Phase I&II National Pollutant Discharge Elimination System
Permit No. 99-DP-3313 MD0068276
Permit Term October 2005 to October 2010

ANNUAL REPORT UPDATE
OCTOBER 21, 2013

Submitted to:

Water Management Administration
Maryland Department of the Environment
1800 Washington Boulevard
Baltimore, MD 21230

Submitted by:

Maryland State Highway Administration
Office of Environmental Design
707 North Calvert Street, C-303
Baltimore, MD 21202

Date: October 21, 2013

RE: Annual NPDES MS 4 Phase I & II Report Update
Permit term 10/2005 to 10/2010
Permit No. 99-DP-3313 MD0068276
Continuation

Mr. Raymond Bahr
Sediment, Stormwater and Dam Safety Program
Water Management Administration
Maryland Department of the Environment
1800 Washington Boulevard, Suite 440
Baltimore, MD 21230

Dear Mr. Bahr:

The Maryland State Highway Administration (SHA) is pleased to submit this updated annual report for the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit as a continuation of coverage under the expired permit issued in October 2005. The updated report covers the time period of October 2012 through September 2013 and includes both Phase I and Phase II Counties. In correspondence dated July 1, 2013, SHA notified MDE that their annual Phase I report would also include Phase II Counties.

SHA remains committed to the environmental compliance and stewardship towards the preservation and restoration of the Chesapeake Bay, as well as local watersheds and streams. We submitted a re-application for the NPDES Phase I MS4 permit on October 21 2009. SHA will continue to comply with the existing permit until the new permit is received from MDE.

SHA has continued its progress this past year in fulfilling the requirements and the purposes of this permit. SHA has worked closely with the MDE over the last year to coordinate efforts with the Bay TMDL.

Included in this delivery is one hard copy and an electronic version of the annual report along with an accompanying ESRI file geodatabase and several Microsoft Excel files. All of which were prepared in compliance with specifications outlined in the SHA's National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Discharge Permit, which was provided to SHA on June 26, 2012.

If you have any questions or need any additional information regarding this delivery, please contact Ms. Karen Coffman at 410-545-8407 (kcoffman@sha.state.md.us) or me at 410-545-8644 (rshreeve@sha.state.md.us).

Sincerely

Robert Shreeve, Deputy Director
Office of Environmental Design

Attachment

CC: Karuna Pujara
Dana Havlik
Sonal Sanghavi
Doug Simmons
Greg Welker

Phase I and II National Pollutant Discharge Elimination System
Permit No. 99-DP-3313MD0068276
Permit Term October 2005 to October 2010

Annual Report Update
October 21, 2013

Submitted to:

Water Management Administration
Maryland Department of the Environment
1800 Washington Boulevard
Baltimore, MD21230

Submitted by:

Maryland State Highway Administration
Office of Environmental Design
707 North Calvert Street, C-303
Baltimore, MD21202

SHA State Highway Administration

Executive Summary

The Maryland State Highway Administration (SHA) is submitting this updated annual report for the NPDES Phase I and II Municipal Separate Storm Sewer System (MS4) permit that was issued in October 2005 by the Maryland Department of the Environment (MDE) Water Management Administration (WMA). This annual report covers the time period October 2012 to September 2013.

A general overview that highlights significant achievements over the last report period is provided below.

Source Identification

The impervious accounting condition has been completed for the eleven Phase I and II counties and the three Phase II municipalities, and impervious restoration has been completed during this reporting period. Furthermore, GIS applications have become fully integrated and a regular schedule has been developed for data collection updates.

Discharge Characterization

We continue to investigate and research topics in order to maximize water quality in our construction methods, permanent stormwater runoff controls, decisions in design, and location of roadways and maintenance techniques. Previous reports have included reports for research projects completed in the past. One current study seeks to optimize denitrification in bioretention soil mix by investigating treatment time and carbon source material.

Management Program

Our program continues to effectively incorporate all permit components. We have successfully integrated the stormwater environmental site design (ESD) regulations into roadway design and construction projects and continued to measure our performance in the areas of erosion and sediment control (ESC) during construction and our internal business goal of maximizing the number of functionally adequate stormwater facilities statewide.

The ESC Program developed and implemented the ESC Quality Assurance Toolkit (QA Toolkit). This tool allows field inspectors to enter inspection results directly into a field that is connected to the general ESC inspection database through the internet. This improves efficiency, accuracy of data entry and reporting.

Watershed Assessment

Coordination with local NPDES jurisdictions continues. SHA has also worked in cooperation with other agencies to develop a Watershed Resource Registry (WRR) as a national pilot as a tool to integrate land use, environmental and transportation planning.

Watershed Restoration

SHA met the requirement for twenty-five restoration projects and looks forward to the next permit with increased watershed restoration goals. As the Bay TMDL efforts are underway, SHA has increased its coordination efforts with local MS4s to integrate its watershed assessments and needs to SHA's prioritization of projects and site selection. Projects have included stream restoration at Minebank Run, Long Draught Run, and Red Branch and regional pond retrofits in Carroll County.

Assessment of Controls

The Long Draught Branch stream restoration project has been re-initiated. The budget for construction funding is allocated for FY 2015 and 2016. We will continue the project with the post-construction monitoring when the project is completed. The Wet Infiltration Basin Transitional Performance Study will augment data on assessment of controls.

Program Funding

In this tough economic climate, the NDPES remains a top funding priority. Our NPDES program remains fully funded. Also, despite the challenging economic situation, SHA and MDOT have begun funding Bay TMDL efforts and also supported procurement of NPDES engineering contracts.

Total Maximum Daily Loads

The current SHA NPDES Phase I permit states that MDE has determined that owners of stormdrain systems that implement the requirements of the permit will be controlling stormwater pollution to the maximum extent practicable. However, given the current mandate to restore the Chesapeake Bay by 2025 and the draft MS4 Phase I permits that require that jurisdictions meet assigned waste load allocations (WLAs) for the Bay and local watershed TMDLs, SHA has taken many steps in order to position ourselves to meet these requirements.

Table of Contents

List of Tables

List of Figures

Phase I&II National Pollutant Discharge Elimination System
Permit No. 99-DP-3313 MD0068276
Permit Term October 2005 to October 2010

PART ONE

STANDARD PERMIT CONDITIONS AND RESPONSES

PART ONE

Standard Permit Conditions and Responses

Introduction

The Maryland State Highway Administration (SHA) is committed to continuing our National Pollutant Discharge Elimination System (NPDES) Program efforts, and is pleased to partner with the Maryland Department of the Environment (MDE), the Environmental Protection Agency (EPA) and other NPDES jurisdictions in order to achieve the program goals.

The original NPDES phase one and two permit guided SHA through establishing our NPDES program. (The permit, MS-SH-99-011, was issued on January 8, 1999 and expired in 2004.) The current permit (99-DP-3313, MD0068276, issued October 21, 2005 and expired on October 21, 2010) focused on improving water quality benefits, developing an impervious accounting database and developing a watershed-based outlook for stormwater management and NPDES program elements. SHA submitted a re-application for the NPDES Phase I Municipal Separate Storm Sewer System (MS4) permit on October 21 2009 and are anticipating a draft permit from MDE. SHA will continue to comply with the existing permit until the new permit is received.

This is the third update to the final annual report that was submitted October 2010 for the expired permit. The report covers the period from October 2012 through September 2013. Part One lists permit conditions and explains SHA activities over the last year to comply with each one. Wherever possible, future activities and schedules for completion are provided. Part Two of this report discusses the SHA Stormwater Management (SWM) Facility Program in depth. Appendices are included at the end of the report that contains research reports, examples of data and other detailed information.

A CD is also included that contains portable document format (PDF) files of the entire report and delivery of database updates in the new MDE Attachment A formats. We have included updated database tables and spatial files according to the recently revised Attachment A, Annual Report Databases. Some data was not available for the newer fields and a document is included on the attached CD that explains any assumptions or unresolved data issues for these tables. New tables for all the SHA NPDES MS4 Phase I and II data, and include records that were delivered in the past as the data requirements have changed (except where noted on the document included on the CD).

A Administration of Permit

Administration coordinator for the NPDES Program is listed below and an organizational chart detailing personnel responsible for major program tasks is included on the following page as Figure 1-1.

Mr. Robert Shreeve
Deputy Director
Office of Environmental Design
(410) 545-8644
rshreeve@sha.state.md.us

The SHA coordinator for the MS4 permit is:

Ms. Karen Coffman
Office of Environmental Design
(410) 545-8407
kcoffman@sha.state.md.us

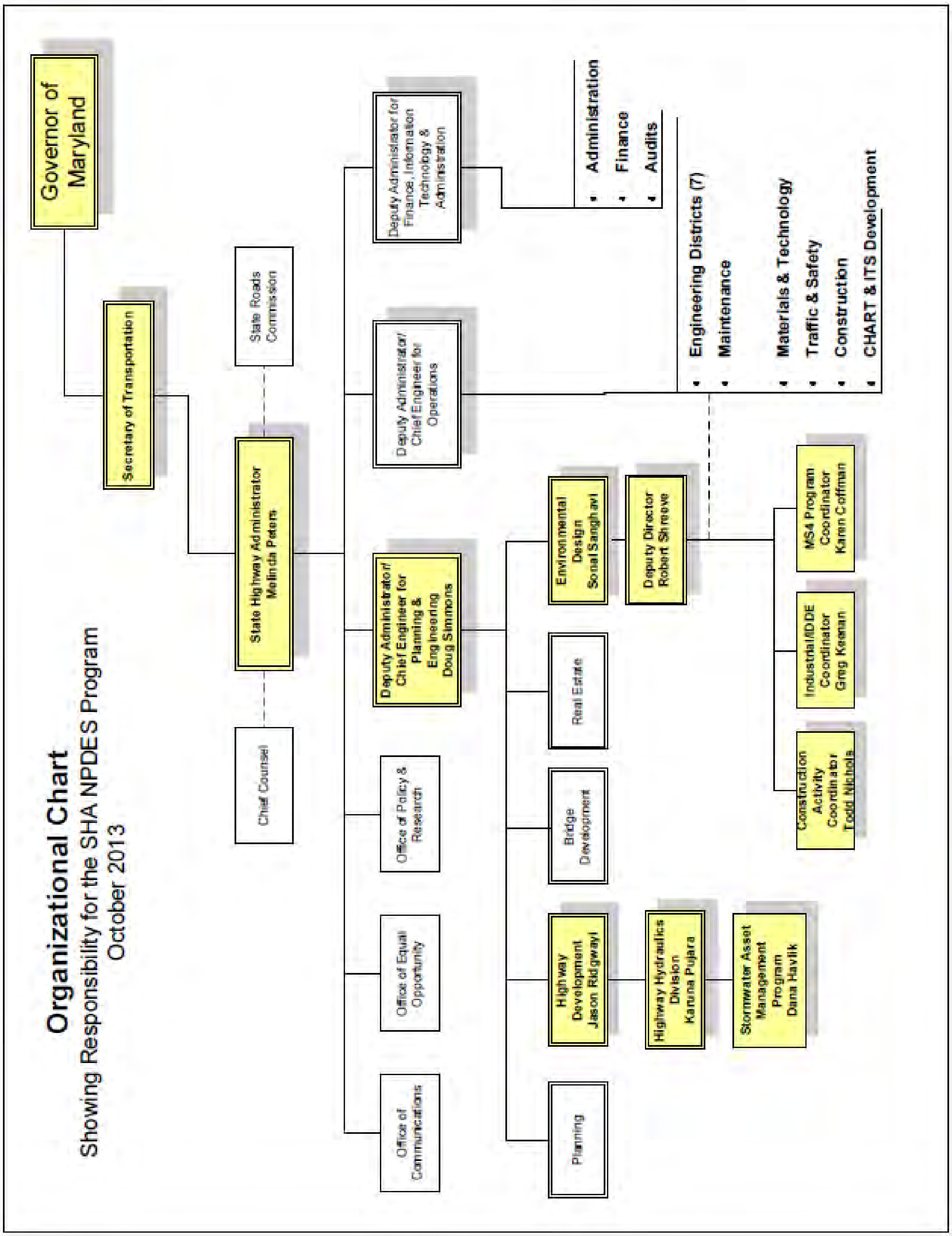


Figure 1-1 2013 Organizational Chart for SHA NPDES MS4 Permit Administration

B Legal Authority

A description of the legal authority maintained by SHA was restated in the fourth annual report dated October 21, 2009 and remains unchanged.

C Source Identification

According to the permit language, source identification deals with identifying sources of pollutants and linking those sources to specific water quality impacts on a highway district basis. Source identification is also tied to impervious surfaces and land uses.

For this permit term, MDE has defined the source identification effort as completing the description of the SHA storm drain and BMP system, submitting BMP data to MDE and creating an impervious surface account.

Maryland SHA has successfully completed the GIS development of SHA storm drain systems within the nine Phase I MS4 counties, two Phase II counties, and three Phase II municipalities. Maryland SHA has initiated identification of SHA storm drain systems outside of the permit areas. We are utilizing advances in technology and software improvements to more effectively and efficiently collect and maintain data sets. These process improvements will enhance communication between offices regarding the goals and needs for NPDES.

C.1 Describe Storm Drain System

Requirements under this condition include:

a) *Complete Source identification requirements by October 21, 2009;*

b) *Address source identification data compatibility issues with each jurisdiction where data are collected. Data shall be organized and stored in formats compatible for use by all governmental entities involved;*

c) *Continually update its source identification data for new projects and from data gathered during routine inspection and repair of its municipal separate storm sewer system; and*

d) *Submit an example of source identification for each jurisdiction where source identification is being* compiled.

C.1.a Complete Source Identification

SHA completed the identification and GIS development for our storm drain systems and stormwater management facilities in 2008, well before the October 21, 2009 deadline. Our focus has shifted to updating our source identification information for the nine MS4 counties, two Phase II counties, and three Phase II municipalities. We are also updating our current data structure to integrate new data standards provided in the latest version of Attachment A. Information on source identification updates and updates to the data structure is included under section C.1.c, Update Source ID Data.

C.1.b Data Compatibility

SHA continues to provide data to the other NPDES jurisdictions and MDE as well as acquire data from them. The NPDES data generated by SHA is deployed using the ESRI Geodatabase data format in an ArcSDE enterprise environment and is either natively compatible with other jurisdictions, or can be exported to ESRI shape file format. The Geodatabase Schema and Data Dictionary can be reviewed in Appendix A.

MDE is currently in the process of updating their NPDES data requirements and SHA has coordinated with their consultant, Maryland Environmental Services (MES) by providing our TMDL data standards, NPDES Standard Procedures and geodatabase structure to them. SHA intends to continue involvement in this process with MDE.

Geospatial Database Development

SHA has developed a geospatial database for our source identification and inspection data. This database will be expanded to include other components of the program as they are brought together and as we update our standard procedures and inspection manuals. All of the SHA NPDES data including source identification, SWM facility inspections, outfall screening, outfall inspections, and impervious area acre amounts are currently housed in the database.

A SHA-wide web-based application, known as eGIS, was developed to display content themes for decision making purposes. Content themes allow the user to overlay datasets without extensive knowledge of the ESRI tool sets. NPDES data has been included as a content theme in eGIS. See Figure 1-2below for an example.

Google Earth is an alternative method to present and communicate NPDES asset information to parties outside of the SHA network firewall. It provides a discrete and user-friendly framework for information to be communicated to SHA Districts and the consultant community through the distribution of KML and KMZ files that open directly in Google Earth. Refer to Figure 1-3 for a screenshot of information displayed in Google Earth.

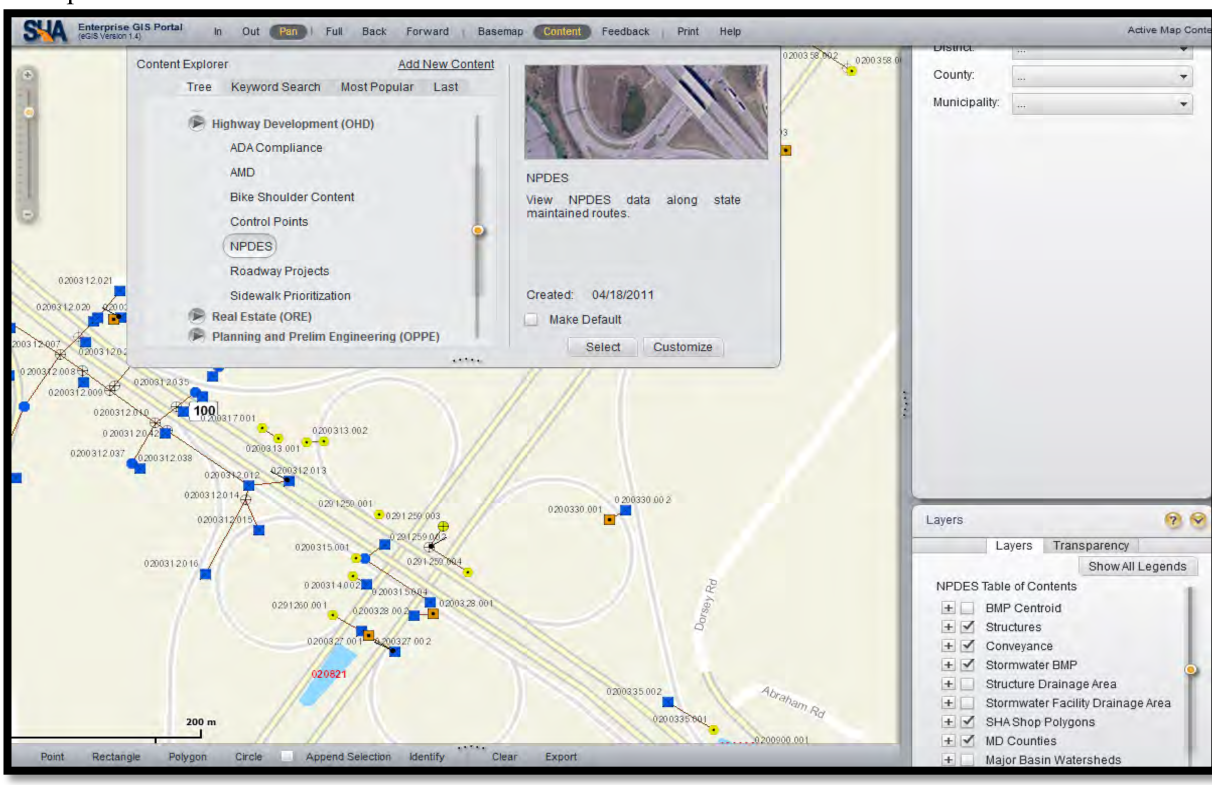


Figure 1-2   eGIS Viewer Screenshot of SHA NPDES Dataset

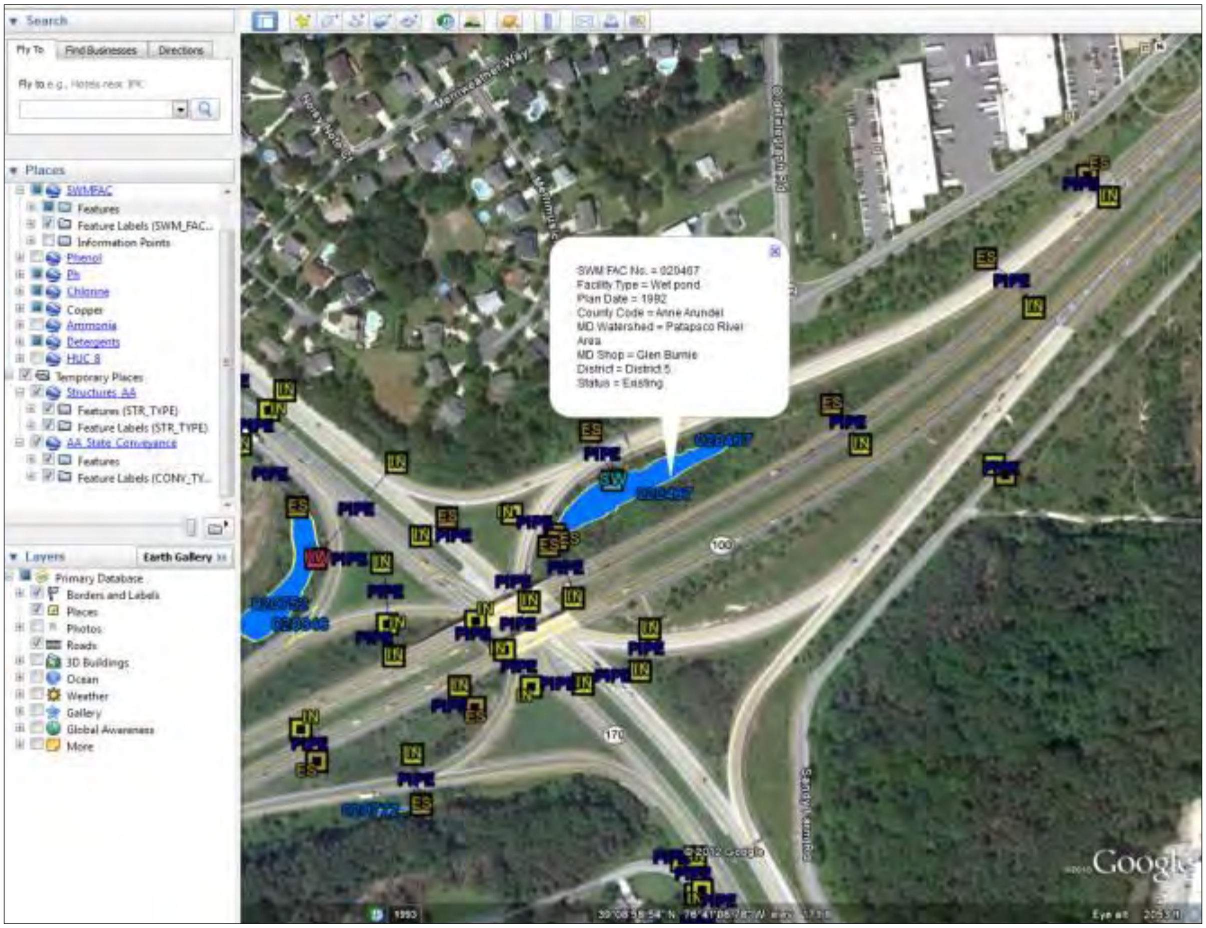


Figure 1-3 Google Earth Screenshot of SHA NPDES Data Uploaded as KML

NPDES Software Development

Descriptions of GIS software application development underway were included in the 2010 Annual Report. Application updates are performed using available resources and employing new technological advances. Table 1-1 represents the upgrade status.

