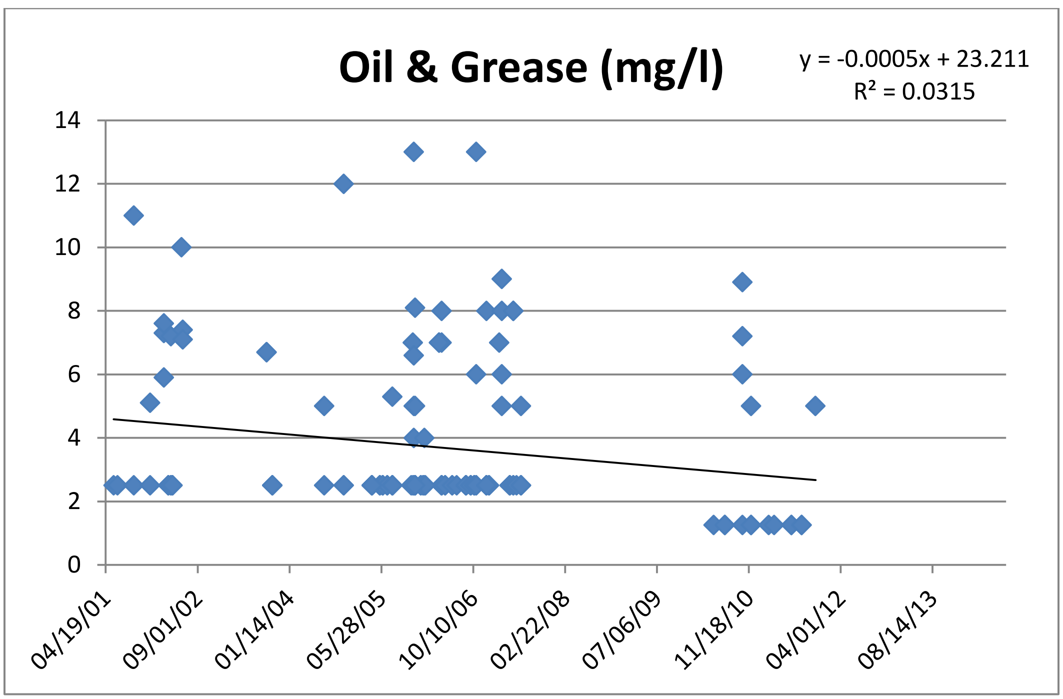

Figure 17: Oil & Grease, City-Wide

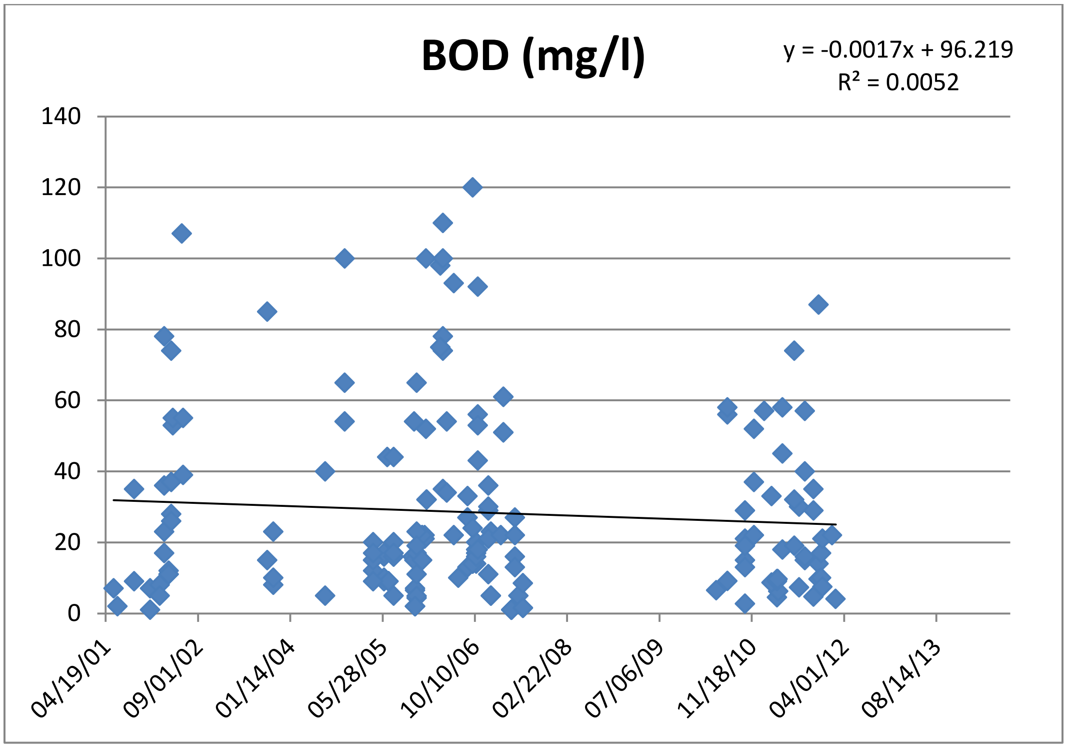

Figure 18: BOD, City-Wide

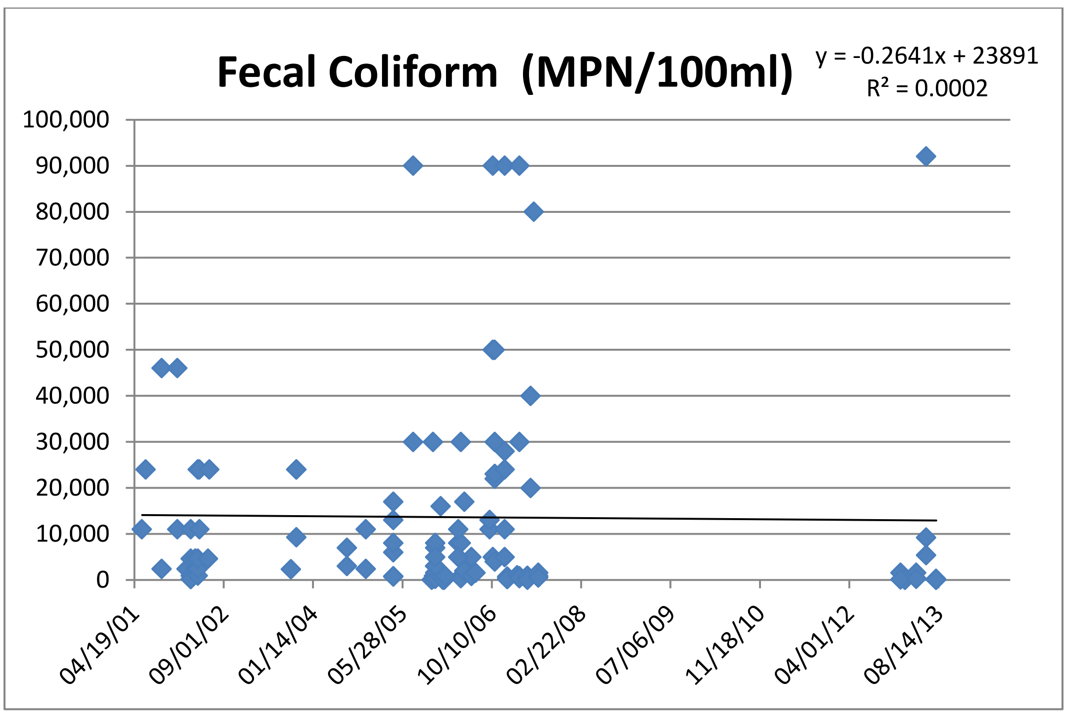

Figure 19: Fecal Coliform, City-Wide

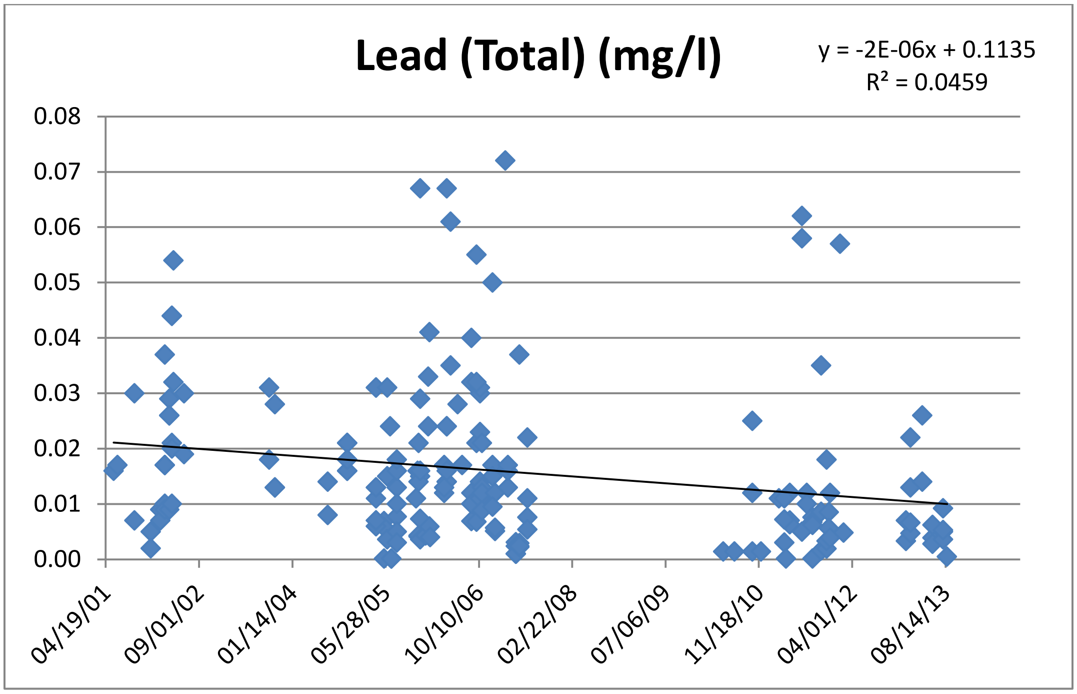

Figure 20: Lead, City-Wide

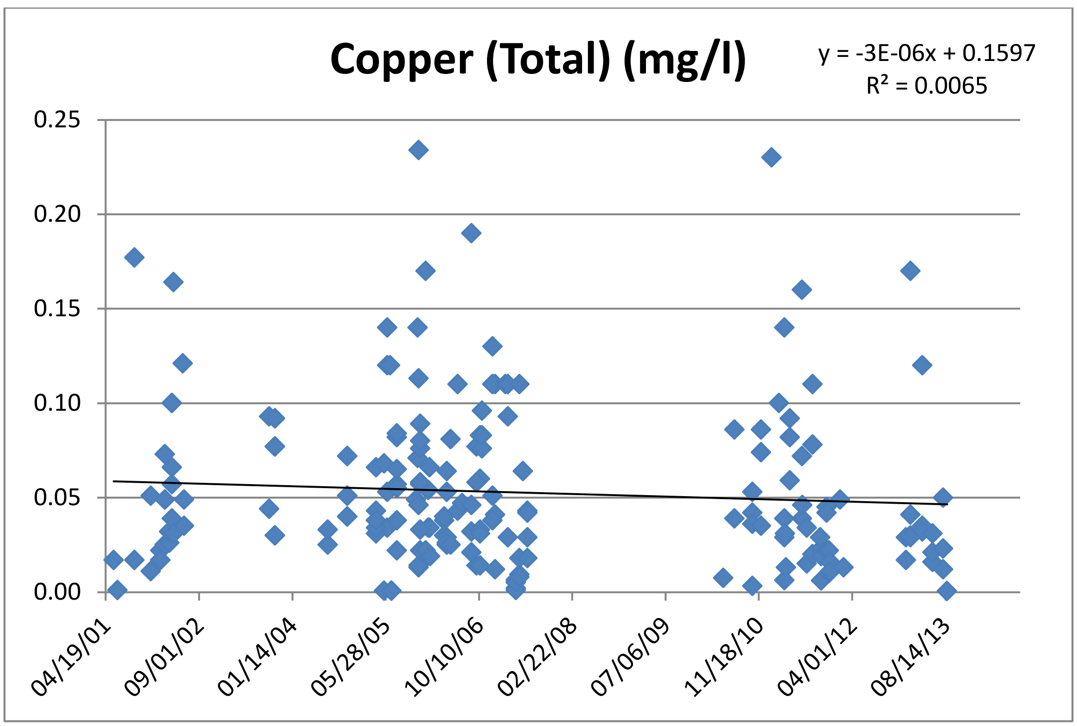

Figure 21: Copper, City-Wide

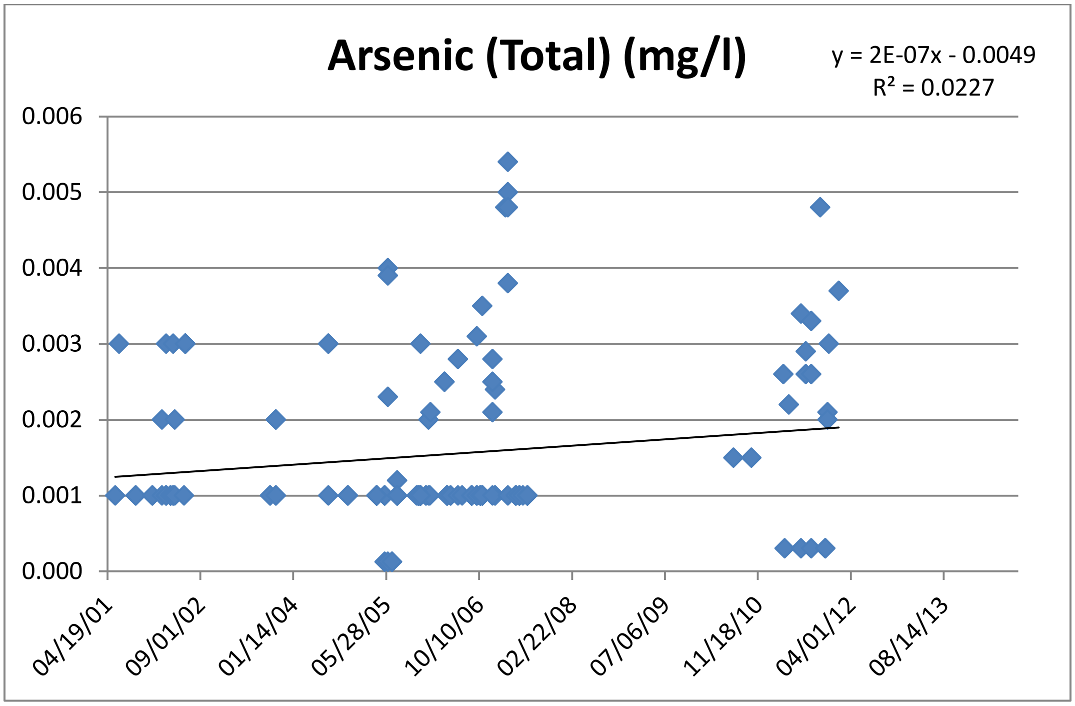

Figure 22: Arsenic, City-Wide

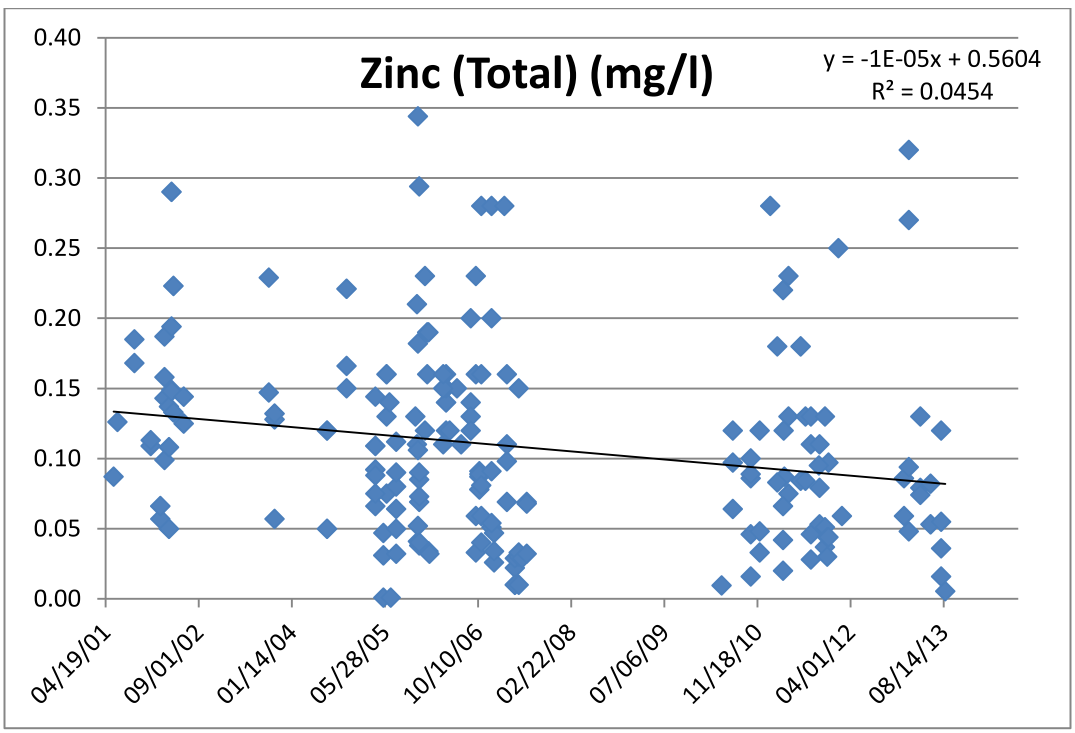

Figure 23: Zinc, City-Wide

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U.S. EPA. 2012. *Authorization to Discharge under the National Pollutant Discharge Elimination System Municipal Separate Storm Sewer System Permit.* NPDES Permit No. DC0000221. Modification #1.

Appendix F
Technical Memorandum

BMPs and BMP Implementation

Consolidated TMDL Implementation Plan – Comprehensive Baseline Analysis
May 08, 2015

Table of Contents

1 Introduction 1
2 Purpose 1
3 Technical Approach 2
4 Results and Discussion 65
References 67

DISTRICT DEPARTMENT OF THE ENVIRONMENT

List of Tables

Table 1: DDOE Approved BMPs 2
Table 2: Consolidated BMP Data Fields 5
Table 3: Geocode Notes and Counts 9
Table 4: BMPs in the MS4 Area 14
Table 5: Effect of Cutoff Value on TSS Loading 15
Table 6: Summary of BMP Dataset with the 10,000 sq ft Cutoff 16
Table 7: Mean Literature Values Derived from Literature and WIPs 18
Table 8: Partition Coefficient Summary 19
Table 9: Pollutant Removal Efficiencies by BMP Type, Anacostia River Watershed 22
Table 10: Pollutant Removal Efficiencies by BMP Type, Rock Creek Watershed 23
Table 11: Pollutant Removal Efficiencies by BMP Type, Potomac River Watershed 24
Table 12: Summary of Model Input Variables 27
Table 13: Runoff Reduction Efficiency Equations 31
Table 14: Non-structural BMPs Evaluated for Inclusion in TMDL IP Modeling Tool 34
Table 15: Edge-of-Stream 2011 Interim Approved Removal Rates per Linear Foot of Qualifying Stream Restoration (lb/ft/yr) 38
Table 16: Summary of Stream Restoration Credits for Individual Restoration Projects from "Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects" 39
Table 17: Percent Removal of Pollutants Though Street Sweeping for Qualifying Lane Miles 42
Table 18: Swept Mileage in Direct Drainage Areas 43
Table 19: Swept Mileage in MS4 Area 45
Table 20: Existing and Planned/Proposed Dog Parks and Drainage Locations 50
Table 21: Trash Removal Strategies for Anacostia Trash TMDL 60
Table 22: Additional Trash Removal Strategies 63

List of Figures

Figure 1: BMP Drainage Area Assignment Decision Tree 11
Figure 2: BMP Pilot Study Area Locations 12
Figure 3: Pie Chart of BMP Drainage Area by Type, Percentage of Total Drainage Area 14
Figure 4: Model BMP Representation 26
Figure 5: Infiltration Trench Annual Runoff Reduction Efficiency 29
Figure 6: Green Roof Annual Runoff Reduction Efficiency 29
Figure 7: Permeable Pavement Annual Runoff Reduction Efficiency 30
Figure 8: Bioretention Annual Runoff Reduction Efficiency 30
Figure 9: Cistern Annual Runoff Reduction Efficiency 31
Figure 10. Location of existing and proposed trash trap BMPs 64
Figure 11: BMP Load Reduction Method Selection 66

1 Introduction

The District Department of Environment (DDOE) is required to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) as established in the District's Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES) permit (U. S. EPA 2011 and U. S. EPA 2012). The IP will define and organize a multi-year process centered on reducing pollutant loads originating within the District MS4. The level of pollutant control will be based on past TMDL studies performed to protect impaired water bodies in the District. The IP will include a summary of the regulatory compliance strategy to satisfy TMDL-related permit requirements, a summary of data and methods used to develop the IP, specific prioritized recommendations for stormwater control measures, a schedule for implementation and attainment of Waste Load Allocations (WLAs), and a method for tracking progress. Substantial public involvement will be sought in plan development.

This Technical Memorandum on BMPs and BMP Implementation inventory development and load reduction effectiveness is one in a series of technical memoranda that provide detailed information on research, analysis, programs and procedures that support development of the Consolidated TMDL IP.

2 Purpose

This document discusses existing BMPs and future BMP implementation, and focuses on the development of the existing BMP inventory and the effectiveness of BMPs at reducing loads. BMPs are the structures, programs, and practices employed to reduce runoff and pollutant loads. Implementation of BMPs to a specific level is required to achieve the load reduction necessary to meet MS4 WLAs. BMP implementation to meet MS4 WLAs includes both existing BMPs and future BMPs. In order to determine the specific BMP implementation level that is required to meet MS4 WLAs, the "gap" between existing conditions (i.e., baseline conditions minus any load reduction achieved by existing BMPs) and the WLA must be quantified. This requires identifying the inventory of existing BMPs and the load reduction associated with each existing BMP. Once the "gap" between existing conditions and the WLA is determined, BMP implementation scenarios can be developed to achieve additional load reduction and meet the WLA. The implementation scenarios are dependent on the number and type of BMPs chosen and the load reduction associated with each proposed BMP. Thus it is critical to inventory the existing BMPs to understand how much has already been done, and also to determine how to assign load reductions to individual BMPs. The method for assigning load reductions to individual BMPs is necessary for both existing and future BMPs.

The purpose of this Technical Memorandum is to document the development of the existing BMP inventory and the development of load reduction methods for the various BMPs used (or planned for use) in the District. Specifically, the information in this memorandum addresses the following requirement for the Comprehensive Baseline Analysis Report:

- An analysis of BMPs that have been implemented since WLAs were first established.

In addition, the information on BMP inventories and the evaluation of load reduction effectiveness for different BMPs will allow two other requirements for the Baseline Report to be addressed. These are:

- An analysis of pollutant load reductions that have been achieved by those implemented BMPs.
- Adjusted pollutant loads reductions remaining that are necessary to achieve WLAs.

3 Technical Approach

Within the District, thousands of BMPs have been installed or implemented. In order to quantify the effect of these BMPs on pollutant load, the structural and non-structural BMPs have been inventoried and a methodology for calculating their load reductions has been developed.

3.1 Structural BMPs

3.1.a 2013 Stormwater Management Rule

In July 2013, DDOE released the Rule on Stormwater Management and Soil Erosion and Sediment Control (DDOE 2013a). This rule and associated Stormwater Management Guidebook (DDOE 2013b) represent a shift in the District's approach to stormwater. The new rules focus on the amount of water retained by a structural BMP. Retention is defined as keeping a volume of stormwater runoff on site through infiltration, evapotranspiration, storage for non-potable use, or some combination of these (DDOE 2013b). The Guidebook lays out 13 classes of BMPs that have been approved for use in the District. These categories and associated sub-types are included in Table 1.

Table 1: DDOE Approved BMPs

BMP Category	Code	BMP
Green Roof	G-1	extensive green roof
	G-2	intensive green roof
Rainwater Harvesting	R-1	rainwater harvesting
Impervious Surface Disconnect	D-1	simple disconnection to a pervious area
	D-2	simple disconnection to a conservation area
	D-3	simple disconnection to a soil compose amended filter path
Permeable Pavement Systems	P-1	porous asphalt
	P-2	pervious concrete
	P-3	permeable pavers
Bioretention	B-1	traditional bioretention
	B-2	streetscape bioretention
	B-3	expanded tree pits
	B-4	stormwater planters
	B-5	residential rain gardens
Filtering Systems	F-1	surface sand filter
	F-2	1-chamber underground sand filter
	F-3	3-chamber underground sand filter
	F-4	perimeter sand filter
Infiltration	I-1	infiltration trench
	I-2	infiltration basin
Open Channel Systems	O-1	grass channel
	O-2	dry swale

Table 1: DDOE Approved BMPs		
	O-3	wet swale
Ponds	PN-1	micro pool extended detention pond
	PN-2	wet pond
	PN-3	wet extended detention pond
Wetland	W-1	shallow wetland
	W-2	extended detention shallow wetland
Storage Practices	S-1	underground detention
	S-2	dry pond
Proprietary Practices	PP-1	proprietary practice
Tree Planting and Preservation	TP-1	tree preservation
	TP-2	tree planting

In order for a structural BMP to receive retention credits during the development of stormwater management plans, the BMP will have to be from the list in Table 1. Therefore, these structural BMP types are the focus of research and database development.