Data Management and Editing Tools Manual

A new addition to SHA standardized procedures for the NPDES program is the SHA *Data Management and Editing Tools Manual*. This manual outlines the data management workflow, discusses office and field editing applications that are used to assist in data collection and discusses the procedures and process for quality control of the stormwater database. SHA data managers and editors will utilize the procedures outlined in the manual to manage all the data and GIS needs for the SHA NPDES program.

Table 1-1 Status GIS Applications

Phase of Development	% Complete
SWM Program Module	100
SWM Facility Numbering Module (eGIS)	100
WQ Bank/Imperviousness Accounting Module	100
eGIS Integration	100

C.1.c Update Source Identification Data

Since the initial source identification has been completed for all the NPDES MS4 Phase I counties, the permit activity requirement for this condition now focuses on updating the source data. During the past year, SHA completed full MS4 updates in Anne Arundel and Baltimore counties, and updates to Howard County have been initiated. These updates include an improved procedure for delineating drainage areas to SWM facilities. In addition, SHA is taking steps to develop the necessary skill set to have the database management performed by SHA in-house staff rather than use more costly consultant services.

Source identification updates are performed with the goal to meet the required three-year cycle and we have improved our processes in order to target this update cycle timeframe. Future updates have been scheduled to meet this goal once the maintenance and remediation efforts have been completed for a particular county.

Future updates will be performed as specified in Table 1-2. The latest data collected is as follows:

Phase I

Anne Arundel County – Updated identifications of the separate storm water system and outfall and BMP inspections were completed during this reporting period and are included in this report.

Baltimore County– Updated identifications of the separate storm water system and outfall and BMP inspections were completed in 2012.

Carroll County – Updated identifications of the separate storm water system and outfall and BMP inspections were completed in 2013.

Charles County – Identifications of the separate storm water system is nearing completion and inspections of SWM BMPs are in-progress. It is expected that updated identifications will be completed in November 2013.

Frederick County – Updated identifications of the separate storm water system and outfall and BMP inspections were completed and included in the 2011 Report.

Harford County Updated identifications of the separate storm water system and outfall and BMP inspections were completed and included in the 2011 Report.

Howard County – Updated identifications of the separate storm water system and outfall and BMP inspections were completed in 2013.

Montgomery County – Updated identifications of the separate storm water system and outfall and BMP inspections were included in the 2011 Report.

Prince George's County – Updated identifications of the separate storm water system and outfall and BMP inspections were completed during this reporting period and are included in this report.

Phase II

Cambridge, Cumberland and Salisbury Cities– This original inventory work was completed in April 2011.

Cecil County– The GIS inventory of SHA storm drain, BMP and outfall information and inspections in Cecil County was completed in 2008.

Washington County –The GIS inventory of SHA storm drain, BMP and outfall data and inspections in Washington County was completed in 2013.

Table 1-2 Source ID Schedule

County	Previous SWM Inspections	Previous MS4 Inspection	SWM Initiate	MS4 Initiate	SWM Complete	MS4 Complete
Allegany	June-04	Not Required	January-12	Not Required	July-12	Not Required
Washington	April-09	April-09	March-12	April-12	July-12	August-12
Baltimore	October-03	January-04	January-12	February-12	May-12	June-12
Garrett	October-04	Not Required	January-12	Not Required	July-12	Not Required
Howard	April-04	April-04	January-12	February-12	May-12	June-12
Carroll	November-07	November-07	March-12	March-12	July-12	July-12
Charles	October-07	October-07	March-12	March-12	July-12	July-12
Saint Mary's	November-08	Not Required	February-14	October-14	January-14	June-14
Calvert	March-09	Not Required	September-13	September-13	March-14	March-14
Wicomico	June-09	Not Required	December-13	December-14	November-14	June-14
Worcester	June-09	Not Required	December-13	December-14	February-14	June-14
Somerset	June-09	Not Required	January-14	January-14	December-14	May-14
Dorchester	July-09	Not Required	January-14	January-14	December-14	May-14
Queen Anne's	October-02	Not Required	February -14	February -14	July-14	July-14
Kent	November-02	Not Required	February -14	February -14	July-14	July-14
Talbot	December-07	Not Required	February -14	February -14	July-14	July-14
Caroline	September-08	Not Required	February -14	February -14	July-14	July-14
Cecil	September-08	September-08	March-14	March-14	July-14	July-14
Prince George's	May-09	May-09	August-14	January-15	August-14	February -14
Anne Arundel	August-10	August-11	August-14	August-14	December-14	December-14
Harford	April-11	April-11	September-14	September-14	January-15	March-14
Frederick	March-11	March-11	December-14	May-15	January-15	September-15
Montgomery	June-11	June-11	March-14	March-14	September-14	September-14
Salisbury	December-11	December-11	April-14	December-14	October-14	June-15
Cambridge	December-11	December-11	April-14	December-14	October-14	June-15
Cumberland	January-12	January-12	September-14	January-15	March-15	July-15

C.2 Submit BMP Data

Database tables are included on the attached CD as noted in the Introduction.

C.3 Create Impervious Surface Account

This condition requires that SHA provide a detailed account of impervious surfaces owned by SHA and an account of those acres of impervious surface controlled by stormwater management, broken out by SHA engineering district. This account will be used to identify potential areas for implementing restoration activities.

We completed the impervious accounting requirement and the baseline accounting numbers were reflected in the 2010 report. Table 1-3 displays the baseline untreated impervious numbers for SHA by county and the progress of the restoration based on the requirement for twenty-five restoration projects (permit condition G.1). Figure 1-4 provides a graphic illustration of the progress.

Table 1-3 SHA Pavement Restoration Accounting by County

County	Baseline Total Impervious (AC)	Baseline Untreated Impervious (AC)	Baseline Treated Impervious (AC)	Impervious Acres Restored by Permit Condition (AC)	Impervious Acres Restored by Permit Condition (%)	Adjusted Untreated Impervious (AC)	Total Impervious Treated (%)
Anne Arundel	4,002	3,156	846	67	2.1%	3,089	22.8%
Baltimore	4,141	3,790	350	279	7.4%	3,511	15.2%
Carroll	1,329	1,285	44	0	0%	1,285	3.3%
Cecil	1,213	1,198	15	0	0%	1,198	1.2%
Charles	1,420	1,344	76	2	0.1%	1,342	5.5%
Frederick	2,354	2,166	188	2	0.1%	2,164	8.1%
Harford	2,078	1,949	129	21	1.1%	1,928	7.2%
Howard	2,211	1,982	229	15	0.7%	1,968	11.0%
Montgomery	3,428	2,882	546	8	0.3%	2,874	16.2%
Prince George's	4,188	3,792	395	26	0.7%	3,766	10.1%
Washington	2,209	2,163	46	0	0%	2,163	2.1%
Totals	**25,288**	**25,707**	**2,864**	**419**	**2.7%**	**25,288**	**11.5%**

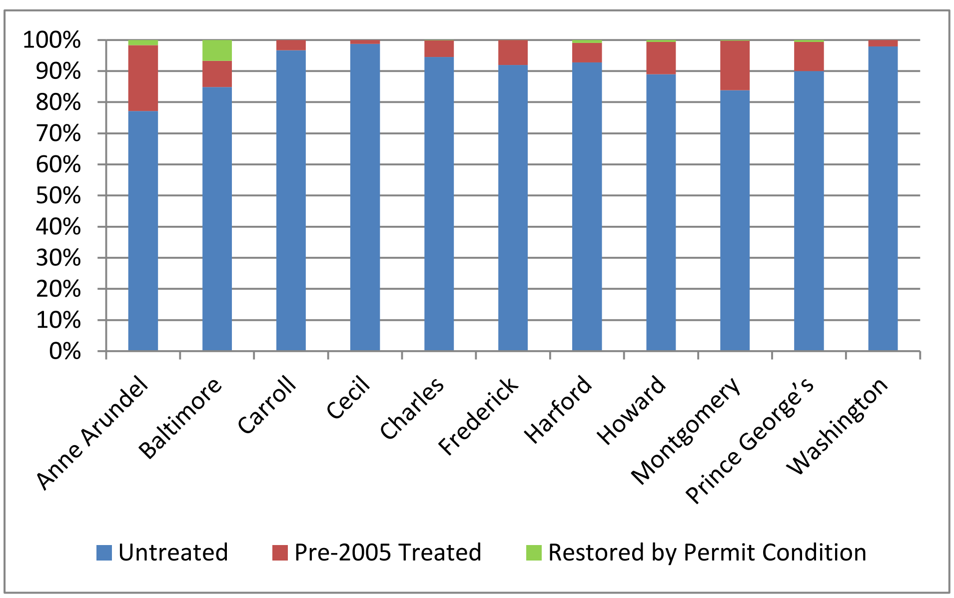


Figure 1-4 SHA Impervious Restoration Progress by County

Impervious Layer Updates

The impervious layer depicting impervious surfaces owned and treated by SHA has been updated during the past reporting cycle. SHA has initiated development to update several counties of impervious data during the reporting period, including Carroll County, Harford County and Charles County. SHA performed an update to the associated drainage area delineations for stormwater BMPs in order to provide more accurate data of SHA and non-SHA impervious surfaces draining to each BMP. A new effort to quantify treatment based on the MDE NPDES Accounting Protocol will be initiated during FY 2014.

Future updates to the remaining SHA Phase I MS4 impervious layers are planned, including Anne Arundel County, Frederick County, Howard County, Montgomery County and Prince Georges County.

Table 1-4 indicates the current status of each Phase I and Phase II MS4 county:

Table 1-4 Impervious Layer Update Status

County	Impervious Layer Update Status
Anne Arundel County	Planned
Baltimore County	Complete
Carroll County	In Progress
Cecil County	Complete
Charles County	In Progress
Frederick County	Planned
Harford County	In Progress
Howard County	Planned
Montgomery County	Planned
Prince George's County	Planned
Washington County	Complete

D Discharge Characterization

SHA continues efforts to measure and quantify characteristics through environmental research of stormwater runoff that flows from the highway network and associated facilities. Similar analyses are performed for discharges from SWM facility assets and other stormwater control measures (SCMs) implemented.

Auto-samplers are used as much as possible since it is often difficult to determine the exact timing of when precipitation events will occur and to allow sufficient travel time to sampling locations, enhancing the value and usefulness of our monitoring efforts..

For several years, research has examined several areas, including:

- Grass swales
- Thermal impacts
- Pollutant removal efficiencies
- Urban runoff
- Wet infiltration
- Bioretention
- Sand filters

The pollutants monitored in the pertinent discharge characterization studies includes:

- pH
- Temperature
- Total suspended solids (TSS)
- Nutrients
    - Total phosphorus (TP)
    - Total Kjeldahl nitrogen (TKN)
    - Oxidized nitrogen (nitrate and nitrite)
- Heavy metals (total)
    - Copper (Cu)
    - Lead (Pb)
    - Zinc (Zn)
- Chlorides

In some instances, other monitored items include oil, grease and other hydrocarbons; turbidity; and fecal coliform.

The data from our research efforts and discharge characterization activities may be used towards new designs and evaluations of both existing and proposed SCMs. The information is also used to assess the effectiveness of current SWM asset function and service as the basis for long-term decision-making strategies.

Past research and discharge characterization activity data associated with the previous MS4 Phase I permit term (1999-2004) included the following.

Annual Report: Pindell School Road Storm Sampling, KCI, March 7, 2000.

National Highway Runoff Study: Comparison to MSHA Sampling Results, KCI, December 2001.

Dulaney Valley Road I-695 Interchange Stream Monitoring at the Tributary to Hampton Branch, KCI, Annual Reports dating 2000 to 2003.

Additional activities that have been previously reported in annual reports as noted by specific publication dates are as follows.

First Annual Report (October 2006):

Low Impact Development Implementation Studies in Mt. Rainier, *MD*, University of Maryland, December 2005.

Grassed Swale Pollutant Removal Efficiency Studies (Part II – MDE/SHA Swale Comparison), University of Maryland, October 2006.

Mosquito Surveillance/Control Program for SWM Facilities in Baltimore, Howard, Montgomery and Prince Georges Counties (2003-2005), Millersville University, October 2006.

Second Annual Report (October 2007):

Grassed Swale Pollutant Removal Efficiency Studies (Part III – Grass Check Dams),University of Maryland, August 2007.

Literature Review: BMP Efficiencies for Highway and Urban Stormwater Runoff, Progress Report, University of Maryland, September 2007.

Underground SWM Thermal Mitigation Studies, Progress Report, University of Maryland, August 2007.

Prediction of Temperature at the Outlet of Stormwater Sand Filters, Progress Report, University of Maryland, August 26, 2007.

Third Annual Report (October 2008):

Grassed Swale Pollutant Removal Efficiency Studies: Field Evaluation of Hydrologic and Water Quality Benefits of Grass Swales with Check Dams for Managing Highway Runoff (Part III continuation),Progress Report, University of Maryland, October 2008.

Thermal Impact of Underground Stormwater Management Storage Facilities on Highway Stormwater Runoff, Progress Report, University of Maryland, October 2008.

Fourth Annual Report (October 2009):

Field Evaluation of Water Quality Benefits of Grass Swale for Managing Highway Runoff (Part III – Grass Check Dams), Progress Report, University of Maryland, July 2009.

Nutrient Removal Optimization of Bioretention Soil Media, Progress Report, University of Maryland, August 2009.

Field Evaluation of Wet Infiltration Basin Transitional Performance, Progress Report, University of Maryland, August 2009.

Fifth Annual Report (January 2010) – Reports included in Appendices but not directly discussed in the report:

Field Evaluation of Water Quality Benefits of Grass Swale for Managing Highway Runoff, Progress Report, University of Maryland, July 2009.

Field Evaluation of Wet Infiltration Basin Transitional Performance, Progress Report, University of Maryland, August 2009.

Nutrient Removal Optimization of Bioretention Soil Media, Final Report, University of Maryland, September 2010.

Annual Report Update (October 2011):

Although there were no reports or findings that were included, new studies on enhancing nitrogen and phosphorus removal in existing and proposed SWM facilities were initiated and work on the field evaluation of wet infiltration basin transitional performance continued.

Annual Report Update (October 2012):

Field Evaluation of Wet Infiltration Basin Transitional Performance, Progress Report, University of Maryland, July 2012.

Management of Nitrogen in Stormwater Runoff Using a Modified Conventional Sand Filter, University of Maryland, August 2012.

Denitrification Optimization in Bioretention Using Woodchips as a Primary Organic Carbon Source, First Year Progress Report, University of Maryland, July 2012.

Recently Completed Studies

A progress report about the field evaluation of wet infiltration basin transitional performance was included in the previous year's report and the study was completed not long thereafter, and a study photo and diagram are included in Figures 1-5 and 1-6. This final report is included in Appendix B, *Final Report: Evaluation of Transitional Performance of an Infiltration Basin Managing Highway Runoff.*

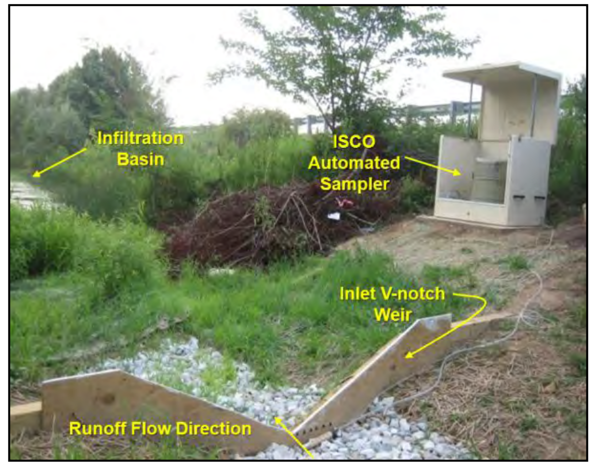


Figure 1-5 Wet Infiltration Basin Study – Site Monitoring Set Up

Current Studies

Newly initiated studies and continuing research efforts remain on schedule. Efforts currently underway, as well as those efforts which have been recently concluded, are as follows.

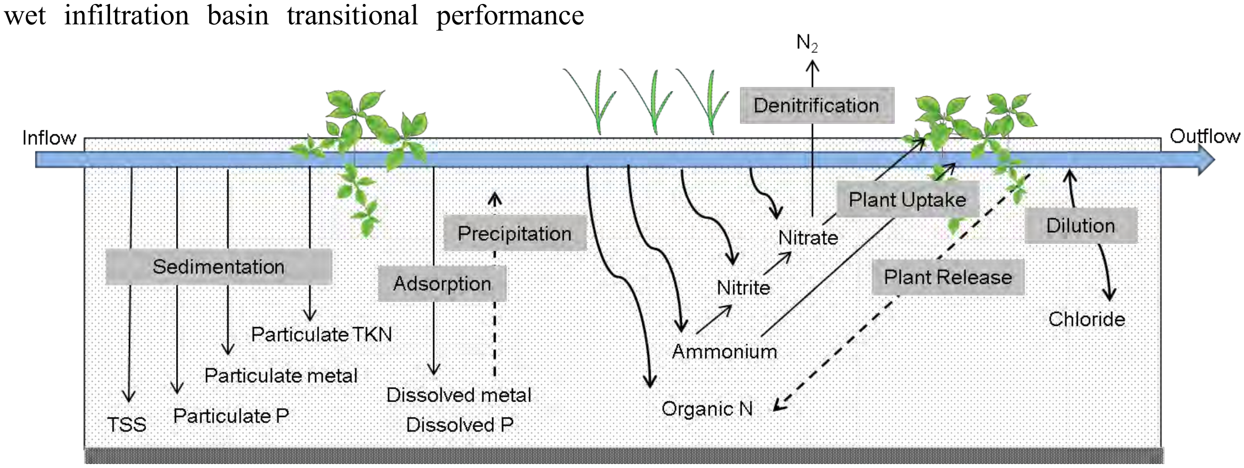


Figure 1-6 Wet Infiltration Basin Study – Schematic Working Diagram

Advanced Denitrification in Bioretention Systems using Woodchips as an Organic Carbon Source

In efforts to better meet TMDL goals, we are interested in understanding how SWM facilities may be enhanced to increase their nutrient removal efficiency. Because the greatest potential for enhanced performance appears to be with bioretention facilities, this facility type was chosen for closer examination.

The technology of bioretention systems is still in its infancy, and while these facilities have proven effective in removing many stormwater runoff pollutants, they lag in nitrogen removal efficiency. Recent research, performed by the University of Maryland, focused on the optimization of the denitrification process of the nitrogen cycle. By creating an anoxic zone and providing a source of organic carbon, denitrifying microorganisms may colonize the media and convert nitrate-N into nitrogen gas, which may then be harmlessly released into the atmosphere.

Column tests were conducted to evaluate several parameters and how they affect nitrate concentration in effluent generated by the filtering of artificial stormwater runoff: filter media contact time, limestone concentrations, and woodchip volumes. Additional woodchip parameters examined included tree species, woodchip size, and the percentage of woodchip mass in relation to the amount of bioretention filter media. The denitrification process appeared to follow pseudo-first-order kinetics. A 0.8 day average media contact time appeared to show the highest nitrate removal percentage at about 82 percent. Longer media contact times correspond to higher nitrate removal efficiencies. Willow oak and red maple woodchips appear to offer the highest total nitrogen removal efficiencies at 62 percent. Using smaller woodchips and at higher woodchip mass amounts also corresponded to greater nitrate removal efficiencies, but it also appeared to increase the amount of organic nitrogen leaching from the system and into the effluent. Optimal conditions appear to be a bioretention media containing 4.5 percent by mass of 5 mm willow oak woodchips, as shown in the photo in Figure 1-7 below.

The report is still in draft form and a final report will be included in the next annual report.

Figure 1-7 Wood Chip Filtering Media

Management of Nitrogen in Stormwater Runoff Using a Modified Conventional Sand Filter

Surface sand filters have been a common SWM facility type used between 2003 and 2010, and sand filters continue to be a popular choice when conditions are appropriate for its use, such as at salt barn facilities; however, sand filters are not necessarily an optimal choice for reducing nutrient concentrations in stormwater runoff. Because of the large number of sand filters in our asset inventory, and because we're interested in techniques to retrofit this type of facility to increase nitrogen and phosphorus removal efficiencies, the University of Maryland continued to examine ways in which nitrogen removal may be enhanced in sand filter facilities.

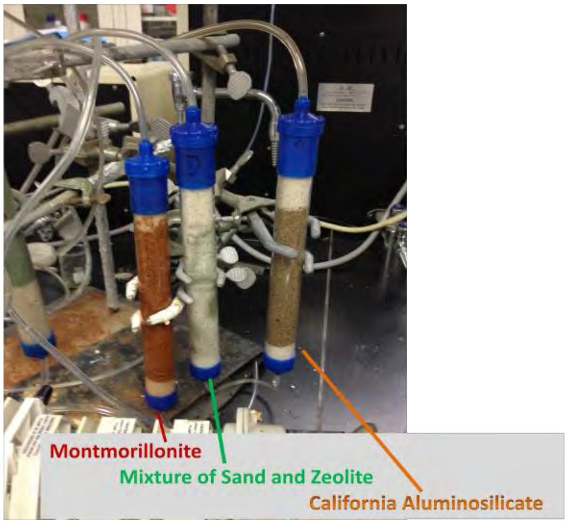


Figure 1-8 Modified Conventional Sand Filter Testing

To reduce nitrogen loading, a proposed design divides the sand filter into three zones to promote ammonification, nitrification, and denitrification as shown in Figure 1-8 above. Nitrification was observed to automatically occur during low nitrogen loadings and dry periods, without any modifications to sand filter design; however, to achieve adequate media contact time for key biological denitrification processes to occur, sorptive materials must be incorporated into the sand filter bed.

The first phase of the project focused on the selection of adsorbents that would increase the uptake of ammonium. Clays, recycled materials, and sands were selected as adsorbents. The time necessary for sorption to reach equilibrium with these materials was found to be 24 hours; however, due to the low sorption capacity and instability in the structure of clay agglomerates, testing of Georgia attapulgite and brown montmorillonite were abandoned. Sorption tests continued with California aluminosilicate (CA), crushed brick (BR), red montmorillonite (MR), and clinoptilolite zeolite (ZT). The sorption capacity of ZT was found to be the greatest of all adsorbents, followed by MR.

The current phase focuses on small scale column studies for the sorption of ammonium which will provide more comprehensive determinations on adsorbent performance. Based on the results, the column studies will be expanded to examine nitrification and sorption simultaneously to quantify the rate of nitrification and determine the optimum media thickness.

Enhancements for N and P Removal from Stormwater Management Facilities for Multi-Modal Transportation Infrastructure in Maryland: Multi-Criteria Plant Selection for Vegetated Stormwater Control Measures

In a newly-initiated study, the University of Maryland is examining vegetation selection used in bioretention and similarly-related vegetated SCMs (swales, bioswales, rain gardens, and planter boxes). While current criteria for plant selection are primarily based on survival, aesthetics and context, there may be facility performance benefits associated with specific plant species that may be quantified.

In the relationship between plants and soils, vegetation is known to help maintain soil porosity through root building and decay, promote nutrient extraction, and host beneficial microbial consortia in the rizosphere; however, we have found that during construction activities, successful vegetation establishment has also been a challenge, and we are concerned that this may also affect facility performance as well as aesthetic appeal and sustainability.

From the current study, expected outputs include recommendations on vegetation for use in bioretention-type SWM facilities. The evaluation criteria include the ability to provide enhanced facility performance while considering aesthetics and cost associated with establishment and maintenance. Because of the many criteria that play a role in vegetation selection, some flexibility in selection recommendations will be included to help tailor plant selection to specific sites and needs.

Recommended Stormwater Control Measures for Multi Modal Transportation Infrastructure in Maryland and Roadmap for Suggested Research Efforts to Promote Greater Effectiveness and Sustainability of Stormwater Runoff Management Techniques

In another recently initiated study, the University of Maryland is completing a comprehensive literature review on SCMs. A toolbox of recommended SCMs will be developed for multi-model transportation network stormwater runoff management. In addition, a roadmap of suggested research efforts for stormwater runoff management techniques that would provide greater effectiveness and sustainability will be synthesized and used in long-term research decision-making.

The study concentrates on addressing needs specific to our organization, with a particular focus on the following.

- Applications to linear highway networks.
- Treatment of sediment (S), nitrogen (N), and phosphorus (P), as these are the three specific pollutants emphasized in the latest Chesapeake Bay TMDL regulations.
- Highlights of technologies for treatment of pathogens, which is anticipated to be a future pollutant of interest.

Progress-to-date has included a compilation of peer reviewed literature on urban SWM that has focused on three common SCMs: bioretention, swales and permeable pavements.

The examination has included relative performance in regards to TSS, N, P, and/or pathogen removal. Other aspects also being examined are maintenance, life span, life cycle, and associated costs. The draft report will be available in November 2013 and the final report will be available in January 2014.

E Management Program

A management program is required to limit the discharge of stormwater pollutants to the maximum extent practicable. The idea is to eliminate pollutants before they enter the waterways. This program includes provisions for environmental design, erosion and sediment control, stormwater management, industrial facility maintenance, illicit connection detection and elimination, and personnel and citizen education concerning stormwater and pollutant minimization.

E.1 Environmental Design Practices

This permit condition requires that SHA take necessary steps to minimize adverse impacts to the environment through the roadway planning, design and construction process. Engaging the public in these processes is also required.

The Maryland State Highway Administration has a strong environmental commitment that has only increased as the new Stormwater Management Act of 2007 was implemented in May 2010. Through this legislation, emphasis was placed on the use of environmental site design (ESD) techniques. We are actively working ESD measures into roadway projects.

SHA also continues to adhere to processes that ensure that environmental and cultural resources are evaluated in the planning, design, construction and maintenance of our roadway network. This includes providing opportunity for public involvement and incorporating context sensitive design and solution principles. We also ensure that all environmental permitting requirements are met by providing training to our personnel (see E.6.b below) and creating and utilizing software to track permitting needs on projects as they move through the design, advertisement and construction processes.

NEPA/MEPA Process

SHA's National Environmental Policy Act/ Maryland Environmental Policy Act (NEPA/MEPA) design and planning process, includes developing and obtaining approval on environmental documentation for any project proposed utilizing state or federal funding. SHA also assists local jurisdictions through the environmental documentation process so they remain eligible to receive state/federal funds such as Transportation Enhancement Program/Transportation Alternatives Program funds. An early step in the process is to identify the natural, community, and cultural resources that exist in the project study area and determine the level of environmental documentation and stakeholder involvement needed. The final environmental document may be a Categorical Exclusion (CE) for minor impacts, Finding of No Significant Impact (FONSI) for more substantial impacts or Environmental Impact Statement (EIS) for major impacts or when stakeholder controversy surrounds the project.

Increasingly, SHA is evaluating stormwater needs during the NEPA process to address Environmental Site Design requirements. This movement requires that stormwater concepts be developed during the planning process, and has affected the development process in several ways. Beginning the stormwater process earlier allows more realistic concepts to be presented during public meetings and allows more accurately assessments of right-of-way needs. The drawback to this approach, however, can be that assumptions made in terms of the stormwater requirements may not be the final approved requirements. This last effect can have negative impacts on the permit approval process, public expectations, right-of-way acquisitions, and design schedules. SHA encourages the stormwater regulatory reviewers to participate in the planning process by attending interagency meetings, reviewing concept plans, and providing valid comments and concept approvals at the planning stage in the design.

It should be noted, however, that the planning process for major projects and the project development timeline can be greater than cycles of regulatory changes for water quality. This further introduces complexity in decision making and public perception of accuracies of SHA projects and processes.

Effort is made to avoid or minimize environmental impacts. If impacts are unavoidable, however, mitigation is provided and monitored per regulatory requirements.

E.2 Erosion and Sediment Control

Requirements under this condition include:

a) *Use of MDE's 2011 Standards and Specifications for Soil Erosion and Sediment Control, or any subsequent revisions, evaluate new products for erosion and sediment control, and assist MDE in developing new standards; and*

b) *Perform responsible personnel certification ('Green Card') classes to educate highway construction contractors regarding erosion and sediment control requirements and practices. Program activity shall be recorded on MDE's "green card" database and submitted as required in Part IV of this permit.*

E.2.a MDE ESC Standards

SHA continues to comply with Maryland State and Federal laws and regulations for erosion and sediment control (ESC) as well as MDE requirements for permitting. We maintain compliance with the NPDES Stormwater Construction Activity permit for projects that disturb one acre or more of land.

We continue compliance with the Maryland Erosion & Sediment Control Guidelines for State and Federal Projects published in January 1990 and revised in January 2004. In December 2011, MDE published the 2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control. Projects are designed and constructed in compliance with the new specifications. SHA developed a field guide to support the 2011 MDE specifications. This laminated book is also used as a field tool where users have the option of writing (dry erase) notes in the book.

SHA has implemented changes to construction inspection practices to maintain compliance with the NPDES Construction Activity Permit. We continue to submit applications for coverage under this general permit for all qualifying roadway projects.

SHA ESC Quality Assurance Ratings

SHA continues to use our improved Quality Assurance rating system for ESC on all roadway projects. This effort is designed to improve field implementation of ESC measures through a rating system (by issuing grades A – F) and by including incentive payments to the contractor for excellent ESC performance. Under this system, the contractor incurs liquidated damages for poor ESC performance.

SHA tracks QA inspections and ratings for reporting to our business plan and StateStat. Increased numbers of inspections and better documentation have improved the overall performance of our ESC program. Incentive payments are made when the contractor receives an ESC rating score of 85% or greater over the course of each rating quarter (three months). A final incentive payment is also made for projects with an overall (average) rating of 85% or better.

On SHA design-build projects compensation for E&S response action related to severe weather is addressed by specification. This compensation is in addition to the incentive for excellent performance as stated above.

Liquidated damages are imposed on the contractor if the project receives a 'D' or 'F' rating. If two ratings of 'F' are received on a project, the ESC certification issued by SHA will be revoked from the contractor project superintendent and the ESC manager for a period of six months and successful completion of the certification training. This system of rewarding good performance and penalizing poor performance has shown to improve contractor responsibility for ESC practices. It has also improved water quality associated with earth disturbing and construction activities.

In FY 2013, a record number of inspections (4073) on a record number of projects (286) reviewed, yielded an overall compliance of 99.5 percent (See Figures 1-9 and 1-10).

SHA revised standard forms currently used in ESC construction tracking to include NPDES construction activity permit related issues in an effort to increase compliance with both State and Federal ESC regulations. These forms are listed below and copies were included in the 2012 Annual Report in Appendix D:

- OOC03 – District Engineer's Certificate of Completion of Work
- OOC60 – Erosion and Sediment Control Field Investigation Report
- OOC61 – Independent Quality Assurance Erosion and Sediment Control Field Investigation Report

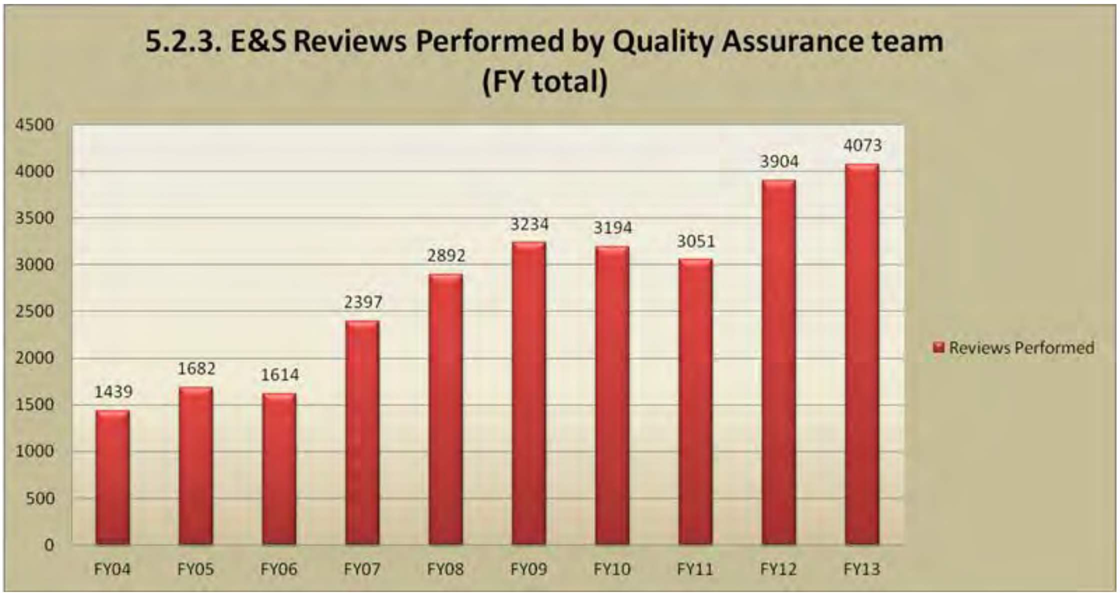


Figure 1-9 Erosion and Sediment Control Reviews Performed for FY2013

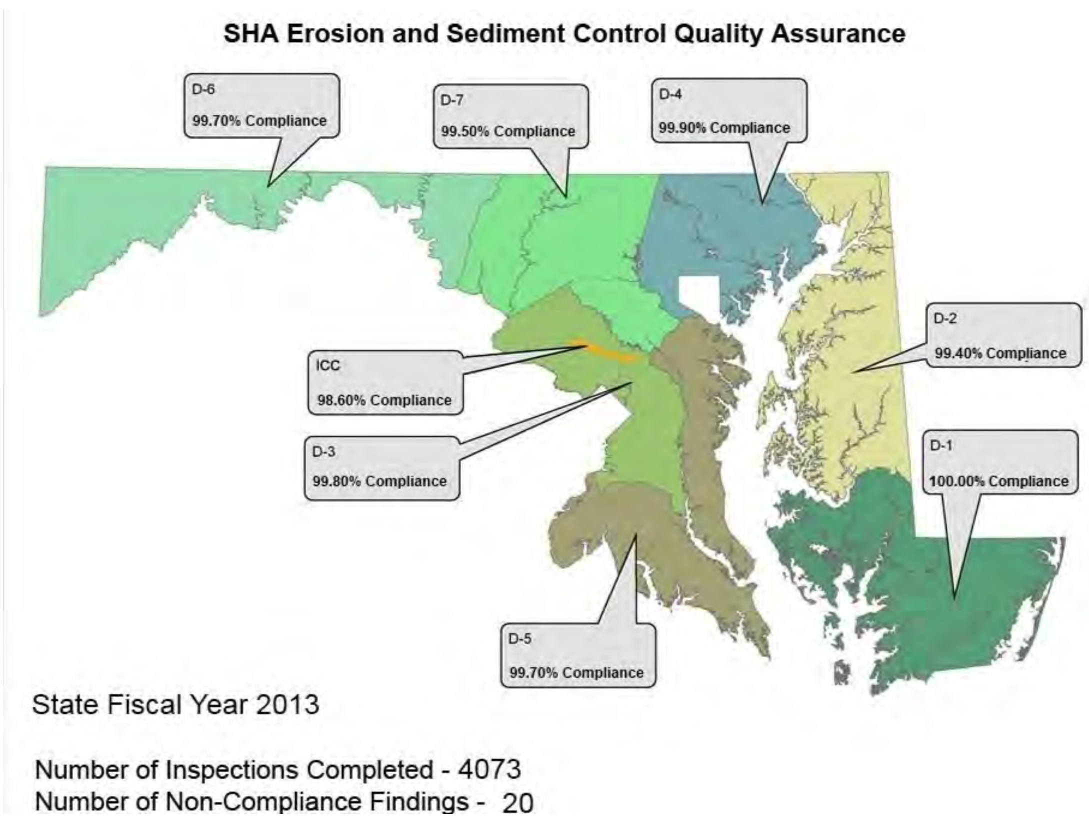


Figure 1-10 Erosion and Sediment Control Quality Assurance for FY2013

E.2.b Responsible Personnel Training for Erosion and Sediment Control (Green Card Certification)

SHA continues to provide MDE's Responsible Personnel Training for Erosion and Sediment Control to SHA personnel, consultants, and contractors.

SHA Basic Erosion and Sediment Control Training (Yellow Card Certification)

In addition to Green Card Training classes, SHA continues to present the Erosion and Sediment Control training initiated in 2004. Most classes now include certification for the MDE Green Card. This Level I training is recommended for contractors and field personnel. It covers key requirements of the NPDES permit. Also covered are resources, and personnel for construction projects, erosion and sediment control (ESC) specifications/inspections, process for ESC modifications during construction, and stabilization. This certification expires three years from the date of issuance. SHA has provided recertification classes and an on-line recertification course. In the past year, SHA developed an on-line application for Yellow Card, which was launched in July 2013

Table 1-5 SHA ESC Training

Type of Training	No. Certified
Responsible Personnel (Green Card)	482
Level I (Yellow Card)	516
Level I (Yellow Card Recertification)	118
Level II (Designer's Training)	15

SHA also developed a Level II training intended for ESC design professionals. The Level II training began in June 2007 and was revised in 2013. We intend to continue development and improvement to this training in the coming year. Table 1-5 details the number of personnel certified for each of the training levels for the reporting period.

E.3 Stormwater Management

The continuance of an effective stormwater management program is the emphasis of this permit condition. Requirements under this condition include:

a) Implement the stormwater management design principles, methods, and practices found in the 2000 Maryland Stormwater Design Manual, the 2009 update, and COMAR;
b) Implement a BMP inspection and maintenance program to inspect all stormwater management facilities at least once every three years and perform all routine maintenance (e.g., mowing, trash removal, tarring risers, etc.) within one year of the inspection; and
c) Document BMPs in need of significant maintenance work and prioritize these facilities for repair. The SHA shall provide in its annual reports detailed schedules for performing all significant BMP repair work.

E.3.a Implement SWM Design Manual and Regulations

SHA continues to comply with Maryland State and Federal laws and regulations for stormwater management (SWM) as well as MDE requirements for permitting. We also continue to implement the practices found in the *2000 Maryland Stormwater Design Manual* and the *Maryland Stormwater Management Guidelines for State and Federal Projects, April 15, 2010* for all projects. We have also implemented the requirements in the revised Chapter 5 of the 2000 Manual for environmental site design (ESD) and the Stormwater Management Act of 2007 for all new projects.

E.3.b Implement BMP Inspection & Maintenance Program

Our continuing Stormwater Management (SWM) Facilities Program inspects, evaluates, maintains, remediates and enhances SHA

BMP assets to maintain and improve water quality and protect sensitive water resources. Inspections are conducted on a cyclical basis as part of the NPDES source identification and update effort (see Section C, above). Maintenance and remediation efforts are accomplished after the inspection data has been evaluated and ranked according to SHA rating criteria.

Details of the SWM Facility Program are included as Part 2 of this document. Discussion of inspection results and maintenance, remediation, retrofit and enhancement efforts undertaken over the past year is included in that section.

Stormwater As-Built Certification Process

SHA continues to improve the SWM facility as-built certification process in order to comply with the SWM approval and COMAR. This process assures verification of proper construction of the SWM facilities meeting the design intent. Throughout the construction process, the design engineer coordinates with the Office of Construction and the contractor to perform required inspections during construction and to document the information in the MDE approved as-built tabulations. The contactor's engineer certifies that the SWM facility was constructed according to the approved design plans and within allowed tolerances as stated in the SHA issued Special Provision that is part of the contract documents. SHA has made the delivery of this certification a separate pay/bid item in the construction estimate.

The SHA project engineer coordinates with MDE on the review and approval of the stormwater as-built certified plan. The construction project cannot be closed and accepted for maintenance until the as-built certification and plans have been accepted by MDE. Copies of the final approved certifications are retained by SHA and integrated into the storm drain and BMP GIS/database. This information is then used as source identification updates are planned and assigned.

E.3.c Document Significant BMP Maintenance

See Part 2 for SWM Facilities Program updates on major maintenance, remediation and BMP retrofits.

E.4 Highway Maintenance

Requirements under this condition include:

a) *Clean inlets and sweep streets;*

b) *Reduce the use of pesticides, herbicides, and fertilizers through the use of integrated pest management (IPM);*

c) *Manage winter weather deicing operations through continual improvement of materials and effective decision making;*

d) *Ensure that all SHA facilities identified by the Clean Water Act (CWA) as being industrial activities have NPDES industrial general permit coverage; and*

e) *Develop a "Statewide Shop Improvement Plan" for SHA vehicle maintenance facilities to address pollution prevention and treatment requirements.*

E.4.a Inlet Cleaning and Street Sweeping

Mechanical sweeping of the roadway is essential in the collection and disposal of loose material, debris and litter into approved landfills. This material, such as dirt and sand, collects along curbs and gutters, bridge parapets/curbs, inlets and outlet pipes. Sweeping prevents buildup along sections of roadway and allows for the free flow of water from the highway, to enter into the highway drainage system.

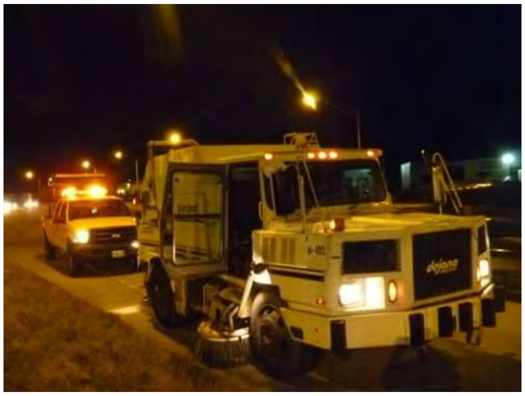


Figure 1-11 Street Sweeping often takes place at Night due to High Traffic Volumes in Urbanized Counties

The SHA desired maintenance condition is 95% of the traveled roadway clear of loose material or debris. In addition, 95% of closed section roadways (curb and gutter) should have less than 1 inch depth of loose material, debris, or excessive vegetation that can capture debris, in the curb and gutter.

SHA also owns and operates four vacuum pump trucks that routinely clean storm drain inlets along roadways. Sediment and trash make up the majority of the material that is removed. The vacuum trucks operate in central Maryland, spanning the following Counties: Anne Arundel, Baltimore, Calvert, Carroll, Charles, Frederick, Harford, Howard, Montgomery, Prince Georges and St. Mary's. This practice ensures safer roadways through maintaining proper drainage and improves water quality in Maryland streams by removing captured sediment and trash before they enter adjacent waterways.

Figure 1-12 SHA Shop Personnel Operating Vacuum Truck to Clean Roadside Debris

Figure 1-13 Inlet Before and After Vacuuming

Pollutant Reductions for Inlet Cleaning and Street Sweeping

Sweeping and inlet cleaning are recognized as valid pollutant source reduction BMPs, however the means for crediting reductions is not well defined at this point. We are evaluating appropriate load reductions that can be claimed by SHA in meeting local and Bay TMDLs. This accounting will be added to reports for the next permit term.

The SHA Office of Environmental Design (OED) is working with the SHA Office of Maintenance (OOM) to document current routes, to extend these activities to watershed-based, priority roadways and to characterize and quantify material and debris removed as a result of these activities. The result will be the development of procedures to optimize reporting of reductions associated with each of these activities and to better understand pollutant loads gathered from highways. It is hoped that this understanding will result in additional impervious surfaces treatment.

E.4.b Reduction of Pesticides, Herbicides and Fertilizers

SHA has standards for maintaining the highway system and one of these standards is the *SHA Integrated Vegetation Management Manual for Maryland Highways, October 2003* (IVMM). This manual incorporates the major activities involved in the management of roadside vegetation including application of herbicides, mowing and the management of woody vegetation. In order to maximize the efficiency of funds and to protect the roadside environment, an integration of these activities is employed.

Herbicide Application

The majority of SHA vegetation management is accomplished mechanically, through the use of mowers and brush axes. However, in areas where mechanical control is not practical or feasible, SHA manages vegetation through the use of targeted applications of herbicide.

SHA promotes the safe and responsible use of herbicide for this purpose. All SHA employees and contractors who apply herbicide on SHA rights-of-way must be registered with the Maryland Department of Agriculture (MDA) and operate under the supervision of a MDA-licensed pesticide applicator.

Environmental stewardship is a primary focus of SHA's business plan, and SHA encourages the use of selective herbicides and targeted application, rather than the broad application of non-selective herbicides. The use of herbicide is based on the plant species that is being targeted, so that the effects on other plants are minimized and soil residual activity is limited. Application rates are based on the minimum amount required to control the targeted plant species, so that the potential for runoff and non-point source contamination also is minimized.

Herbicide application equipment is routinely inspected and calibrated to ensure that applications are accurately applied in accordance to the IVMM, Maryland State law and the herbicide label.

Nutrient Management Plans

State law (COMAR 15.20.04-08 – Nutrient Management Regulations) requires SHA to develop a Nutrient Management Plan (NMP) for all fertilizer applications. SHA uses slow-releasing nitrogen based fertilizers with application rates based on soil testing. Topsoil is sampled and tested for major plant nutrients, pH, and organic material. The test results are used to develop a NMP to ensure optimal nutrient levels and growing conditions and to avoid the application of excess fertilizer.

Mowing Reduction & Native Vegetation Establishment

A major initiative at the SHA is to reduce the extent of mowed areas within our right-of-way. The Administration's Turfgrass Management Policy has been revised to provide consistent guidance to decrease the size of mowed areas and the number of mowing cycles per year.

Several projects have been completed throughout the state to install and maintain reforestation and native meadow areas. Reforestation and native meadow areas require none to minimal mowing, preserve native vegetation, and enhance erosion control and nutrient uptake.