3.1.b Development of an Existing Structural BMP Database

BMP data in the District exists in multiple disparate data sources developed for different purposes by different agencies, including DDOE, DDOT, GSA, and DC Water. Data from these sources exists in multiple formats with different schema and variable degrees of completeness and accuracy. For modeling purposes, the complete universe of BMP data needed to be compiled into a single source using consistent formats and schema.

DDOE is undertaking a significant internal effort to update its primary BMP database. This effort will involve consolidating and homogenizing data and conducting intensive research to fill data gaps. The end result will be a primary BMP database that can be used by DDOE for a number of reporting, tracking, and analytical purposes. Unfortunately, the timing for completion of this primary database is beyond that required for the initial development of the consolidated TMDL implementation plan. Consequently, it was necessary to develop an interim consolidated BMP database that can be used in initial pollutant load modeling and implementation planning work. This interim database can be leveraged by DDOE as a starting point for its larger primary BMP database development efforts. Once the final primary BMP database is completed, it is expected that it would seamlessly replace the interim database.

The following sequence of steps was taken to merge the various BMP datasets and begin the data refinement process. A pilot QA analysis was also completed that involved detailed review of a subset of As-built plans and was meant to examine the reliability of the data and the fitness of assumptions used in the database consolidation.

Step 1 – Compiling Existing Data

The first step in the process was to compile all of the existing BMP records in the District into a single dataset. As noted above, several sources of BMPs from different agencies were utilized in this process. A unique ID was assigned in the compiled dataset to keep a relationship between the original BMP record and its source. The following is a list and brief description of the data sources:

- **RiverSmart Homes spreadsheets (RSH)**: This DDOE dataset exists as a series of spreadsheets and includes BMPs from the RiverSmart Homes program. The dataset includes 3,183 records from 2009-2013.
- **RiverSmart Communities spreadsheet (RSC)**: This DDOE dataset exists as a single spreadsheet and includes BMPs from the RiverSmart Communities program. The dataset includes 21 records from 2012-2013.
- **DDOE BMP Tracking Database – General table (TDGN)**: This dataset exists as a table contained within DDOE's BMP tracking database. Records in this dataset include all BMPs that were submitted to DDOE for plan review prior to 2007. This dataset includes 1,589 records from 2000-2007.
- **DDOE BMP Tracking Database – Construction Details table (TDCD)**: This dataset also exists as a table contained within DDOE's BMP tracking database. This dataset represents BMPs from plans that were reviewed and approved by DDOE and includes 2,809 records from 2000-2013.
- **DDOE BMP Tracking Database – Stormwater Facility table (TDSW)**: This dataset also exists as a table contained within DDOE's BMP tracking database. This dataset represents BMPs that were field verified to be constructed and includes 666 records from an unknown period of time.
- **Green Roofs spreadsheet (GR)**: This DDOE dataset exists as a single spreadsheet and includes 235 green roof records through 2014.
- **GSA BMP spreadsheet (GSA)**: This dataset includes all BMPs on Federal property operated by the GSA. It includes 62 BMP records that were last updated in 2013.
- **Federal partners spreadsheet (FED)**: This dataset includes all BMPs on federal property operated by the District of Columbia Army National Guard, U.S. Army Installation Management Command, National Park Service, and National Zoological Park. It includes 78 BMP records from an unknown period of time.
- **DC Water Clean Rivers Project (DCCR):** That dataset includes all BMPs from DC Water's Clean Rivers Project. This includes 23 records from an unknown period of time.

Notes on the DDOE BMP Tracking Database

The DDOE BMP Tracking Database was originally developed to track stormwater management plan review. As such, each record represents an individual site plan, which in turn could contain multiple BMPs. Fields for up to three BMPs were included in each record. To fit within the consolidated BMP database, each plan record was split into the appropriate number of BMP records. For example, if the original plan record contained three BMPs, this record was split into three BMP records in the compiled database.

The three tables of the DDOE BMP Tracking Database were meant to track plan review through various stages of the review process (*i.e.*, plan submittal, plan approval, construction inspection and approval). Review of the database revealed that records were not always consistently included in the appropriate tables for their status in the review process. For example, BMPs known to be constructed may have been included in the TDGN table but may not have been included in the TDCD or TDSW table. Similarly, BMPs included in the TDSW table may not have been included in the TDGN table. There were also no consistently populated relational database keys that could be used to track BMP records from one table to another. To prevent potential omission of a large subset of BMPs, all BMPs from the three data tables were retained in the compiled database. This decision introduced some duplication of BMP records that would need to be resolved in later steps in the refinement process.

- **District Department of Transportation (DDOT):** This dataset includes all BMPs operated by DDOT. This includes 42 records from 2005 -2014.

Each dataset source utilizes a unique set of data fields. Some of these fields were common to all datasets, but many were not. The fields from each dataset that were determined to be important for pollutant load reduction modeling and implementation planning were retained for the interim consolidated database. Table 2 presents a list of fields that were retained in the database.

Table 2: Consolidated BMP Data Fields

Field	Description
ID	An ID value existed for all DDOE tables. Datasets without an ID field (*e.g.,* RSH, RSC, GR, *etc.*) were assigned a sequential numeric value.
BMP_ID	This is a created field that combines the abbreviation of the dataset name (*e.g.,* RSH, TDGN, *etc.*) with *ID* (*e.g.,* 270) to generate a unique ID (*e.g.,* RSH_270) for an individual BMP. As noted previously, some DDOE datasets had 1, 2, or 3 BMPs associated with an individual record. To differentiate these BMPs, an additional number (_1, _2, & _3) was added to the BMP_ID (*e.g.,* TDGN_270_1, TDGN _270_2, TDGN _270_3).
BMP_Type	Type of BMP
BMP_Area	Footprint or area of BMP (in square feet)
DrainArea	Drainage area of BMP (in square feet)
Retention_Volume	Retention volume of BMP (in gallons)
NumberPractices	Number of practices
BuiltDate	Date BMP constructed
SewType	Reported sewershed type
Description	Miscellaneous notes on construction or project
Facility_Name	Name of facility where BMP is constructed
Address_Full	Address on record
LotNo	Lot number
SquareNo	Square number
Lat	Latitude (in decimal degrees)
Lon	Longitude (in decimal degrees)
PlanNo	DDOE Plan number
FileNumber	DDOE File number
Bldg_Permit	Building permit number
WPDNo	DDOE WPD number

Table 2 represents the data deemed necessary for pollutant load reduction modeling and implementation planning. These are the primary data fields in the consolidated database. Additional interim fields were also added to facilitate tracking of changes made to the database. These interim fields are noted in *italics* within the remainder of the document along with an explanation of their purpose and use. Following consolidation of all datasets, approximately 8,544 BMP records were initially contained within the interim BMP database.

Step 2 – Refining BMP Records

Compiling data from these disparate sources introduces a number of potential issues, including data inconsistencies among sources and duplication of records. Furthermore, data from individual datasets have the potential to be unreliable or incomplete. These issues and the assumptions considered to resolve these issues are further discussed below.

Data Consistency

As previously noted, data from these sources often exist in multiple formats and use different schema (*e.g.*, text versus numeric fields, inconsistent measurement units). In addition, inconsistencies in terminology (*e.g.*, different spelling or misspelling of BMP types) often exist between and within certain sources. Format and terminology was homogenized by selecting a single format or term and converting all data appropriately. The fields where data were modified or refined and any new interim fields that were created are explained below.

- **BMP_Type** – After initial consolidation there were over 300 different BMP types. Many BMPs were identical but often spelled or formatted differently. A new field was created called *BMPType_Cln* that contained corrected misspellings and consistently labeled practice types. Any notes that indicated multiple BMPs or other information (*e.g.*, 2-DCWQSF or 6-bioretention) was retained in the *Note* field.
- **DrainArea** – Drainage area records were reported in various measurement units. All drainage area records were converted to square feet. Additionally, green roof records in the GR table did not contain a drainage area, but contained a "practice area." The practice area was assumed to be equivalent to the DrainArea.
- **BuiltDate –** The BMP built date was not always populated however other dates were available which could inform approximate built dates. Other fields such as date approved, as built received date, completed/appointment/install date, and status date from TDGN, TDCD, RSH, and RSC, respectively, were used to populate the *BuiltDate* field.
- **SewType** – Multiple terms were used to designate the type of sewer system to which the BMP flows (*e.g.*, MS4, separated, CSO, etc.). The BMPs were intersected with the sewershed delineation after determining their spatial locations. BMPs were labeled as "MS4", "CSS", or "Unknown."
- **Address_Full –** Addresses were reported in multiple formats. Some minor corrections were made to prepare the data for the spatial location process.
- **Lat and Lon** – Latitude and longitude values were presented in several formats. All latitudes and longitudes were converted to decimal degree.

Crosswalk between BMP Type and DC stormwater regulations

The BMP designations in the BMP Type field were a result of years of tracking. Over time, the names for BMPs types and classes have changed. Additionally, no standard terminology existed in the tracking databases. Therefore, it was necessary to develop a cross walk between the BMP Type field and the BMP classes approved in Table 1. BMP Types not found in DC's guide were labeled as unknown and considered to not be a BMP.

Duplication of Records

Given that the initial data sources were developed for different purposes and by different agencies, there is significant potential for inclusion of a particular BMP in more than one record. As previously noted, this is especially true for the records that originated from the three DDOE BMP Tracking Database tables.

Upon review, a large number of the BMPs in the TDGN table were deemed to be duplicates of BMPs in the TDCD table. Duplicates were identified and flagged (using the *Duplicate* field) if they shared a common address, BMP type, drainage area, and WPD plan number. Duplicate records were also possible, but were less prevalent, between other source datasets (*e.g.*, some green roofs from the GR table were also contained in tables from the DDOE Tracking Database). Since WPD plan number is not a field in datasets outside of the DDOE BMP Tracking Database, it could not be used in determination of duplicate records from these datasets. As such, records outside of the DDOE BMP Tracking Database were deemed to be duplicates and flagged if they came from different sources and shared a common address, BMP type, and drainage area.

Among all the datasets, a total of 1,622 duplicates were identified and removed. This reduced the number of BMP records within the consolidated database to 7,088 records.

Data Completeness and Reliability

Missing data is the most common issue in the consolidated database. The most important fields were determined to be BMP types, locational identifiers (e.g., latitude/longitude or address), and drainage areas. No BMP records were missing BMP types. A total of 6,664 BMP records were missing specific spatial locations (i.e., latitude/longitude) and 3,842 records were missing drainage areas. While other data fields are important, a concerted effort to populate data missing from these fields was not undertaken for development of the interim BMP database at this time.

Missing data was resolved using a variety of approaches and assumptions depending on the data type. The approaches and assumptions for populating spatial information are presented below in *Step 3 – Geocoding BMPs*. Approaches and assumptions for populating drainage area data are presented in *Step 4 – Populating Drainage Area Fields.*

Reliability or accuracy of reported data is difficult to determine. For the most part, reported data was determined to be accurate by default for lack of a dependable means for checking data. The pilot QA analysis, discussed later, revealed that reported drainage areas were most often inaccurate. BMP types and spatial locations were often accurately reported.

As a result of this finding, GIS analysis of parcel areas was undertaken to test verification of drainage areas. The idea behind this analysis was to compare the reported drainage area with either the parcel area or the impervious area within the parcel. This comparison would inform whether a drainage area was potentially over-reported, but it would not work for under-reported drainage areas. For example, if a reported drainage area was significantly larger than the parcel area associated with the BMP, then this would raise a flag about the accuracy of the drainage area. Similarly, if the drainage area of a BMP type easily associated with a particular impervious area (e.g., a green roof) was reported to be larger than the impervious area type associated with a parcel, then this too would raise a flag about drainage area accuracy. While this approach appears sound in theory, it was revealed in testing that this approach was complicated by idiosyncrasies with parcel boundaries in the District (i.e., presence of multiple adjacent parcels that represent a single development or BMP drainage areas that extend beyond parcel boundaries into public space). Because this approach yielded so many “false positives” it was not considered a reliable indicator of drainage area accuracy. Additional discussion of drainage area accuracy is provided in *Step 4 – Populating Drainage Area Fields.*

Another issue related to data reliability revolves around the question of whether BMPs have actually been built. From the DDOE BMP Tracking Database, only BMPs from the TDSW table have been confirmed to be built. BMPs from the TDGN and TDCD tables include BMPs that have been submitted for plan review and that have approved plans, respectively, but have not necessarily been constructed.

By including all BMPs from these tables, we've assumed that all BMPs from the DDOE BMP Tracking Database have been built. As noted previously, all BMPs were included because of inconsistencies in populating the three primary data tables in the DDOE BMP Tracking Database. The pilot review discussed at the end of this document demonstrates that this assumption may be sound, as only 11 percent of the BMPs researched were potentially unbuilt. Of these unbuilt BMPs, more than half were from plans that were less than two years old. This suggests that most unbuilt BMPs are likely still in the queue to be constructed and should be included in the database. Furthermore, there are large numbers of BMPs encompassing large drainage areas in the TDGN and TDCD tables, so by excluding them, there is a potential to significantly undercount the number of BMPs in the District.

Step 3 – Geocoding BMPs

Several methods were used to determine missing spatial locations of BMPs including the District's Master Address Repository (MAR) geocoder, a list of previously researched locations from Steve Saari at DDOE (Saari list), and a manual geocoding process. The following sequence of steps was followed to assign a spatial location for each BMP record.

1. BMP records with a latitude and longitude (TDSW, GR tables) were used without further processing. These BMPs were labeled as *"0-Record has lat/long"* in the *GeocdNote* field.
2. The MAR geocoder was performed on BMP records with addresses at a 91.5% accuracy level, which is the recommended level. If the MAR process provided a spatial match and the Saari list also provided a location for the same address, the Saari list location took precedence. These BMPs were labeled as *"1-MAR>=91.5%, MAR address not equal to Saari, use Saari."*
3. If the MAR process address is equal to the address reported from the Saari list, then the location from the MAR process was used. These BMPs were labeled as "*2-MAR>=91.5%, MAR address equal Saari, use MAR*."
4. If the MAR process provided an address that was not in the Saari list, then the location from the MAR process was used. These BMPs were labeled as *"3-MAR>=91.5%, address not in Saari, MAR used."*
5. If the MAR process accuracy level for an address was less than 91.5% and the location was provided in the Saari list, then the Saari list spatial location was used. These BMPs were labeled as *"4-MAR<91.5, use Saari."*
6. If the MAR process accuracy level for a record was less than 91.5% and the location was provided in the Saari list in state plane coordinates, then the Saari list spatial location was used. These BMPs were labeled as *"5-MAR<91.5, use Saari State Plane."*
7. If the MAR process accuracy level for a record was less than 91.5% and the location was provided in the Saari list in decimal degree coordinates, then the Saari list spatial location was used. These BMPs were labeled as *"'6-MAR<91.5, use Saari Lat/Long."*
8. If a BMP was manually located using a non-geocodable address, facility name, or other relevant information, then spatial location from Google Maps was used. These BMPs were labeled as "*7-Manual geocode, Google Maps*."
9. If MAR's interactive process was used to determine spatial locations, then the BMPs were labeled as *"8-MAR<91.5, MAR interactive process used for location."*
10. If BMP was manually located and found to be within the CSO, these were labeled as *"9-Structure within CSO."*

11. If after reviewing DDOE plans and determining that the proposed structure was not built from Google Maps, these were labeled as *"10-Structure not built per Google Maps."*
12. If BMP was not able to be located manually they were labeled as *"11-Can't locate."*
13. If BMP was not manually located because it is a duplicate record it was labeled *"12-Duplicate, not located."*

Table 3 provides a summary count for each step articulated above.

Table 3: Geocode Notes and Counts

Geocode Note	Count
0-Record has lat/long	470
1-MAR>=91.5%, MAR address not equal to Saari, use Saari	33
2-MAR>=91.5%, MAR address equal Saari, use MAR	740
3-MAR>=91.5%, address not in Saari, MAR used	5548
4-MAR<91.5, use Saari	246
5-MAR<91.5, use Saari State Plane	209
6-MAR<91.5, use Saari Lat/Long	11
7-Manual geocode, Google Maps	229
8-MAR<91.5, MAR interactive process used for location	169
9-Structure within CSO	190
10-Structure not built per Google Maps	17
11-Can't locate	381
12-Duplicate, not located	467

Once BMPs were spatially located, the universe of BMPs known to be within the MS4 area could be identified. In total, 3,191 of the 7,088 BMPs in the District are within the MS4 area and were retained in the interim database.

Step 4 – Populating Drainage Area Fields

For many BMPs in the database, the drainage area was not reported. For records with null or zero values, several approaches were used to populate a drainage area. The full decision process for the assignment of drainage areas is seen in Figure 1. The assumptions used in this process are presented below. Per DDOE instruction, drainage areas for all BMPs in the RSH program were assumed to be a default value. The default drainage areas are as follows:

- rain barrels = 0.005 acres/rain barrel
- permeable pavement = 0.005 acres/practice
- bioretention = 0.01 acres/practice

For all other BMPs, three scenarios were followed to populate the drainage area. This process is shown in Figure 1 and also described below:

1.) Single BMP on a property with a drainage area. For this scenario the drainage area is known and no additional steps were necessary.

   a. Records from GR, DDOT, GSA, FED, DCCR or RSH were considered valid and in need of no further review. It was labeled as “DA VALID” in the *DA_VALID* field.
   b. Records from TDGN, TDCD, TDSW, or RSC are reviewed.

2.) Multiple BMPs on a property with the same drainage area. For this scenario, the drainage area is divided amongst the BMPs. Per DDOE instructions, the drainage area for these BMPs was divided as follows: the first BMP “_1” was assigned 2/3 of the BMP drainage area and the remaining 1/3 area was divided evenly amongst the other BMPs (_2, _3, etc.). This “2/3 Rule” was only applicable to records from the TDGN and TDCD tables.

   For all other BMPs where a single drainage area was reported for multiple BMPs at a property, the drainage area was divided evenly among the BMPs. Values as a result of this step are reported in the *DA_Divide* field.

   a. Records from GR, DDOT, GSA, FED, DCCR or RSH were considered valid and in need of no further review. It was labeled as “DA VALID” in the *DA_VALID* field.

3.) BMPs with no drainage area recorded. For this scenario there are two conditions:

   a. BMP is spatially located. The BMP point is intersected with DC OCTO’s Owner Polygon layer which details the area of the parcel. The parcel area is assumed to be equal to the drainage area. The “2/3 rule” and drainage area divide was then applied to this value.
   b. BMP is not spatially located. The BMP is discarded and not used.

After this process, all records had an assigned drainage area. A series of checks were performed to ensure the drainage areas were reasonable when compared to their respective parcel and impervious areas.

For rainwater harvesting, green roofs, and impervious surface disconnect BMPs, the drainage area was compared to the building areas within the parcels in which they were located. Since these practices treat the footprint of the building area, the drainage areas should not be greater than the building area. If a drainage area was found to be greater than the building area, then the drainage area of the BMP was changed to be equal to the building area. However, for green roofs a different convention was applied. The average percentage of building area occupied by green roofs in the GR table was found to be 28%. Therefore, if a green roof drainage area was greater than the building area, a new assigned drainage area equal to 28% of the building area was used.

For permeable pavement BMPs, the drainage area was compared to the impervious area within the parcel, not including the building footprint. If the reported drainage area is greater than the non-building impervious area, then the drainage area was changed to be equal to the non-building impervious area.

For all other BMP types, the drainage area was compared to the parcel area where the BMP is located. If the drainage area was determined to be greater than the parcel area, then the drainage area was changed to be equal to the parcel area.

The final drainage areas resulting from the checks described above are shown in the “DA_Final” column of the database.

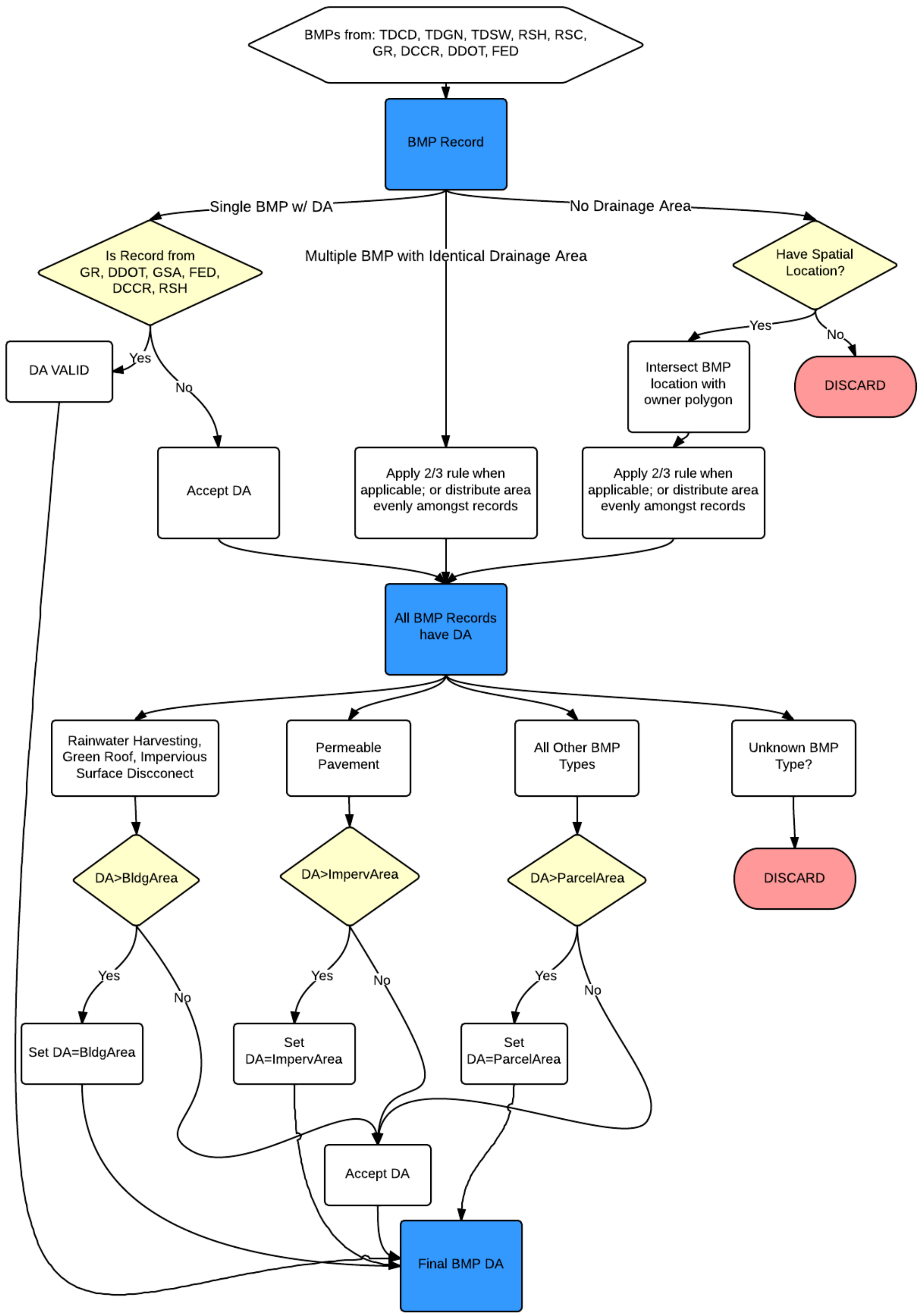

Figure 1: BMP Drainage Area Assignment Decision Tree

3.1.c Database Review and Drainage Area Analysis

Pilot QA Analysis

As discussed throughout this technical memorandum, a pilot QA analysis was conducted to examine the reliability of the BMP data and the suitability of assumptions used in the database consolidation. The QA analysis involved a detailed review of As-built plans from two pilot areas. The As-built plans for each BMP within each pilot area were reviewed to confirm three primary data elements reported in the consolidated BMP database: BMP type, spatial location, and drainage area. The As-built plans were also reviewed along with aerial imagery (from DC OCTO and Google Maps) to determine if the BMPs were actually built.

The two pilot areas were chosen randomly from a larger set of areas with densely clustered BMPs. The two pilot areas are the commercial Tenleytown corridor and the residential Palisades neighborhood. See Figure 2 for an overview map of the pilot areas.