E.4.c Winter Deicing Operations

SHA continues to test and evaluate new winter materials, equipment and strategies in an on-going effort to improve the level of service provided to motorists during winter storms while at the same time minimizing the impact of its operations on the environment.

One method employed to decrease the overall application of deicing materials is to increase application of deicing materials prior to and in the early stages of a winter storm (anti-icing). This prevents snow and ice from bonding to the surface of roads and bridges and ultimately leads to lower material usage at the conclusion of storm events, thus lessening the overall usage of deicers.

SHA is wrapping up its pilot program using GEOMELT 55, a de-sugared sugar beet molasses that may be blended with brine. This organic material, also known as beet juice, lowers the freezing point of the brine to -30 degrees. GEOMELT 55 also enables the brine to adhere to bridges and road surfaces better and longer, which extends the effectiveness of the deicer.

In addition, SHA is continuing its 'sensible salting' training of State and hired equipment operators in an on-going effort to decrease the use of deicing materials without jeopardizing the safety and mobility of motorists during and after winter storms.

Table 1-6on the following page lists materials used by SHA in winter deicing operations.

New Road Salt Management

On May 20, 2010 the Governor approved Senate Bill 775, requiring SHA, in consultation with the Department of the Environment (MDE), to develop a best practices road salt management guidance document by October 2011. This document is necessary to reduce the adverse environmental impacts of road salt storage, application and disposal on Maryland's water and land resources.

SHA posted the Statewide Salt Management Plan on its website in October 2011. The plan was subsequently updated on October 1, 2012. The plan provides guidance on snow and ice control operations with an emphasis on lessening the impact of salt on the environment. The plan covers all aspects of winter operations including:

- Safety and mobility of motorists during and after winter storms,
- Defining levels of service provided during winter storms,
- Establishing long-term goals to lessen the usage of salt, and reduce its impact on the environment,

- Salt and other winter materials,
- Material storage and handling,
- Winter storm fighting equipment,
- Training initiatives,
- Winter storm management from pre-storm preparations through post-storm operations,
- Post-storm material and equipment cleanup,
- Post-storm and post-season data analysis,
- Public education and outreach, and
- Testing and evaluation of new materials, equipment, and strategies for continual improvement.

Table 1-6 SHA Deicing Materials

Material	Characteristics
Sodium Chloride (Rock and Solar Salt)	The principle winter material used by SHA. Effective down to 20° F and is relatively inexpensive.
Abrasives	These include sand and crushed stone and are used to increase traction for motorists during storms. Abrasives have no snow melting capability.
Calcium Chloride	A solid (flake) winter material used during extremely cold winter storms. SHA uses limited amounts of calcium chloride.
GEOMELT 55	A de-sugared sugar beet molasses may be blended with the brine. Also known as "beet juice," this organic material lowers the freezing point of the brine to –30º F. The light brown material is environmentally safe and does not stain roadway surfaces
Salt Brine	Liquid sodium chloride or liquefied salt is a solution that can be used as an anti-icer on highways prior to the onset of storms, or as a deicer on highways during a storm. Used extensively by SHA. Freeze point of -6° F.
Magnesium Chloride (Mag)	A liquid winter material used by SHA for deicing operations in its northern and western counties. It has a freeze point of -26° F and has proven cost effective in colder regions.

Winter Operations Training

SHA Annual Snow College – This training is offered every fall for new maintenance shop hires as well as 20% of veteran shop forces. The goal is to train all maintenance personnel over a five year period and repeat the process. This ensures that all maintenance personnel are exposed to current trends and technologies. The training presentations are included in the Statewide Salt Management Plan, Appendices II and III and topics covered include all aspects of winter operations with an emphasis on sensible salting. See Table 1-7 numbers trained this reporting period.

Annual Maintenance Shop Winter Meetings – Abbreviated salt management training is provided to all SHA maintenance forces annually at winter shop meetings. No data was available for 2013 on numbers trained.

Table 1-7 SHA Snow College Training

SHA District (Shops)	No. Participants
1 (D, WI, WO, SO)	28
2 (CE, K, QA, CO, T)	20
3 (MG, MF, PL, PM)	35
4 (BG, BH, BO, HA)	21
5 (AA, AG, CV, CA, CH, SM)	15
6 (G, AL, WA)	34
7 (F, CL, HO)	71
Total Trained	224

Hired Equipment Operator Training – This training is provided to hired equipment contractors and operators every fall. The training presentations are included in the Statewide Salt Management Plan and topics covered include effective plowing, sensible salting and adhering to all pertinent SHA policies and procedures. No data was available for 2013 on numbers trained.

E.4.d Industrial Permit Coverage

As discussed in the previous Annual Report, SHA developed and implemented a Compliance Focused Environmental Management System (CFEMS) to ensure multi-media compliance at all maintenance facilities statewide. The CFEMS covers procedures for management of environmental compliance issues, including those related to Industrial NPDES at maintenance facilities, such as spill response, material storage and vehicle washing. It includes the implementation of Standard Operating Procedures (SOPs), routine compliance inspections and environmental training covering a variety of media areas including stormwater management and spill prevention and response.

The CFEMS is being implemented in a phased approach. Environmental assessments at 161 SHA facilities were completed in June 2013 for all Phases of the assessment program. In July 2013, SHA added Phase IV facilities to its routine compliance inspection program, to include movable bridges, communications facilities, rest area/welcome centers, and truck inspection and weighing stations. Recommendations for stormwater improvements at these facilities continue to be addressed as part of Phase IV.

As shown in Table 1-8, certain facilities are currently covered under the General Discharge Permit (02-SW). SHA has provided 2 sets of formal comments to MDE regarding the pending update to 12-SW, and is awaiting a formal response. The SHA Environmental Compliance Division (ECD) is continuing to perform routine inspections at all SHA facilities through its District Environmental Coordinators (DEC) to ensure stormwater pollution prevention BMPs are implemented. The DECs are responsible for ensuring compliance with applicable permits, plans and regulations at facilities in their region.

Table 1-8 Industrial NPDES Permit Status

District	Maintenance Facility	Permit Type
1	Berlin[1]	General
	Cambridge	General
	Princess Anne	General
	Salisbury	General
	Snow Hill	General
2	Centreville	Individual – SW
	Chestertown	General
	Denton	General
	Easton	General
	Elkton	General
3	Fairland	General
	Gaithersburg	General
	Laurel	General
	Marlboro	General
4	Churchville	Individual – SW
	Golden Ring	General
	Hereford	Individual – SW[2]
	Owings Mills	General
5	Annapolis	General
	Glen Burnie	General
	La Plata	General
	Leonardtown	Individual – SW[2]
	Prince Frederick	General
6	Hagerstown	General
	Hancock	General
	Keyser's Ridge	Individual – GW
	La Vale	General
	Oakland	General
	Dayton	Individual - SW[2]

Table 1-8 Industrial NPDES Permit Status

District	Maintenance Facility	Permit Type
7	Frederick	General
	Thurmont[1]	General
	Westminster	General
	Brooklandville Complex	General
Offices/ Other Facilities	Hanover Auto Shop	Individual - SW[3]

Notes: SW = Surface Water, GW = Groundwater

1 Phase II Facility (Satellite / Salt Storage Facility)

2 Currently collecting all wastewater for pump and treat in a storage tank - therefore generating no discharge

3 Vehicle wash discharge connected to sanitary sewer in 2009, SW provisions of individual permit remain in effect

The SHA ECD also continues to encourage maintenance facilities to present funding requests for stormwater related improvements such as erosion stabilization, material storage improvements, and spill prevention / containment devices.

E.4.e Statewide Shop Improvement Plans

As described above, SHA continues to maintain an effective Industrial Stormwater NPDES Program through ECD to ensure pollution prevention and permit requirements are being met at SHA maintenance facilities. SHA annually updates its combined Storm Water Pollution Prevention Plans (SWPPP)/SPCC Plans. As a continuing best management practice SHA has developed SWPPPs for facilities not required to have one (e.g. salt storage facilities). Throughout 2013, SHA continued to address potential stormwater pollution issues by implementing Best Management Practices (BMPs) and designing/constructing capital improvements. BMPs were identified during pollution prevention plan updates and routine inspections facilities. The status of BMP implementation for maintenance facilities is tracked by each District Environmental Coordinator during routine inspections. Potential capital improvements are prioritized based on risk to human health and the environment and funding availability. The following list details the major pollution prevention efforts and maintenance facility improvements since the last annual report.

Completed Projects:

- Annual review and update of SPCCP/SWPPP at 106 SHA facilities
- Petroleum storage tank system upgrades continued at various SHA maintenance facilities
- Upgrades finalized to structures used for inlet cleaning waste dewatering at Glen Burnie and Owings Mills Shops (See Figure 1-14)
- Grit Chamber assessment and upgrade design completed for Prince Frederick and Thurmont

Ongoing Projects:

- Initial assessment reports and preliminary design completed for erosion issues noted at various facilities statewide
- Design of structures for inlet cleaning waste dewatering at La Plata shop and Mt. Airy Salt Storage Facility
- Statewide oil-water separator maintenance program
- Statewide discharge sampling and reporting program for facilities with Individual Discharge Permits
- Routine compliance inspections at all Phase I facilities (primary maintenance) Phase II facilities (satellite and salt storage), Phase III (offices & laboratories and Phase IV (moveable bridges, rest areas, weigh stations, etc.)
- Annual multimedia compliance training provided to maintenance shop personnel

Figure 1-14 Structure used for Inlet Cleaning Waste Dewatering

Figure 1-15 Stormwater Outfall Improvements at SHA Maintenance Shop

Figure 1-16 Installation of Earthen Berm around Soil Stockpile

Table 1-9 Capital Expenditures for Pollution Prevention BMPs

Fiscal Year	Expenditure
2005	$ 613,210 - actual
2006	$ 592,873 - actual
2007	$ 450,608 - actual
2008	$ 590,704 - actual
2009	$ 478,889 – actual
2010	$ 613,766 - actual
2011	$ 595,984 - actual
2012	$ 664,577 - actual
2013	$ 917,902 - actual
2014	$ 1,850,000 - projected

Table 1-9 above shows the SHA capital expenditures towards industrial pollution prevention BMPs from the current and past six fiscal years. Projected expenditures for FY14 are also included.

E.5 Illicit Discharge Detection and Elimination

Requirements under this condition include:

a) *Conduct visual inspections of stormwater outfalls as part of its source identification and BMP inspection protocols*

b) *Document each outfall's structural, environmental and functional attributes;*

c) *Investigate outfalls suspected of having illicit connections by using storm drain maps, chemical screening, dye testing, and other viable means;*

d) *Use appropriate enforcement procedures for eliminating illicit connections or refer violators to MDE for enforcement and permitting.*

e) *Coordinate with surrounding jurisdictions when illicit connections originate from beyond SHA's rights-of-way; and*

f) *Annually report illicit discharge detection and elimination activities as specified in Part IV of this permit. Annual reports shall include any requests and accompanying justifications for proposed modifications to the detection and elimination program.*

E.5.a Visual Inspections and Remediation of Outfalls

The SHA Storm Drain and Outfall Inspection and Remediation Program (SOIRP) has seen an expansion over the past year from the original focus on the physical conditions and structural functionality of NPDES defined major outfalls which were documented using Chapter 4 of the *SHA NPDES Standard Procedures*, to performing comprehensive inspections of all SHA pipe outfalls. This expansion was initiated in an effort to locate and eliminate significant sources of pollution within the SHA highway drainage systems as well as address issues with degraded drainage infrastructure. In addition to assessing the current structural condition of the pipe and outfall structure, the inspections also identify eroded downstream channels that are contributing to the pollution of Maryland's waterways and the Bay, with the intent to restore these sites to reduce the pollutant loads.

The new outfall channel assessment criteria has been incorporated into the SOIRP through an new protocol and revisions to the SHA NPDES geodatabase structure. A new assessment protocol has been developed as Chapter 8, Rapid Assessment Guidelines for Outfall Channels and widely implemented throughout several highway corridors. It has become part of the SHA routine inventory and inspections conducted in compliance with permit source identification requirements. This protocol describes the standard data collection and documentation required for performing outfall channel assessments and is used in conjunction with Chapter 4 by targeting unstable outfalls with poor ratings for further assessment for remediation. SHA is taking proactive approach to address failing infrastructure issues to prevent emergency repair situations. The record management system is currently under development with the intent to include the collected data within the structure of the SHA NPDES Geodatabase.

The outfall channel inspections have been initiated along twenty four road corridors within the following NPDES Phase I and II Permit counties:

Anne Arundel County (6 corridors)
MD 2,MD 3, MD 4, I097, MD 32, MD 10

Baltimore County (4 corridors)
I-83, MD 151, I-70, US 40

Cecil County (1 corridor)
US 40

Harford County (1 corridor)
MD 24

Howard County (3 corridors)
MD 32, US 40, MD 100

Montgomery County (2 corridors)
MD 119
MD 97

Prince Georges County (7 corridors)
I-495, MD 210, US 301, MD 5, MD 4, MD 214, MD 202

In addition, SHA incorporated the outfall assessment protocol into the SHA county wide NPDES inspections in Carroll County.

As a result of these investigations, several outfall stabilization projects have been initiated as listed below in the Table 1-10.

Table 1-10 Current Outfall Stabilization Projects

Project Number	Road	County	Location Description	No. of outfalls	Project Status
AA757	MD 2	AA	Between I-695 and US 50	5	Under design
MO637	US 29	MO	At SWM Facility 150173	1	Under construction
PG092	MD 216	PG	NB at Patuxent River Bridge	1	Under construction
HO408	MD 100	HO	Behind noisewall between MD 104 and Long Gate Parkway	1	Construction completed 2012
BA712	I-695	BA	Minebank Run at Cromwell Bridge Road	5	Under Design
BA487	I-83	BA	Gunpowder Falls	2	Construction completed 2012
BA487	MD 147 I-695	BA	Various locations (Phase 2)	4	Under Construction
AW730	I-83	BA	Near Cold Bottom Road	4	Design initiated
PG554	MD 4	PG	At MP 2.6	1	Construction completed 2012
PG712	I-495	PG	400 ft N of Ramp 2 MD 450 WB to I 95 NB	1	Under Design
CH374	US 301	CH	From MD 6 to Glen Albin Road	2	Emergency repair completed 2012
BA144	I-795	BA	Near Red Run Buleward	2	Construction completed 2012
HA365	US 1	HA	Conowingo Road Slope and Outfall Stabilization	1	Construction completed 2012
AA	I-97	AA	North of Benfield Blvd	1	Under Design
BA487	Various	BA	5 sites within BA County	5	Under Construction
AW 730	Various	PG	Various locations	37	Under design
M0160	I-270	MO	At Montrose Road	1	Under Design
AX158	MD 202	PG	Near Campus Way	1	Completed
XY138	MD185	MO	At Rock Creek	1	Construction Completed 2013

SHA continues to undertake projects related to outfall channel stabilization with drainage system improvements. The goal of these projects is to protect the receiving streams, improve the water quality within the watershed and restore failing drainage infrastructure to extend the drainage assets service life. Some of the projects are individually advertised, some less complex or more urgent sites are addressed with open ended construction contract after the design plan is developed and permitted. An example of such a project is an outfall at MD 185 and Rock Creek in Montgomery County that was completed in May 2013 and is shown below in Figures 1-17 and 1-18.

Figure 1-17 MD185 at Rock Creek Outfall restoration during and after construction

Figure 1-18 MD 185 at Rock Creek Drainage Improvement during and after construction

Another example of outfall remediation is MD 202 in Prince George's County as shown in the Figures 1-19 through 1-23 below. SHA has developed an efficient process though innovative contracting to deliver outfall stabilization project in less than half of the time it usually takes for a bid build project to be implemented.

Figure 1-19 MD 202 Outfall stabilization before construction

Figure 1-20 MD202 Outfall stabilization installation of drop structure

Figure 1-21 MD 202 Outfall stabilization headwall construction

Figure 1-22 MD 202 Outfall stabilization during construction

Figure 1-23 MD 202 Outfall stabilization after construction

MD 100 - Outfall and Drainage Swale Stabilization between MD 104 and Long Gate Parkway

This project was developed in partnership with Howard County Department of Public Works that incorporated the SHA outfall reconstruction and drainage swale stabilization behind the sound wall into the overall stream restoration project design. SHA provided design and construction funding for the stabilization portion of the project and contributed funding from Transportation Enhancement Program for the stream restoration of Tributary to Red Branch

Run. The overall project was completed in winter 2012. See Figures 1-24 through 1-26.

Figure 1-24 MD 100 Outfall stabilization before construction

Figure 1-25 MD 100 drainage swale stabilization before construction

Figure 1-26 MD 100 Outfall and drainage swale stabilization after construction

E.5.b Document each Outfall's Attributes

SOIRP outfall inspections are currently being conducted on outfalls in Charles, Calvert, and St. Mary's Counties. Inspections are conducted using the SHA SOIRP Program outfall inspection protocol, Chapter 4, of the *SHA NPDES Standard.* As discussed above, based on the inspection ratings developed from the Chapter 4 protocol, those with the poorest ratings are assessed for repair or remediation using the newly developed outfall assessment protocol, Chapter 8 of the SHA standard procedures. Details of each protocol and current work for the report period are discussed below.

SOIRP Pipe and Outfall Inspections (Chapter 4)

The first step in the expanded SOIRP process is to perform a visual evaluation of pipe and outfall conditions when pipes connect to headwalls or endwalls, and when pipes terminate at their own outfall locations, such as end sections, projecting pipes, or in some cases, connect directly to culverts. Pipes are rated on a scale of 0 to 5 to identify the overall condition of the pipe and outfall.

The inspection results are based on issues visually identified by the inspection crew. Often it is difficult to evaluate an entire pipe length, so the inspection is based only on what the inspection crew can visually identify. If the upstream end of the pipe is in worse condition than the downstream end, the inspection team assigns the worst rating (5). Photographs are taken for ratings of 3, 4, or 5 which are poor ratings and as deemed necessary. These pipes and outfalls are then subjected to a second assessment (based on Chapter 8 discussed below) to determine the form and level of remediation necessary.

Outfall Channel Rapid Assessment Guidelines (Chapter 8)

The protocol for assessing outfalls is Chapter 8, Rapid Assessment Guidelines for Outfall Channels: Outfall Condition and Restoration Potential, and was included in the 2012 report as Appendix F. Use of this protocol is the second step in the SOIRP process and assesses each targeted outfall that was rated 3-5 in step one for remediation potential and urgency. The outfalls may be contributing to channel erosion, thus resulting in sediment transport to downstream receiving channels. SHA has two overall goals for these second level assessments. The first goal is for data collection and repair recommendations to augment our efforts in maintaining SHA infrastructure that will include GPS-locating of outfall channels downstream from SHA outfall structures, and completing standard inspection forms to be linked with the spatial outfall features. The GPS and form data are compiled into an outfall assessment geodatabase that is compatible for future migration into the SHA geodatabase inventory. This data will be used to prioritize the repair of SHA-owned infrastructure

E.5.c Illicit Connection Investigations

Over the past annual reporting period, October 2012 through September 2013, illicit discharge screenings were completed in Howard, Carroll and Charles Counties. As illicit discharges are found SHA sends the inspection reports to local NPDES coordinators for elimination. SHA has focused on following up on existing illicit discharges and connections that have been reported in previous annual reports, as well as illicit discharges that were discovered during this reporting period. A consultant team was contracted to revisit both existing, and recently reported, illicit discharges to determine if the connection was properly eliminated. During this reporting period it was determined that out of the 174 outfalls screened, 73 had a discernible flow, 24 were sampled and 3 identified illicit discharges will require additional jurisdictional follow-up to eliminate the connections (See Table 1-11 summarizing past and present illicit discharges). In addition, the consultant team also performs on-call inspections of illicit discharges that are reported by SHA field staff or the public. SHA continues to remain committed to detecting and eliminating illicit discharges throughout our system.

Table 1-11 Illicit Discharges Investigated from February 2001 to Date

County	Illicit Discharges Investigated	Illicit Discharges requiring Jurisdictional follow-up[1]
Anne Arundel	5	3
Baltimore	1	0
Carroll	22	3
Cecil	7	2
Charles	7	0
Frederick	16	4
Howard	19	2
Montgomery	3	3
Totals	**80**	**17**

[1]SHA is currently in the process of updating our IDDE Notification Protocol and will deliver investigation reports to the appropriate jurisdiction after the process revisions are completed.

E.5.d Use Appropriate Enforcement Procedures

Currently, SHA notifies the NPDES coordinator or their IDDE designated contact at the counties or jurisdictions in which the illicit discharges or connections to SHA storm drain system are discovered. In order to achieve better disconnection results and increase public awareness of the issue, SHA is working to implement a process to notify property owners who are suspected to be the origin of illicit discharges. Educational materials on non-stormwater discharges and MS4 permits will be included with the notification. On February 20th, 2013 SHA met with representatives from the Office of the Attorney General's (OAG) Environmental Crime Unit (ECU) and representatives from MDE's Water Management Administration (WMA). The purpose of the meeting was to discuss SHA's IDDE program and enforcement protocol. It was noted that MDE/WMA has enforcement responsibility for illicit discharge compliance throughout the entire state of Maryland. Therefore areas located outside Phase I and II NPDES counties will still need to follow SHA's disconnection protocol. SHA will first attempt to work with local jurisdictions to eliminate illicit connections. If this effort is not successful, then MDE/WMA will get involved to assist SHA and the local jurisdiction. MDE/WMA also has the option of coordinating with OAG's ECU to resolve the illicit connection. This process has not been fully implemented due to reorganization and recent reassignment of responsibilities with regard to the illicit discharge program within SHA. The process will be fully implemented before the next reporting period.

E.5.f Annual Report Illicit Discharge Detection and Elimination Activities

Over the reporting period from October 2012 to September 2013, outfalls were screened in three Phase I counties for illicit discharges: Carroll, Charles and Howard. The geodatabase containing this data is included on the attached CD. Table 1-12 below shows information for the seventeen illicit discharges requiring jurisdictional and property owner follow-up. SHA's Environmental Compliance Division (ECD) has been recently assigned oversight of SHA's IDDE program for SHA. ECD is in the process of reviewing the current IDDE management program and process to determine areas that can be streamlined or updated. ECD will continue to coordinate with surrounding jurisdictions and property owners to eliminate illicit discharges.