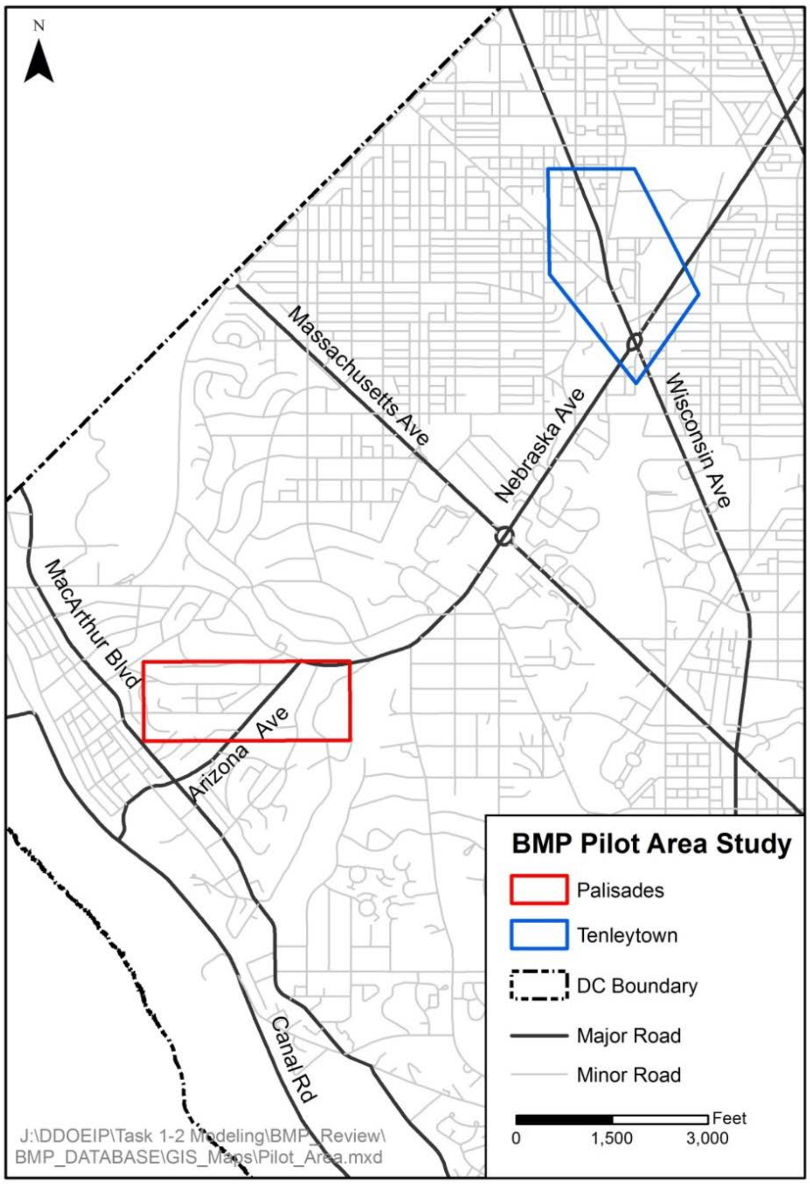

Figure 2: BMP Pilot Study Area Locations

The results of the pilot QA analysis revealed the following:

- There was no consistent correlation between the drainage area reported in the database and the drainage area reported on the plans. The database drainage area and plan drainage area did not match for over 95 percent of the BMPs..
- For all BMPs, the BMP type reported in the database matched the BMP type reported on the plans.
- For all BMPs, the spatial location reported in the database matched the spatial location reported on the plans.
- Most BMPs appeared to be built, based on review of As-built drawings and aerial imagery. For 11% of BMP records, the BMP did not appear to be built.

Drainage Area Analysis

As confirmed by the QA pilot analysis, the decision processes outlined above resulted in a reasonable assessment of BMPs in the District. The processing steps resulted in a single database representing 5,726 structural BMPs. Within the MS4 area, a total of 3,191 BMPs were identified. Based upon processing described so far, these BMPs suggest a cumulative drainage area equal to 16% of the District land area and 23% of the MS4 area. Following discussion within DDOE and best professional judgment, it is believed that this level of treatment does not currently exist within the District.

One source of drainage area error may be the use of parcel area as a surrogate for drainage area. This process, documented in the sections above, can allow for the over representation of drainage areas. For example, two BMPs in the National Arboretum were assigned a drainage area equivalent to the entire area of the Arboretum grounds as it is recorded under one very large parcel. Clearly, this is an over representation of the actual drainage area. Figure 3 represents the breakdown of drainage areas by BMP as a percentage of total BMP drainage area in the MS4. Table 4 compares the drainage area controlled by specific BMP types to the number of BMPs of that type. Based on this information, it is possible to see that a small number of BMPs make up a significant portion of the drainage area. For example, filtering systems control 28% of the drainage area, but they make up only 8% of the total number of BMPs. Likewise, proprietary practices control 36% of the drainage area but make up only 19% of the BMPs. This implies that individual filtering systems and proprietary practices control large drainage areas, which is unlikely given the typical design of these BMP types.

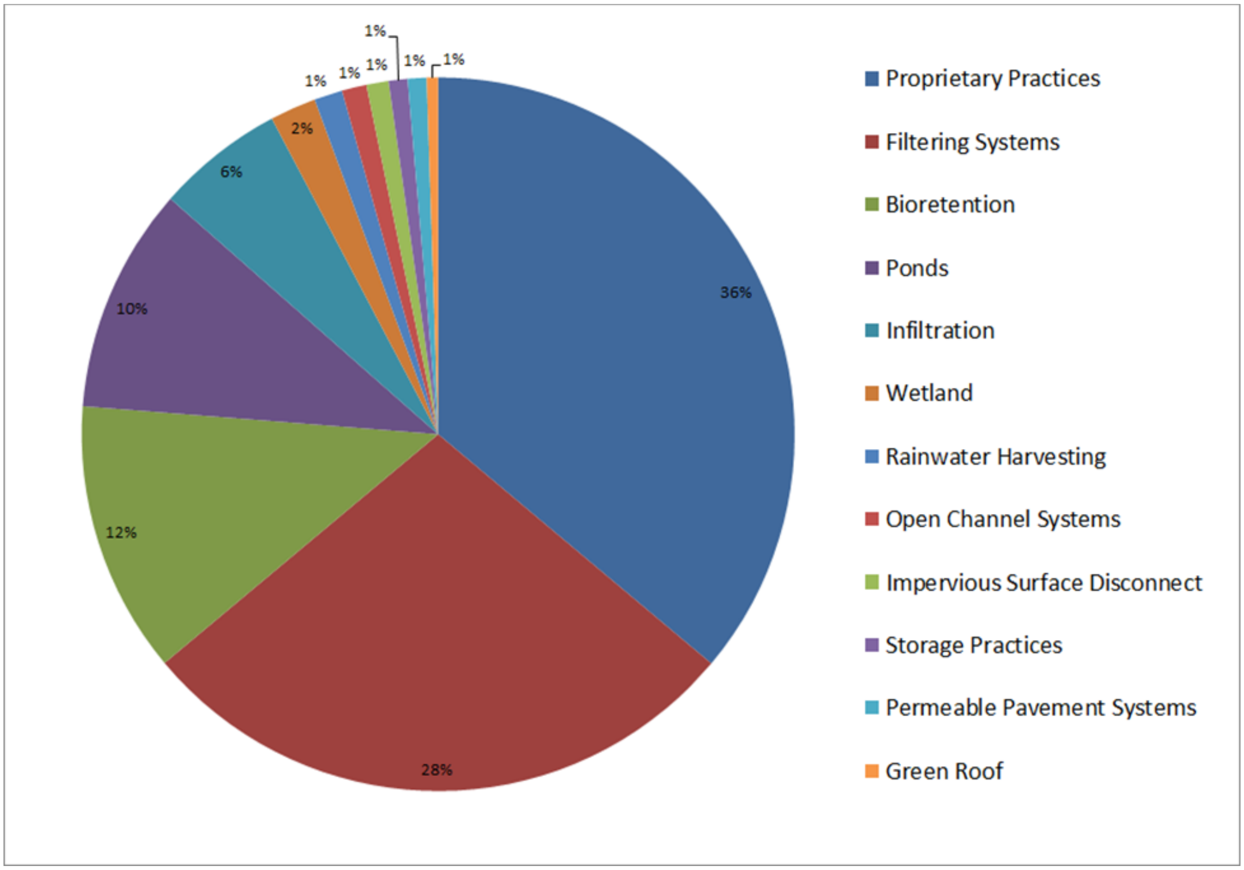

Figure 3: Pie Chart of BMP Drainage Area by Type, Percentage of Total Drainage Area

Table 4: BMPs in the MS4 Area				
BMP Category	**DA (sq ft)**	**% Total DA**	**Count**	**% of Total Count**
Bioretention	32,764,688	12%	479	15%
Filtering Systems	73,940,221	28%	266	8%
Green Roof	1,373,870	1%	79	2%
Impervious Surface Disconnect	2,673,714	1%	13	0%
Infiltration	15,419,824	6%	321	10%
Open Channel Systems	2,978,427	1%	84	3%
Permeable Pavement Systems	2,263,775	1%	78	2%
Ponds	27,170,548	10%	17	1%
Proprietary Practices	95,970,064	36%	595	19%
Rainwater Harvesting	3,411,537	1%	1,200	38%
Storage Practices	2,274,965	1%	46	1%
Wetland	5,553,217	2%	15	0%
Total	*265,794,849*	*100%*	*3,193*	*100%*

For modeling a conservative approach to current conditions it was determined to conservatively remove most BMPs with likely overestimation of drainage areas, through the use of a drainage area cutoff was evaluated. The cutoff value, a drainage area in square feet, represents a point at which a BMP drainage area exceeds reasonably assumed size (based on best professional judgment). If a BMP drainage area is beyond this cutoff, it will be removed from the modeling exercise but can later be re-incorporated if better field verified information is collected. It should be noted that the cutoff only applies to BMPs that were assigned a drainage area through the desktop analysis. If a BMP record from the GR, DDOT, GSA, FED, DCCR, or RSH datasets had a drainage area, it is considered correct regardless of if it is greater than the cutoff value.

Multiple cutoff values were applied to the BMP dataset and anecdotal information is shown herein for theoretical drainages areas of 100,000 and 10,000 square feet. The filtered BMP datasets were then applied through IP Modeling Tool to evaluate its effect on current condition. The results of this analysis are presented in Table 5.

Table 5: Effect of Cutoff Value on TSS Loading

Watershed Name	Load Remaining (All BMPs)	Load Remaining (BMPs < 100,000 sq. ft.)	Load Remaining (BMPs < 10,000 sq. ft.)	% Difference between All BMPs and 100,000 sq. ft.	% Difference between 100,000 and 10,000 sq. ft.
	TSS	TSS	TSS		
	lbs/year	lbs/year	lbs/year		
Anacostia Lower	268,143	428,858	441,046	37.47	2.76
Anacostia Upper	2,104,585	2,191,367	2,227,927	3.96	1.64
ANATF_DC	1,822,176	2,167,892	2,208,296	15.95	1.83
ANATF_MD	700,197	730,586	743,376	4.16	1.72
Lower Beaverdam Creek	959	959	959	0.00	0.00
Northwest Branch	547,341	573,104	584,507	4.50	1.95
POTTF_DC	1,380,291	1,579,049	1,610,748	12.59	1.97
POTTF_MD	183,236	195,282	198,101	6.17	1.42
Watts Branch	308,719	325,867	332,416	5.26	1.97
Watts Branch - Lower	71,349	78,271	82,457	8.84	5.08
Watts Branch - Upper	237,370	247,596	249,958	4.13	0.95

As shown, there is a large difference in load reductions when BMPs[1] with drainage areas > 100,000 square foot are removed from the data set. However, there is very little difference between the 100,000 and 10,000 square foot cutoffs. 10,000 square feet is roughly a quarter acre and is in line with average parcel area in the District. Therefore, this was deemed a reasonable cutoff value. Additionally, the 10,000 square foot cutoff removes more BMPs initially and is therefore conservative, and helps ensure that BMP effectiveness is not over-represented in the current conditions gap analysis.

A breakdown of the existing BMPs used in this modeling analysis is provided in Table 6.

[1] All BMPs refers to the entire group of BMPs with drainage area estimates that have gone through the decision process described in Figure 1.

Table 6: Summary of BMP Dataset with the 10,000 sq ft Cutoff				
BMP Category	**DA (sq ft)**	**% of DA**	**Count**	**% of Count**
Bioretention	1,502,789	9%	353	16%
Filtering Systems	246,558	2%	55	2%
Green Roof	1,286,887	8%	75	3%
Impervious Surface Disconnect	21,087	0%	4	<1%
Infiltration	1,089,177	7%	208	9%
Open Channel Systems	404,352	3%	47	2%
Permeable Pavement Systems	346,570	2%	53	2%
Ponds	4,245,328	27%	3	<1%
Proprietary Practices	1,849,796	12%	214	10%
Rainwater Harvesting	547,959	3%	1,186	53%
Storage Practices	221,322	1%	17	1%
Wetland	4,122,128	26%	11	<1%
Total	**15,883,953**	**100%**	**2,226**	**100%**

It is important to note that the BMP dataset is not static. As more information is obtained about BMPs they can be re-run in the model to modify the current level of load reduction to meet WLAs.

3.1.d Structural BMP Modeling

As established in the previous sections, only location, type, and drainage areas are known for existing BMPs. However, storage volumes will be included where appropriate for all new BMPs that will be cataloged in the updated database. Therefore, a two pronged approach to BMP modeling is being taken. In general, BMPs with known storage volumes will be modeled on a volume basis, while other BMPs will be modeled with pollutant removal efficiency estimates. As new information about existing BMPs (e.g., storage volume) becomes available and is entered into the database, the modeling approach can be changed from pollutant removal efficiency to volume reduction. A thorough discussion of these modeling processes follows.

Pollutant Removal Efficiency Approach

Without knowledge about the design of a BMP beyond the drainage area, use of pollutant removal efficiencies is the common method for modeling a BMP's ability to remove pollutants. Multiple avenues for developing an average or representative pollutant removal efficiencies were explored. The results of this research are presented below.

International Stormwater BMP Database

Use of the International Stormwater BMP Database (2013) to develop pollutant removal efficiencies was explored. Although the use of pollutant removal efficiencies (as percent removal) is discouraged by the administrators of the International Stormwater BMP Database (Wright Water Engineers et al. 2007), it is still the best way to represent BMPs given the available data. Therefore, using both local and national paired BMP data from the database, linear regressions where inflow concentrations predicted outflow concentrations were developed and examined. This analysis returned extremely poor measures of fit and also raised questions about the normality of data in the International Stormwater BMP Database. This led to the conclusion that the database was not suited for the development of pollutant removal efficiencies. It also showed how looking at concentrations, rather than mass removal, did not capture enough of a BMP's design to predict its ability to remove pollutants.

Literature Review

Since no relationship was found between inflow and outflow pollutant concentrations in the International Stormwater BMP Database, a literature review was undertaken to identify peer reviewed journals and previously approved Watershed Implementation Plans (WIPs) that studied the pollutant removal efficiency of structural BMPs. The focus of this research was on a BMPs ability to remove pollutant load. The literature review was completed in multiple phases. Each phase provided more data points that could be used to develop an efficiency matrix by pollutant and BMP type.

The literature search was conducted for the 13 BMP categories approved for use in the District of Columbia Table 1. Some of the categories contain more than one subtype of BMP. Therefore, keyword searches for both the general BMP categories and the specific BMP subtypes were utilized. Each BMP group was researched for 22 of the TMDL pollutants, excluding trash[2]. During the literature search, removal efficiencies based on concentration were also collected. Although these data are not being used in the modeling they were kept as a reference point for the ability of a BMP to reduce a pollutant.

For most of the BMP categories, widespread research has been completed on the reduction of nutrients, such as phosphorus and nitrogen. There was also a substantial amount of research on total suspended solids removal by BMPs. While there was some literature on fecal coliform BMP efficiencies, it was only available for a few of the BMP categories. Some metals, including copper, lead and zinc, showed high removal efficiencies for many of the BMPs. However, arsenic removal has not researched been for many of the BMPs and no mercury removal efficiency data were found.

In addition to the review of peer reviewed journals, additional research was conducted to identify WIPs across the United States. This additional review provided removal efficiencies for nutrients, BOD, fecal coliform and TSS. However, the BMP review did not provide BMP removal efficiencies for heavy metals or organic pollutants. The data from the BMP review was incorporated into the first phase of literature review.

There were many gaps in the matrix due to the lack of literature on organic pollutants Table 7, which comprise almost half of the TMDL pollutant list. Based on this data gap, a second tier of research was undertaken. Research was undertaken to find literature on using TSS as a surrogate for organics. Organic compounds have physical and chemical characteristics that give them the affinity to adsorb onto particulates such as suspended solids. Papers or reports that show a correlation between TSS loads and loads of the listed organic compounds were researched. Some of the literature showed a correlation between an increase of sorbed PAH concentrations to particulates and the decreasing size of the adsorbent particulates. Organics and metals bind to smaller particles such as clay and silt. Ashley (1999) shows the correlation of the binding of organics to silt, clay and total organic carbon. Hwang (2005) performed a characterization study on PAHs in the Anacostia River, which resulted in an increase of sediment bound PAHs during storm flow. Although there was research that showed the increase of loads and concentrations during stormwater and higher concentration of organics in sediments, literature was not found that illustrated a quantitative correlation of TSS percent removal efficiencies with the percent removal efficiencies of the listed organic compounds.

[2] Trash will be managed primarily through non-structural BMP practices and was therefore excluded from this research effort.

Table 7: Mean Literature Values Derived from Literature and WIPs

Removal (%)	Green Roofs	RWH*	ISD*	PP*	Bio-retention	FS*	Infiltration	Open Channel	Ponds	Wetland	Storage Practices	Proprietary	TPP*
Arsenic													
BOD						40	51	30		63	27		
Chlordane													
Copper	0				45						54		
DDD													
DDE													
DDT													
Dieldrin													
Fecal Coliform	23	0	0.2	19	59	48		0	67	71	80	60	17
Heptachlor Epoxide													
Lead	10			95	50						54		
Mercury													
Oil and Grease													
PAH1													
PAH2													
PAH3													
TN	43	40	13	59	52		79				67	30	68
TP	45	40	13	61	50		82				66	38	74
TPCB													
Trash													
TSS	80	40	43	82	58	83	88	65	60	78	58	65	85
Zinc	14			94	50						55		

* Rainwater Harvesting; Impervious Surface Disconnect; Permeable Pavement; Filtering Systems; Tree Planting and Preservation

Partition coefficients

Due to the lack of literature on BMP pollutant load reductions associated with non-conventional pollutants, the use of partition coefficients was explored. The use of partition coefficients to link non-traditional pollutants to TSS is a common approach in water quality modeling (Chapra 1996). The use of this approach for BMP removal has also been proposed (Novotny 2003).

Heavy metals and organic compounds tend to bind onto particulates such as total suspended solids. Partition coefficients such as octanol-water coefficients (K_{ow}) and organic carbon partition (K_{oc}) can help determine how organic compounds and heavy metals will adsorb to total suspended solids. The partition coefficients, K_p and K_{oc}, were used to correlate TSS removal efficiencies and removal of metals and organics, respectively. In order to quantify this for the calculation of pollutant removal efficiencies, a mathematical model was used. The partition coefficient equation was used to calculate the particulate fraction, which is the fraction of the total mass of each of the pollutant that exists in particulate form (i.e., particle bound).

Pollutant removal efficiency for particle-bound pollutants was calculated based on the following two assumptions:

- The fraction of the total concentration in particle-bound form for a given pollutant can be characterized using partition coefficients taken from the scientific literature
- The fraction of pollutant removed can be calculated from the fraction of pollutant in particle-bound form and the assumed removal efficiency for total suspended solids.

Determination of Fraction of Pollutants in Particle-bound Form

The distribution between dissolved and particle-bound form for many pollutants is described using linear partitioning theory. This theory states that a partition coefficient and the suspended solids concentration can be used to describe the fraction of total pollutant in particulate form as follows:

$$fp = \frac{m \times Kp}{1 + m \times Kp}$$

where:

fp = fraction of total pollutant concentration in particulate from

m = suspended solids concentration

Kp = partition coefficient

Partition coefficients for organic pollutants depend on the organic carbon content of the solids. This work assumes that total suspended solids in stormwater runoff are comprised of 2.4% organic carbon, based upon work in the District published by Hwang and Foster, 2006. The resulting partition coefficients, and their sources, are shown in Table 8.

Table 8: Partition Coefficient Summary		
Pollutants	**Kp (L/mg)**	**Source**
Arsenic	0.0200	Mills et al, 1985
Chlordane	0.0036	Chapra, 1989
Copper	0.0300	Mills et al, 1985
DDD	0.0316	Chapra, 1989
DDE	0.0631	Chapra, 1989
DDT	0.0437	Chapra, 1989
Dieldrin	0.0001	Chapra, 1989
Fecal Coliform Bacteria	0.0500	Chapra, 1996
Heptachlor Epoxide	0.0000	Chapra, 1989
Lead	0.1000	Mills et al, 1985
Mercury	0.0200	Mills et al, 1985
PAH1	0.0003	Chapra, 1989 (average of group)
PAH2	0.0074	Chapra, 1989 (average of group)

Table 8: Partition Coefficient Summary		
Pollutants	**Kp (L/mg)**	**Source**
PAH3	0.3021	Chapra, 1989 (average of group)
PCBs	0.0224	Chapra, 1989 (used value for Arochlor 1248)
TSS		fp = 1
Zinc	0.0500	Mills et al, 1985

Determination of Fraction Removed

The fraction of total pollutant removed by a given BMP is calculated as a function of the fraction of pollutant in particle-bound form and the assumed removal efficiency of the BMP for suspended solids. This is expressed as:

fr = rTSS x fp

where

fr = fraction of total pollutant removed

rTSS = assumed removal efficiency of the BMP for suspended solids

fp = fraction of total pollutant concentration in particulate form

The rTSS, or removal efficiency of the BMP for TSS, used in the partition analysis is primarily derived from established Chesapeake Bay Program efficiencies. For BMPs with no established TSS removal, literature derived TSS removals were used. However, the high TSS removals for green roofs, impervious disconnects, and rainwater harvesting were deemed to be incompatible with the way our model is generating loads. These practices only treat specific areas, such as rooftops, which generate lower pollutant loads. High removals from these BMPs would be an overestimate of their effect. It should be noted that there is added benefit from BMPs like green roofs because they reduce stormwater flow and the ability of stormwater to wash off pollutants in the rest of the watershed. However, this factor has not been studied by the literature used in the development of percent reductions. The literature based percent reductions are for pollutants through the practice. They do not quantify the effect of reduced stormwater volume on the rest of the watershed. Therefore, it was deemed necessary to assign lower TSS reductions for roof-based BMPs. To do this in a systematic way, a ratio of rooftop event mean concentration (EMC) to watershed EMC was used to scale the TSS removals. The following example shows how the ratio was applied to obtain TSS percent removals for green roofs, rainwater harvesting, and impervious surface disconnects.

$$\frac{Rooftop\ EMC}{Scaled\ TSS\ \%\ Removal} = \frac{Watershed\ EMC}{Literature\ Based\ TSS\ \%\ Removal}$$

$$Green\ Roof: \frac{22.5\ mg/l}{x} = \frac{58.3\ mg/l}{80\%}\quad x = 30.8\%$$

$$Rainwater\ Harvesting: \frac{22.5\ mg/l}{x} = \frac{58.3\ mg/l}{40\%}\quad x = 15.4\%$$

$$Impervious\ Surface\ Disconnect: \frac{22.5\ mg/l}{x} = \frac{58.3\ mg/l}{43\%}\quad x = 16.6\%$$

The final key in the development of particulate fractions is the input TSS concentration. The TSS EMC for DC was used in the model to calculate the fraction particulate coefficient for each pollutant. Since the TSS concentration is dependent on the three major watersheds, the process was completed for each major watershed. This resulted in the development of three watershed specific removal efficiency tables (Tables 9, 10 and 11).