Table 1-12 Illicit Discharges Requiring Jurisdictional Follow-up

Number	County	SHA-Structure #	IDDE-Field Inspection Date	Pollutant
1	Anne Arundel	0202689.001	08-16-2012	Copper
2	Anne Arundel	0201478.001	08-17-2012	Ammonia
3	Anne Arundel	0290516.001	08-17-2012	Ammonia and Detergents
4	Carroll	0600412.002	08-31-2012	Sewage
5	Carroll	0600413.004	08-31-2012	Undetermined
6	Cecil	0710170.001	04-17-2012	Copper
7	Cecil	0710169.001	04-12-2012	Copper
8	Frederick	1001515.003	08-31-2012	Sewage
9	Frederick	1000783.002	08-24-2012	Sewage
10	Frederick	1020959.003	08-24-2012	Laundry Wastewater
11	Frederick	1000146.003	08-24-2012	Sewage
12	Montgomery	1501376.001	04-21-2004	Detergents
13	Montgomery	1500716.001	06-30-2004	Chlorine
14	Montgomery	1500848.001	06-29-2004	Detergents
15	Howard	1300455.001	10-23-2012	Chlorine
16	Howard	1301092.001	10-23-2012	Ammonia & Copper
17	Carroll	0601008.001	03-04-2013	Sewage

E.6 Environmental Stewardship

Requirements under this condition include:

a) *Environmental Stewardship by Motorists*

   i) *Provide stream, river, lake, and estuary name signs and environmental stewardship messages where appropriate and safe,*

   ii) *Create opportunities for volunteer roadside litter control and native tree plantings; and*

   iii) *Promote combined vehicle trips, ozone alerts, fueling after dark, mass transit* *and other pollution reduction actions for motorist participation.*

b) *Environmental Stewardship by Employees*

i) *Provide classes regarding stormwater management and erosion and sediment control;*

ii) *Participate in field trips that demonstrate links between highway runoff and stream, river, and Chesapeake Bay health;*

iii) *Provide an environmental awareness training module for all areas of SHA;*

iv) *Provide pollution prevention training for vehicle maintenance shop personnel;*

v) *Ensure Integrated Pest Management instruction and certification by the Maryland Department of Agriculture for personnel responsible for roadside vegetation maintenance; and*

vi) *Promote pollution prevention by SHA employees by encouraging combined vehicle trips, carpooling, mass transit, and compressed work weeks.*

E.6.a Environmental Stewardship by Motorists

SHA continues many initiatives that encourage or target public involvement and participation in water quality programs. These initiatives cover the areas of litter control, watershed partnerships, community planting efforts and public education.

SHA public involvement and participation initiatives for the past year include:

Annual Earth Day Celebration –To commemorate this year's Annual Earth Day celebration, The SHA Earth Day Team sponsored a series of Learning Sessions and activities to promote environmental awareness and stewardship. The Learning Sessions were held at SHA Headquarters from April 15-24, 2013. The topics included selecting environmentally friendly home cleaning products, tree selection and care, creating home rain gardens, and entomology of "good and bad" bugs. Earth Day participants were also able to participate in a service project and lend a hand in giving SHA Headquarters building a landscaping make-over.

Adopt-a-Highway Program

This program encourages volunteer groups (family, business, school or civic organizations) to pick up litter along one to three mile stretches of non-interstate roadways four times a year for a two year period as a community service. Table 1-13 identifies the participation for the AAH program over the current reporting period.

Table 1-13 Adopt-a-Highway Program

County	Groups	No. Bags	Miles Adopted
Anne Arundel	4	88	4.8
Baltimore	34	566	39.78
Carroll	7	164	9.63
Cecil	0	0	0
Charles	0	0	0
Frederick	8	134	12.41
Harford	1	11	1.16
Howard	7	164	9.67
Montgomery	5	113	6.24
Prince George's	0	0	0
Washington	18	396	24.48
Cumberland, Cambridge, Salisbury	0	0	0
Totals	84	1636	108.17
Data extracted from the Adopt-A-Highway database for the period 10/01/2012 to 09/23/2013			

Sponsor-a-Highway Program

SHA also has a program that allows corporate sponsors to sponsor one-mile sections of Maryland roadways. Table 1-14 shows the miles currently being sponsored. The Sponsor enters into an agreement with a maintenance provider for litter and debris removal from the sponsored highway segment.

Table 1-14 Sponsor-a-Highway Program

County	Available Miles	Miles Sponsored
Anne Arundel	56.40	73.84
Baltimore	18.84	87.085
Carroll	0	0
Cecil	0	0
Charles	25.47	1.00
Frederick	13.80	9.88
Harford	5.81	3.61
Howard	20.73	30.228
Montgomery	3.42	45.044
Prince George's	53.18	56.418
Washington	15.34	1.2
Cumberland, Cambridge, Salisbury	0	0
Totals	212.99	308.31
Data extracted from the Sponsor-A-Highway database for the period 10/01/2012 to 09/23/2013		

Partnership Planting Program

SHA develops partnerships with local governments, community organizations and garden clubs for the purpose of beautifying highways and improving the environment. Community gateway plantings, reforestation plantings, streetscapes and highway beautification plantings are examples of the types of projects that have been completed within the Partnership Planting Program. Table 1-15 lists the number of plants, counties of participation and numbers of volunteers for the last reporting period. A photo from a Cecil County Partnership Planting is in Figure 1-27 on the following page.

Table 1-15 Partnership Planting Program

NPDES County or Municipality	No. Trees/Shrubs	No. Volunteers
Anne Arundel	0	0
Baltimore	0	0
Cambridge	0	0
Carroll	2000 Bulbs	16
Cecil	100 Trees	12
Charles	0	0
Cumberland	0	0
Frederick	2000 Bulbs	14
Harford		
Howard	60 Trees /2000Bulbs	24
Montgomery	0	0
Prince Georges	0	0
Salisbury	0	0
Washington	0	0
Data extracted from the Partnership Planting Program database for the period 10/01/2012 to 09/30/2013		

Transportation Alternatives Program

SHA Administers the Federal Highway Transportation Alternatives Program (TAP) for the State of Maryland. This program had been the Transportation Enhancement Program (TEP), but was modified under MAP-21 legislation in 2012 for project grants awarded in 2013. In this capacity, SHA looks for opportunities to share the potential benefits of applying for funding under this program with projects that fall under the eligible funding categories.

For potential projects that fall under the funding category 'Mitigation of Water Pollution due to Highway Runoff', SHA Office of Highway Development and Office of Environmental Design take the initiative with watershed groups, local municipalities, community groups and counties to encourage their participation in this program. SHA provides assistance to potential project sponsors by advising on proposal content, reviewing drafts and then providing guidance on Federal Aid requirements for construction document preparation and advertisement. A full list of projects funded through the TAP or TEP program are included in Section G.

Figure 1-27 Partnership Planting from October 2012 along MD 272 in Cecil County

Maryland Quality Initiative (MdQI) 2013 Conference: 'Quality Transportation – A Hybrid Approach'

The mission of MdQI is to provide the Maryland transportation industry a forum that fosters coordinated and continuous quality improvement in order to ensure safe, efficient, and environmentally sensitive transportation networks to meet the needs of all transportation stakeholders. This industry conference is held annually each winter and brings together public and private design and construction industry professionals in a forum of workshops, round table discussions, exhibits and networking. This year's conference was held January30-31 at the Baltimore Convention Center and approximately 700 engineers, consultants and contractors attended the conference. The participants included both public and private industry representatives. The website is 'mdqi.org'.

Multiple topics were discussed including major projects, new technologies, procurement processes, and consensus building. One session focused specifically on environmental quality and the TMDL program, as described below:

Moving Ahead with Greener, Cleaner, Safer Roadways: Sustainability is an important consideration in roadway development and maintenance practices, and sustainability measures include environmental, economic, and social implications. This session included discussions related to the benefits of environmental quality, and specifically discussed the benefits of environmental restoration projects related to SHA's TMDL program. See Figure 1-28 below for a screenshot from the presentation.

Figure 1-28 Screenshot from the Moving Ahead with Greener, Cleaner, Safer Roadways Presentation

E.6.b Environmental Stewardship by Employees

SHA continues to provide environmental awareness training to its personnel and is committed to continuing these efforts in the future. We have provided updated data for these efforts through the following training and awareness programs listed below:

SHA Recycles Campaign

In support of the SHA Business Plan, the Environmental Compliance and Stewardship Key Performance Area launched the SHA Recycles Campaign on April 22, 2008 to raise awareness and encourage change in consumer culture throughout the organization. The goal of this campaign is to reduce waste and litter by making conservation a priority, reusing what we previously discarded, and recycling as much as possible.

The SHA Recycles Campaign is working to build a consortium of stakeholders across the entire SHA organization towards this collective goal. The campaign encourages all employees to give feedback on what can be done to save energy and fuel, reduce or eliminate waste, improve current recycling efforts, or change business practices to conserve resources. It provides education and outreach through displays and presentations at SHA events such as the Annual Earth Day Celebration, and office-wide training and recognition days.

A State-wide Recycling Task Force has also been formed at SHA to examine key issues in recycling and identify ways to improve the SHA Statewide Recycling Program.

Million Tree Initiative

In the fall of 2008, the Maryland State Highway Administration (SHA), the Maryland Department of Natural Resources (MDNR), Federal Highway Administration (FHWA), and the Maryland Department of Safety and Correctional Services (DPSCS) formed a partnership to plant trees along Maryland roadsides and in State right-of-way. The tree-planting program directly supports Governor Martin O'Malley's *Smart, Green and Growing* initiative. SHA funded the trees and materials; MDNR is funding the labor, which is provided by inmates from DPSCS. On May 4, 2011, Governor O'Malley planted the One Millionth Tree with Inmates.

Environmental Awareness Training (Chesapeake Bay Field Trips)

This training is provided to all new employees and other employees seeking to improve their environmental awareness. This field trip demonstrates the link between highway runoff and its impacts on streams, rivers and on the health of the Chesapeake Bay. A total of five trips were taken between October 2012 and October 2013 including trips in December 2012 and April, June and two trips in September 2013. Over this period 118 participants attended.

Office of Highway Development (OHD) University

Our Office of Highway Development continues its OHD-University training program that targets office employees and continues to invite others throughout our organization to participate. The technical training sessions, which are offered annually, provide formal professional development opportunities for staff members. While the program primarily targets new engineers, there are additional benefits for the more experienced attendees, including gaining greater understanding of policy and design updates and revisions or changes to permitting requirements. A myriad of key topics associated with the planning, design, construction, and maintenance of roadway networks are discussed, including SWM, ESC, permits, and specific NPDES concerns. During the current reporting period, the total number of employees who completed the relevant training sessions was 22.

Statewide Pesticide/Vegetation Management Training

There are several types of internal training sessions for pesticide management that SHA provides annually. They include registration, re-certification, right-of-way pre-certification preparation, aquatic pre-certification preparation, and herbicide updates. The number of participants at each of these training sessions is listed below in Tables 1-16 to 1-18. There was no Vegetation Management Conference (ENV200) or (ENV220) or Aquatic Pesticide Certification Preparation training held in 2013.

Table 1-16 Pesticide Applicator Registration (ENV100)

SHA District	Number Trained
3 (MO, PG)	29
4 (BA. HA)	17
5 (AA, CH)	52
Totals	98

Table 1-17 Pesticide Core and Right-of-Way Certification Preparation Class (ENV210)

SHA District	Number Trained
3 (MO, PG)	5
4 (BA. HA)	6
5 (AA, CH)	8
Totals	19

Table 1-18 Maryland Pesticide Safety Conference

SHA District	Number Trained
3 (MO, PG)	7
4 (BA. HA)	19
5 (AA, CH)	11
Totals	37

Maryland Department of Transportation (MDOT) Water Quality Policies and Water Quality Clearing House Web Page

This is a continuing effort that provides information on department-wide water quality policies and other regulations applicable to transportation projects. This webpage is periodically updated with regulatory/policy changes and can be accessed at www.mdot.state.md.us and clicking on the 'Environmental Programs' link on the left-hand panel. The tabs at the top of the page lead to information on state and environmental self audit program; regulations for transportation facility operations such as storage tanks and spill prevention and response; environmental resources such as Smart, Green & Growing, MDE, MDNR and EPA; MDOT environmental resources such as environmental stewardship in the 2009 MD Transportation Plan and the 2013 Annual Attainment Report on Transportation System Performance; and an information brochure for the MDOT Office of Environment.

SHA Environment and Community Web Page

SHA has developed an environmental awareness web page that is located on the SHA internet site (www.marylandroads.com). A recent addition to this webpage is a page called 'Cleaner, Greener Practices and Initiatives'. The webpage includes the following topics:

Innovation and Design

- LEED
- Signal Systemization
- HOV
- Geographic Information System & Environmental Inventory Tool

Initiatives

- Diesel and Biodiesel Fuels
- Recycling
- Litter Education.

Maintenance

- Winter Operations
- Mowing Reduction
- Idling Policy
- Vehicle and Equipment Fleet
- Road Sweeping & Ditch/Culvert Cleanings
- Litter Removal
- Statewide Salt Management Plan

Descriptions from select links are included below.

Litter Education Link: "As an additional public service, SHA offers support for litter awareness events at schools and civic events. The program can provide materials such as coloring books, brochures, speakers and visits from our Litter Critter characters." Contact information is provided.

Diesel and Bio-Diesel Fuels Link: "SHA is acting now to reduce the environmental impact of diesel fuel usage. Our first step was to find ways to reduce our overall diesel usage through policies such as our engine idling policy. We also replaced many diesel vehicles with flex-fuel vehicles (which can use more than one type of fuel) and replaced antiquated equipment with newer fuel-efficient equipment. In some cases, we were able to reduce our inventory of equipment.

One of our major changes was to introduce bio-diesel fuels into our supply. Currently, SHA uses a 5% bio-diesel blended fuel (also known as B5) where conventional diesel is blended with a biodegradable, renewable fuel derived from soy beans. Bio-diesel reduces our use of non-renewable fossil fuels and it significantly reduces the amounts of particulates, carbon monoxide and unburned hydrocarbons released into the atmosphere. The B5 blend is also "ultra-low-sulfur." Reducing sulfuric acid emissions into the environment greatly reduces the formation of harmful acid rain and the amount of dry acidic deposits that can accumulate in places such as the ground, buildings, homes or trees.

Finally, all of SHA's pre-2004 dump trucks have been brought up to 2004 emissions standards via Diesel Catalyst Retrofit Technology. This technology reduces emissions by converting harmful diesel exhaust pollutants to carbon dioxide and water via a catalyst. This technology reduces unburned hydrocarbons and carbon monoxide by 90%. Particulate matter (PM) reductions vary from 20-50%. To put it simply, these retrofits turn harmful compounds normally found in our diesel exhaust to safe components."

Recycling Link: "Reusing and recycling is one of the many steps we take to help provide future generations with a cleaner, safer environment. We realize the importance of environmental cleanliness and conservation, and have established several recycling practices to reduce our carbon footprint and protect climate change. (Carbon footprint is the amount of greenhouse gas emissions generated by a person, business, or other type or organization.)

One of our practices is supporting the goals of Maryland's Smart, Green and Growing initiative and using effective recycling programs throughout the community. We remain committed to recycling no less than fifty percent of solid waste each year. For example, we reuse asphalt when possible on our projects, and recycle materials from construction projects.

SHA formed a task force in 2009 to help identify ways to improve our statewide recycling program. Our task force, known to many as a network of "recycling champions", includes members from the University of Maryland, the Maryland Department of the Environment, and the Environmental Protection Agency.

Working with the local construction industry is another important step we take as part of our recycling practices. This partnership helps to generate ideas on environmentally safe ways of recycling pavement for future highway projects. For example, we have worked with a local contractor that produces 100 percent recycled crushed graded aggregate base, which is a product typically applied to roadways prior to paving. Over 13,000 tons of natural aggregate have been saved though this program.

In addition to reusing and recycling pavement materials, we are also focusing on reducing emissions and waste from our machinery and equipment. By reducing emissions and waste, we lessen the overall output of substances into the air that could lead to climate change. We are moving forward with using a five percent blend of bio-diesel fuel in equipment as well as recovering and recycling motor oil, filters, and batteries to meet our goals of saving the environment, one step at a time.

We continue to partner with our fellow state agencies, the construction community, and others to successfully implement our recycling practices and keep Maryland healthy and beautiful."

Litter Removal Link: "A critical aspect of year round highway maintenance is the removal of litter from shoulders and drainage systems. SHA uses a multi-pronged approach to litter control utilizing SHA employees, state workers, contractors as well as labor donated through the Sponsor-A-Highway program and partnerships with Adopt-A-Highway volunteers. SHA also continues its public outreach to educate the public about the hazards of littering and its impact on the environment.

The MD SHA has taken several steps to "green" our litter removal efforts. Instead of just picking up litter, we now provide our crews and volunteers with the means to separate recyclables from trash. All seven of our Districts are currently recycling roadway litter in a formal manner. As our recycling efforts increase, the volume of waste taken to landfills continues to decrease."

Employee Commuter Reduction Incentives

SHA offers several incentives to reduce the number of drivers and/or number of commuter days/miles per week by Administration employees. Fewer commuter days and miles mean less vehicle pollutants entering the watershed.

Alternate work schedules include flexible work hours allowing employees to work compressed workweeks reducing the total number of commuting days and miles.

Teleworking allows employees to work from a remote location (presumably at or close to home) and also reduces the number of commuting days and miles per week. Each office has or is developing a teleworking policy.

Car-pooling has been encouraged at SHA for many years and reduces the number of commuters on the road. SHA car-pooling incentives include prioritizing parking space allocation to those in a designated car pool and Administration assistance in locating a carpool within the employee's residential area through parking database.

Finally, employee ID badges allow state employees to acquire a free State Transit Employee Pass (STEP) that allows free access to MTA mass transit including the Baltimore area subway, light rail, and buses. This encourages the use of mass transit by SHA employees who live within the Baltimore area.

SHA Vehicle and Equipment Idling Policy

On September 22, 2009, the former SHA Administrator issued a policy regarding reduction in idling of engines for state equipment and vehicles. The purpose is to reduce fuel consumption by state forces, and if adhered to, will result in pollutant load reduction as well.

F Watershed Assessment

The watershed assessment effort described by the permit includes continuing to provide available geographic information system (GIS) highway data to permitted NPDES municipalities and MDE; completing the impervious surface accounting by the fourth annual report; select sites for retrofitting impervious areas with poor or no control infrastructure; and working with NPDES municipalities to maximize water quality improvements in areas of local concern.

F.1 GIS Highway Data to NPDES Jurisdictions and MDE

SHA continues to make the SHA GIS storm drain and BMP data available to NPDES jurisdictions (when requested) and MDE.

We periodically coordinate with the MDE Science Services Administration on data issues for the Bay and local TMDL modeling.

F.2 Complete Impervious Accounting by Fourth Annual Report

SHA completed the impervious accounting requirement for the all Phase I counties, by the fourth annual report, October 2009.

The issue of treatment credit accounting for impervious surfaces treated by entities other than the jurisdiction that has ownership of the surfaces is still not resolved between MDE and the MS4 jurisdictions. SHA has currently taken credit only for SHA-owned surfaces and not included in the accounting any non-SHA impervious surfaces to date. Although it is anticipated that this additional treatment credit will be applied to SHA in the future, thus increasing treatment currently provided.

The impervious accounting has been expanded to include Phase II counties, Washington and Cecil and the results are included in this report under Section C.3. Work to develop SHA impervious accounting for the three jurisdictions (Cambridge, Cumberland and Salisbury) is underway and anticipated for completion by the next annual report.

F.3 Impervious Area Retrofits

SHA continues to identify and develop sites that prove suitable for SWM facilities that provide water quality treatment of existing impervious areas within the SHA controlled R/W. We have also implemented alternative BMPs such as Urban Tree Planting, Urban Stream Restoration and Pavement Reduction as part of our Chesapeake Bay TMDL implementation plan discussed in Section J.

F.4 Maximize Water Quality Improvements in Areas of Local Concern

As a transportation agency focusing on providing and maintaining a highway system that supports local and statewide economic development, we ensure that our projects meet all necessary SWM and water quality regulations. In addition, as part of the terms of our permit conditions, we also adhere to the watershed restoration goals and priorities that have been established by local NPDES jurisdictions.

Our past achievements in maximizing water quality improvements within areas of local concern have been discussed in detail during previous reporting periods. Activities have included the following.

- Documenting watershed goals and priorities in partnership with the Maryland Department of Transportation (MDOT).
- Piloting a watershed-based SWM assessment on US 301 in partnership with Prince George's and Charles counties.
- Commencing work on a draft framework for implementing a watershed-based approach for SWM using a grant from the Environmental Protection Agency (EPA) and as part of the Green Highways Partnership (GHP) between SHA, the EPA, and the Federal Highway Administration (FHWA).
- Performing a retrofit study of the Indian Creek watershed in partnership with local, state, and federal officials.
- Preparing for TMDL milestones and allocation reductions.

Updates for on-going or recently-reported endeavors are as follows.

Green Highways Partnership

The Green Highways Partnership (GHP) is an approach intended to provide sustainable transportation infrastructure through improved environmental compliance, protection, and preservation. Formally launched by the U.S. Environmental Protection Agency (EPA) in 2005, the GHP is a voluntary, public/private network that promotes collaboration in developing 'green' transportation solutions.

With the increased focus on TMDLs, the GHP endeavor was placed on hold by the EPA in 2010.

Watershed Resource Registry

The Watershed Resource Registry (WRR) is a national pilot to integrate land-use planning, regulatory, and non-regulatory decision making using the watershed approach. SHA, through the Green Highways Partnership, developed a GIS-based pilot Registry through a project proposed by the SHA for Route 301 in Prince George's and Charles Counties. The WRR Technical Advisory Team members sought to develop a framework for integrated watershed management that could be transferred nationally. The project team initially targeted southwest Maryland as a pilot region. Today, GIS-based WRR opportunity outputs have been compiled for the entire State of Maryland and are available through a web-based user interface.

SHA has used the WRR since Spring 2012. The WRR application has been valuable for gathering environmental inventory information, assessing watershed needs, and identifying potential mitigation sites. It can also be used to provide backup information for justifying mitigation site selection in support of various regulatory permitting processes. The web application also compliments initial field reconnaissance by providing the ability to export data about a location onto a print map including latitude / longitude coordinates which can be keyed into a GPS for navigation purposes

The intent is to roll the WRR out nationally to private sector, local, state and federal governmental entities. As a result, the web application, modeling, and overall framework was developed in a manner that allows for the solution to be scaled with relative ease. This technology can be used for a variety of watershed-based land-use planning efforts. Benefits of the WRR include:

- Reduced costs through more efficient administration of regulatory and non-regulatory - programs and less review/site assessment/coordination time
- Improved environmental outcomes
- Supports integrated decision making among multiple users
- Uses a common watershed-based platform
- Provides access to updated, consistent, and defensible data
- Results in enhanced protection and targeted restoration of resources
- Achieves multiple environmental objectives
- Is a model approach for addressing potential new stormwater requirements (offsite mitigation, credits, offsets) on a watershed basis
- Is transparent, predictable, and reliable
- Promotes stakeholder and public involvement
- Provides transferability to other states nationwide

Beginning in October, 2012, end user testing has occurred with key agencies within Maryland to gather feedback on the application. During this time, coordination between the WRR Technical Advisory Committee members will review and address agency feedback. Web hosting and technical support geared to the web application and separate outreach website is ongoing. Cyclical updates to WRR models in order to maintain an accurate depiction of potential restoration and preservation areas within the State is also ongoing.

Framework to Implement a Watershed-Based Approach for Managing Stormwater

A working draft on the framework to implement a watershed-based approach to SWM remains under development and includes recommendations regarding how to cultivate partnerships, determine specific watershed needs, establish accountability, optimize budget spending, and promote sustainable systems. We await feedback from the EPA before finalizing the document.

Green Infrastructure Expansion

To help better preserve and protect ecosystems, we began examining green infrastructure – hubs and corridors – to increase ways of expanding these areas or increasing corridor connections between hubs as part of improvements associated with transportation projects. In addition to providing improved habitat size and providing more corridors for migration or movement routes of wildlife, further benefits may include enhanced SWM via greater green space and reduced runoff. From the last reporting period, no significant progress has been made in this area.

Recycled Materials Task Force

The Office of Materials and Technology created a task force to review, analyze, and implement the use of recycled materials in transportation projects. Pertinent design offices actively participate in quarterly meetings. Design expertise includes materials, hydrology, environmental regulations, habitats and ecosystems, and highways. Members of regulatory agencies as well as industry manufacturers and suppliers also participate. As a result of these meetings, SHA routinely uses recycled and reclaimed materials in transportation projects. Examples include the use of recovered crushed glass for use in filtration-type SWM facilities and the use of recovered asphalt in the use of sub-base materials. The use of recycled brick has been examined but to-date, there does not appear to be any added benefits, particularly with regards to enhancing SWM pollutant removals.

Local 8-Digit Impairments and TMDLs

With the TMDL requirements anticipated for the next permit term, which is expected to focus on waste load reductions for urban stormwater runoff, we will be shifting our efforts to prioritize key segments of the Chesapeake Bay watershed along with local TMDL watersheds in which we are named as a contributor to the waste load allocation (WLA). Establishment of the 2-year milestones has begun and we have been making progress towards meeting set goals to achieving Bay TMDL requirements while demonstrating compliance with local TMDLs. We are programming and developing policies to coincide with the anticipated load reduction goals.

Additional endeavors in which we are currently involved are covered in Section G.

G Watershed Restoration

Requirements for this permit condition include developing and implementing twenty-five significant stormwater management retrofit projects to improve water quality of highway runoff that are beyond typical stormwater management maintenance. The retrofit projects include innovative alternatives to reduce pollutant loads, mitigate for adverse impacts of urbanization and highway runoff and provide significant water quality benefits on the watershed scale. The projects implemented include functional enhancements and upgrades of ineffective facilities to meet current SWM design standards and improve the pollutant removal efficiencies as well as construction of new BMPs to treat previously untreated impervious areas. The watershed restoration projects include stream and drainage outfall restoration to stabilize degrading channels and prevent sediment transport to downstream reaches.

The second aspect of this permit requirement is cooperation with local governments and watershed groups and contribution to local watershed restoration activities by constructing or funding retrofits within locally targeted watersheds. Based on this permit condition, SHA is required to submit annual reports on watershed activities in terms of costs, schedules, implementation status and impervious acres proposed for management.

G.1 Implement 25 Significant SWM Retrofit Projects

The requirement that twenty-five projects be completed was met and reported on in past annual reports. We are continuing our efforts to maximize treatment of our baseline untreated impervious in anticipation of a percentage treatment requirement for our next permit term.

SHA continues to retrofit exiting SWM facilities to improve their pollutant removal efficiencies and use innovative methods to address water quality treatment.

Stormwater Facility Enhancements & Retrofits

These projects were developed outside of roadway development stormwater management requirements and consist of upgrading stormwater BMPs to current regulations, constructing new SWM facilities to treat addition impervious surface, stream stabilization and restoration, and drainage outfall channel stabilization projects. Table 1-19 lists these projects to date which total 113 and amount to approximately 923 acres. Our current level of treatment is 3%.

Figure 1- 29 MD 147 and I-695 SE Loop – SWM Water Quality Retrofit Project shortly after construction

Table 1-19 Watershed Restoration Projects

Projects by Watershed	Retrofit Type	Status	Restored Impervious Acres
Lower Susquehanna River – 02-12-02			
BMP 120076	BMP retrofit	Complete	2.82
Bush River Area – 02-13-07			
BMP 120069	BMP Retrofit	Complete	4.16
BMP 120072	BMP Retrofit	Complete	4.68
BMP 120073	BMP Retrofit	Complete	3.99
BMP 120075	BMP Retrofit	Complete	1.77
BMP 120081	BMP Retrofit	Complete	2.39
BMP 120082	BMP Retrofit	Complete	1.00
Gunpowder River – 02-13-08			
I-83 Outfall Stabilization of Tributaries to Gunpowder Falls	Stream stabilization	Complete	7.85
Minebank Run Restoration, Drainage and WQ Improvements	Stream restoration, outfall stabilization, SWM retrofit	Design	236.8
BMP 030389*	BMP Retrofit	Complete	2.43
Patapsco River – 02-13-09			
BMP 020120	BMP Retrofit	Complete	17.73
BMP 020121	BMP Retrofit	Complete	0.96
BMP 020122	BMP Retrofit	Complete	0.92
BMP 020625	BMP Retrofit	Design	2.46
BMP 030281	BMP Retrofit	Complete	8.35
MD 139 Tributary to Towson Run Stabilization	Stream Stabilization	Complete	260.30
BMP 020111	BMP Retrofit	Complete	6.04
BMP 020112	BMP Retrofit	Complete	0.56
BMP 020098	BMP Retrofit	Complete	0.68
BMP 020099	BMP Enhancement	Complete	0.75
BMP 020476	BMP Retrofit	Complete	3.79
BMP 020477	BMP Retrofit	Complete	Combined with 020476
BMP 130197	BMP Retrofit	Complete	0.44
BMP 130207	BMP Retrofit	Complete	1.57
BMP 130221	BMP Retrofit	Complete	0.17
BMP 130210	BMP Retrofit	Complete	0.24
BMP 130217	BMP Retrofit	Complete	0.10
I-695 Tributary to Steamers Run*	Stream Stabilization	Under construction	182.00
West Chesapeake Bay – 02-13-10			
BMP 020019	BMP Retrofit	Complete	1.22
BMP 020022	BMP Retrofit	Complete	1.06
BMP 020027	BMP Retrofit	Complete	1.59
BMP 020029	BMP Retrofit	Complete	0.88
BMP 020031	BMP Retrofit	Complete	2.29
BMP 020088	BMP Retrofit	Complete	3.53

Table 1-19 Watershed Restoration Projects

Projects by Watershed	Retrofit Type	Status	Restored Impervious Acres
BMP 020481	BMP Retrofit	Complete	2.09
BMP 020522	BMP Retrofit	Complete	1.70
BMP 020273	BMP Retrofit	Complete	1.18
BMP 020491	BMP Retrofit	Complete	1.79
BMP 020185	BMP Retrofit	Complete	0.48
BMP 020198	BMP Retrofit	Complete	0.68
BMP 020201	BMP Retrofit	Complete	1.01
BMP 020205	BMP Retrofit	Complete	1.16
BMP 020206	BMP Retrofit	Complete	0.49
BMP 020210	BMP Retrofit	Complete	0.36
BMP 020220	BMP Retrofit	Complete	0.72
BMP 020258	BMP Retrofit	Design	3.27
BMP 020260	BMP Retrofit	Design	1.41
BMP 020268	BMP Retrofit	Design	7.08
BMP 020393	BMP Retrofit	Design	4.35
BMP 020394	BMP Retrofit	Design	3.27
BMP 020014	BMP Retrofit	Design	2.20
BMP 020015	BMP Retrofit	Design	1.22
BMP 020016	BMP Retrofit	Design	0.95
BMP 020017	BMP Retrofit	Design	0.44
BMP 020018	BMP Retrofit	Design	0.89
Patuxent River – 02-13-11			
BMP 160059	BMP Retrofit	Complete	3.2
BMP 020488	BMP Retrofit	Complete	5.56
BMP 160217	BMP Retrofit	Complete	0.64
BMP 160219	BMP Retrofit	Complete	0.91
BMP 160380	BMP Retrofit	Complete	3.42
BMP 020301	BMP Retrofit	Complete	2.30
BMP 020311	BMP Retrofit	Complete	0.28
BMP 020437	BMP Retrofit	Complete	4.13
BMP 020299*	BMP Retrofit	Complete	1.09
BMP 130149	BMP Retrofit	Complete	0.48
BMP 130150	BMP Retrofit	Complete	1.02
BMP 130154	BMP Retrofit	Complete	0.47
BMP 130159	BMP Retrofit	Complete	0.02
BMP 130160	BMP Retrofit	Complete	0.52
BMP 130162	BMP Retrofit	Complete	0.66
BMP 130179	BMP Retrofit	Complete	2.10
BMP 130180	BMP Retrofit	Complete	0.43
BMP 130187	BMP Retrofit	Complete	0.13
BMP 130188	BMP Retrofit	Complete	0.12
BMP 130189	BMP Retrofit	Complete	0.03
BMP 130190	BMP Retrofit	Complete	0.03
BMP 130191	BMP Retrofit	Complete	0.05
BMP 130192	BMP Retrofit	Complete	0.05
BMP 130193	BMP Retrofit	Complete	0.10
BMP 130194	BMP Retrofit	Complete	0.22

Table 1-19 Watershed Restoration Projects

Projects by Watershed	Retrofit Type	Status	Restored Impervious Acres
BMP 130232	BMP Retrofit	Complete	0.03
BMP 130242	BMP Retrofit	Complete	0.72
BMP 130243	BMP Retrofit	Complete	3.49
BMP 150228	BMP Retrofit	Complete	0.13
BMP 150331	BMP Retrofit	Complete	0.23
BMP 130047	BMP Retrofit	Complete	1.39
Lower Potomac River – 02-14-01			
BMP 160456	BMP Retrofit	Complete	1.70
BMP 080014	BMP Retrofit	Complete	0.24
BMP 080039	BMP Retrofit	Complete	0.10
BMP 080040	BMP Retrofit	Complete	0.10
BMP 080041	BMP Retrofit	Complete	0.12
BMP 080042	BMP Retrofit	Complete	0.11
BMP 080043	BMP Retrofit	Complete	0.28
BMP 080044	BMP Retrofit	Complete	0.20
BMP 080083	BMP Retrofit	Complete	0.06
BMP 080095	BMP Retrofit	Complete	0.48
Washington Metropolitan-02-14-02			
BMP 160607	BMP Retrofit	Complete	0.41
BMP 160609	BMP Retrofit	Complete	Combined with 160607
BMP 160653	BMP Retrofit	Complete	15.80
Long Draught Branch Restoration	Stream Stabilization	Design	228
BMP 150002	BMP Retrofit	Complete	0.31
BMP 150003	BMP Retrofit	Complete	1.69
BMP 150004	BMP Retrofit	Complete	Combined with 150003
BMP 150005	BMP Retrofit	Complete	Combined with 150003
BMP 150172	BMP Retrofit	Design	1.25
BMP 150173*	BMP Retrofit	Construction	1.18
BMP 150301	BMP Retrofit	Complete	0.28
BMP 150362	BMP Retrofit	Complete	1.03
BMP 150380	BMP Retrofit	Complete	1.05
BMP 150550	BMP Retrofit	Complete	1.26
BMP 150076	BMP Retrofit	Complete	1.25
BMP 150059	BMP Retrofit	Design	4.67
BMP 150556	BMP Retrofit	Design	5.65
Middle Potomac River – 02-14-03			
Tributary to Tuscarora Creek Stabilization at US 340 and US 15	Stream Stabilization	Complete	1.94
BMP 150270	BMP retrofit	Complete	0.08
*Projects added since last report.			

Pavement Retrofit Projects

SHA continues development and implementation of existing SWM facilities enhancements as well as continues site search for water quality improvement projects. Funding had been allocated for design and construction of SWM retrofit projects to meet future waste load reductions and impervious treatment requirements. Future projects include conversion of older SWM facilities originally designed to manage water quantity into water quality sites. In addition, SHA is actively working on implementation of water quality treatment of pavement through median bioswales designed within open section roadway medians in Phase I and Phase II counties.

Stream Project Assessments

MD SHA has been designing stream restoration and stabilization projects as part of larger highway projects for fulfilling mitigation requirements, to ensure safe roadside areas for the travelling public, and to ensure new bridge openings are in sync with the geomorphology and long term stability. Other projects have been implemented to provide stable conveyances from roadway outfalls or to minimize sediment transport beyond the stream's natural rate resulting in water quality improvements. These projects that address mostly physical degradation issues of natural stream channels have been often perceived as additional impacts to aquatic resources. This perception is the case even though they are remediating past human impacts and the proposed work is intended to improve physical and/or biological indexes. Because actual environmental benefits are challenging to quantify without monitoring data and scientific analysis, SHA initiated assessment and monitoring studies of completed and proposed stream restoration projects. The results of these studies will be used to make recommendations for design or construction changes as well as potential improvements to restoration strategies and methods. The data has been collected since 1998 at a total of 14 sites and includes assessments for benthic, macro invertebrates, fishes and physical habitat. The stream assessments have been performed by Dr. R. P. Morgan at the University of Maryland, Frostburg, Center for Environmental Service and his students.

The latest monitoring report is included as Appendix C.SHA and UMD have been monitoring the following sites:

- US 15 Monocracy River/Tuscarora Creek:-Pre-construction
- I-695 at Minebank Run Stream (Lower Site): Pre-construction testing (see Figure 1-30)
- MD 117 Long Draught Branch: Post construction monitoring (see Figure 1-31)
- Plumtree Run from east of Ring Factory Rd. to north of MD 24: Pre-construction monitoring
- MD 144 Upper Little Patuxent River: Pre-construction monitoring

Figure 1-30 I-695 at Minebank Run (Lower Site) Stream Restoration Pre-Construction Monitoring Site

Figure 1-31 MD 117 at Long Draught Branch (Middle Site) Stream Restoration Pre-Construction Monitoring Site

Restoration Project Database Delivery

Data related to the retrofit projects was submitted with previous reports and can be made available upon request.

G.2 Contribute to Local NPDES Watershed Restoration Activities

SHA actively participates in local water quality improvement projects and supports watershed interest groups and local jurisdictions in their watershed restoration activities. In addition, SHA has participated directly or indirectly in developing watershed plans as well as provided funding. The SHA oversees the Federal Transportation Alternatives Program (TAP) and encourages the use of these funds by local jurisdictions and interest groups to fund water quality projects to mitigate the adverse impacts of roadway runoff.

The following is a summary of watershed activities undertaken during the report period:

I-695 at Minebank Run Stream Restoration, Drainage and Water Quality Improvements– SHA

This project was initiated to address multi outfall stabilization, stream restoration, SWM retrofits and reforestation. Minebank Run is within Gunpowder River watershed that is targeted by Baltimore County for restoration. The topographic survey has been completed; design work on this project was initiated in 2011. Several pre-application and design concept scoping meetings with regulatory agencies have been conducted in past 2 years and the concept design has been developed. The final design plans will be developed in the next year. The project is scheduled for construction in 2015-2016. This project will result in significant pollutant load reductions for the Gunpowder River watershed as well as improve local drainage infrastructure issues. It will also address adverse impacts of upstream urbanization through upland SWM water quality retrofits within the I-695 interchange, providing stable conveyance of the surface drainage and restoration of the main channel to address degradation. This reach is located between two stream restoration projects lead by Baltimore County, therefore SHA has been coordinating with Baltimore County on the restoration efforts (see Figures 1-32 and 1-33).

Figure 1-32 Minebank Run main channel downstream of I-695 outfall before restoration

Figure 1-33 Tributary to Minebank Run, degraded outfall channel downstream from Cromwell Bridge Road before restoration

Westminster SWM Regional Pond – Carroll County

This project is proposed by Carroll County and SHA sponsored for TEP funding that has been awarded. The project proposes retrofit of a regional stormwater management facility to treat currently untreated impervious surfaces within a 250 acre watershed. SHA has been providing technical review and guidance for navigating the Federal Aid approval process. SHA will receive a portion of the water quality credit associated with the treatment of the SHA impervious surfaces within the drainage area. The preliminary estimate indicates SHA credit to be about 25 acres of impervious and 30 acres of pervious surfaces. The project was advertised on August 22, 2013 and opened for bids on October 9, 2013. It is anticipated to be constructed in FY 2014-2015 (see Figure 1-34).

Figure 1-34 Location of Westminster Regional Pond Retrofit Project

Finksburg Industrial Park Regional SWM Facility – Carroll County

This project is proposed by Carroll County within Liberty Reservoir watershed to meet local TMDL reduction goals. It is sponsored by SHA for TEP funding. The project proposes retrofit of a regional stormwater management facility to treat a 152 acre drainage area. SHA provides technical review and guidance through the project development and federal funding approval process. The facility is designed to provide water quality treatment for 22.12 acres of impervious area, out of which 4 acres of SHA owned impervious surfaces at MD 91 and MD140 will be treated within this facility (see Figure 1-35).

Figure 1- 35 Location of Finksburg Industrial Park Pond Retrofit Project

Laurel Lakes Task Force – Prince George's County

The I-95/Contee Road project recently received design funding. Due to procurement and right-of-way challenges, SHA is pursing remediation of the outfall separate from the overall project. The project is being designed in accordance with the Stormwater Management Act of 2007, implementing ESD features.

South River Federation – Anne Arundel County

The BMP upgrade projects mentioned in the last annual report were delayed to address in-stream issues.

Whitehall Creek Watershed – Anne Arundel County

This is a TEP funded stream restoration project undertaken by Anne Arundel County. The project is located downstream of the triple 81-inch x 59-inch culverts under Whitehall Road, east of the US 50/MD179 interchange. SHA has provided technical review as well as assistance through the procurement process. The project was advertised on September 17, 2012 and opened for Bids on November 6, 2012. Construction was completed in summer 2013 and planting is anticipated to be installed in fall 2013.

Brampton Hills – Tributary to Red Branch Restoration- Howard County

This project was sponsored by TEP and administered by the Howard County Department of Public Works, Environmental Division. The project consisted of 2,100 linear feet of Tributary to Red Branch stream restoration, 400 linear feet of SHA drainage outfall channel stabilization as well as side ditch restoration behind the sound wall along MD 100. The project construction was completed in summer 2012 (See Figures 1-36 through 1-39).

Figure 1- 36 Tributary to Red Branch restoration before and after construction

Figure 1-37 Tributary to Red Branch restoration before and after construction

Figure 1-38 Tributary to Red Branch restoration before and after construction

Figure 1- 39 Tributary to Red Branch and flood plain restoration before and after construction

Dorsey Run Stream Restoration – SHA

This restoration project is located in Jessup, MD off Dorsey Run Road, west of MD 175. This project was designed to reduce stream channel erosion, to improve floodplain reconnection and to restore adjacent wetlands. The purpose is to enhance/create 12 acres of floodplain wetlands and restore/stabilize 1,970 feet of stream channel by installation of in-stream structures to reduce storm flow energy and create backwater. This is another SHA sponsored TEP project and it was constructed by MD Department of Natural Resources. The construction started in December 2010 and the project was completed in September 2013.

G.3 Report and Submit Annually

SHA had completed and submitted information on the twenty-five required watershed restoration projects and other activities to meet the permit requirement in past reports. This included retrofit proposals, costs, schedules, implementation status and impervious acres receiving treatment though the project implementation. Documentation in the form of construction plans, cost estimates and schedules for additional projects can be provided to MDE upon request. SHA continues planning and design activities to address various drainage, stormwater management and water quality issues not only in the watersheds within 11 NPDES counties, but in watersheds statewide.

SHA also continues to reach out to the local agencies, watershed groups and jurisdictions to partner on a variety of environmental mitigation and water quality improvement projects through TEP sponsorship program. SHA participates in local watershed steering committees and attends field meetings with watershed groups to discuss opportunities for stream restoration and stormwater retrofits to address stream degradation and reduce sediment transport in highly urbanized and sensitive watersheds. SHA continues evaluating opportunities to implement watershed restoration projects in cooperation with local jurisdictions as well as address citizens concerns regarding drainage issues, flooding, erosion, sediment, highway runoff, stormwater management, TMDL and other environmental issues.

Stormwater Management Initiatives in the Severn River Watershed

SHA met with representatives from Anne Arundel County and the Severn River Watershed Commission to review SHA initiatives to improve water quality in the Severn River Watershed. This meeting included a field review to identify and assess local issues (see Figure 1-40) and a detailed presentation of SHA's best management practices installed within the watershed to address stormwater management and water quality (see Figure 1-41).

Figure 1- 40 Field meeting with Anne Arundel Countyand Severn River Commission

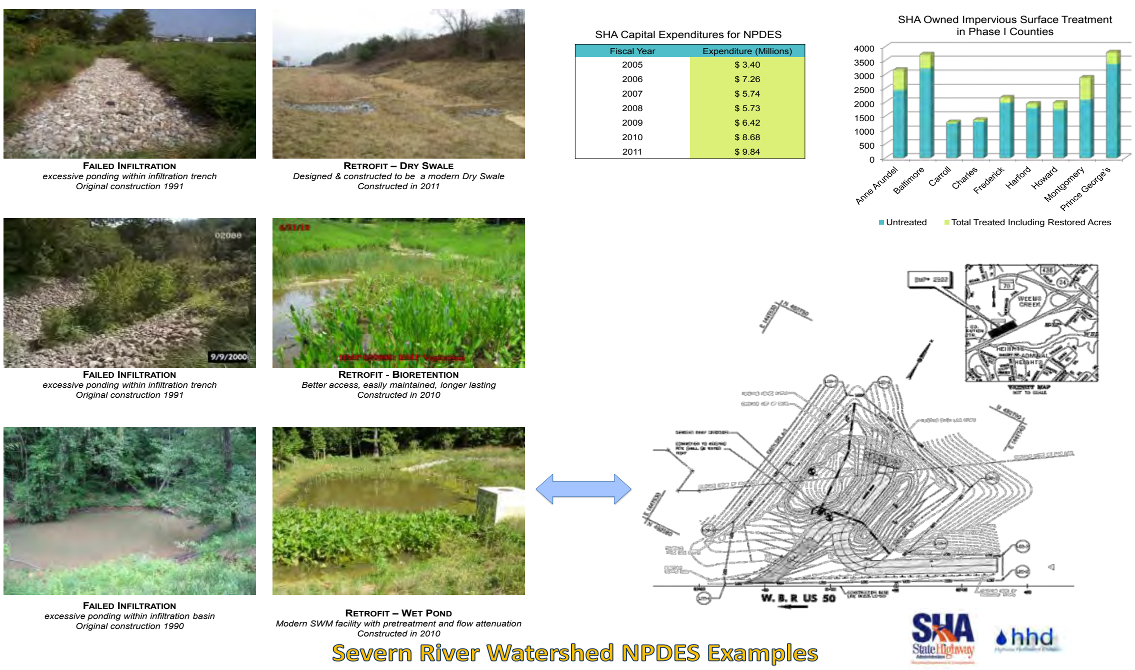


Figure 1- 41 SHA Presentation of SWM Initiatives in Sever River Watershed to Anne Arundel County and Severn River Commission

H Assessment of Controls

This condition requires that SHA develop a proposal and receive approval for a watershed restoration project by October 21, 2006; develop and receive approval for a monitoring plan that should include chemical, biological and physical monitoring according to parameters specified in the permit and submit data annually.