Table 9: Pollutant Removal Efficiencies by BMP Type, Anacostia River Watershed

Percent Removal Method	ANACOSTIA												
	Green Roof	Rainwater Harvesting	Impervious Surface Disconnect	Permeable Pavement Systems	Bio-retention	Filtering Systems	Infiltration	Open Channel Systems	Ponds	Wetland	Storage Practices	Proprietary Practices	Tree Planting and Preservation
Arsenic	18	9	10	42	45	48	56	40	36	36	21	6	0
BOD	0	0	0	0	0	40	51	30	0	63	27	0	0
Chlordane	7	3	3	15	16	17	20	14	13	13	7	2	0
Copper	21	10	11	48	52	55	65	46	41	41	24	7	0
DDD	22	10	11	49	52	56	66	47	42	42	24	7	0
DDE	25	12	13	58	62	66	78	55	49	49	29	8	0
DDT	24	11	12	53	57	61	72	51	46	46	27	8	0
Dieldrin	0	0	0	0	0	0	1	0	0	0	0	0	0
Fecal Coliform Bacteria	24	12	13	55	59	63	75	53	47	47	27	8	0
Heptachlor Epoxide	0	0	0	0	0	0	0	0	0	0	0	0	0
Lead	27	13	14	62	66	70	84	59	53	53	31	9	0
Mercury	18	9	10	42	45	48	56	40	36	36	21	6	0
Oil and Grease	0	0	0	0	0	0	0	0	0	0	0	62	0
PAH1	1	0	0	2	2	2	2	2	1	1	1	0	0
PAH2	11	5	6	25	26	28	33	24	21	21	12	4	0
PAH3	30	14	15	67	72	77	91	64	57	57	33	10	0
TN	43	40	13	47	58	40	83	42	20	20	13	5	0
TP	45	40	13	50	68	60	85	43	45	45	15	10	0
TPCB	19	9	10	44	47	50	59	42	37	37	22	6	0
TSS	31	15	16	70	75	80	95	67	60	60	35	10	0
Zinc	24	12	13	55	59	63	75	53	47	47	27	8	0

Table 10: Pollutant Removal Efficiencies by BMP Type, Rock Creek Watershed

Percent Removal Method	ROCK CREEK												
	Green Roof	Rainwater Harvesting	Impervious Surface Disconnect	Permeable Pavement Systems	Bio-retention	Filtering Systems	Infiltration	Open Channel Systems	Ponds	Wetland	Storage Practices	Proprietary Practices	Tree Planting and Preservation
Arsenic	17	8	9	38	41	43	52	36	33	33	19	5	0
BOD	0	0	0	0	0	40	51	30	0	63	27	0	0
Chlordane	6	3	3	12	13	14	17	12	11	11	6	2	0
Copper	20	10	10	45	48	51	61	43	38	38	22	6	0
DDD	20	10	10	46	49	52	62	44	39	39	23	7	0
DDE	24	12	13	55	59	63	75	53	47	47	28	8	0
DDT	22	11	12	51	54	58	69	48	43	43	25	7	0
Dieldrin	0	0	0	0	0	0	0	0	0	0	0	0	0
Fecal Coliform Bacteria	23	11	12	52	56	60	71	50	45	45	26	7	0
Heptachlor Epoxide	0	0	0	0	0	0	0	0	0	0	0	0	0
Lead	27	13	14	60	64	68	81	57	51	51	30	9	0
Mercury	17	8	9	38	41	43	52	36	33	33	19	5	0
Oil and Grease	0	0	0	0	0	0	0	0	0	0	0	62	0
PAH1	1	0	0	1	1	1	2	1	1	1	1	0	0
PAH2	9	5	5	21	23	24	29	21	18	18	11	3	0
PAH3	29	14	15	66	71	76	90	63	57	57	33	9	0
TN	43	40	13	47	58	40	83	42	20	20	13	5	0
TP	45	40	13	50	68	60	85	43	45	45	15	10	0
TPCB	18	9	9	40	43	46	54	38	34	34	20	6	0
TSS	31	15	16	70	75	80	95	67	60	60	35	10	0
Zinc	23	11	12	52	56	60	71	50	45	45	26	7	0

Table 11: Pollutant Removal Efficiencies by BMP Type, Potomac River Watershed

Percent Removal Method	POTOMAC												
	Green Roof	Rainwater Harvesting	Impervious Surface Disconnect	Permeable Pavement Systems	Bio-retention	Filtering Systems	Infiltration	Open Channel Systems	Ponds	Wetland	Storage Practices	Proprietary Practices	Tree Planting and Preservation
Arsenic	14	7	7	32	34	37	43	31	27	27	16	5	0
BOD	0	0	0	0	0	40	51	30	0	63	27	0	0
Chlordane	4	2	2	9	10	11	13	9	8	8	5	1	0
Copper	17	8	9	39	42	45	53	37	33	33	20	6	0
DDD	18	9	9	40	43	46	54	38	34	34	20	6	0
DDE	23	11	12	51	54	58	69	49	44	44	25	7	0
DDT	20	10	10	45	49	52	62	43	39	39	23	6	0
Dieldrin	0	0	0	0	0	0	0	0	0	0	0	0	0
Fecal Coliform Bacteria	21	10	11	47	51	54	64	45	41	41	24	7	0
Heptachlor Epoxide	0	0	0	0	0	0	0	0	0	0	0	0	0
Lead	25	12	13	57	61	65	77	54	48	48	28	8	0
Mercury	14	7	7	32	34	37	43	31	27	27	16	5	0
Oil and Grease	0	0	0	0	0	0	0	0	0	0	0	62	0
PAH1	0	0	0	1	1	1	1	1	1	1	0	0	0
PAH2	7	4	4	17	18	19	23	16	14	14	8	2	0
PAH3	29	14	15	65	70	74	88	62	56	56	32	9	0
TN	43	40	13	47	58	40	83	42	20	20	13	5	0
TP	45	40	13	50	68	60	85	43	45	45	15	10	0
TPCB	15	7	8	34	36	39	46	33	29	29	17	5	0
TSS	31	15	16	70	75	80	95	67	60	60	35	10	0
Zinc	21	10	11	47	51	54	64	45	41	41	24	7	0

Volume Approach

As previously noted, DDOE's new stormwater management regulations (DDOE 2013a) establish an on-site stormwater retention standard for both new development and redevelopment projects. There are multiple retention volumes that must be met depending on the location of the project and the type of project. For instance, "major land disturbing" projects must retain runoff from a 1.2 inch storm, while certain redevelopment projects or "major substantial improvement" projects are required to manage runoff from a 0.8 inch storm. The regulations provide flexibility for meeting these and other various retention standards, including the use of multiple BMPs and managing a portion of the retention volume offsite. Given the inherent variability in sizing of BMPs that stems from these regulations, the assignment of a single universal removal rate for a BMP is not appropriate or technically defensible.

For BMPs that follow these new retention requirements, LimnoTech proposes using volume-based efficiencies that can be tied to the amount of retention provided by a BMP. Before developing and implementing a protocol to calculate volume-based efficiencies, LimnoTech performed a limited literature review of other methods that seek to establish similar efficiencies. The primary method identified from the literature review was documented in "Recommendations of the Expert Panel to Define Removal Rates for New State Stormwater Performance Standards" developed by Schueler and Lane (2012) for the Chesapeake Bay Program's Urban Stormwater Work Group (CBP Work Group).

The CBP Work Group lumps BMP types into two categories: stormwater treatment practices (e.g., wet ponds, constructed wetlands, filtering practices) or runoff reduction practices (e.g., bioretention, infiltration practices, permeable pavement). The CBP Work Group approach developed nutrient and sediment removal rates for these composite categories of BMPs based on the amount of runoff treated or reduced. The removal rates are presented as BMP removal rate adjustor curves based on runoff depth managed (i.e., treated or reduced) per impervious acre.

The adjustor curves were developed from a table of general nutrient removal rates developed previously by the Chesapeake Stormwater Network. The annual mass nutrient removal rates associated with the BMPs assigned to each category were averaged for the composite BMP categories. These rates were deemed "anchor" rates for the composite BMPs for one inch of managed runoff.

A simple rainfall frequency spreadsheet analysis using data from Washington, D.C., was used by the CBP Work Group to estimate how the anchor removal rates would change based on different depths of runoff managed by the composite BMPs. The rainfall data was taken from Reagan National Airport between 1977 and 2007. The percent of the annual rainfall that would be captured by a practice designed for a specific depth was estimated by summing the precipitation for all of the storms less than the design depth, plus the product of the number of storm events greater than the design depth multiplied by the design depth. This value was then divided by the sum of the total precipitation for the period. This information was effectively used to scale the anchor pollutant removal rates to complete the adjustor curves for runoff reduction greater than or less than 1 inch.

While this simplified approach appears reasonable, the resultant adjustor curves were only developed for total nitrogen, total phosphorus, and total suspended solids. In addition, the analysis looks at composite BMPs rather than individual BMP categories. For the IP Modeling Tool, pollutant removal rates are needed for individual BMP types and for a much larger set of pollutants. Finally, the simplified rainfall frequency approach does not account for antecedent conditions, rainfall intensity, or reduction mechanisms within a BMP. LimnoTech felt that a continuous simulation modeling approach could be used to better approximate runoff reduction for distinct BMP types.

In order to establish the runoff reduction expected by implementing specific BMPs, multiple long-term hydrology model simulations were performed to determine runoff reduction percentage as a function of BMP type and design depth (or volume) of the BMP.

Methodology

EPA's SWMM hydrologic model was used to simulate rainfall, runoff, and BMP runoff reduction. BMPs are represented in SWMM as idealized LID Controls (Rossman 2010).

For all BMPs except green roofs and cisterns, rainfall is simulated to fall on a 1 acre sub-catchment that is 100% impervious. The runoff from that catchment is routed to a second sub-catchment that only contains the analyzed BMP practice. The BMP practice is sized in order to capture a specific rainfall depth, for example 1.2" of rainfall over the area of the contributing sub-catchment. The model iteratively cycles through a variety of runoff depths in order to produce a runoff reduction curve. Each runoff reduction curve is derived from multiple SWMM model simulations using a range of BMP practice volumes. Each BMP is modeled as a control volume with one loss mechanism (either evapotranspiration or infiltration, depending on the BMP) that represents all possible losses from the BMP. Any inflow in excess of the storage volume and losses will bypass the BMP and not be included as runoff reduction. Additionally, any flow lost through an underdrain, if available bypasses the BMP and is not included as runoff reduction. Figure 4 shows a schematic of the BMP treatment process. All modeled processes are shown in the figure, although not all processes are modeled for every BMP type.

A continuous timeseries of hourly rainfall data was used for the period of 1983-2012. Precipitation was recorded at Ronald Reagan National Airport.

Several different types of BMPs were modeled in SWMM. A summary of input parameters is shown in Table 12 and described in detail.

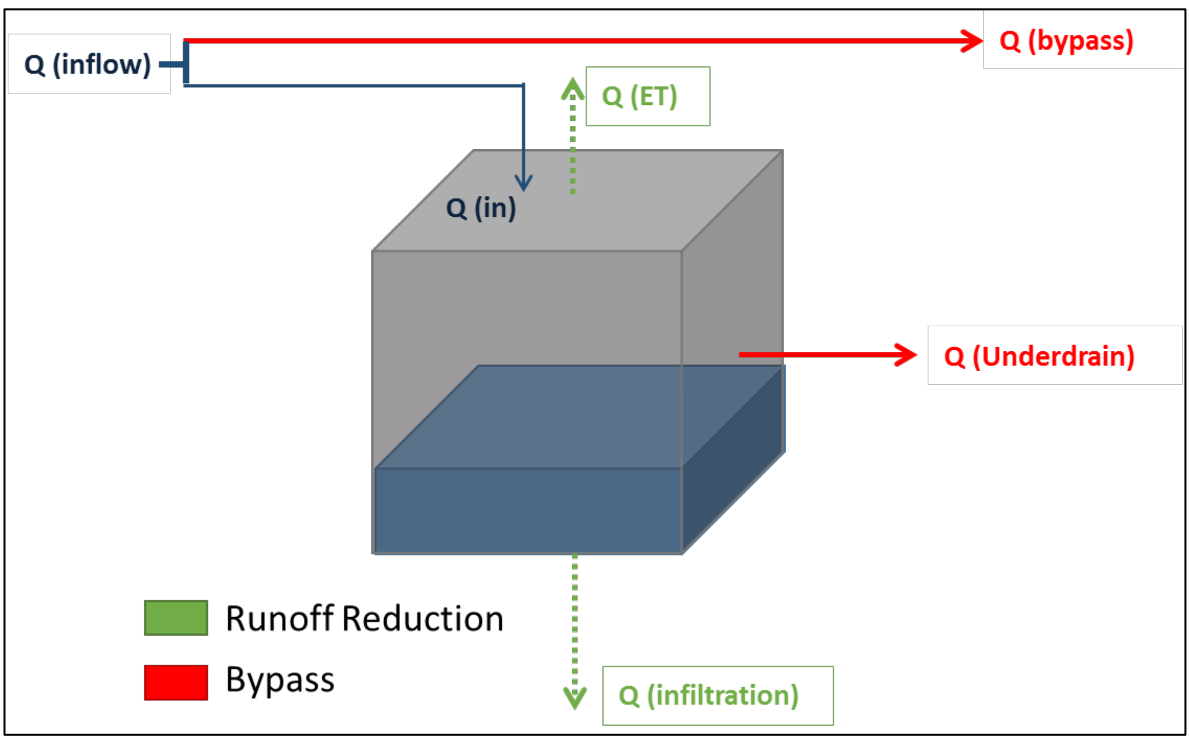

Figure 4: Model BMP Representation

Table 12: Summary of Model Input Variables

Variables	Infiltration Basin	Green Roof	Enhanced Permeable Pavement (with Underdrain)	Enhanced Perm Pavement (no Underdrain)	Enhanced Bioretention (with Underdrain)	Enhanced Bioretention (no underdrain)	Standard Bioretention
Hydrology							
Precipitation	1983-2012 Continuous rainfall						
Runoff catchment area	1 unit area						
Runoff catchment impervious	100%						
ET	None						
LID							
Time to empty	48 hours	N/A	48 hours	48 hours	72 hours	72 hours	72 hours
LID infiltration rate	Variable	None	Variable: Set to drain storage within regulated time				
LID storage volume	Variable: Sized to hold 0" - 1.7" depth		0" - 1.7"	0"-1.7"	0" - 1.7"	0"-1.7"	0"-1.7"
underdrain height	N/A	N/A	0" - 1.3"	N/A	0" - 1.3"	N/A	0" - 0.57"
underdrain coefficient	N/A	N/A	0.2	N/A	0.2	N/A	0.2
underdrain exponent	N/A	N/A	0.5	N/A	0.5	N/A	0.5
Dry day delay	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Surface storage	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LID ET	None	Wash DC Monthly Average PET	None				
Loss mechanism pathway	Infiltration	ET	Infiltration	Infiltration	Infiltration	Infiltration	Infiltration

Infiltration Basin

Infiltration basins are modeled as a constant-volume basin with a volume equal to the specified rainfall capture depth over the contributing watershed. It is assumed that the infiltration basin storage must be emptied within 48 hours, so the infiltration rate is set to empty a full basin within 48 hours. Infiltration is the only modeled loss mechanism. Any inflow in excess of the capacity of the BMP bypasses the BMP and is not included in the reduction calculation.

Green Roof

Green roofs are modeled as a constant-volume basin with a volume equal to the specified rainfall capture depth falling directly onto the green roof. The primary loss mechanism for a green roof is evapotranspiration. The retained runoff is subject to evapotranspiration based on average monthly potential evapotranspiration values for Washington, D.C. (NRCC 2014). Any inflow in excess of the capacity of the BMP is considered to bypass the BMP and is not included in runoff reduction.

In application, a green roof would be expected to allow some flow to be lost via exfiltration through the media, which would be considered to bypass and not included in runoff reduction. While the model does not explicitly represent this mechanism, assuming that all inflow in excess of the roof storage volume bypasses the practice gives an accurate runoff reduction estimate.

Permeable Pavement (with and without an underdrain)

Enhanced permeable pavement is modeled as a constant-volume basin with a volume equal to the specified rainfall capture depth over the contributing watershed. It is assumed that enhanced permeable pavement storage must be emptied with 48 hours, so the infiltration rate of the underlying soil is set to empty a full basin within 48 hours. Infiltration is the only modeled loss mechanism. Any inflow in excess of the capacity of the BMP bypasses the BMP and is not included in reduction.

If an underdrain is included in enhanced permeable pavement, the volume of storage below the underdrain is equal to the specified rainfall capture depth over the contributing watershed. Above the underdrain, a volume equal to twice the storage volume is available. Any inflow in excess of the capacity of the BMP, including underdrain losses, bypasses the BMP and is not included in reduction.

Standard permeable pavement is assumed to have negligible volume reduction based on assumptions in the Stormwater Management Guidelines.

Bioretention (with and without an underdrain)

Enhanced bioretention is modeled as a constant-volume basin with a volume equal to the specified rainfall capture depth over the contributing watershed. It is assumed the bioretention storage must be emptied within 72 hours, so the infiltration rate is set to empty a full storage volume within 72 hours. Infiltration is the only modeled loss mechanism. Any inflow in excess of the capacity of the BMP bypasses the BMP and is not included in reduction.

If an underdrain is included, the total volume of storage is equal to the specified rainfall capture depth over the contributing watershed. The underdrain is placed at 2/3 the height of storage. Both the area above and below the underdrain are emptied within 72 hours. Any inflow in excess of the capacity of the BMP and any underdrain losses are considered to bypass the BMP and are not included in runoff reduction.

For standard bioretention, the total volume of storage is equal to the specified rainfall capture depth over the contributing watershed. The underdrain was placed at a height that yields a 60% volume reduction for a 1.2" depth design volume. This percentage was based on expected runoff reduction for a standard bioretention practice and was provided by the Center for Watershed Protection. This reduction factor is also used in the DDOE Stormwater Management Guidelines.

Cisterns

Cisterns are modeled using a logistical regression based on comparing the DDOE Rainwater Harvesting Calculator to a SWMM model with similar assumptions. The Rainwater Harvesting Calculator accounts for daily variations in a variety of demands and uses of retained stormwater, and it assigns credits based on the amount of space available for a potential storm event after all demands are accounted for. Our model methodology calculates volume reduction as a function of total captured rainfall. The regression analysis links the Rainwater Harvesting Calculator results to this model methodology.

Results

For each BMP type, a range of BMP control volumes were evaluated and compared to the runoff reduction achieved by the modeled BMP. A polynomial best fit line was fit to the relationship to allow determination of runoff reduction as a function of BMP control depth. Figures 5 through 9 show the control depth to runoff reduction relationship for the BMPs that were evaluated.

In order to use these curves to determine the expected runoff reduction of an already-constructed BMP, the depth value should be the regulated volume as determined by DDOE (2013b). For green roofs, the depth is the actual depth of storage available to runoff and should only include void space available in the storage media. A summary of the resulting runoff reduction volume polynomial equations is seen in Table 13.