H.1 Restoration Site Approved by October 21, 2006

The Long Draught Branch restoration project was previously approved as our restoration site. This project has undergone difficulties in obtaining joint permit approval for construction. SHA has initiated alterations in the previously proposed design in order to address the concerns of multiple agencies and obtain the required permits. The budget for construction funding is allocated for FY 2015 and 2016. Once the project is constructed, SHA plans to continue post-construction monitoring on this project in accordance with the permit requirements and the previously delivered monitoring plan (See SHA First Annual Report, 2006, Appendix K). In the interim, biological monitoring continues as mentioned in the Section G of this report.

H.2 Monitoring Requirements

Based on the previous approval of the Long Draught Branch project by MDE-WMA, significant pre-construction monitoring (physical, chemical and biological) was performed. The final report for the pre-construction monitoring data was included in the SHA Third Annual Report, 2008, Appendix I. Since the project has been delayed, the post-construction monitoring data will not be available until after the construction is completed.

In the interim, SHA pursued monitoring of a failed infiltration basin and these monitoring results were included in the Appendix A of the 2012 Annual Report. The final report for this study is included as Appendix B of this report.

H.3 Annual Data Submittal

Monitoring data for Long Draught Branch pre-construction monitoring was included with previous reports. As new monitoring data becomes available, it will be delivered to MDE according to permit database format requirements.

I Program Funding

This condition requires that a fiscal analysis of capital, operation and maintenance expenditures necessary to comply with the conditions of this permit be submitted, and that adequate program funding be made available to ensure compliance.

In 2006, SHA had procured open-end consultant contracts in the amount of $9 million in order to accomplish both the current Phase I and Phase II NPDES permits. We are currently in the process of procuring additional open-ended consultant contracts in the amount of $48 million for the next six years to continue our engineering efforts for the future.

SHA utilizes Capital Funds (Fund 74 – Drainage and Fund 82 – TMDL) for engineering and construction related activities associated with the NPDES MS4 Permit. Recently, SHA established the Fund 82 category for TMDL related engineering and construction activities. In addition to the funding commitment from these two funds, SHA seeks additional funding from a variety of sources such as the Chesapeake Bay Trust fund, State Planning and Research (SPR)funds, Transportation Alternatives Program (TAP) funds and SHA Operations and Maintenance funds in completing NPDES requirements.

Currently, SHA tracks only capital fund spending for the NPDES program as a whole and breaks out a few items such as NPDES Stormwater Facility Program and industrial activities. According to our current records, the total spent for the MS4and the Industrial NPDES are listed in Table 1-20.

Table 1-20 SHA Capital Expenditures for NPDES (State Fiscal Years)

Fiscal Year	Expenditure (Millions)*
2005	$ 3.40
2006	$ 7.26
2007	$ 5.74
2008	$ 5.73
2009	$ 6.42
2010	$ 8.68
2011	$ 11.62
2012	$ 19.20
2013	$ 28.54
* Includes Fund 74, 82, Industrial, SPR and TEP Funds.	

J Total Maximum Daily Loads (TMDLs)

The current SHA NPDES Phase I permit states that MDE has determined that owners of stormdrain systems that implement the requirements of the permit will be controlling stormwater pollution to the maximum extent practicable. However, given the current mandate to restore the Chesapeake Bay by 2025 and the draft MS4 Phase I permits that require that jurisdictions meet assigned waste load allocations (WLAs) for the Bay and local watershed TMDLs, SHA has taken many steps in order to position ourselves to meet these requirements. But while we are looking forward in developing funding and activities, we are not prepared to report on all these activities in detail for this report period, but rather, will include them in milestone progress reports and annual reports for the next permit term. Expenditures reflected in Table 1-20 reflect this increased activity.

Some of the activities undertaken to provide SHA with the tools to address WLAs and impervious restoration requirements anticipated for the next permit term include:

- As of April 2013, SHA has consolidated our TMDL Program within the Office of Environmental Design. The purpose of this consolidation is to focus efforts and resources on complying with the requirements of SHA's NPDES MS4 Permit and the Bay TMDL.

- As a part of SHA's newly consolidated TMDL Program, a County Coordination Team has been developed to focus on relationship building and information sharing. The purpose is to fully understand the intricacies of each county so SHA can better plan and execute effective projects for nutrient and sediment reductions.

- An MOU was executed on June 17, 2013 with the Department of Natural Resources (DNR) to establish a financial agreement and task development framework in order to implement partnership projects. SHA is also in the process of developing a MOU with various environmental resource agencies including: DNR, MDE, ACOE, FWS and EPA, to develop a review framework for TMDL projects within regulated resources. The purpose of this agreement will be to establish time commitments for TMDL project reviewers and a framework for discussing project components, permitting requirements and credit establishment.

- As a result of Federal and State Transportation Trust Funds and House Bill 1515, the Transportation Infrastructure Investment Act of 2013, SHA has been allocated funding to comply with the WIP II. The appropriations are listed in Table 1-21. Based on the current funding available, SHA is in the process of identifying BMPs that are in-line with milestone goals.

- SHA has completed the 'roadway disconnection' protocol and is currently in the process of identifying treatment credit by conducting pilot studies on various roadways within NPDES counties. SHA has delivered the draft protocol to MDE and is currently awaiting a response.

Table 1-21: Programmed Funding by Fiscal Year

State Fiscal Year	2014*	2015**	2016**	2017**	2018**	2019**
Funding	$34.7 Million	$45 Million	$65 Million	$85 Million	$100 Million	$100 Million

**Funding is from the Federal and State Transportation Trust Fund*
***Funding is from the Transportation Infrastructure Investment Act 2013*

- SHA updated NPDES Standard Procedures to include the latest outfall channel inspection protocol that will help identify potential sites for restoration. Outfalls are being inspected along highway corridors where bioswale projects have been implemented.

- The new outfall inspection protocol has been incorporated into the cyclical MS4 inspection within MS4 Phase I and II Counties based on the following tentative schedule:
    - Anne Arundel County – December 2014
    - Baltimore County –June 2012 (completed), next inspection 2015
    - Charles County – May 2013 (on-going)
    - Carroll County – July 2012 (completed), next inspection 2015
    - Cecil County – November 2014
    - Frederick County – January 14
    - Harford County – April 2014
    - Howard County – June 2012 (completed), next inspection 2015
    - Montgomery County – September 2014
    - Prince Georges County – June 2014
    - Washington County-August 2012 (completed), next inspection 2015

- The SHA is in the process of reviewing existing database schemas for various BMP tracking systems along with MDE's draft reporting geodatabase and other internal reporting requirements. Using this as the base, a needs assessment to identify the necessary requirements was conducted. SHA is now in the process of prioritizing and identifying functionality required for each major program component including: Planning; Project Design and Implementation; Monitoring; Reporting and Maintenance. In order to fulfill the needs of the program SHA plans to develop and implement the following tools/systems:
    - Spatial Data Structure
    - Modeling Framework for Scenario Planning
    - Mapping Interface through SHA's Enterprise GIS System
    - Monitoring and Inspection Field Tools
    - Standard Filing and Document Archive System administered through SHA's TMDL SharePoint Site and ProjectWise

Phase I&II National Pollutant Discharge Elimination System
Permit No. 99-DP-3313 MD0068276
Permit Term October 2005 to October 2010

PART TWO

STORMWATER FACILITIES PROGRAM

PART TWO

Stormwater Facilities Program

A Introduction

The SHA Stormwater Facilities Program which oversees the inspection, assessment, maintenance and remediation of the SHA stormwater management BMPs and the SHA Stormdrain and Outfall Inspection and Remediation Program (SOIRP) are components of a broader program under the Highway Hydraulics Division (HHD) called the Stormwater Asset Management Program (SWAMP). SWAMP oversees management of SHA stormwater assets as well as the NPDES permit compliance activities for the municipal separate storm sewer system (MS4) permits. This part of the report provides a summary of the Stormwater Facilities Program activities between October 2012 and September 2013.

According to the latest inventory, SHA owns approximately 3088 stormwater management (SWM) facilities statewide. SWM facilities manage highway runoff from qualitative and quantitative aspects. In the coming years due to extensive BMP construction, it is expected that over 4200 BMPs will be maintained by SHA by 2016. Since 1999, SHA has managed a comprehensive program that provides identification, inspection, evaluation, repair, and remediation of SWM facilities to ensure continued effectiveness in managing water quality and protecting sensitive water resources.

The Program's primary goal, which is tied directly to the SHA Business Plan goal of providing a positive contribution to the water quality of the Chesapeake Bay, is to ensure that SHA's SWM facilities are fully functional and perform as intended. In addition, the Program has a secondary goal to strategically enhance overall SWM facility function of existing facilities to meet or exceed the latest SWM standards.

The Program encompasses four major components:

- Identification, inspection, and database management of SHA's stormwater assets.
- Repair and remediation of SWM facilities.
- Visual, functional, and environmental enhancement, upgrade, and retrofit of SWM facilities, including upgrades related to safety.
- Site and SWM facility monitoring, research, and innovative technology tool development.

B Inventory and Inspections

The following section summarizes the inspection methodology and inventory review to provide a status of all known SWM facilities that manage stormwater runoff from SHA assets.

B.1 Inspection Protocol

The inspection protocol is documented in Chapter 3 of *"Maryland State Highway Administration Stormwater NPDES Program, Standard Procedures – Performance Rating."*

During initial field assessments, individual parameters of each SWM facility are scored (on a scale 1 to 5). Scores are used to establish an overall SWM facility performance rating as follows:

1 **No Issues.** The SWM facility is functioning as designed with no adverse conditions identified. There are no signs of impending deterioration.

2 **Minor Problems.** The SWM facility functions as designed, but minor issues are observed that may worsen to the next rating level if not repaired in a reasonable timeframe.

3 **Moderate Problems.** The SWM facility functions as designed, but efficiency,

performance and function have been significantly compromised and may worsen to the next rating level if not repaired in a reasonable timeframe.

4 **Major Problems.** The SWM facility no longer functions as designed and efficiency has been compromised. Repair or remediation should be performed.

5 **Severe Problems.** The SWM facility no longer functions as designed and efficiency as well as several critical parameters have been compromised. The SWM facility shows signs of deterioration and/or failure, requiring immediate remedial action.

The remedial inspection protocol describing field assessment methodologies used for determining the observed functionality of a SWM facility and providing guidance for remedial actions is included in Chapter 7 of the *"Maryland State Highway Administration Stormwater NPDES Program Standard Procedures."* The assessments and recommended action ratings provide consistency that enables SHA to adequately allocate sufficient timing and funding that ensures an appropriate schedule of remediation activities.

SHA Remediation Ratings

Remedial activities are determined by remedial ratings. The rating system is based on the field inspection rating, facility performance, facility function, integrity of key functional components, visual appearance, scope of remedial activities needed, and the complexity of the work. The ratings are as follows:

I **No Response Required.** The SWM facility is functioning as designed. Re-schedule for the next multi-year inspection assessment period.

II **Minor Maintenance.** The SWM facility is functioning as designed, but routine and preventative action should be performed to sustain effective performance. Activities can typically be performed within an 8-hour workday by an average remediation crew.

III **Major Maintenance or Repair.** The SWM facility no longer functions as designed and significant repair is necessary to restore original functionality. The facility is repaired to remain within the existing facility footprint. Activities are more significant than minor remediation and likely require heavy equipment mobilization, construction materials and Maintenance of Traffic (MOT) plans.

IV **Retrofit Design.** The SWM facility no longer functions as designed and cannot be restored to the original function as designed without a complete re-design and construction of a facility with a larger footprint, a different SWM facility type, or additional SWM facilities in the vicinity of the existing facility.

V **Immediate Response.** The SWM facility has catastrophically failed and public safety hazards exist that require immediate corrective action.

VI **Abandonment.** The SWM facility is unsustainable and no longer provides sufficient benefit to warrant remedial design.

B.2 Inventory

SHA's SWM facility inventory database is frequently updated as new facilities are brought online. Updates occur statewide for all of SHA's highway and facility infrastructure in each Maryland county, including all Phase I and II MS4 locations as well as those locations not presently covered under the Phase I or II permits. Inventoried SWM facilities include those owned and maintained by SHA as well as those owned and maintained by other jurisdictions, municipalities, or entities because the SWM facilities receive and manage stormwater runoff from the SHA highway network. Table 2-1 summarizes the total number of SWM facilities that intercept and manage stormwater runoff from the SHA highway network and highway-related assets; the information is grouped by county.

The SHA SWM facility inventory includes all SWM facilities that intercept and manage runoff from SHA's highway network and roadway-related assets and includes SWM facilities not owned or maintained by SHA, but by other entities, including but not limited to counties, municipalities, other state agencies, and private entities.

Compared to the previous reporting period, several counties show an increase in the total number of SWM facilities managing runoff from SHA roadway networks and assets. Increases may occur for several reasons, including but not limited to, new developments adjacent to SHA roadways, improvements to the SHA roadway network, and construction of new SWM facilities in areas of the roadway network previously not serviced by adequate SWM facilities.

Table 2-1 Total SWM Facilities Intercepting and Managing Stormwater Runoff from SHA's Highway Network and Assets

County	Routine Maintenance	Minor Maintenance	Major Maintenance	Retrofit/ Enhancement Design
Allegany	23	23	9	2
Anne Arundel	166	280	94	56
Baltimore	48	96	81	14
Calvert	2	15	0	0
Caroline	4	3	0	0
Carroll	57	7	1	0
Cecil	6	9	0	0
Charles	93	3	0	0
Dorchester	1	27	0	0
Frederick	178	19	0	0
Garrett	3	5	1	6
Harford	69	63	0	6
Howard	373	79	34	8
Kent	4	2	0	0
Montgomery	90	216	29	5
Prince Georges	95	116	48	10
Queen Anne	36	71	0	0
Saint Mary's	18	15	1	0
Somerset	5	5	0	1
Talbot	5	1	0	1
Washington	196	13	5	4
Wicomico	21	26	0	0
Worcester	77	8	0	0
Totals	1570	1102	303	113
	2672		416	

B.3 Field Inspections

Initial SWM facility field inspections and inventories have been completed for all counties, both MS4 and non-MS4 counties. The information is used to verify existing data in the SHA database as well as determine the SWM facilities functional rating and provide any necessary remedial action recommendations. The statewide inventory is continuously updated on a county-by-county basis.

C Repair and Remediation

This section summarizes the status of SHA repair and remediation activities in response to identified deficiencies of SWM facilities. Since SHA has a goal to ensure complete functionality and efficiency of all SHA owned and maintained SWM facilities, deficiencies are corrected in a timely manner. In addition, SHA seeks to enhance function beyond existing level of service as the need or opportunity arises to increase pollutant removal efficiency or to treat additional impervious surfaces.

Response actions are divided into four major categories of activities: no action, minor or routine upkeep and preventative maintenance, major repair, and retrofit or enhancement. Retrofit projects may include reconstruction of a facility to restore function, or to enhance the facility to deliver improved function, e.g. a non-functional infiltration trench may be retrofitted to a bioretention facility with an enhanced filter to increase pollutant removal efficiency. Figure 2-1 shows the remediation ratings within SHA Districts

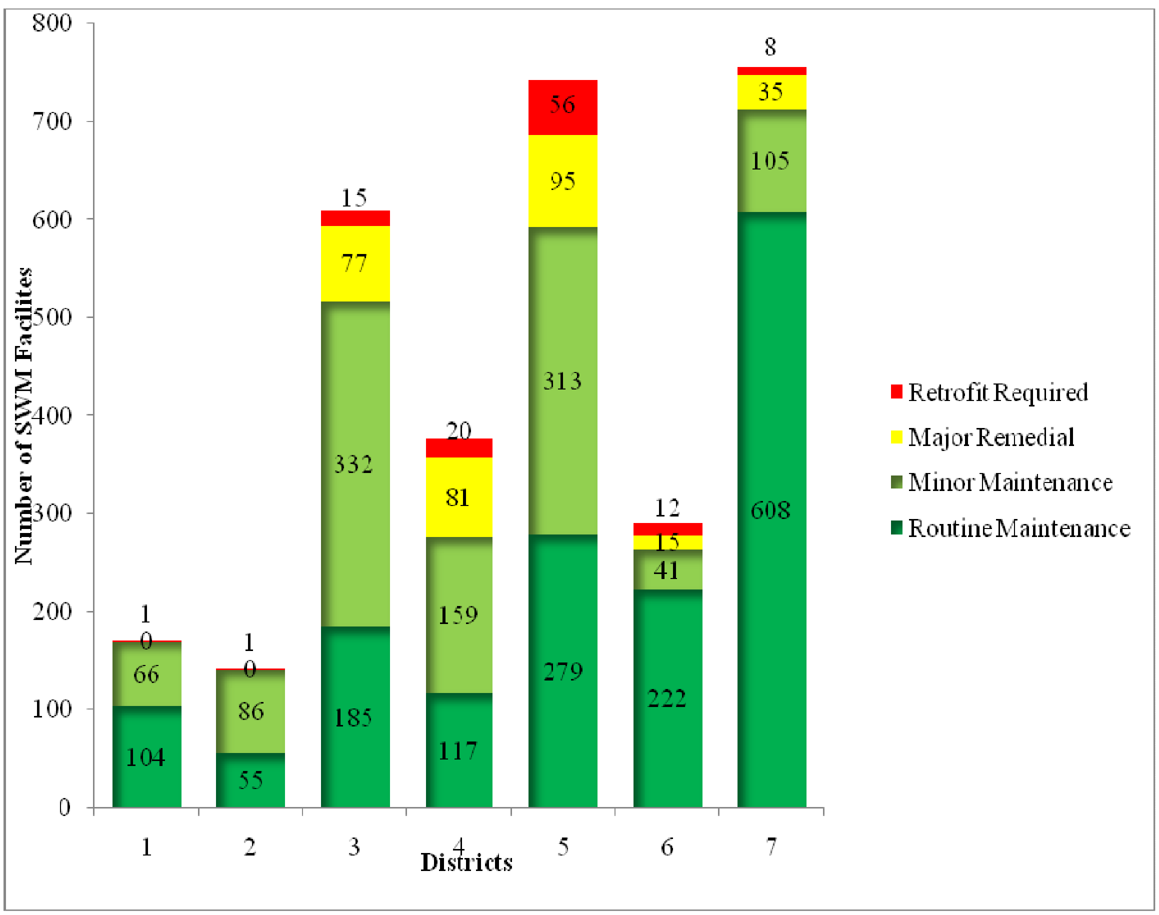


Figure 2-1 Historic Trend for SWM Facility Inventory and Remediation Ratings

C.1 Routine Upkeep

Routine upkeep or minor and preventive repairs are generally activities that address minor deficiencies and may include actions such as mowing, brush cutting, vegetative thinning, unwanted woody vegetation removal, invasive weed removal, and trash or debris removal. These activities greatly help to maintain performance of a SWM facility and prevent or eliminate deteriorative conditions of key SWM facility elements. SWM facilities requiring routine upkeep are assigned "II" rating by SHA.

SHA is currently performing most of the work using two (2) open-end asset management construction contracts. An additional contract has been advertised and will be activated by November 2012. Additional coordination is planned with district maintenance departments to better address the routine maintenance needs of the growing inventory. Pilot activities have been conducted in District 7 and District 3 with success.

Activity schedules are based on local needs. In addition, geospatial data is used to assist in combining activities together such that activities can be performed on multiple facilities in proximity to one another and allowing greater efficiency of work completion at lower costs. Entire roadway corridors can often be completed within a few weeks.

Figure 2-2 Routine maintenance activities in progress on SWM facility 230011

C.2 Major Repair

Major repair activities are performed to address significant deficiencies of SWM facilities and are also performed through an open-end construction contracts. The purpose of the repair activities is to restore the performance of a SWM facility as well as prevent failure of specific functional elements. Actions may include dredging, sediment removal, and obstruction removal within pipes. Work also may include removal of sediment from facilities to maintain the required water volume. SWM facilities that require major or remedial repair are assigned a "III" rating by SHA.

Figures 2-3, 2-4, 2-5 and 2-6 show a SWM facility that required vegetation management and sediment removal.

Figure 2-3 SWM Facility 020697 prior to remedial maintenance

Figure 2-4 Works in progress on SWM facility 020697

Figure 2-5 SWM Facility 020296 prior remedial maintenance

Figure 2-6 Nearing Completion of work on SWM Facility 020296

C.3 Retrofits - Design-Build and Asset Warranty

SHA is presently developing design-build and asset warranty (DBAW) contracts to administer the asset remediation and improvement portion of the NPDES program to include all SHA drainage assets. The contract will use the design-build project framework already developed and implemented by SHA. The scope includes strategically planned activities to preserve functionality and sustain efficiency of SHA SWM facilities, remediate pipe assets that have exceeded the designed lifespan, and replace or enhance hydraulics structures. All of these activities require preliminary engineering. Contracts will cover entire districts but will consist of multiple specific sites. Each site will adhere to NEPA and federal authorization procedures.

Design engineers determine the remedial actions that need to be completed for the targeted SWM facilities to return to the designed intention. This means that the facilities are currently not functioning as originally intended and engineering solutions are needed to return the facilities to their original state. These facilities require a SWM facility type change and retrofit and permit, involving detailed engineering and coordination. Pipe assets deemed to need major remediation must also be addressed. The design-build (DB) team will generate plans and construct the necessary improvements.

All work will require a warranty for function. The warranty will be assed based on the criteria found in the SHA NPDES Standard Procedures Manual. The term of the warranty is 18 months after the completion of construction activities. SWM facilities must be inspected and receive an inspection rating of 'A'. Conveyance systems will be required to receive an inspection rating of '1'. Drainage structures will be required to have no associated structure issues. Any items found to be deficient must be repaired by the DB team contractor at no additional cost to SHA for the duration of the warranty period.