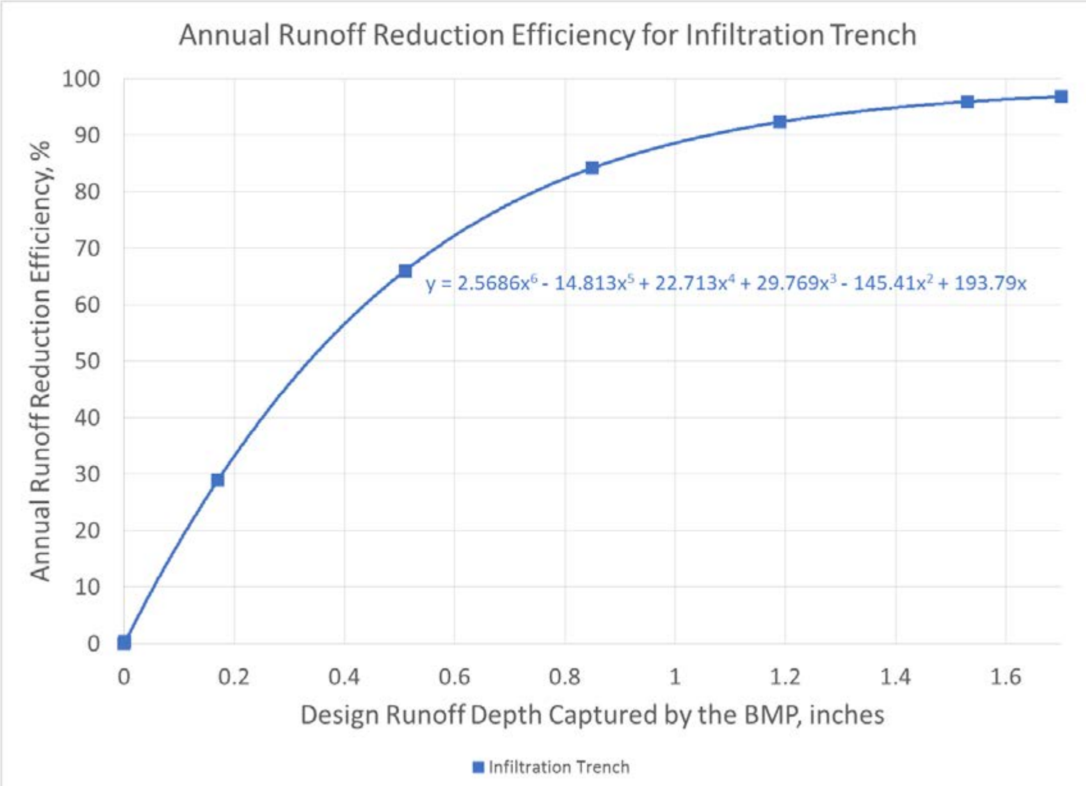

Figure 5: Infiltration Trench Annual Runoff Reduction Efficiency

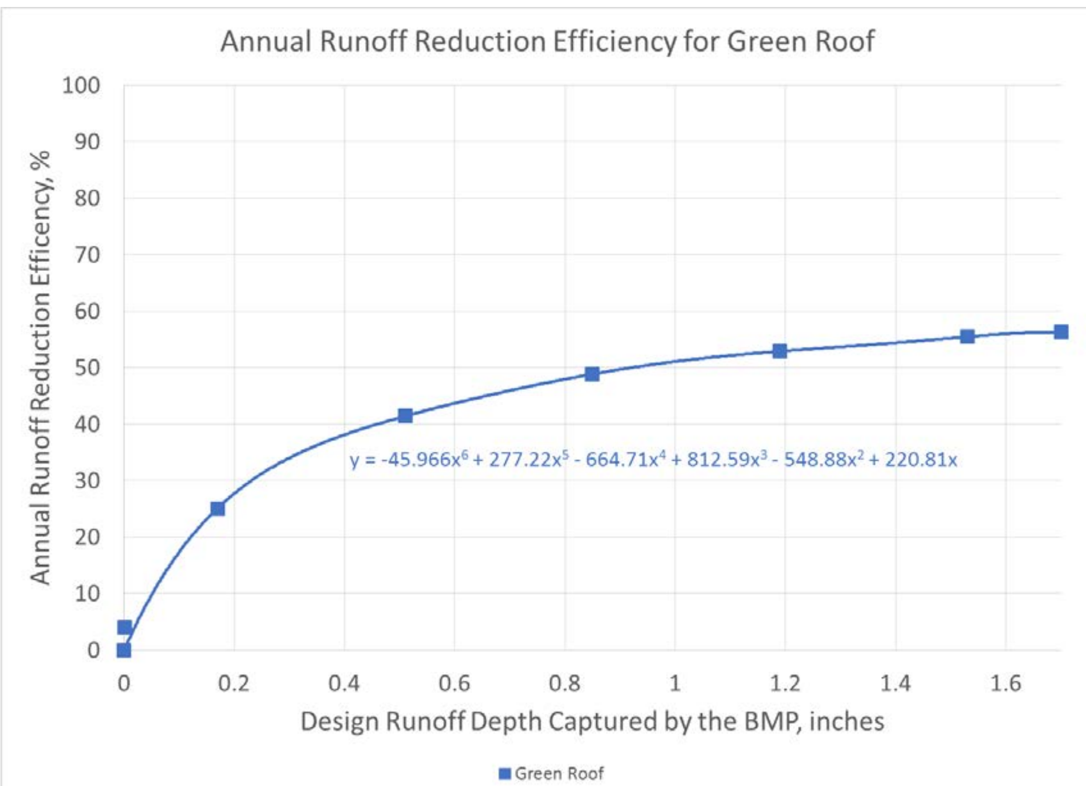

Figure 6: Green Roof Annual Runoff Reduction Efficiency

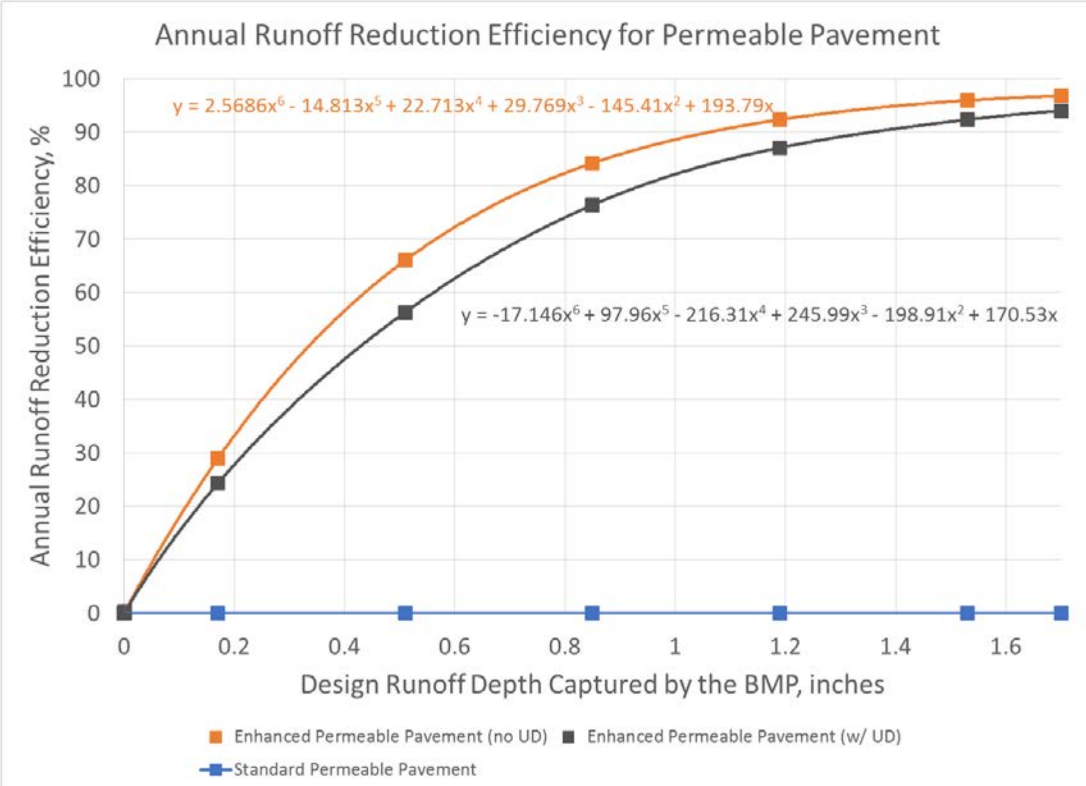

Figure 7: Permeable Pavement Annual Runoff Reduction Efficiency

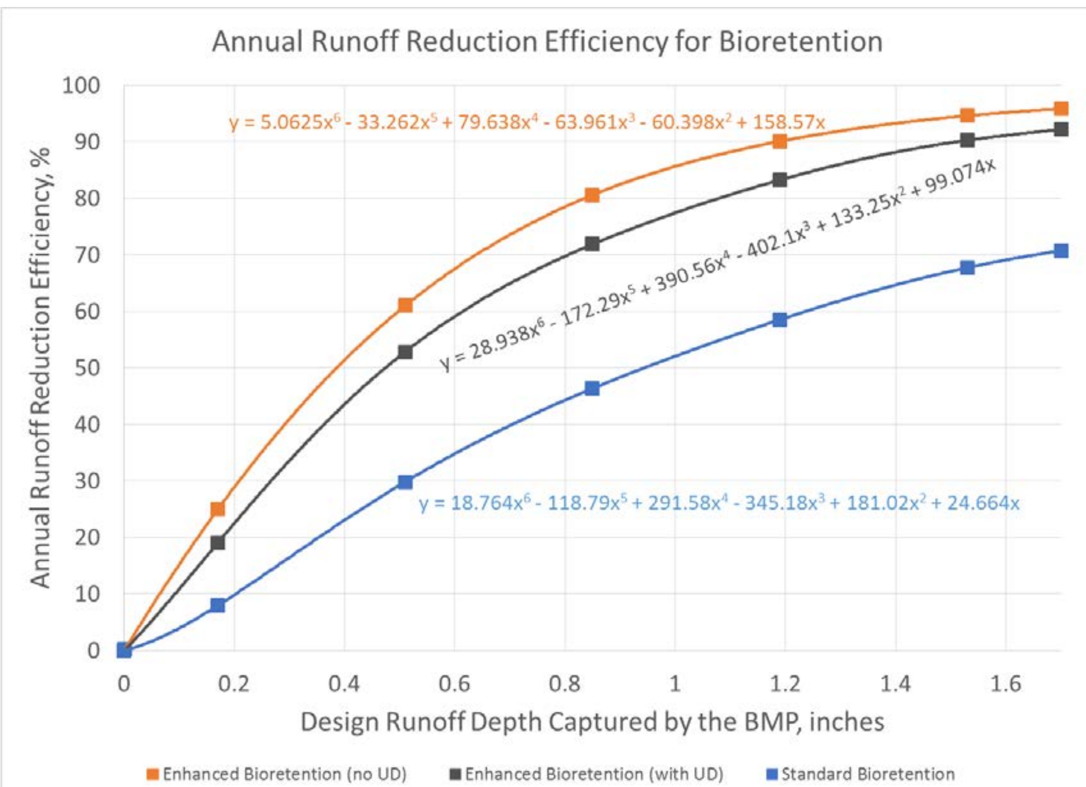

Figure 8: Bioretention Annual Runoff Reduction Efficiency

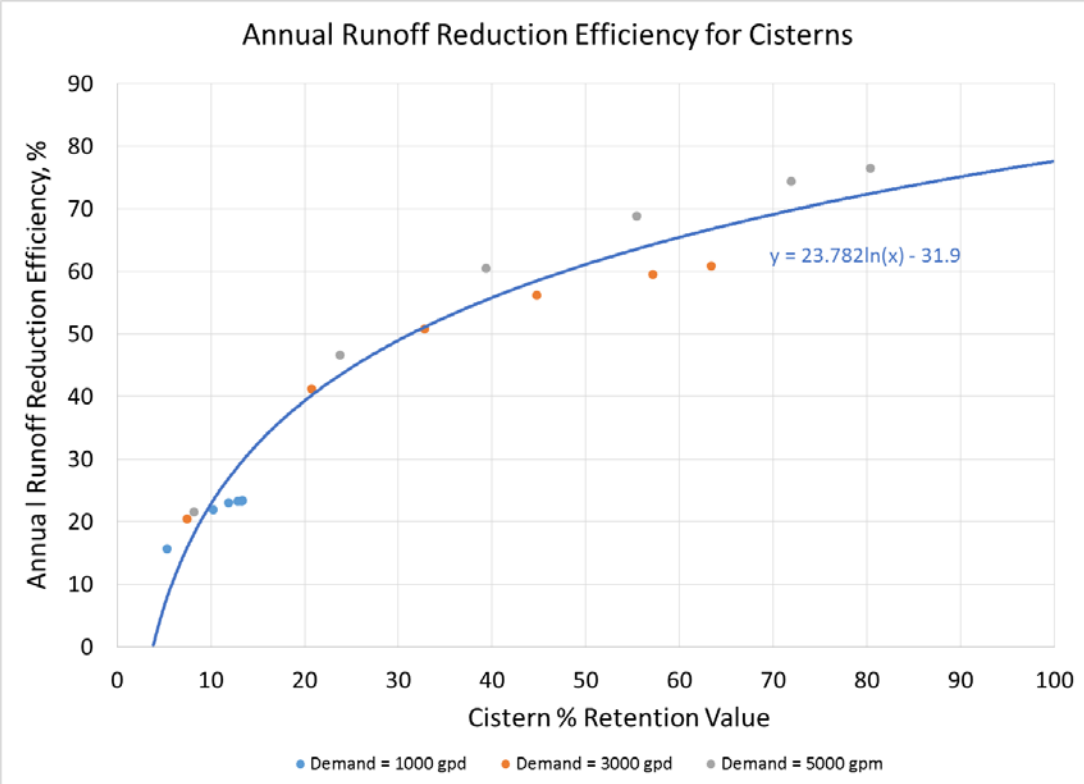

Figure 9: Cistern Annual Runoff Reduction Efficiency

Table 13: Runoff Reduction Efficiency Equations	
BMP	**Annual Runoff Reduction Efficiency Equation[1]**
Infiltration Trench	$y = 2.5686x^6 - 14.813x^5 + 22.713x^4 + 29.769x^3 - 145.41x^2 + 193.79x$
Green Roof	$y = -45.966x^6 + 277.22x^5 - 664.71x^4 + 812.59x^3 - 548.88x^2 + 220.81x$
Standard Permeable Pavement	No reduction
Enhanced Permeable Pavement, With Underdrain	$y = -17.146x^6 + 97.96x^5 - 216.31x^4 + 245.99x^3 - 198.91x^2 + 170.53x$
Enhanced Permeable Pavement, No Underdrain	$y = 2.5686x^6 - 14.813x^5 + 22.713x^4 + 29.769x^3 - 145.41x^2 + 193.79x$
Standard Bioretention	$y = 18.764x^6 - 118.79x^5 + 291.58x^4 - 345.18x^3 + 181.02x^2 + 24.664x$
Enhanced Bioretention, With Underdrain	$y = 28.938x^6 - 172.29x^5 + 390.56x^4 - 402.1x^3 + 133.25x^2 + 99.074x$
Enhanced Bioretention, No Underdrain	$y = 5.0625x^6 - 33.262x^5 + 79.638x^4 - 63.961x^3 - 60.398x^2 + 158.57x$
Cistern	$y = 23.782\ln(a) - 31.9$

1 In these equations, the variable “x” denotes the design runoff depth captured by the BMP and the variable “y” denotes the annual runoff reduction percent efficiency. For Cisterns, the variable “a” denotes the cistern efficiency, as entered in DDOE’s BMP database.

Other Volume Based BMPs

Stormwater volume retention can also be calculated for a few other structural BMPs without the need for long term simulations in SWMM. These structural BMPs include rain barrels and tree planting and tree preservation.

According to DDOE the average rain barrel installed in the District is 130 gallons. Discussions with DDOE and DC Greenworks, one of the major rain barrel installers in the District, indicate that a conservative estimate on the number of times a rain barrel is emptied is once per quarter. Therefore, the runoff retention for a rain barrel can be modeled as:

1 Barrel x 130 gallons x 4 Drawdowns/Year = 520 Gallons/Year/Rain Barrel

Ideally if a rain barrel was emptied on a more frequent basis it would retain more water. This could be a scenario to explore in future modeling tasks.

For the purposes of stormwater retention volume credits, DDOE has quantified the benefits of tree planting and preservation on a per tree basis (CWP 2013). The IP Modeling Tool tracks load and volume reductions provided by planting new trees but does not track the preservation of existing trees, since the effect of existing trees on pollutant loads and load reductions are assumed to be accounted for in the selection of EMC values and runoff coefficients. DDOE assumes that new trees retain on average 10 cubic feet per rain event per tree.

The annual volume reduction from planted trees was estimated by applying a deciduous tree specific interception capacity of 0.043 inches per rain event (Breuer, 2003), where precipitation was considered a new rain event if there was at least six hours with no recorded precipitation prior to any detected precipitation. Intercepted precipitation was converted to a volume by assuming a canopy area of 490 square feet, which is average for medium-sized trees (MNPCA, 2014). Using the model precipitation period, an average cumulative depth of 4.27 inches per year, or 1,586 gallons/year, is intercepted per tree.

3.2 **Non-structural, Source Control, and other BMPs**

DDOE's Stormwater Management Guidebook (2013) defines a non-structural BMP as "a land use, development, or management strategy to minimize the impact of stormwater runoff, including conservation of natural cover, or disconnection of impervious surface." Non-structural BMPs consist of programmatic, operational, and restoration practices that help prevent or minimize pollutant loading or runoff generation. Typical non-structural BMPs include pollution prevention and good housekeeping, public outreach and education, buffer planting, street sweeping, land management, and stream restoration. DDOE's MS4 permit includes requirements to implement many non-structural BMPs, including public education, operation and maintenance of various stormwater management systems, and green practices. However, the typical focus of these non-structural BMPs is on instituting best practices, but not necessarily on quantifying pollutant removal. Therefore, one of the key challenges in implementing non-structural BMPs in the IP Modeling Tool is to identify, track, and quantify mechanisms for reducing pollutant load.

Unlike typical structural BMPs, such as wet ponds, bioretention, or sand filters, which work by controlling runoff through engineered mechanisms and for which runoff pollutant reduction can typically be measured directly, the pollutant reduction impacts of non-structural BMPs or source control measures, are typically not easily measured. Non-structural BMPs such as pollution prevention and good housekeeping, public outreach and education focus on impacting human behavior, which in turn can impact pollutant loading. For example, a non-structural BMP such as storm drain stenciling, which involves marking storm drains to educate the public about the impacts of discharging pollutants down the storm drain, is intended to influence the behavior of the public by raising awareness and discouraging people from discharging pollutants down the storm drain. Similarly, source control measures such as pollution prevention and good housekeeping are intended to raise awareness and educate the public about minimizing the exposure of potential pollutants to runoff, thereby minimizing the potential for pollutants to enter the storm drain system. While these types of BMPs are undoubtedly useful components of the toolbox for reducing pollutant discharges, their impact is difficult to measure directly.

In other cases, the pollutant removal impact of non-structural BMPs may be easier to measure, but the measurements of these impacts are made in terms of direct pollutant removal instead of through BMP efficiency or runoff reduction. For example, street sweeping, catch basin cleaning, illicit discharge detection and elimination, and pet waste management work through the direct removal of pollutants from the environment. Finally, some non-structural BMPs work by creating or restoring natural conditions that either reduce runoff, reduce erosion, or promote infiltration, all of which reduce pollutant loading. For example, stream restoration reduces in-stream erosion, and stream buffers, tree planting, impervious area reduction, and other BMPs reduce runoff and/or promote infiltration, thereby reducing loading.

The variety of non-structural BMPs and their various mechanisms for reducing pollutant loading makes them a challenging category of BMPs to include in BMP modeling. For many of these BMPs, there is not as much research available to help quantify their impacts, while for others, the information required in order to quantify the BMP's impact can be difficult to acquire at the required scale. The following sub-sections describe the methods used to identify potential non-structural BMPs used in the IP Modeling Tool, and identify the pollutant reduction associated with that BMP and the data that is necessary to calculate that pollutant reduction.

3.2.a Literature Review and BMP Applicability

A literature review was conducted to evaluate the feasibility of including individual non-structural BMPs in the IP Modeling Tool. The literature review focused on identifying non-structural BMPs for which load reduction impacts could be quantified, either directly or indirectly. The identification of BMPs for which load reduction impacts could be quantified required two specific types of information:

- A quantifiable aspect of the BMP (for example, the number of lane-miles swept using street sweeping, the number of public outreach sessions conducted or the number of stream miles restored); and
- A method for linking the quantifiable aspect of the BMP to a specific pollutant load reduction (for example, a unit load reduction per lane-mile swept, or a unit load reduction per stream mile restored).

Both of these types of information are required for a BMP before that BMP can be implemented for pollutant load reduction tracking in the model. If information is available for only one component, the BMP cannot be used in the model. A good example is public outreach and education. While it is straightforward to quantify the amount of public education that is performed (for example, it is easy to track the number of outreach sessions conducted or the number of people attending the sessions), there is no established mathematical relationship between attending an outreach session and reducing pollutant load. In other words, there is no direct relationship that quantifies the impact of the outreach, such as if you were able to relate "1 person attending 1 outreach session = X pounds of reduction of pollutant Y per year." Similarly, if it was known from the scientific literature that "street dirt" collected during street sweeping operations typically had concentrations of X pounds of total suspended solids per pound of street dirt collected, but the actual amount of street dirt collected from street sweeping was not tracked by the municipality, then this BMP could not be quantified for pollutant load reduction either. The literature review focused on collecting this type of required information for the various non-structural BMPs.

The list of potential non-structural BMPs was limited to those that DDOE is currently implementing, plus those with a good base of published scientific literature. A summary of the non-structural BMPs researched for potential inclusion in the IP Modeling Tool is provided in Table 14 below. The table includes the name of the non-structural BMP, the types of pollutants that are typically removed by that BMP, a preliminary assessment as to whether the BMP could be quantified for pollutant load reduction, and notes on the BMP, such as whether there were guidance documents or regulatory programs that recognize specific pollutant load reductions from these BMPs.

Table 14: Non-structural BMPs Evaluated for Inclusion in TMDL IP Modeling Tool

Non-Structural BMP Type	Pollutants Targeted	Potentially Quantifiable?	Notes
Bag Fee	Trash	Unknown	
Brownfield Restoration	None	Unknown	
Catch Basin Cleaning	TN, TP, TSS, Bacteria, Metals, Organics	Y	Chesapeake Bay Program Expert Panel provides methodology for load reduction for this BMP in its street sweeping literature; however, this BMP is not “approved”
Coal Tar Sealant Removal	PAH	Y	Load removal can be estimated based on USGS monitoring of stormwater samples
Gross Solids Removal/Removal of Excess Vegetation	TN, TP	Unknown	
Illicit Discharge Detection and Elimination	TN, TP, TSS, Bacteria, Organics	Unknown	Under consideration by the Chesapeake Bay Program for inclusion as an “approved” BMP.
Impervious Surface Removal	TN, TP, TSS, Bacteria, Organics	Y	
Native Landscaping/Planting	TN, TP, TSS, Metals	Unknown	
Pet Waste Campaign	TP, Bacteria	Unknown	Methodology for tracking pollutant removal developed by the Center for Watershed Protection and used for planning purposes in the City of Richmond
Phosphorus Fertilizer Ban	TP	Y	Chesapeake Bay Program Expert Panel provides methodology for load reduction for this source control BMP
Pollution Prevention/Good Housekeeping	TN, TP, TSS, Metals	Unknown	
Public Education	Unknown	Unknown	
Sewer Cleaning	Unknown	Unknown	

Table 14: Non-structural BMPs Evaluated for Inclusion in TMDL IP Modeling Tool			
Non-Structural BMP Type	**Pollutants Targeted**	**Potentially Quantifiable?**	**Notes**
Sheetflow to Conservation Areas	TN, TP, TSS	Y	Credit in MDE "Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated"
Soil Amendments to prevent erosion	TN, TP, TSS	Unknown	
Stream Restoration	TN, TP, TSS	Y	Credit in Chesapeake Bay Program
Street Sweeping	TN, TP, TSS, Metals, Organics	Y	Credit in Chesapeake Bay Program
Underground Storage Tank Management	None	Unknown	Mostly petroleum-oriented; possibly metals
Urban Nutrient Management	TN, TP, Bacteria	Y	Credit in Chesapeake Bay Program; Tracking mechanism not sufficiently in place in DC to take credit for programmatic reduction (DDOE)

As described, a number of different non-structural BMP types were investigated, ranging from programmatic activities (street sweeping; illicit discharge detection and elimination; underground storage tank management) to land conservation/management (native landscaping/planting; urban nutrient management) to source management (phosphorus fertilizer ban; sewer cleaning). DDOE is currently implementing many of these BMPs (e.g., underground storage tank management; brownfield restoration; bag fee; pollution prevention/good housekeeping), and is capable of implementing the others. But the primary question in need of evaluation was whether each of these specific BMPs could be quantified and linked to a specific pollutant load reduction.

The literature review consisted of research of primary and secondary literature (i.e., review of other literature reviews), and, in many cases, follow up communications with the authors of the primary literature. This included:

- Summarizing the BMP and the types of pollutants that it was designed to mitigate;
- Identifying best practices for implementing the BMP;
- Identifying potential elements of the BMP that could be quantified;
- Identifying potential links from the quantifiable elements of the BMP to pollutant load; reductions and determining how these links could be translated into the model; and
- Reviewing case studies to determine if the quantification methods and results could be applied to the District.

Each of these elements was critical in helping to determine if a specific non-structural BMP could be included in the IP Modeling Tool. For example, if there was a way to quantify the BMP (for example, counting the number of public education sessions held), but no specific method for quantifying the pollutant load reduction resulting from those public education sessions, then the BMP could not be used in the model. Similarly, if the case studies included information that allowed quantification of a pollutant load reduction benefit, but the case studies were done in situations that did not reflect conditions in the District (e.g., they were conducted in areas with significantly different rainfall patterns or climate), then thee case studies were not used.

For each non-structural BMP, the literature was reviewed and determinations were made as the potential applicability of that BMP to the District. As described above, some of these BMPs were already being used in the District, and review revolved around whether or not they could be quantified and linked to specific load reductions. For other BMPs that were not currently being used in the District, the additional element of whether implementation was feasible in the District was evaluated.

While non-structural BMP information is available from across the U.S. and even internationally, much of the recent information has been developed for the Chesapeake Bay region for evaluation for use to meet the Chesapeake Bay TMDL. The Chesapeake Bay Program has “approved” methods accounting for load reductions for a number of BMPs (e.g., street sweeping, urban nutrient management, stream restoration) and is evaluating additional BMPs for potential approval (e.g., illicit discharge detection and elimination). Having a methodology approved by the Chesapeake Bay Program provides extra confidence that the BMP can have a specific, quantifiable role in pollutant load reduction to meet WLA requirements. This factor is especially important when non-structural BMPs are presented to stakeholders. While BMPs approved by the Chesapeake Bay Program are “approved” only for nutrients and sediment, the use of partition coefficients to relate the removal of additional pollutants (e.g., metals, organics) to sediment removal again provides additional confidence in these BMPs to be a successful part of the load reduction strategy to meet MS4 WLAs.

In addition to the fact that some of the non-structural BMPs reviewed for use in the IP Modeling Tool have been approved by the Chesapeake Bay Program, many of these BMPs have been investigated by local researchers, including the Center for Watershed Protection and the Chesapeake Stormwater Network. Because these entities are local, much of their research has also been done locally, and thus their findings are likely to apply to conditions that are found in the District.

For those BMPs that were determined to be quantifiable, a conceptual model was developed. This conceptual model described how the BMP was to be quantified and how the quantification of that BMP was to be translated into a pollutant load reduction. It also defined the types of data that were needed in order to model the impact of the BMP. In several cases, the draft conceptual models were discussed with researchers identified from the literature review to validate the proposed approach. In many cases, these researchers included staff from the Center for Watershed Protection, which has done much of the local research on many of these BMPs. Internal review of the non-structural BMPs proposed for inclusion in the IP Modeling Tool were then conducted between DDOE and its consultant team to determine which BMPs were feasible for inclusion in the model. These discussions focused on what non-structural BMPs were already being implemented in the District, whether it was feasible to include these BMPs as existing BMPs in the Comprehensive Baseline Analysis, and what data was available for modeling each specific BMP. In some cases, if sufficient data was already being collected to allow quantification of pollutant load reduction for a specific BMP, that BMP was included as an existing BMP for the Comprehensive Baseline Analysis. In other cases, if the BMP was not currently being implemented or if the BMP was being implemented but insufficient data was currently being collected to quantify the pollutant load reduction from that BMP, use of that BMP was reserved for consideration as a potential future BMP for inclusion in load reduction scenarios.

Based on the literature review and additional evaluations, the following non-structural BMPs were identified for current or future inclusion in the IP Modeling Tool:

- Stream restoration
- Street sweeping
- Catch basin cleaning
- Pet waste removal

- Illicit discharge detection and elimination
- Impervious surface reduction
- Coal tar sealant ban
- Phosphorus fertilizer ban

Each of these BMPs is discussed in detail in the following sub-sections.

3.2.b Stream Restoration

Description and Pollutants Targeted

Stream restoration is the practice of the re-establishment of pre-disturbance aquatic functions and related physical, chemical, and biological characteristics to a degraded stream. Stream restoration is a widely-used BMP because it focuses on directly rehabilitating the impacted resource. Stream restoration decreases in-stream erosion, thereby reducing loading of TSS and nutrients. The practice also creates ancillary benefits in addition to load reduction, including improved wildlife habitat, potential increases in public accessibility/use, and upgraded aesthetics.

Several stream restoration projects have been conducted or are planned for District waterbodies, including Watts Branch (completed), Nash Run (planned), Springhouse Run (planned), Pope Branch (planned), and Broad Branch (planned). These projects have been/are being conducted by several different entities, including DDOE, DC Water and the U.S. Fish and Wildlife Service, depending on who owns the land. Many of the projects are being combined with landside improvements, including rehabilitating sanitary sewers, constructing stormwater management facilities, and reducing the amount of stormwater runoff from impervious areas.

Methodology for Modeling Load Reduction

The methodology described by the Chesapeake Bay Program is used for the purposes of modeling stream restoration for pollutant load reduction in the IP Modeling Tool. Use of the Chesapeake Bay Program methodology is beneficial for several reasons.

- It is well vetted and accepted by EPA for tracking load reductions for both the Bay TMDL and other TMDLs.
- It is based on local data and representative of conditions that occur in the District.
- It is acceptable to other stakeholders.

The Chesapeake Bay Program methodology for tracking load reductions from stream restoration is continuing to evolve. The most recent information is available from the “Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects” document, which was accepted by the Urban Stormwater Work Group in February 2013 and, as of January 2014, was updated with “Test-Drive Revisions” approved by the Expert Panel. At the present time there are actually two methods for determining load reduction. The first is to use the “Revised Interim Rate” for load reductions; the second is to use one or more protocols established by the Expert Panel to define pollutant removal reductions achieved by individual stream restoration projects.

The Chesapeake Bay Program originally established a method for determining load reduction from stream restoration in 2003. However, subsequent research on the nutrient and sediment dynamics associated with urban stream restoration suggested that the original credit for stream restoration was too conservative. A revised interim credit that had originally been developed by the Baltimore Department of Public Works based on additional studies on urban stream erosion rates of stream located in Maryland

and southeastern Pennsylvania was proposed in 2011. In April, 2013, the Watershed Technical Work Group decided that the interim rate will apply to historic projects and new projects that cannot conform to recommended reporting requirements as described in the "Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects" document. The Revised Interim Rate is based on the linear footage of stream restored, and it provides "edge-of-stream" load reductions for TN, TP and TSS in pounds per year per linear foot of stream restored (Table 15)

Table 15: Edge-of-Stream 2011 Interim Approved Removal Rates per Linear Foot of Qualifying Stream Restoration (lb/ft/yr)

	TN	TP	TSS
Revised Interim Rate	0.075	0.068	248*

*The Expert Panel document indicates that a sediment delivery ratio of 0.181 and 0.061 should be applied to non-coastal plain and coastal plain, respectively, to account for the differences between edge-of-field and edge-of-stream sediment removal rate.

Thus, if 100 linear feet of stream were restored, the load reduction for TN would be:

100 ft. * 0.075 lbs TN/ft./yr. = 7.5 lbs TN/yr

This load reduction is applied to the TMDL watershed in which the stream is located.

As described in the Expert Panel document, this methodology will be applied in the TMDL IP Modeling Tool for all existing stream restoration projects, plus any future projects that do not conform to the protocols in the document. However, it is anticipated that many future stream restoration projects will conform to the reporting protocols described in the Expert Panel document, and that they will be eligible for additional load reduction. The Expert Panel lays out four protocols that are approved to determine load reduction. Different protocols are applied depending on the type of restoration work being done, and all three protocols may be applied to a single restoration project if applicable. These protocols and the types of load reduction that can be achieved are summarized in Table 16 below.

Table 16: Summary of Stream Restoration Credits for Individual Restoration Projects from "Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects"					
Protocol #	**Name**	**Units**	**Pollutants**	**Method**	**Reduction Rate**
1	Prevented Sediment	Pounds per year	TSS TN, TP	Define bank retreat using BANCS or other method	Measured N/P content in streambed and bank sediment
2	Instream Denitrification	Pounds per year	TN	Define hyporheic box for reach	Measured unit stream denitrification rate
3	Floodplain Reconnection	Pounds per year	TSS TN, TP	Use curves to define volume for reconnection storm event	Measured removal rates for floodplain wetland restoration projects
4	Regenerative Stormwater Conveyance	Pounds per year	TSS, TN, TP	Define the drainage area and the depth volume reduction	Application of removal curves

The **prevented sediment** protocol requires the user to take the following steps:

1. Determine the restored length of the stream.
2. Estimate stream sediment erosion rates.
3. Convert erosion rates to sediment, nitrogen, and phosphorus loadings.
4. Determine reduction attributed to restoration (typically 50% unless monitoring shows otherwise).

The equations required to perform these calculations are provided in the Expert Panel document and are included in the IP Modeling Tool.

The **instream denitrification** protocol applies to stream restoration projects where in-stream design features are incorporated to promote biological nutrient processing, with a special emphasis on denitrification. Qualifying projects receive credit under Protocol 1 (Prevented Sediment) and use this protocol to determine enhanced nitrogen removal through denitrification within the stream channel during base flow conditions.

The instream denitrification protocol requires the user to take the following steps:

1. Determine the total post construction stream length that has been reconnected using the bank height ratio of 1.0 or less.
2. Determine the dimensions of the hyporheic box where denitrification is assumed to occur according to the protocols in the Expert Panel document.
3. Multiply the hyporheic box mass by the unit denitrification rate (1.06 x 10-4 pounds/ton/day of soil). This provides an estimate of the TN reduced through the stream restoration project.
4. Compute the annual N load for the watershed. If the TN credit calculated in step 3 exceeds 40 percent of the watershed TN load, then the load reduction is adjusted to 40 percent of the watershed TN load.

The **floodplain reconnection** protocol provides an annual mass sediment and nutrient reduction credit for qualifying projects that reconnect stream channels to their floodplain over a wide range of storm events. Qualifying projects receive credit for sediment and nutrient removal under Protocol 1 (Prevented Sediment) and denitrification in Protocol 2 (if applicable) and use this protocol to determine enhanced sediment and nutrient removal through floodplain wetland connection.

The floodplain reconnection protocol requires the user to take the following steps:

1. Estimate the floodplain connection volume in the available floodplain area.
2. Estimate the nitrogen and phosphorus removal rate attributable to floodplain reconnection for the floodplain connection volume achieved.
3. Compute the annual N, P and TSS load delivered to the project.
4. Multiply the pollutant load by the project removal rate to define the reduction credit.

The specific calculations and curves for this protocol are summarized in the Expert Panel document.

Appendix C, Stream Erosion Methodology, discussed how in-stream erosion was included in the existing TMDLs in the District. As described in Appendix C, in-stream erosion has been assigned as a nonpoint source load with respect to TMDLs in the District, with the exception of the Chesapeake Bay TMDL, in which in-stream erosion was accounted as part of the MS4 WLA. This exception is due to the fact that the Chesapeake Bay segment sheds account for land differently than do the other TMDLs in the District. In contrast to local (non-Chesapeake Bay) TMDLs, which identify MS4 area from direct drainage area on a fine scale, the Chesapeake Bay TMDL does not break out MS4 area from direct drainage area at the same fine scale. Instead, it aggregates all land in the MS4 sewershed as MS4 area, whether or not the area is served by MS4 pipes or not. Therefore, with respect to the Chesapeake Bay TMDL, in-stream erosion from streams within the MS4 area are considered as part of the MS4 load.

This categorization of in-stream erosion as part of the Ms4 load versus the nonpoint source load has ramifications for the stream restoration BMP. Because one of the main purposes of stream restoration is to address in-stream erosion, it is important to determine what load (MS4 WLA or nonpoint source LA) stream restoration will reduce. Based on the discussion above, stream restoration projects will reduce load from the nonpoint source LA, except in the case of the Chesapeake Bay TMDL, for which stream restoration projects will reduce load from the MS4 WLA.

The TMDL IP Modeling Tool will be designed to accept input for all of the required data for each of these protocols and will perform the load reduction calculations such that potential load reduction can be calculated for all protocols that apply to a given stream restoration project.

Internal tracking data on completed and planned stream restoration projects in the District was used as the basis to determine existing and projected load reduction from stream restoration projects. The internal data included the name of the stream reach, the amount of linear feet included in the project, and the date. For completed projects, the date indicates the year in which the project was completed. For planned projects, the date is the year in which the project is expected to be completed. The date data will be used to determine when in the planning cycle load reduction credit should be taken for that project.

3.2.c Street Sweeping

Description and Pollutants Targeted

Street sweeping removes dirt, debris, and trash that has accumulated on streets. Research summarized by CWP (2006) indicates that the source of pollutants that accumulate on street surfaces include run-on, atmospheric deposition, vehicle emissions, breakup of the street surface, littering, sanding, and other depositional mechanisms. CWP also notes that the "street dirt" (defined as the sediment or particulate matter found on the street surface [and any associated pollutants] that are washed off by a storm event) component of the material accumulating on the streets is "generally accepted as a major source of pollutants in stormwater" and that studies "have analyzed street sediment and found measurable quantities of nutrients, metals, hydrocarbons, bacteria, pesticides, organochlorine and other toxic chemicals (e.g. PCBs and PAHs)." Street sweeping results in direct removal of these potential pollutants from the environment, thereby reducing the pollutants that are available to accumulate in runoff and be discharged to District waterbodies.

The District has also identified street sweeping as an important BMP for removing trash and meeting the Trash TMDL in the Anacostia watershed. The methodology for modeling load reduction for trash is discussed in a separate sub-section below.

There are several street sweeping technologies available, with the primary methods being mechanical cleaning (e.g., through the use of brushes) and vacuum cleaning. Currently, DPW uses mechanical street sweepers.

Methodology for Modeling Load Reduction

The methodology described by the Chesapeake Bay Program will be used to account for street sweeping for pollutant load reduction in the IP Modeling Tool. Use of the Chesapeake Bay Program methodology is beneficial for the several of the same reasons cited for stream restoration above, including the fact that the method is well vetted and should be acceptable to stakeholders.

The Chesapeake Bay Program approved methodology for street sweeping is limited to approved removal rates for TN, TP, and TSS. However, as noted above, street dirt is also a source of metals, organics, bacteria, and other pollutants, and this street sweeping can reduce loads of these pollutants as well. Partition coefficients related to TSS removal are used to quantify removal of these other pollutants, as discussed in Section 3.1.d, Structural BMP Modeling, above.

The Chesapeake Bay Program has approved two different methodologies for accounting for load reduction from street sweeping: the Qualifying Lane Miles approach and the Mass Loading Approach. Each method is discussed below[3].

The Qualifying Lane Miles approach provides load reduction for roads that are swept at least 25 times per year. As described in the Chesapeake Bay Program Documentation for Scenario Builder Version 2.4 describes, "the regularity of the street sweeping…reduces nitrogen, phosphorus, and sediment whereas less regular street sweeping reduces only sediment." The Qualifying Lane Miles approach requires the following:

1. Report # qualifying lane miles swept per year.
2. Convert lane miles to acres. The conversion is done by assuming that street sweepers sweep a 10 foot-wide swath of roadway during sweeping operations (if both sides of the street are swept, this can be changed to 20 feet). The 10 foot (or 20 ft) width is multiplied by the number of qualifying lane miles to quantify square feet, and then divided by 43,560 to convert square feet to acres.
3. Calculate baseline TN, TP, and TSS loads in lbs per acre for the swept areas using the Simple Method and the appropriate EMCs for the watershed being swept

[3] The Expert Panel is in the process of evaluating street sweeping for potential changes in load reduction. The Panel prepared a memo on Street Sweeping/BMP Era Recommendations on March 1, 2011. However, the recommendations in this memo have not been officially adopted, and the methodology described herein and used in the IP Modeling Tool reflects the official information in the Chesapeake Bay Program Documentation for Scenario Builder Version 2.4 (revised January 2013) and the Chesapeake Assessment Scenario Tool (CAST), which was accessed on-line ion May 2014.

4. Calculate the total load for the area swept (in lbs) by multiplying the number of acres calculated in Step 2 by the loading rate per acre calculated in Step 3
5. Use Table 17 below to calculate reductions

Table 17: Percent Removal of Pollutants Though Street Sweeping for Qualifying Lane Miles			
Technology	**TSS**	**TN**	**TP**
Mechanical	10	4	4
Vacuum	25	5	6

6. Because the Qualifying Lane Miles approach is based on qualifying lanes being swept at least 25 times/yr, the removal rate is in lbs/yr.

The District Department of Public Works (DPW) currently employs mechanical sweepers for street sweeping, and therefore the "Mechanical" row in this table will be used to calculate load reductions.

The Mass Loading Approach uses the actual mass of material removed through street sweeping and applies factors to calculate the mass of pollutants removed. In this method, the amount of "street dirt" removed by street sweeping from streets swept at least 25 times per year is quantified ("street dirt" is defined under the *Description and Pollutants Targeted* section above). Load reduction is calculated as follows:

1. Quantify the "street dirt" component of the street sweepings by removing trash and larger debris. The "street dirt" is considered to be TSS, so the entire quantity of street dirt is considered TSS removed
2. Multiply the TSS (in lbs) by 0.00175 to calculate the TN removed (in lbs)
3. Multiply the TSS (in lbs) by 0.0007 to calculate the TP removed (in lbs)
4. This calculation is done on an annual basis, and thus the removal rate is expressed in lbs/yr.

The DPW does regular street sweeping, including daytime operations in signed and unsigned areas, and nighttime operations in the downtown core and highways. Records from street sweeping operations include the date, the route number, the number of miles swept and the tons of debris collected. However, the tons of material swept includes non-street dirt components, such as trash, debris, and larger items. Therefore, the Mass Loading approach cannot currently be used to quantify the impact of street sweeping, and the Qualifying Lane Miles approach is used.

Street sweeping is done for a number of different types of routes, including "signed," "unsigned," highway/arterial, and downtown/business district routes. Good data on street sweeping frequency and locations is available for signed routes, which make up only 56 miles of the approximately 966 miles in the MS4. Minimal data on street sweeping is available for the remainder of the MS4. For example, street sweeping on unsigned routes is opportunistic and can vary day-to-day. DPW does not currently track the specific areas that are swept as part of unsigned routes. This is important for purposes of load reduction modeling, because current criterion for accounting for load reductions from street sweeping established by CBP for the Chesapeake Bay TMDL require that streets must be swept a minimum of 26 times per year (i.e., bi-weekly), or the swept debris must be weighed, in order to receive credit for load reduction. The lack of existing data on "unsigned," highway, and downtown routes made it difficult to verify whether any particular street swept on these routes met the relevant criteria for inclusion for load reduction . Therefore, street sweeping on these routes do not currently qualify for load reduction. Altogether a total of 36 "signed" routes met the criteria of being swept at least 26 times during 2012. These routes make up close to 90 percent of the signed route mileage in the MS4. Improved data collection on "unsigned," highway, and downtown routes in the future may allow the District to receive additional load reduction credit from this activity in the future. Routes are most dense in the CSS, so the addition of routes in the MS4 may be an opportunity for further load reduction credits.

In order to determine the qualifying lane miles to be used in the IP Modeling Tool, the following approach was used. First, street sweeping data for 2012 was received from DPW and reviewed to determine its feasibility for use in the Tool. Data included the type of operation (daytime vs. nighttime; highway, downtown, signed, or unsigned area; route ID; day and time that the route was swept; and the number of miles that were swept). GIS files containing information on the location of the routes was also received from DPW. Only data from the daytime operations in signed areas had sufficient resolution (i.e., sufficient data on the length of the route, the location of the route, and the number of times that the entire route was swept on an annual basis) in order to be included for this approach. The length of each daytime signed route was determined through a comparison of the route lengths reported by DPW and an analysis of the GIS data provided by DPW. GIS information on the route data and locations were provided in the form of GIS polylines. Each route had multiple polyline fragments with individual lengths and attributes. Lengths of each fragment were calculated, and fragment lengths were summed for each route to acquire a route length. In the majority of cases, the routes were longer according to the GIS calculated lengths. In order to make the comparison and determine the appropriate route length to use in the IP Modeling Tool, each polyline (route) fragment was sorted by its location and type of drainage area it belonged (i.e.: CSS, MS4, or DD). Within each drainage group, if the full route of each fragment had been swept at least 25 times in 2012, then the length of the fragment was multiplied by a multiplier, which was calculated as the given mileage as a percent of GIS mileage. Finally, adjusted fragment lengths were summed for each segment. Results are shown for adjusted and unadjusted lengths (Tables 18 and 19). These values represent the mileage that can be credited for load reductions.

Table 18: Swept Mileage in Direct Drainage Areas

DD Mileage Summary			
Segment	**ID**	**Miles**	**Miles (with multiplier)**
Anacostia Lower	2	0.00	0.00
Anacostia Upper	4	0.22	0.18
ANATF_DC	6	0.00	0.00
ANATF_MD	8	0.00	0.00
Battery Kemble Creek	40	0.00	0.00
Broad Branch	62	0.00	0.00
C&O Canal	42	0.00	0.00
Dalecarlia Tributary	44	0.00	0.00
Dumbarton Oaks	64	0.00	0.00
Fenwick Branch	66	0.00	0.00
Fort Chaplin Tributary	10	0.00	0.00
Fort Davis Tributary	12	0.00	0.00
Fort Dupont Tributary	14	0.00	0.00
Fort Stanton Tributary	16	0.00	0.00
Foundry Branch	46	0.00	0.00
Hickey Run	18	0.00	0.00

Table 18: Swept Mileage in Direct Drainage Areas			
DD Mileage Summary			
Segment	ID	Miles	Miles (with multiplier)
Kingman Lake	20	0.00	0.00
Klingle Valley Run	68	0.00	0.00
Lower Beaverdam Creek	22	0.00	0.00
Luzon Branch	72	0.00	0.00
Melvin Hazen Valley Branch	74	0.00	0.00
Nash Run	24	0.00	0.00
Normanstone Creek	76	0.00	0.00
Northwest Branch	26	0.00	0.00
Oxon Run	28	0.00	0.00
Pinehurst Branch	78	0.00	0.00
Piney Branch	80	0.00	0.00
Pope Branch	30	0.00	0.00
Portal Branch	82	0.00	0.00
Potomac Lower	48	0.00	0.00
Potomac Middle	50	0.00	0.00
Potomac Upper	58	0.00	0.00
POTTF_DC	52	0.00	0.00
POTTF_MD	54	0.00	0.00
Rock Creek Lower	70	0.23	0.15
Rock Creek Upper	86	0.00	0.00
Soapstone Creek	84	0.00	0.00
Texas Avenue Tributary	32	0.00	0.00
Tidal Basin	56	0.00	0.00
Washington Ship Channel	60	0.00	0.00
Watts Branch	34	0.00	0.00
Watts Branch - Lower	36	0.00	0.00
Watts Branch - Upper	38	0.00	0.00

Table 19: Swept Mileage in MS4 Area			
MS4 Mileage Summary			
Segment	ID	Miles	Miles (with multiplier)
Anacostia Lower	2	0.67	0.58
Anacostia Upper	4	36.20	31.53
ANATF_DC	6	32.27	27.07
ANATF_MD	8	4.35	3.63
Battery Kemble Creek	40	0.00	0.00
Broad Branch	62	0.00	0.00
C&O Canal	42	0.00	0.00
Dalecarlia Tributary	44	0.00	0.00
Dumbarton Oaks	64	0.00	0.00
Fenwick Branch	66	0.00	0.00
Fort Chaplin Tributary	10	0.22	0.20
Fort Davis Tributary	12	0.00	0.00
Fort Dupont Tributary	14	0.00	0.00
Fort Stanton Tributary	16	0.36	0.32
Foundry Branch	46	0.00	0.00
Hickey Run	18	0.22	0.16
Kingman Lake	20	1.60	1.21
Klingle Valley Run	68	0.00	0.00
Lower Beaverdam Creek	22	0.00	0.00
Luzon Branch	72	1.53	1.48
Melvin Hazen Valley Branch	74	0.00	0.00
Nash Run	24	0.00	0.00
Normanstone Creek	76	0.00	0.00
Northwest Branch	26	4.35	3.63
Oxon Run	28	9.31	8.14
Pinehurst Branch	78	0.00	0.00
Piney Branch	80	0.00	0.00
Pope Branch	30	0.44	0.39
Portal Branch	82	0.00	0.00
Potomac Lower	48	9.60	8.39
Potomac Middle	50	1.33	0.01
Potomac Upper	58	0.00	0.00
POTTF_DC	52	11.49	10.22
POTTF_MD	54	0.00	0.00

Table 19: Swept Mileage in MS4 Area			
MS4 Mileage Summary			
Segment	ID	Miles	Miles (with multiplier)
Rock Creek Lower	70	0.00	0.00
Rock Creek Upper	86	1.90	1.84
Soapstone Creek	84	0.00	0.00
Texas Avenue Tributary	32	0.24	0.21
Tidal Basin	56	0.00	0.00
Washington Ship Channel	60	1.33	0.01
Watts Branch	34	21.38	19.02
Watts Branch - Lower	36	0.37	0.32
Watts Branch - Upper	38	21.01	18.71

For each of the watersheds shown in Tables 18 and 19, the mileage in the "Mileage (with Multiplier" column is used in the Qualifying Lane Miles approach calculations summarized above to determine the number of pounds per year of TSS, TN, and TP removed from street sweeping in that watershed. Load reductions were calculated for both the MS4 and direct drainage areas in each watershed. Note that the mileage was zero in some watersheds if no qualify lane miles were swept at least 25 times in that watershed in 2012.

While the Qualifying Lane Miles approach is currently used in the IP Modeling Tool, if the street dirt component of street sweepings can be determined in the future, the Mass Loading approach may be used in the future. One advantage of using the Mass Loading Approach is that it is a more direct measure of the impact of street sweeping on pollutant removal than is the Qualifying Street Lanes approach.

Street Sweeping for Trash Removal

Street sweeping has been identified as a BMP for trash removal in the *Anacostia River Watershed Trash TMDL Implementation Strategy* (December 2013). For the purposes of trash removal, specific "environmental hotspots" (e.g. blocks found to contain high trash amounts). Trash removal is calculated as follows:

1. The total area of roadways within the environmental hotspots is calculated in acres.
2. This area is then multiplied by 50 percent because the hotspot areas are unsigned and therefore only approximately half of the roadway (the middle of the road) is swept in these areas.
3. The area is then multiplied by the trash loading coefficient of 31.12 lbs/acre developed for the trash TMDL to generate a total mass loading value in lbs/acre.
4. That total mass in pounds is then multiplied by 16 since DPW sweeps environmental hotspots twice per month, 8 months per year.
5. To be conservative, this result is then multiplied by 50 percent because not all hotspots may be routinely swept.

3.2.d Storm Drain Catch Basin/Inlet Cleaning

Description and Pollutants Targeted

Storm Drain catch basin/inlet cleaning is similar to street sweeping in that it is a BMP designed to remove pollutants that have accumulated in the watershed. However, in contrast to street sweeping, which focuses on collecting material that has accumulated on streets, catch basin cleaning focuses on removing material that has been washed off streets and into storm drains. The material retained in catch basins can vary widely based on many factors including the design of the catch basin, the land use of the surrounding area, and the frequency of street sweeping in the catchment, among other factors. Catch basin design is an important factor in capturing materials washed off the streets, because storm drains designed with sumps capture more material than those without sumps. A literature review by the CWP (2006) also summarizes findings that "the pollutant removal capability of catch basins is fundamentally constrained by the design which retains coarse grained sediments but bypasses finer grained sediment that typically contains higher concentrations of nutrients and metals." The land use of the surrounding area is important, and multiple researchers have found different loading rates associated with different land use types. Finally, the frequency of street sweeping is important because more frequent street sweeping can removed the materials that would otherwise enter storm drains.

Pitt (1985, as cited in CWP 2006) found that accumulation studies show that the amount of polluted sediment in the storm drainage system (inlets and catch basins) is about twice the amount on the streets at any given time. Measured catch basin accumulation rates in swept catchments are about 40-80 lb/acre/yr in residential catchments where the higher rate is due to catch basins located on, or just downstream from, uncurbed streets with significant off-street sediment sources. In the same study, inlet accumulation rates were about half of catch basins ranging from 24-32 lb/acre/yr. Law. et. al., (2008) did a study in Baltimore County, MD and found that material removed from the inlets consisted largely of sediment and leaves where, on average 52 percent of the material accumulated was leaves, 39 percent was sediment, and 9 percent was trash. Particle size-distribution for the inlet material was found to be similar to the distribution for "street dirt" that was discussed in the *Street Sweeping* section above. Both the literature review and the Baltimore County study show that pollutants accumulated in storm drains include nutrients, metals, and TSS. Nutrients are associated with both the organic leaf material and also with the sediments. While some metals are also retained in the storm drains, metals are typically associated with small particle sizes, which are not retained efficiently in storm drains (Lager, 1977, as cited in CWP 2006).

Methodology for Modeling Load Reduction

While the studies cited in the sub-section above provide a good amount of information on materials accumulated in storm drains, overall, there is not much information on the impact of storm drain cleaning on pollutant removal. As described in the Chesapeake Bay Program Documentation for Scenario Builder Version 2.4 (revised January 2013), "only a few ... studies provide sufficient data to statistically determine the impact of ... storm drain cleanouts on water quality and to quantify their improvements. Therefore, the CBP has not approved storm drain cleaning for load reduction for the Chesapeake Bay TMDL. However, storm drain cleaning is often discussed along with street sweeping in CBP-related documents, and thus there is some information on approaches to quantifying the impacts storm drain cleanout from CBP. Specifically, the Expert Panel memo on Street Sweeping/BMP Era Recommendations (2011) has a "Note on Catch Basin Cleaning" which states that "the projected nutrient reduction associated with an enhanced storm drain cleanout program would be computed using the mass loading approach described in ... this memo." The Mass Loading Approach was described for street sweeping above. Again, as with street sweeping, the Mass Loading Approach is focused on removal rates for TN, TP, and TSS. However, as noted above, partition coefficients related to TSS removal will be used to quantify removal of these other pollutants, as discussed under the structural BMP discussion above.

With respect to catch basin cleaning, the Mass Loading Approach uses the estimates of the mass of material removed through catch basin cleaning and applies factors to calculate the mass of pollutants removed. In this method, the amount of "street dirt" removed by street sweeping from streets swept at least 25 times per year is quantified ("street dirt" is defined under the *Description and Pollutants Targeted* section above). Load reduction is calculated as follows:

1. Quantify the "street dirt" component of the street sweepings by removing trash and larger debris. The "street dirt" is considered to be TSS, so the entire quantity of street dirt is considered TSS removed
2. Multiply the TSS (in lbs) by 0.00175 to calculate the TN removed (in lbs)
3. Multiply the TSS (in lbs) by 0.0007 to calculate the TP removed (in lbs)

DC Water cleans every catch basin in the District an average of once annually. However, the District does not currently have information on the amount of debris removed from catch basin cleaning; thus the benefits of this source control measure cannot be quantified numerically. Therefore, this BMP cannot currently be included in the IP Modeling Tool. Improved data collection on the amount of debris removed from catch basin cleaning may allow the District to take load reduction credit from this activity in the future. A pilot project that evaluated catch basin cleaning and quantified the amount of debris removed from catch basin cleaning would allow inclusion of this BMP in future load reduction modeling efforts.

3.2.e Pet Waste Removal

Description and Pollutants Targeted

Pet waste is an important contributor to pollutant loads in an urban environment. One of the main ways that pet waste loading can be reduced is to increase the amount of pet waste that pet owners pick up and dispose properly. This requires a behavior change in pet owners who do not typically clean up after their pets. There are multiple ways to encourage this type of behavior change, including public education and outreach, and also through provision of designated dog parks where bags for cleaning up pet waste are provided on-site. Recent research has focused on estimating behavior changes in people using dog parks – primarily in estimating the increase in people who pick up after their pets if they use dog parks, and the corresponding decrease in pet waste that is available to be washed into receiving waters. These behavior changes and the corresponding decreases in pet waste that can enter receiving waters can be quantified to determine load reduction.

Methodology for Modeling Load Reduction

CWP's Watershed Treatment Model (WTM) includes a methodology for quantifying load reductions from increased pet waste removal. This methodology quantifies load reductions for nitrogen, phosphorus, and bacteria. The WTM methodology focuses on the use of generic "pet waste program" that projects reduction in pet waste through public education. The WTM methodology estimates the impact of the public education program in terms of the percent of people who walk their dogs but do not pick up after them. The public education program is assumed to decrease the number of people who do not pick up after their dogs, thereby reducing the amount of pet waste that can be washed into receiving waters. However, there is not much quantification data to evaluate the accuracy of these estimates. In a separate study for the City of Richmond, VA (CWP 2013), CWP modified this methodology to focus on behavior changes for people using dog parks. The modification focusing on dog parks quantified the number of bags used at dog parks. When combined with an estimate of the percentage of people who modify their behavior and pick up after their dog when they are at a dog park, but who would not normally pick up after their dog if they were not at a dog park, this methodology quantifies the behavior change associated with increased pet waste pick-up, and the associated load reduction from this increased pick-up.

Specifically, the calculation is as follows:

> Pet waste removed = # pet waste bags used * # lbs waste generated/ dog/ day * Concentration of pollutant in dog waste * % Daily waste captured/bag * % delivered to stream * % of bags used to properly dispose of waste * 365 day/yr * % of dog walkers who rarely clean up after pets

Where:

- # pet waste bags used – this is the one variable piece of data in the equation. This is a reported value that attempts to measure the use of dog parks by pet owners
- # lbs waste generated/dog/day – the WTM uses a value of 0.32 lbs waste/dog/day, and this value was retained for us in the IP Modeling Tool. This is a literature-based value.
- Concentration of pollutant in dog waste - the WTM uses values of 0.23 lbs TN, 0.01 lbs TP, and 1E+10 colonies of bacteria per lb of dog waste. Those values were retained for the purposes of the IP Modeling Tool.
- % Daily waste captured/bag – the WTM estimates that 33 percent of a dog's daily waste is captured when it is picked up in a bag, and this value was retained for us in the IP Modeling Tool.
- % delivered to stream – these are standard delivery ratios of 0.25 for TN, 0.75 for TP, and 0.35 for bacteria. These values were retained for us in the IP Modeling Tool.
- % of bags used to properly dispose of waste – the WTM uses a value of 0.75, and this value was retained for us in the IP Modeling Tool. This factor is an estimate based on literature values that attempts to account for the fact that not all bags used at dog parks are used to dispose of pet waste. Some may be taken and not used; some pet waste may use more than one bag, etc., and this factor accounts for these circumstances.
- 365 day/yr – this is a conversion factor to convert from daily measures of pet waste production to the annual expression of load removal
- % of dog walkers who rarely clean up after pets - the WTM uses a value of 0.40, and this value was retained for us in the IP Modeling Tool. This factor is an estimate based on literature values that attempts to account for the increase in people that pick up after their pets when using a dog park, but would not otherwise clean up after their pets if they did not use dog parks. Thus, this factor makes this calculation into a true load reduction because it accounts for the behavior change in people using dog parks and discounts the load removed to account for people who would clean up after their dogs anyway (and thus who never contribute to the pollutant load in the first place). Specifically, the factor indicates that 40% of the people using bags at dog parks would not otherwise clean up after their pets, and thus this is an actual load removal, while the remaining 60% of the people using dog parks would clean up after their pets even if they did not use dog parks, so their use of bags at dog parks should not be considered true load removal.

A list of existing and planned/proposed dog parks in the District is provided in Table 20. These parks are managed by the District Department of Parks and Recreation (DPR), but are run on a day to day basis by local user organizations (e.g., Shaw Dog Park Association Committee; Newark Street Park K-9 Friends).

DPR does not track bag usage at the parks. Discussions with DPR indicate that the dog parks are provided with an initial supply of bags by DPW, but thereafter, bags must be supplied by the local users. Subsequent exchanges with several user organizations (including the Shaw Dog Park Association Committee and the Langdon Dog Park Association) indicate that the local user organizations do not track bag usage either. In many cases, they receive donated bags from third parties, such as the Friendship Animal Hospital, but the quantity of these donations is not tracked. Therefore, it is not currently possible to quantify the impact of this BMP.

Table 20: Existing and Planned/Proposed Dog Parks and Drainage Locations

Name	Ward	Address	Drainage
Existing Dog Parks			
Gage - Eckington Dog Park	1	286 V Street, NW	CSS
Walter Pierce Dog Park	1	20th Street, NW and Calvert Street, NW	Direct Drainage
S Street Dog Park	2	S Street, NW and 17th Street, NW	CSS
Shaw Dog Park	2	11th Street, NW and Rhode Island Avenue, NW	CSS
Chevy Chase Dog Park	3	41st Street, NW and Livingston Street, NW	MS4
Guy Mason Dog Park	3	3600 Calvert Street, NW	MS4
Newark Street Dog Park	3	39th Street, NW and Newark Street, NW	MS4
Upshur Dog Park	4	4300 Arkansas Avenue, NW	CSS
Langdon Dog Park	5	2901 20th Street, NE	MS4
Kingsman Dog Park	6	D Street, NE & Tennessee Avenue, NE	CSS
Planned/Proposed Dog Parks			
Lansburgh Dog Park	6	Delaware Avenue, SW (between I and M Sts)	CSS
Francis Dog Park	2	25th & M Street, NW	CSS
Virginia Avenue Dog Park	6	11th Street & Virginia Avenue, SE	CSS

It may be possible to track load reductions from this BMP in the future if bag usage is tracked and reported in the future. The number of bags used per park would then be used in the IP Modeling Tool to calculate annual load reductions of TN, TP and bacteria from pet waste removal using the calculation described above. This annual load reduction would then be assigned to the TMDL watershed or watersheds in which that specific dog park is located.

3.2.f Illicit Discharge Detection and Elimination

Description and Pollutants Targeted

Illicit Discharge Detection and Elimination (IDDE) is a standard MS4 NPDES requirement that requires MS4 permittees to do annual, systematic field investigations of their MS4 system to find and eliminate illicit/illegal discharges. These illicit discharges can be sources of pollutants to receiving waters, and thus by eliminating these discharges, the permittee eliminates pollutant loads to streams. The types and amounts of pollutant loads that can be eliminated by an effective IDDE program are dependent on the types of illicit discharges that are detected and eliminated through the program. Therefore, eliminating these discharges would remove these types of pollutants from the system.

Section 4.7 of DDOE's MS4 permit summarizes requirements with respect to IDDE. Section 4.7.1 states that DDOE will "implement an ongoing program to detect illicit discharges…and to prevent improper disposal into the storm sewer system." The permit then describes the requirements for the IDDE program, which include:

- Continue to implement an illicit connection detection and enforcement program to perform dry weather flow inspections in target areas.
- Visual inspections of targeted areas.
- Tracking and reporting illicit discharges, and reporting progress on stopping targeted illicit discharges, and in appropriate cases, chemical testing immediately after discovery of an illicit discharge.
- All necessary inspection, surveillance, and monitoring procedures to remedy and prevent illicit discharges.
- The permittee shall submit an inspection schedule, inspection criteria, documentation regarding protocols and parameters of field screening, and allocation of resources as a part of each Annual Report.

The District maintains an illicit discharge program designed to detect and eliminate illicit discharges within the District. DDOE conducts dry weather field screening of all sewersheds as required by its NPDES MS4 permit. The inspection program includes approximately 600 identified outfalls that are inspected at least once every five years. The inspection schedule for individual outfalls is based on priority, which is in turn based on whether the outfall is within an identified common "problem area," whether there is continual flow, etc. High priority outfalls are inspected every 6 months. As described in the 2014 MS4 Annual Report, in FY2014 DDOE staff conducted 46 illicit discharge investigations. Appendix A.3 of the 2014 Annual Report summarizes the specifics of these investigations and identifies pollutants such as oil, paint, sewage, unspecified chemicals, and other types of pollutants as part of these discharges.

Researchers have acknowledged IDDE programs as potential BMPs to achieve load reduction to meet TMDL implementation requirements. Chesapeake Stormwater Network (CSN) and the CWP have published several articles and given several presentations on how an IDDE program may be used as a BMP to achieve load reduction. An Expert Panel was convened in July 2012 to evaluate the use of this BMP for the Chesapeake Bay TMDL. The charge of the Expert Panel was to review the available literature and determine if (and how) a load reduction credit could be developed for IDDE. However, no additional documentation of the work of the Expert Panel has been identified and no recommendations have been issued by the Panel.

Methodology for Modeling Load Reduction

The proposed methodology for using IDDE for load reduction follows the protocols outlined by CSN (2011). Under this protocol, expanded data collected through the existing IDDE program is used to calculate loads removed through eliminating illicit discharges. Presentations by CWP (2012) provide further context by showing how historical data can be used to make future projections of the average amount of load removed through the IDDE program. This estimate of annual load removed can be incorporated into the IP Modeling Tool to project the impact of IDDE in future load reduction scenarios.

Specifically, the data needed for quantification of loads reduced by IDDE includes an estimate of the flow and a measurement of the pollutant concentration for each individual illicit discharge detected and eliminated. The load for each individual illicit discharge detected and eliminated can then be calculated based on the flow estimate and the pollutant concentration data. Estimates of flow and measurements of pollutant concentration are not currently collected during IDDE investigations, so IDDE protocols will have to be modified to collect these data in the future. However, once these data are collected, long term historical annual averages of pollutant loads eliminated through the IDDE program can be determined. These long term averages can then be used in the IP Modeling Tool to project pollutant load reductions from continuing IDDE programs in the future. Pollutant load reductions can be applied to certain watersheds based on where IDDE is being conducted in a given year.

As discussed above, specific recommendations for how to calculate load reduction credit for IDDE are still being reviewed by the Expert Panel. However, the CSN (2011) has published the following recommended process to collect sufficient data for establishing this load reduction credit:

1. The dry weather flow rate and nutrient concentrations should be measured at suspect outfalls identified during routine outfall screening.
2. The discharge should be tracked back up the storm drain system to its source, using the investigation methods provided by Brown et al (2004).
3. The flow rate and nutrient concentration from the source discharge should be monitored before and after the discharge is physically eliminated
4. Subsequent monitoring should be conducted at the original outfall to conform that dry weather nutrient concentrations have returned to background levels.
5. The nutrient credit is computed by multiplying the daily flow rate and nutrient concentration of the source discharge to derive a daily nutrient load. The daily load can then be multiplied by the number of days from when the suspect outfall was discovered and when the source discharge was physically eliminated.

CWP has expanded upon this protocol by focusing on the use of historic data to project future results of IDDE investigations. Thus, for the purposes of the Consolidated TMDL IP, it is recommended that the CWP modification of the CSN protocol be implemented to begin collecting the data necessary to establish IDDE as a future load reduction BMP. Once sufficient data has been gathered to determine long term average rates for illicit discharge elimination, the data can be used in the model to project pollutant load reductions from continuing IDDE programs in the future.

3.2.g Impervious Surface Removal

Description and Pollutants Targeted

Impervious surface removal is the practice of removing impervious surfaces and restoring the area to a more natural state. This is a practice that has been used by DDOT, for example, to convert impervious median lane dividers into grassy or planted median dividers. Impervious surface reduction typically requires not only for the impervious surface to be removed, but also for the underlying soil to be amended and restored to a less compacted form, and then planted with hardy, sometimes native, plants. Removing impervious surfaces results in less runoff generated from that surface, and as a result this BMP reduces the loads from all pollutants that are typically found in urban runoff.

Methodology for Modeling Load Reduction

The load reduction provided by this BMP is calculated as the difference between the load generated from the impervious surface and the load generated from the equivalent pervious surface. An example is provided below.

Example: calculate the annual TSS load reduction from removing 1 acre feet of impervious area in the Anacostia watershed. The EMC for TSS in the Anacostia is 73 mg/l and annual precipitation is 40 inches. The runoff coefficient for an impervious surface is 0.95 and for a pervious surface is 0.25.

Step 1: calculate the load generated by the impervious surface (see Appendix A, *Technical Memorandum: Model Selection and Justification* for more information on the runoff and load equations):

$$Runoff = \frac{P\ x\ P_j\ x\ R_{vc}}{12} \times A = \frac{40 * 0.9 * 0.95}{12} \times 1 = 2.85\ acre - ft$$

$$Load = R \times C \times 2.72 = 2.85\ \times 73 \frac{mg}{l} \times 2.72 = 566\ \text{lbs/yr}$$

Step 2: calculate the load generated by an equivalent pervious surface:

$$Runoff = \frac{P\ x\ P_j\ x\ R_{vc}}{12} \times A = \frac{40 * 0.9 * 0.25}{12} \times 1 = 0.75\ acre - ft$$

$$Load = R \times C \times 2.72 = 0.75\ \times 73 \frac{mg}{l} \times 2.72 = 149\ \text{lbs/yr}$$

Step 3: calculate the load reduction by subtracting the results of step 2 from step 1:

$$Load\ Reduction = \text{Load (impervious)} - Load\ (pervious) = 566 - 149 = 417 lbs/yr$$

3.2.h Coal Tar Pavement (Sealant) Removal

Description and Pollutants Targeted

Under the Comprehensive Stormwater Management Enhancement Amendment Act of 2008, effective July 1, 2009, it is illegal to sell, use, or permit the use of coal tar pavement products in the District. Violators of this ban are subject to a daily fine of up to $2,500. DDOE maintains a tip line for residents to report suspected use of coal tar, and DDOE follows up with inspections of suspected coal tar applications. If coal tar is identified at a site, it is required to be removed. As of December 2014, over 430,000 sq. ft. (approximately 10 acres) of coal tar had been removed over a 3 year period from 13 locations throughout the District. While it is not clear whether these coal tar installations existed when the original TMDLs were completed (and thus whether these installations contributed to the baseline PAH loadings included in the TMDLs, the load reduction from these removal efforts was included in the IP modeling tool and applied towards achieving MS4 WLAs for PAHs. The reasoning behind the inclusion of this load reduction despite the uncertainty of whether these specific installations of coal tar existed when the original TMDLs were completed, is that coal tar sealers have been used for many years, and pavement sealing is an ongoing activity that is done in many times per year in different locations as the need occurs. Thus it is likely that coal tar applications that were contributing PAHs to stormwater runoff were included in the EMCs used to develop the TMDLs and set MS4 WLAs. This ongoing contribution of PAHs from coal tar would be reflected in the fact that, as PAHs were depleted over time from one application through leaching, new sources were added as new coal tar applications were completed, thus keeping the concentrations and loads of coal tar constant over time. Thus it is appropriate to include removal of sources added after the completion of the TMDLs towards load reduction of PAHs, because it is likely that renewing sources (as opposed to static sources) were included in the original TMDL calculations.

Methodology for Modeling Load Reduction

DDOE has identified areas where coal tar sealant was removed. These areas are used to determine the PAH load reductions associated with those removal efforts. One of the challenges of estimating the removal of PAHs through removal of coal tar sealant was to determine how much of the PAHs in the sealant are ultimately picked up by stormwater. In other words, what is the concentration of PAHs in stormwater from coal tar sealant areas versus from urban areas without coal tar sealant. A study conducted by the USGS analyzed stormwater samples from coal-tar sealant parking lots and compared them with stormwater samples from other parking lots (Mahler, 2012). The results showed that stormwater from non-coal tar sealant parking lots had PAH concentrations that were approximately 93% lower than the PAH concentration in stormwater from coal tar sealant parking lots. It can therefore be expected that, by replacing the coal tar sealant with a non-coal tar sealant, the PAH concentration in stormwater can be reduced by approximately 93%. This removal rate was applied in the IP Modeling Tool to all areas where coal tar sealant was removed:

$$Annual\ Load\ Removed = \text{Annual PAH load from removed area } \times 93\%$$

The annual PAH loads from each area are calculated using the standard runoff and loads equations that are described in Appendix A, *Technical Memorandum: Model Selection and Justification* , and using the PAH EMCs that are described in Appendix D, *Technical Memorandum: Selection of Event Mean Concentrations (EMCs)*.

3.2.i Phosphorus Fertilizer Ban

Description and Pollutants Targeted

Fertilizers can be important sources of nutrients in an urban environment. Management of fertilizers in the District was implemented through the Sustainable DC Act of 2012, specifically Subtitle II(A) – Anacostia River Clean Up and Protection Fertilizer Act of 2012. This subtitle restricts the application of fertilizers, implements a public education program, imposes specific labeling requirements on manufacturers, and establishes a fine structure for violations. Restrictions on fertilizer application include that application must be beyond 25 feet from a waterbody, not during a heavy rainfall or when soil is saturated, only between March 1st and November 15th, and that only fertilizers with less than 0.67 percent phosphate by weight can be used. Additionally, fertilizers with nitrogen can only be applied at a rate of less than 0.7 pounds per 1,000 feet of water soluble nitrogen or less than 0.9 pounds per 1,000 square feet of total nitrogen. The public education program called for creation of a sheet for retailers that sell 50 pound or more bags of fertilizer and a general public awareness campaign addressing the proper application and management of fertilizer and the impact of fertilizer misuse on the environment. The labeling requirement required manufacturers to add information to their labels regarding how to apply fertilizer so as to minimize potential impact to the environment. Violators of the subtitle are subject to penalties for civil infractions.

The District set a 2015 milestone of 18,595 acres subject to total phosphorus reduction based on the District's Urban Phosphorus Legislation. Phosphorus legislation is an approved Chesapeake Bay BMP, and the district's 2013 reported progress on meeting this milestone was 17,211 acres.

Methodology for Modeling Load Reduction

The Chesapeake Bay Program "Recommendations of the Expert Panel to Define Removal Rates for Urban Nutrient Management" (Schueler, 2013) provides specific reduction rates for states where phosphorus is gradually being phased out of fertilizer production or for states who have implemented phosphorus legislation. For the district, the approved current reduction for phosphorus load is 21.2% for all pervious areas. In other words, the existing phosphorus loads from pervious areas can be multiplied by 21.2% to calculate the load reduction provided by this BMP:

$$Annual\ Load\ Removed = \text{Annual phosphorus load from pervious area } \times 21.2\%$$

In 2015, when the District is expected to adopt the phosphorus fertilizer ban legislation, the reduction will increase to 24.7%.

3.2.j Management of Construction Activities

DDOE maintains a plan review erosion control program for new construction, as well as a field inspection program reviews construction and grading plans for stormwater management, erosion and sediment control, and flood plain management considerations. As required by EPA, all new construction in the District must have SWPPPs that "identify all potential sources of pollution which may reasonably be expected to affect the quality of stormwater discharges from the construction site." DDOE also conducts educational training and compliance assistance for construction site operators during the site inspection process.

This activity is not currently quantified for load reduction credit in the IP Modeling Tool, and more research would need to be conducted to determine the feasibility of including load reduction from this activity into the IP Modeling Tool in the future.

3.2.k Vehicle Maintenance/Materials Storage/Municipal Operations

DDOE provides assistance to District agencies, including material storage facilities and equipment storage, in developing Stormwater Pollution Prevention Plans (SWPPPs) to better address spills and contingencies at their facilities. DPW has also purchased alternative fuel vehicles (AFVs) to reduce particulate vehicle emissions that contribute to stormwater runoff. DDOE continues to offer the "Environmental Compliance & Technical Assistance for Auto Service and Repair Shops" workshop to managers, owners, and employees of gasoline stations, repair shops, and maintenance garages.

This activity is not currently quantified for load reduction credit in the IP Modeling Tool, and more research would need to be conducted to determine the feasibility of including load reduction from this activity into the IP Modeling Tool in the future.

3.2.l Landscape and Recreation Facilities Management, including Pesticide, Herbicide and Fertilizer Management

DDOE is in the process of issuing rules under the District's Pesticide Education and Control Amendment Act of 2012 (PECA) to restrict pesticide applications, set up annual reporting requirements, set pesticide registration fees, and establish integrated management principles. DDOE is already conducting multiple programs with pesticide applicators. DDOE's Pesticide Management Program trains commercial applicators in the legal and safe appliance of pesticides and herbicides, while DDOE's Hazardous Materials Branch tracks certified pesticide applicators throughout the District.

This activity is not currently quantified for load reduction credit in the IP Modeling Tool, and more research would need to be conducted to determine the feasibility of including load reduction from this activity into the IP Modeling Tool in the future.

3.2.m Management of Industrial Facilities and Commercial and Institutional Areas

The management plan for stormwater pollution control from industrial facilities emphasizes the tracking of facilities through a database system, the monitoring and inspection of industrial facilities, and the District's spill prevention and response program.

DDOE maintains information of potential sources of stormwater pollution, including a database of construction sites and critical sources such as auto repair shops, dry cleaners, car washes, and other facilities. DDOE inspects critical sources and enforces on any violations. In addition, DDOE maintains a GIS database of industrial facility location data based on field verification, which includes 60 facilities within the MS4 service area that are part of NPDES, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and/or Resource Conservation and Recovery Act (RCRA) databases). The database includes facilities in the District that are registered with Federal and state regulators because they generate, store, or have released hazardous materials. DDOE's Hazardous Waste Division (HWD) inspects and monitors hazardous waste facilities in the District.

This activity is not currently quantified for load reduction credit in the IP Modeling Tool, and more research would need to be conducted to determine the feasibility of including load reduction from this activity into the IP Modeling Tool in the future.

3.2.n Public Education

DC Water, DDOT, DPW, and DDOE conduct public education activities related to stormwater pollution. The stormwater pollution control public education program entails a mixture of programs targeting multiple types of audiences, including businesses, homeowners and property managers, developers and engineers, and the general public. Examples of public education activities include a pet waste removal awareness campaign and storm drain stenciling. DDOE tracks and records stormwater related public education and outreach activities through a database operated and maintained by the Water Protection Division.

The impacts of education and outreach on stormwater management in general, and on load reduction to meet MS4 WLAs in particular, are difficult to quantify. DDOE has funded two studies on the impact of public education on stormwater issues, including a study to evaluate the impact that the Anti-Littering Campaign has affected littering behavior in the Anacostia watershed, as well as a comprehensive study measuring the impact of the District's Bag Law on disposable bag consumption rates. This second study sought to assess the public's experience with the Anacostia River Clean Up and Protection Act. DDOE is currently evaluating the potential to include load reductions attributable to public education and outreach in the implementation plan for the Anacostia Trash TMDL, but no specific quantification methodology has been determined. Based on the difficulty in assessing and quantifying the impacts of public education and outreach on load reduction, these activities are not currently quantified for load reduction credit in the IP Modeling Tool, and more research would need to be conducted to determine the feasibility of including load reduction from education and outreach into the IP Modeling Tool in the future.

3.2.o Hazardous Waste Collection

The District continues to provide household hazardous waste (HHW) collection, under which residents are able bring their HHW materials and unwanted electronics to collection points for proper disposal. DPW operates monthly HHW drop-off sites at the Ft. Totten Transfer Station where residents are able bring their HHW materials and unwanted electronics for proper disposal. In FY 2014, DPW collected:

- 182 tons of unwanted electronics for processing
- 62,175 total pounds of HHW

- 28,620 gallons of Flammable Liquid (Paints, Roofing Tar, Driveway Sealers, etc.)
- 8,000 pounds of waste pesticides solids (Insecticides)
- 11,000 pounds of flammable aerosols

It is likely that HHW collection removes potential pollutants, including metals and PAHs, from the MS4 area. However, it is not currently possible to quantify the pollutant load reduction of this program with respect to MS4 WLAs for several reasons, including:

- The concentrations or loads of individual TMDL pollutants removed through HHW collection is not determined through this program;
- The specific watersheds from which individual components of HGHW are removed is unknown, and thus even if the concentrations or loads of individual TMDL pollutants removed through HHW collection were known, these quantities could not be assigned against a specific watershed WLA;
- It is uncertain whether, if the HHW had not been collected, it would have been discarded in a manner such that pollutants from the HHW could have contaminated runoff and entered the stormwater system.

DDOE also focuses on pet waste program and continues to implement its education and outreach program entitled “Scoop Your Pet’s Poop.” This program is designed to inform citizens of their legal obligation to manage their pet’s waste and to explain the reasons why it is important to do so.

These activities are not currently quantified for load reduction credit in the IP Modeling Tool, and more research would need to be conducted to determine the feasibility of including load reduction from these activities into the IP Modeling Tool in the future. However, it is clear that HHW collection does indeed remove potential pollutants from the District, even though it is unclear by how much.

3.2.p Leaf Collection

Leaves and organic matter can be an important source of nutrients in an urban environment (U.S. EPA, 1999). The District conducts seasonal leaf collection to remove accumulated leaves and organic debris. The fall leaf collection program runs from the first week of November through the second week of January. DPW collects leaves at least twice from each residential neighborhood by “vacuuming” loose leaves residents rake into their treebox(es). In neighborhoods with alley trash/recycling collections, residents can bag leaves, and these will be collected In FY2014, 6,054 tons of leaves were collected through this program.

CBP has determined that leaf collection should not receive credit towards load reductions for the Chesapeake Bay TMDL. Data presented to the Expert Panel on BMP Review (Chesapeake Bay Program Expert Panel on BMP Review Meeting Minutes, January 10, 2014) suggests that nutrient leaching occurs within the first 24 hours of leaf fall, and thus periodic leaf collection does not capture nutrients. Therefore, to be consistent with the reporting under the Bay TMDL, no load reduction credit will be taken for the District’s leaf collection program.

3.2.q Plastic Bag Fee

The Anacostia River Clean Up and Protection Act of 2009, commonly referred to as the “Bag Law” requires all District businesses that sell food or alcohol to charge five cents for each disposable paper or plastic carryout bag. The ultimate goal of the law is to change consumer behavior by encouraging District residents to use reusable bags, thereby reducing bag pollution in waterways. Revenue is deposited into the Anacostia River Clean Up and Protection Fund, a special purpose fund managed by DDOE that is used to implement watershed education programs, stream restoration, trash retention projects and to purchase and distribute reusable bags. A series of surveys to measure the impact of the Bag Law were commissioned by DDOE in 2012-2013. Results of the survey indicate that both residents and businesses reported a significant reduction in disposable bag use across the District and substantial majorities of residents and businesses support the bag fee. In addition, both residents and businesses report seeing many less plastic bags as litter throughout the District.

DDOE quantifies the impact of the bag law and its impact on trash as part of the load reduction strategy for the Anacostia trash TMDL.

3.2.r Styrofoam Container Ban

Title IV Subtitle A of the Sustainable DC Omnibus Amendment Act of 2014 bans the use of plastic foam food and drink containers by January 1, 2016. The District's Anacostia Watershed Trash Reduction Plan (DDOE, 2008) had previously identified Styrofoam containers as one of the largest components of trash in the Anacostia, comprising approximately 10 percent of the trash in the mainstem Anacostia and 5 percent in the tributaries. The Styrofoam ban should help mitigate this problem.

3.2.s Other Existing Efforts

In addition to the programs mentioned above, DDOE tracks, operates, maintains and manages many existing District-owned BMPs. DDOE also sets design standards, inspects, and tracks BMPs installed in the District by private and federal entities. By setting standards and ensuring that BMPs are maintained in good working order, DDOE helps ensure that BMPs are designed properly and that they are functioning as designed. This in turn helps ensure that projected stormwater management and load reductions are achieved by these BMPs.

DDOE tracks all BMPs in a tracking database. Data collected in the database includes BMP type, location, owner, and total and impervious area controlled. By collecting these data, DDOE can calculate expected pollutant load reduction from each BMP. This is critical to modeling expected pollutant load reduction in each watershed, and can be used as input data into the IP Modeling Tool to evaluate whether or not watersheds are meeting MS4 WLAs.

3.2.t Development of an Existing Non-Structural BMP Database

The existing non-structural BMP data that was included in the IP Modeling Data was compiled in a consolidated database and includes the relevant information for each non-structural BMP. Since each non-structural BMP is characterized very differently, each non-structural BMP type is recorded in a separate table within the database. These tables provide a consistent format and schema for recording future non-structural BMP entries.

3.3 **Trash BMPs**

The Trash TMDL for the Anacostia River is unusual in that the WLAs established in the TMDL are expressed in lbs of trash removed per year (or lbs per day in the case of the daily expression of the WLA). Thus the effectiveness of the BMPs implemented for the Trash TMDL must be measured differently than the BMP effectiveness for other TMDLs, which are typically measured as percent removal or calculated based on the amount of runoff removed. Thus the "effectiveness" of individual trash BMPs is assessed directly through the amount of trash removed. In some cases, the amount of trash removed by a BMP is measured directly (e.g., skimmer boats, cleanup days), while in other cases, it is estimated based on related data (i.e., street sweeping, where trash removal is estimated using trash loading rates plus tracking the number of street miles swept; or the District Bag Law, where the impact is assessed by estimating the reduction in plastic bags used by businesses because of the law).

For the purposes of the Consolidated TMDL IP, the BMPs identified in the *Anacostia River Watershed Trash TMDL Implementation Strategy* (DDOE, December 2013) are used in the TMDL IP Modeling Tool. Current activities include a combination of end-of-pipe BMPs placed at MS4 hotspot outfalls, plus a variety of structural and non-structural controls where outfall retrofit is not feasible because of issues such as access and stability of the outfall. The list of BMPs and activities that remove trash includes:

- In-stream and end-of-pipe best management practices (e.g., trash traps)
- Skimmer boat activities
- Stream and river cleanup activities
- Roadway and block cleanup activities (such as the adopt-a-block program)
- Street sweeping of environmental hotspots
- Education and outreach (such as the Watershed Wide Anacostia Campaign)
- Regulatory approaches (such as the Bag Law)

Current trash removal strategies and the estimated amounts of trash removed by each practice are summarized in Table 21 below. Note that for some of the practices (e.g., Kenilworth Bandalong Litter Trap; James Creek Bandalong Litter Trap), the collected empirical data (i.e., the "Total Amount of Trash Actually Being Removed" column) was counted towards meeting load reductions. For other practices (e.g., Marvin Gaye Park Bandalong Litter Trap, sweeping of environmental hotspots; various clean-up activities), best professional judgment was applied to assess reductions through the use of load reduction factors. These factors, which are explained in the "Calculation Methodology" column, were used to calculate the load reductions summarized in the "Annual Load Reduction Counted" column and to evaluate against the MS4 WLA. The load reduction factors were used to help eliminate variables which could cause overestimates of efficiency. Thus the actual or estimated amount of trash removed through these BMPs is much larger than the amount of trash quantified to evaluate achievement of MS4 WLAs. This makes the estimates of trash removal conservative relative to the MS4 WLA. In addition, all trash removed from the Anacostia helps to improve the waterbody, whether or not it is "credited" as being removed from the MS4 area, the nonpoint source direct drainage area, or the CSO area. Therefore, implementation of the trash strategy and related BMPs will help to meet goals beyond MS4 WLAs.

For modeling purposes, the effectiveness of each trash BMP (and thus the effectiveness value used in the IP Modeling Tool) will be reflective of the average of the trash removed by each specific BMP, or the design expectations for the BMP. Thus, for individual existing trash traps, skimmer boats, street sweeping, the effectiveness will be the average of trash removal data for these individual BMPs. All trash modeling and trash TMDL implementation scenario development will be consistent with the Anacostia River Watershed Trash TMDL Implementation Strategy (DDOE, December 2013), at least until and unless this document is superseded by an updated planning document.

Table 21: Trash Removal Strategies for Anacostia Trash TMDL				
Activity Category	**Activity**	**Total Amount of Trash Actually Being Removed (pounds)**	**Annual Load Reduction Counted (pounds)**	**Calculation Methodology**
Trash Traps	Marvin Gaye Park Bandalong Litter Trap	1,296	26	Annual average value taken from empirical data collected between Jan 2012 and November 2014. The average amount of trash collected during this time period is multiplied by 2 percent since that is the approximate proportion of the Watts Branch watershed which lies within District and drains to the trash trap.
	River Terrace Trash Trap	256	256	Current total collected in 2014. Data was only collected during part of 2014.
	Kenilworth Bandalong Litter Trap	2,323	2,323	Annual average taken from empirical data collected between March 2011 and November 2014. No reduction factors are being applied since the entire drainage area above this trap lies within the District.
	Nash Run Trash Trap	2,126	1,595	Annual average taken from empirical data collected between 2009 and 2014. The total amount collected is then multiplied by 75% since that is the approximate proportion of the Nash Run watershed that lies within the District and drains to the trash trap.
	Hickey Run BMP	10,000	2,000	Based on assumed efficiency of 100 percent design capture of device. A reduction factor of 20 percent was applied since glass and plastic bottles may not have been emptied of water.
	James Creek Bandalong Litter Trap	184	184	Annual average taken from empirical data collected between January 2012 and November 2014. No reduction factors have been applied since the entire drainage area for this practice lies within the District.
	Earth Conservation Corps Trash Booms	1,475	124	Amount collected from trap in 2014. Annual average not taken for 2013 and 2014 data since only four months of data was collected in 2013. Reduction factors are applied since a portion of the trash collected is coming from the mainstem of the river. A reduction factor of 16.5% is applied since this the proportion of the Anacostia watershed which lies within the District. A second reduction factor of 50.8 % is applied to account for the District's portion of the Anacostia served by the MS4.

Table 21: Trash Removal Strategies for Anacostia Trash TMDL				
Activity Category	**Activity**	**Total Amount of Trash Actually Being Removed (pounds)**	**Annual Load Reduction Counted (pounds)**	**Calculation Methodology**
Roadway and Block Cleanups	Adopt-A-Block Program	425	85	All cleanup events accounted for are within the MS4 area of the Anacostia watershed. An assumed weight of 25 pounds per bag is applied to calculate the total weight of bags collected. Total weight of trash was multiplied by 20% to account for bottles and other containers not being emptied of water.
Sweeping Environ-mental Hotspots	Sweeping Environ-mental Hotspots	144,768	72,384	The total area of roadways within the environmental hotspots (e.g. blocks found to contain high trash amounts)[3] was calculated. That area was then multiplied by 50 percent because roughly half of the roadway (the middle of the road) is swept in these areas because they are unsigned. That area is then multiplied by the trash loading coefficient of 31.12 lbs/acre developed for the TMDL. That total mass in pounds is then multiplied by 16 since the DC Department of Public Works (DPW) is supposed to sweep environmental hotspots (i.e. blocks with high amounts of trash) twice per month, 8 months out of the year. That result is then multiplied by 50 percent because not all hotspots may always be swept.
Clean-Up Activities	Clean-Up Events	33,507	2,868	Based on empirical data collected during cleanup events within the District's portion of the Anacostia watershed. If a site is located along the mainstem of the river, a reduction factor of 16.5 percent is applied since this the proportion of the Anacostia watershed which lies within the District. A second reduction factor of 50.8 percent is applied to account for the District's portion of the Anacostia served by the MS4. A third reduction factor of 20 percent is applied to account for the fact that not all plastic and glass bottles collected may have been emptied of water before bagged.

Table 21: Trash Removal Strategies for Anacostia Trash TMDL				
Activity Category	**Activity**	**Total Amount of Trash Actually Being Removed (pounds)**	**Annual Load Reduction Counted (pounds)**	**Calculation Methodology**
Clean-Up Activities	Skimmer Boats	1,116,000	9,354	Based on the annual average of material collected by DC Water skimmer boats between 2003 and 2014. The average amount is first multiplied by 16.5 %, which represents the proportion of the watershed that lies within the District. A second reduction factor of 50.8 % was applied to account for the area of the District's portion of the watershed served by the MS4. A third reduction factor of 50 percent was applied since not all material collected by the skimmer boats may have been trash. Finally, a fourth reduction factor of 20 percent was applied since not all plastic and glass bottles collected were emptied of water.
Education and Outreach	Watershed Wide Anacostia Campaign	NA	NA	Efficiency being assessed. DDOE is awaiting results from a grant funded project being undertaken by the Alice Ferguson Foundation. Results should be finalized some time in 2015.
Regulatory Approaches	Bag Law	1,072	272	DDOE currently estimates (based on data collected for the development of the Anacostia Watershed Trash Reduction Plan) that there are 82,431 bags in the river and tributaries. This amount is first multiplied by 50.8 percent, since this is the proportion of the Anacostia River served by the MS4. The amount is then reduced by 50 percent because according to a recent survey report, 50 percent of businesses in the District report a 50% reduction in bag purchases. Finally, the total number of bags is then multiplied by 0.013 lbs., which is the standard weight for a plastic bag.
Total currently removed per year (pounds)		**1,313,432**	**91,471**	
3 - The environmental hotspots which are swept differ from the "hotspot" sewersheds mentioned earlier. The environmental hotspots swept represent a series of blocks found to contain very high amounts of trash.				

In addition to the BMPs described and quantified in the table, there are a number of BMPs that will be implemented, but the impacts of which cannot be easily quantified. These include education and outreach efforts such as the Watershed Wide Anacostia Campaign and trash Meaningful Watershed Education Experiences (MWEEs). While the impact of these BMPs cannot be measured directly in terms of the amount of trash reduction they achieve, they serve as an important component of the strategy and will continue to play a role in changing people's behavior and reducing trash in the Anacostia watershed. The load removed for these currently unquantified BMPs will be incorporated into the IP Modeling Tool if a methodology and supporting data becomes available.

The District intends to achieve the MS4 WLAs for trash in the Anacostia River by 2017 through implementation of the BMPs discussed above, as well as through additional future trash reduction strategies. The future trash reduction strategies are shown in the Table 22 below. Since these are not yet implemented, they are not counted towards the current load reductions achieved.

Table 22: Additional Trash Removal Strategies

Activity Category	Activity	Total Amount of Trash Projected To Be Removed (pounds)	Annual Load Reduction Counted (pounds)	Calculation Methodology
Trash Traps	Gallatin	4,263	4,263	Calculated using the landuse loading coefficients developed for the trash TMDL discounted by 40 percent.
Other Activities			12,613	
Total projected to be removed per year (pounds)			16,876	

A map of the existing and proposed trash trap BMPs is provided in Figure 10.

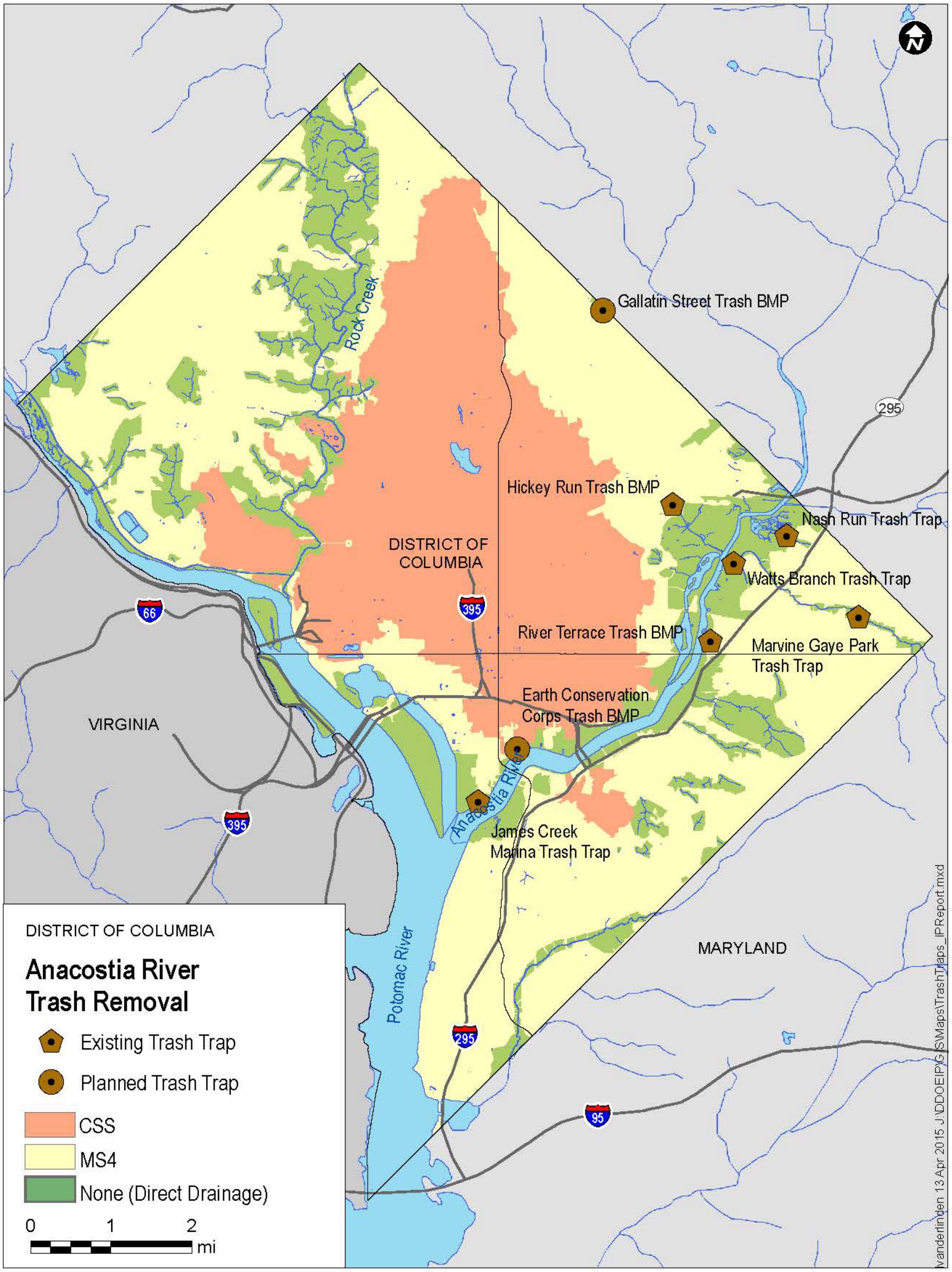

Figure 10. Location of existing and proposed trash trap BMPs

DISTRICT DEPARTMENT OF THE ENVIRONMENT

4 Results and Discussion

The purpose of the research and evaluation described in this document is to summarize the development of the existing BMP inventory and the development of load reduction methods for the various BMPs used (or planned for use) in the District. This information has been summarized in the preceding sections. The development of the BMP database has captured all of the necessary information on existing structural and non-structural BMPs, including the type of BMP and its location. For structural BMPs, other important information includes the drainage area that the BMP controls, while for non-structural BMPs, other information is used to indicate the extent of the BMP's impact. The BMP database allows an analysis of the extent of current BMP implementation.

Additional research was conducted to develop pollutant removal rates for both structural and non-structural BMPs. This involved analysis of the International Stormwater BMP database, as well as other literature, to review existing data on pollutant removal rates, as well as development of curves that relate runoff retention to load reduction. Finally, because of the paucity of research on the removal rates for toxics and some metals, partition coefficients were developed that relate the removal of particle bound pollutants such as metals and toxics to the removal of TSS.

This research provides information that can be used to evaluate how individual BMPs remove pollutants. Once pollutant removal rates for each individual BMP type were developed for each pollutant type (to the extent that this was possible) – either through direct pollutant removal efficiency, through runoff retention, or through the relationship with TSS using a partition coefficient, these removal rates can be used in the IP Modeling Tool to evaluate the impact of BMPs currently being implemented in the District, as well as to evaluate future load reduction scenarios.

The decision tree depicted in Figure 10 below is used to determine the approach for modeling load reductions from any individual structural or non-structural BMP. The first step is to determine if the BMP retention volume is known. If the retention volume is known, then the next step is to determine if the BMP is a rain barrel or a new tree (trees are considered BMPs because they help retain runoff). If the BMP is a rain barrel or a new tree, the lumped average annual reduction is used for the rain barrel or tree, respectively. The lumped average annual volume reduction was determined through an analysis of the canopy size and stormwater interception capacity of typical trees in DC, and, for rainbarrels, an analysis of typical barrel size and usage (including how often rainbarrels are drained)..

If the BMP is not a rain barrel or a new tree, then the runoff reduction curves are applied. Runoff reduction curves were developed for the major categories of retention-based BMPs, including bioretention, permeable pavement, infiltration trenches, cisterns, and green roofs. The efficiency of these BMPs is commensurate with the amount of runoff volume that can be retained by the BMP. For example, a BMP designed to retain runoff from a 0.5-inch storm provides less annual volume reduction than a BMP designed to retain runoff from a 1-inch storm.

The BMP retention volume is not known for many of the existing BMPs because historically this was not an attribute that was typically documented during the permitting process. The BMP retention volume is therefore not known for many of the BMPs implemented before 2013, which is the year during which the new stormwater regulations came into effect and when retention volume was required to be reported as part of the permit application. Additionally, some BMPs such as filters and wet ponds do not provide runoff retention capacity, but rather provide load reductions only. If the BMP treatment volume is not known, then the next step is to determine if the BMP has a prescribed load removal, and if so, to apply this load reduction. A prescribed load removal refers to a load reduction methodology that is based on the design parameters of the BMP. This type of load removal applies to stream restoration, street sweeping, catch basin cleaning, impervious surface removal, and trash reduction strategies, which require information such as the length or area of restoration to calculate the appropriate annual load removal. If the BMP does not have a prescribed removal load, then the percent reduction efficiency values are applied for that BMP. Percent reduction efficiencies were researched for each of the 13 BMP categories and for all 22 pollutants. The result of this research is a lookup matrix with an efficiency value for each BMP and pollutant combination. The percent reduction efficiencies apply uniformly to each BMP category, regardless of how a BMP was designed. As a result, they are regarded as being the least precise in terms of annual load removal estimates.

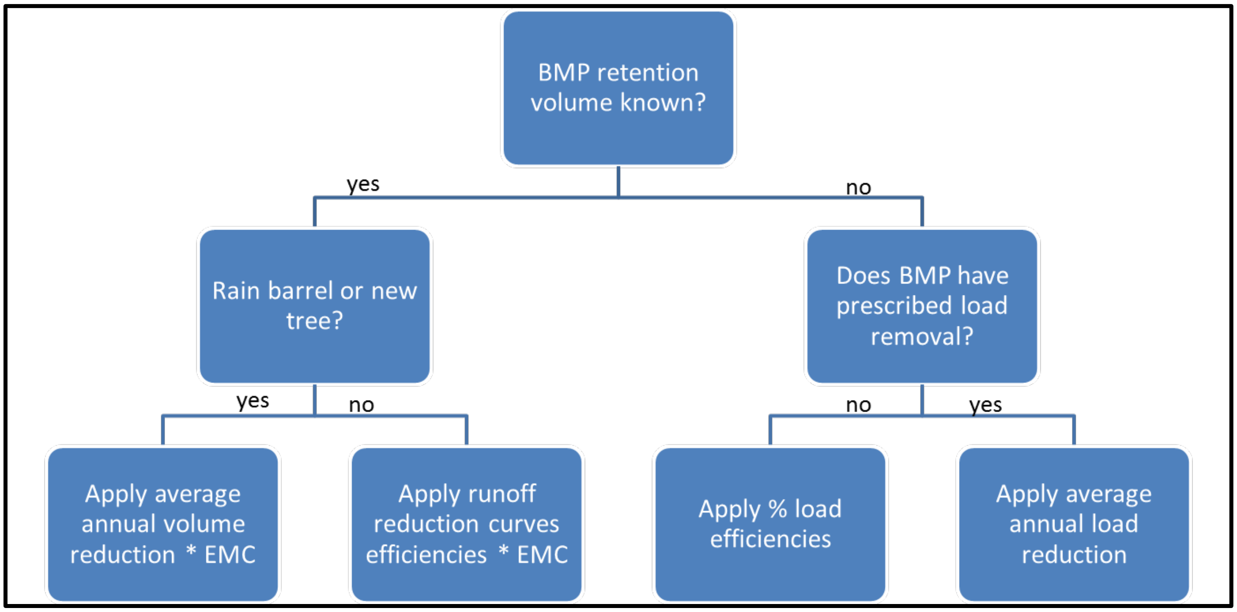

Figure 11: BMP Load Reduction Method Selection

The existing BMPs and the load reduction methodology is applied in the IP Modeling Tool to calculate the load reduction from existing BMPs. Since each BMP is spatially located within the MS4, the reductions provided by each BMP can be aggregated by TMDL watershed. Individual pollutant reductions will be summed by TMDL watershed and subtracted from the baseline load to determine the existing load. The existing load can then be compared to the MS4 WLA to provide the basis for the "gap analysis" and show the additional load reduction necessary to achieve each MS4 WLA.

The pollutant load reduction methodology will also allow the use of the IP Modeling Tool to model future load reduction scenarios that move toward achievement of the MS4 WLAs. These load reduction scenarios will incorporate various factors, such as development and re-development projections, watershed planning information, capital improvement planning, and other factors, to project the specific levels of implementation of individual BMPs that will achieve MS4 WLAs. The projected amount of development/re-development will be important drivers of BMP implementation, because the District's new stormwater regulations require retention of specific amounts of runoff from development/re-development projects, depending on the amount of land they disturb. Thus the expected amount of development/re-development and the subsequent amount of development-driven BMP implementation will impact the remaining BMP implementation needed to meet MS4 WLAs. Future scenarios will use different development/re-development projections in conjunction with analyses such as the opportunity to implement green roofs, DDOT capital projects to control roadway runoff, stormwater management scenarios from the RiverSmart program, etc., to develop scenarios that achieve the MS4 WLAs. These scenarios, along with potential schedules, milestones, and costs, will serve as the basis for discussions with the stakeholder group that will ultimately result in a Consolidated TMDL IP that will lay out the plan to achieve MS4 WLAs.

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