C.4 Immediate Response

In the event of an emergency, SHA immediately performs work to ensure public safety. SHA responds to any outfall or SWM facility that requires immediate repair and remediation. Roadways are closed as necessary and detour routes are implemented as needed. Site assessment and investigation occurs at the subject location within hours by a multi-disciplinary team. On-call contractors are mobilized and plans for repairs are initiated within 24-hours.

D SWM Facility Retrofits, Visual and Functional Enhancement Projects

SHA continuously plans, designs and constructs functional enhancements and retrofits for SWM facilities. Projects are funded using state and federal funds. Site selection for enhancement projects is evaluated using several factors, including feasibility, permitting process complexity, and benefit analysis. SHA often seeks opportunities to improve the efficiencies of older SWM facilities that provide only minimum water quality treatment to achieve greater reduction of pollutant loads from highway runoff. SHA also seeks opportunities to manage greater amounts of untreated roadway areas to existing SWM facilities to increase the amount of highway surfaces being managed for pollutant removal.

Images below show examples of recent SWM Retrofit projects and SWM construction project in Baltimore County.

Figure 2-7 I-695 at MD 147 SWM retrofit after construction

As a part of SHA's greater improvement efforts and gaining increased benefit at smaller costs, projects to improve water quality involve treatment of additional impervious areas as well as provide replacement or upgrade to the existing drainage infrastructure. Projects also include rehabilitation of degraded outfalls, channel restoration, and slope stabilization. In addition to improvements of exiting SWM and drainage assets, SHA has begun SWM retrofits to provide water quality treatment of currently untreated pavement. All relevant information will be compiled and reported with the 2013 Bay TMDL milestone progress report as well as in the future NPDES Annual Reports.

Figure 2-8 I-695 Widening - SWM facility during construction

Figure 2-9 I-695 at Charles Street SWM Retrofit after construction completion

E Data Management

SHA has performed an inventory of all SWM drainage infrastructure in each NPDES county and performs SWM facility inspections in all twenty-three counties. The statewide SWM facility inventory database was finalized in 2011. SHA has also proceeded with re-inspections. A new data collection effort has begun in non –MS4 counties. This effort involves continuous updates of GIS data for source identification and database records of inspection and remediation activities.

SHA has finalized the structure of the ESRI geodatabase and detailed schema that allows for the establishment and enforcement of topologic and/or network rules and unique data entry. Domain rules are updated as needed. The database format has resulted in improved data intelligence and integrity. SHA plans to integrate the geodatabase with other organizational initiatives such as eGIS and iMAP (discussed below) to improve communication between offices.

SHA uses two custom software programs to collect and store geospatial information: the Office Tool and the Field Tool. The Office Tool is used to input data as well as perform quality assurance (QA) reviews. The Field Tool is used with GPS coordinate units to collect and edit field data.

Along with the database format, the customized data viewer tool known as the NPDES Viewer, has been recently enhanced. The tool allows a user to view the spatial information as well as digital images associated with each SWM facility, such as as-built plans, photographs, inspection reports and other pertinent documents. NPDES Viewer is used to view data at various focus levels, such as highway corridors, SHA districts, counties, or watersheds.

A new component for SWM facility maintenance tracking, called the Remediation Tool, has been added to the NPDES Viewer. The application allows the tracking of routine upkeep and major repair activities, associated costs, retrofit project progress, and current functionality of SWM facilities. It also can output reports of data that can be shared with managers and administrators.

F iMAP

The most recent tool incorporating the SWM facility geodatabase that is used for quick data viewing, reporting and spatial display is a web application named iMap. (Screen captures are shown on Figure 2-10). The application can be found at http://www.mdimap.com/sha/

iMap was developed by SHA primarily to report the current status and progress of key SHA Business Plan objectives to the StateStat Committee. The tool has also been used to present the SHA SWM Program to the Lt. Governor's meeting in July 2010. Since then it has become one of the primary tools for reporting SWM Program as well as others SHA programs progress.

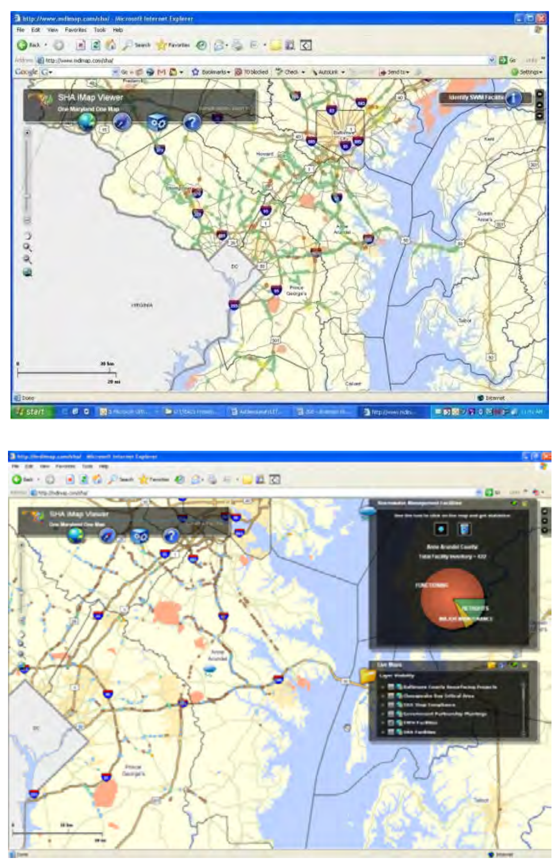


Figure 2-10Screenshot of iMap.

G eGIS

SHA has developed comprehensive mapping solutions for all internal departments and divisions to view spatial data related to project development and operations. eGIS has contents related to all aspects to highway operations and allows planners and engineers to access asset data on a real-time basis.

Current NPDES drainage and SWM facility information has been integrated into the eGIS platform. With eGIS capability, users who are not experienced or familiar with using GIS software are able to view data in an intuitive format. This greatly enhances cross communication and other business functions.

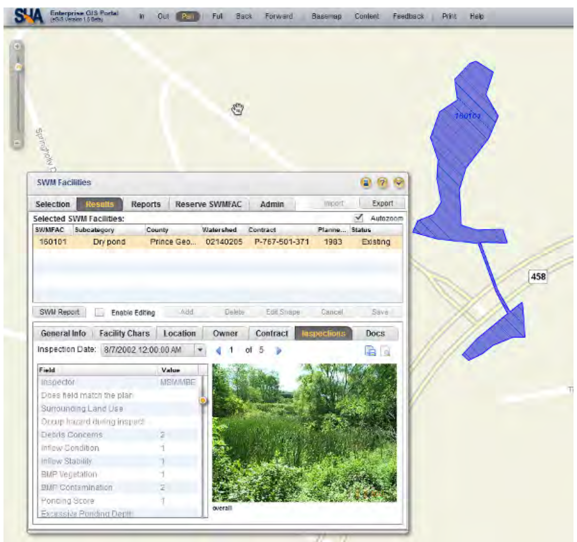


Figure 2-11 Screenshot of eGIS.

H Standard Procedures

Chapter 7 of the *"Maryland State Highway Administration Stormwater NPDES Program Standard Procedures – SWM Maintenance Work Order Development"* has been revised to include knowledge gained over the last few years. The chapter describes the procedure for field assessment of SWM facilities previously designated as requiring remediation after an initial inspection or at any time throughout the inspection cycle. After the preventative cyclical inspections and database updates, final performance ratings and level of functionality are evaluated. SWM facilities with major deficiencies require a detailed Remedial Assessment to determine specific causes of deficiencies, which in turn is used to develop a remedial action plan. The procedures that are outlined in the chapter assist the decision-making process for maintenance, repair, and remediation of SWM facilities. It also provides standardization in the assessment process, instructions for inspection of SWM facilities statewide, as well as examples for identifying and assessing the causes of the deficiencies and recommendations for repairs with relatively consistent results. The intent of the document is not to be an all-inclusive resource manual and other resources are consulted in conjunction with the document. Cost estimating and common causes for facility failure are the updated key portions. Examples of work action are included for common facility types.

I SWM Processor

SHA has developed software, called SWM Processor that facilitates design of SWM facilities for roadway improvements. Figure 2-12 shows a screen capture of the interface. SWM Processor helps with the computational methods as listed in MDE 2000 Stormwater Management Design Manual. The program combines a built-in computation model with a flexible user interface. The software is also able to generate standardized reports. It enables the design engineer to perform calculations efficiently and includes multiple error checking mechanisms. The engineer can save project data, including project information and calculation data, to a centralized database or XML file. The database catalogs all projects that have been entered. External users may install the software and forward computations to be imported into the SHA database system. Consistent computational policies for SWM are needed for long-term success of any comprehensive SWM program.

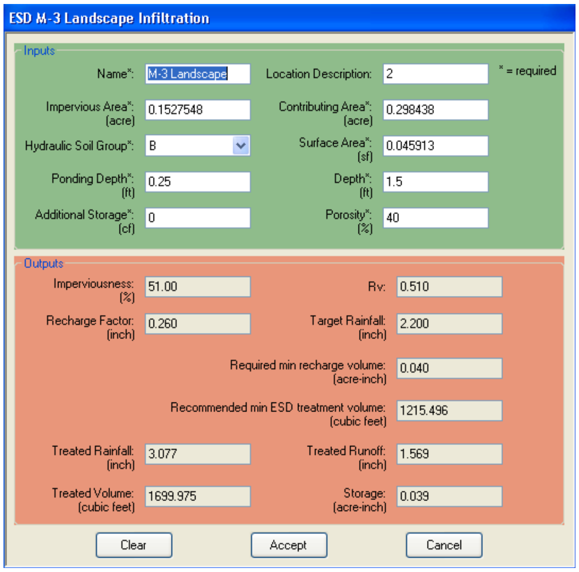


Figure 2-12 Screenshot of SWM Processor

J Qlikview Dashboard

Qlikview is an intelligent business reporting software that allows program managers to make informed and consistent decisions regarding resource allocations. SWM facility upkeep and repair activities are conveniently reported and summarized. Production trends that show current program performance and progress are displayed in formats via a HTML browser. Graphs and charts are updated in real-time as activities are advanced, providing instantaneous decision making support.

Automated queries, based on SWM attributes such as county, watershed, shop, district, and facility type are produced to generate target areas of greater need.

Figure 2-13 Screenshot of Qlikview Dashboard

K Google Earth KML Files

Google Earth KML files are an alternative to eGIS for communicating spatial information specifically for those without connectivity to the SHA intranet such as SHA field personnel. Similar to eGIS, Google Earth KML files enable anyone to view inventory data statewide. However, unlike eGIS, Google Earth KML files are not real-time data, but instead are a snapshot of time based on when the KML was created. KML files have been distributed to each SHA district to aid in locating SWM facilities, drainage structures and conveyances.

Data on Google Earth KML files is presented by type of facility or structure. Users may click on any object to view additional pertinent information, such as structure type, rating, date of last inspection, and contract. Future developments include creating KML files that can be sent to mobile devices and used conveniently in the field without the need for printed hard copies.

Below is an example of a map generated by Google Earth KML:

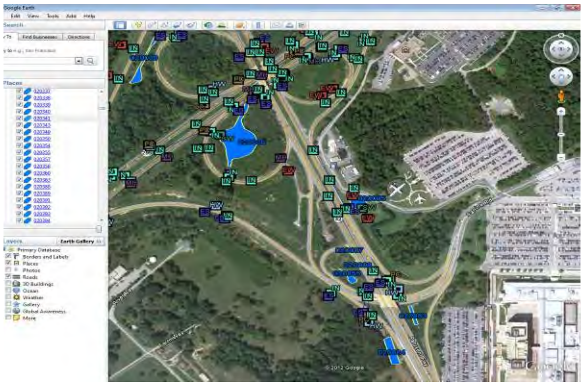


Figure 2-14 KML Coverage View of SHA NPDES Data in Google Earth

L Summary

The NPDES Municipal Separate Storm Sewer System (MS4) permit requires SHA to identify all infrastructure that captures, treats, and conveys stormwater runoff from SHA facilities such as roadways, welcome centers, and park and rides, including hydraulic structures and stormwater management facilities. SHA owns and maintains approximately 3088 SWM facilities. Based on current estimates, SHA also owns and maintains over 130,000 hydraulic structures and 85,000 conveyances statewide. Since 1999, SHA has maintained and managed a comprehensive asset management program to locate, inspect, evaluate, and remediate stormwater facilities to sustain their functionality, improve water quality, and protect sensitive water resources. SHA has developed a comprehensive inspection and rating system to prioritize and plan remedial activities and preventive maintenance to extend the life expectancy of each asset.

The SHA Business Plan goals exceed the NPDES Phase I permit requirements by promoting a complete statewide inventory and maintaining high-efficiency SWM facility performance. A key goal is to maintain 90 percent of all SHA-owned SWM facilities at full functionality. Currently, 86.3% of the SHA-owned and maintained facilities within the inventory meet the functionality goal.

Key program components and structures exemplify a strategic approach to meet NPDES permit requirements, allowing for the enhancement of SWM facility performance efficiency and reducing the pollutant loads contained in highway runoff, significantly improving water quality in the sensitive Chesapeake Bay watershed and the sub-watersheds therein.

Phase I&II National Pollutant Discharge Elimination System
Permit No. 99-DP-3313 MD0068276
Permit Term October 2005 to October 2010

APPENDIX A

SHA DATABASE DICTIONARY

Appendix A: SHA Database Dictionary

A Introduction

The NPDES Annual Report database submittal includes an Esri file geodatabase and several Microsoft Excel files prepared in compliance with table specifications detailed in the *SHA's National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Discharge Permit, Attachment A: Annual Report Databases,* which was provided to SHA on June 26, 2012.

This database dictionary for the submittal incorporates the existing specifications for the required attribute definitions within each table specification and includes additional fields and associated descriptions provided by SHA. Supplemental information for each layer is provided, as necessary, to detail the lineage of the datasets.

B File Formats

The 2013 Annual Report databases for each table exhibit detailed in Attachment A of the permit are provided in Microsoft Excel and an ArcGIS 10.1 file geodatabase named *SHA_AttachmentA_Geodatabase.gdb*. This information was exported from the enterprise SDE geodatabase environment and processed into the required Attachment A table structures. A supplemental ArcGIS 10.1 file geodatabase of the full SHA stormwater facilities enterprise database has also been provided with this submittal.

C Contents

Within the "Databases" folder on the CD deliverable, the following Microsoft Excel files are provided:

- Table A - Storm Drain Outfalls.xls
- Table B - Urban BMP SWM Facilities.xls
- Table C - Impervious Surfaces.xls
- Table C1 – Impervious Watershed Acreages
- Table D - Water Quality Improvement Projects.xls
- Table E - Monitoring Site Locations.xls
- Table E1 - Monitoring Site Locations - Land Use.xls
- Table E2 - Monitoring Site Locations - SWM BMP.xls
- Table F - Chemical Monitoring Results.xls
- Table I - IDDE.xls

The associated spatial databases are provided in support of the deliverable within two separate Esri file geodatabases:

- SHA_AttachmentA_geodatabase.gdb - Includes all Attachment A spatial datasets.
- SHA_NPDES_2013geodatabase.gdb - Includes a full export of the SHA enterprise structural stormwater facility database.

Contents of the SHA_AttachmentA_geodatabase.gdb are listed below and the contents and data structures are described in the following pages:

- TABLE_A_STORM_DRAIN_OUTFALLS *(feature class)*
- TABLE_B_URBAN_BMP_SWM_FACILITIES (*feature class)*

- TABLE_C_IMPERVIOUS_SURFACES *(feature class)*
- TABLE_C1_IMPERVIOUS_WATERSHED_ACREAGES *(table)*
- TABLE_D_WATERQUALITY_IMPV_PROJECTS *(feature class)*
- TABLE_E_MONITORINGSITES_LOCATIONS *(feature class)*
- TABLE_E1_MONITORINGSITES_LANDUSE *(table)*
- TABLE_E2_MONITORINGSITES_SWMBMP *(table)*
- TABLE_E3_MONITORINGSITES_DRAINAGEAREAS *(feature class)*
- TABLE_F_CHEMICAL_MONITORING_RESULTS *(table)*
- TABLE_I_IDDE *(table)*

The contents of the SHA_NPDES_2013geodatabase.gdb are detailed below in Table A-1.

Table A-1 SHA NPDES Geodatabase Contents

DATABASE SPATIAL LAYERS	TYPE	DESCRIPTION
SWMFAC	Feature Class	Polygon feature class that stores the spatial representation outline and tabular information pertaining to structural BMPs. Information includes location, BMP type, feature status, and other overlay attributes such as watershed.
BMP_CENTROID	Feature Class	Point feature class that stores the spatial representation of the SWMFAC polygon feature class records.
STRUCTURES	Feature Class	Point feature class that stores the spatial representation and tabular information pertaining to storm water structures (i.e., inlets, manholes, outfalls, control structures). Information includes structure type, feature status, major outfall (T/F), and other overlay attributes such as watershed.
CONVEYANCE	Feature Class	Line feature class that stores the spatial representation and tabular information pertaining to storm water conveyance (i.e., pipe and ditch). Information includes conveyance type, feature status, invert elevations, and other overlay attributes such as watershed.
DRAINAGE_STRUCTURE	Feature Class	Polygon feature class that stores the spatial representation and tabular information pertaining to structure features, mainly major outfalls. The drainage areas, in acres, is stored in the table.
DRAINAGE_SWMFACILITY	Feature Class	Polygon feature class that stores the spatial representation and tabular information pertaining to structural BMPs. The drainage areas, in acres, is stored in the table.
DATABASE TABLES	**TYPE**	**DESCRIPTION**
END_HEADWALL	Table	Contains the outfall and open upstream structures for a storm drain system, such as endsections, projection pipes, headwall, and endwalls. Information includes the type and material of the end structure.
INLET	Table	Contains the inlet features within the storm drain systems. Information includes the type and material of the inlet, the top of grate, and the length for COG and COS type inlets.
MANHOLE_CONN	Table	Contains the manhole and other connection features within the storm drain system. Information includes the material and top of manhole lid, when applicable.
PUMPSTN	Table	Contains the pump stations within the storm drain system. Information includes the station name, install date, number of pumps, and maximum capacity for the station.
SWMRISER	Table	Contains the storm water BMP control structure, such as box risers and pipe barrel risers. Information includes the material, if a trash rack exists, riser type, and the stage storage elevation.
WEIR	Table	Contains the weirs and emergency spillways related to storm water BMP storage controls. Information includes the material, if a trash rack exists, and the stage storage elevation.

Table A-1 SHA NPDES Geodatabase Contents

DATABASE SPATIAL LAYERS	TYPE	DESCRIPTION
STRUCTURE_ISSUE	Table	Contains issues related to the storm water structure features, and ranks the issue as non-emergency and hazard to public. Selected issues can be buried outfalls, broken grates, damaged slabs, or manhole missing.
FLDSC_SITE	Table	Contains the feature and site location information pertaining to an outfall structure, mainly major outfalls, which are being inspected for damage and screened for illicit discharge. Information included includes location and type of outfall.
INSPECTION	Table	Contains the inspection records for outfall structures that are inspected and screened for illicit discharge. Information includes date inspected, flow observed (Y/N), and scoring values for odor, deposits, vegetation condition, structure condition, and erosion.
FLOW_CHAR	Table	Contains the water sampling results for an illicit discharge chemical sampling of an outfall structure. Information includes a scoring value for the color and clarity of flow, floatable present, water and air temperature, and results for chemical parameters tested for, such as ammonia and chlorine.
FILE_ATTACH_STR	Table	Contains photographs and filenames related to the outfall structure inspection and screening recorded in the INSPECTION table.
BMP_INSPECTION	Table	Contains the inspection records for SWM BMPs that are inspected. Information includes inspection scores for structural, environmental, safety, and functionality parameters. These parameters include riser, embankment, vegetation, performance, safety, and ponding factors.
BMP_INSPECTION_ACTION	Table	Contains records related to maintenance actions observed during a BMP inspection. These actions include removal of sediment, fixing structural issues related to the BMP, and maintenance of vegetation and erosion issues.
CONCERNS	Table	Contains records related to invasive vegetation and/or contaminants, such as oil, observed during the BMP inspection.
FILE_ATTACH_SWM	Table	Contains photographs and filenames related to the BMP inspection recorded in the BMP_INSPECTION table.
DITCH	Table	Contains the ditch features within the storm drain conveyance. Information included includes ditch material and dimensions.
PIPES	Table	Contains the pipe features within the storm drain conveyance. Information includes the type, length, and dimension of the pipe.
PIPE_INSPECTION	Table	Contains the information about the location and overall rating of a pipe that is inspected.
P_INSP_REC	Table	Contains high level information pertaining to a pipe inspection, such as if the pipe discharges to water of the US, if the pipe is blocked, or if scour is occurring.
P_INSP_SUBRATING	Table	Contains detailed rating pertaining to a pipe inspection, such as severe rusting on base of pipe, invert deterioration, complete collapse of the pipe.
P_INSP_PHOTO	Table	Contains photographs and filenames related to the pipe inspection recorded in the PIPE_INSPECTION table.
CONTRACT	Table	Contains the list of contract plan sets related to storm drain features. Information includes the contract number, year, and the location and limits of the project.
FILE_SCAN	Table	Contains the list of contract plan sheets that relate to a storm water management facility. These sheets include title, profiles, details, grading, and/or landscaping plan sheets.
OWNER	Table	Contains a list of owners that maintain the storm drain features within SHA's NPDES database. Information includes contact information of the owner.
METADATA_INFO	Table	Contains information pertaining to how and when the storm drain features was added or edited in the SHA NPDES database.
BASELINE_YEAR	Table	Contains information that associates each SWM Facility record to the 2009 baseline or 2011 current capacity indicator.

D Data Projection

These file geodatabase submittals have been re-projected from SHA's standard projection into the required projection for MDE, specifically NAD_1983_StatePlane_Maryland _FIPS_1900_Meters. The submittal geodatabases are developed in the following original spatial projection: NAD_1983_StatePlane_Maryland _FIPS_1900_Feet.

E BMP / Structure System Numbering Convention

The BMP system numbering methodology applies a unique seven-digit identification number to each asset. The first two (2) digits indicate the county where the system is located. Table A-2 lists the county code numbers for Maryland. For county codes that begin with a zero (ex. Baltimore County 03), the leading zero is not dropped from any naming convention. The remaining five (5) digits represent the unique system number. For example, 130140 is system 140 located in Howard County (County Code 13).

Table A-2 Maryland County Codes

Code	Abbreviation	County Name	Code	Abbreviation	County Name
01	AL	Allegany	13	HO	Howard
02	AA	Anne Arundel	14	KE	Kent
03	BA	Baltimore	15	MO	Montgomery
04	CA	Calvert	16	PG	Prince Georges
05	CO	Caroline	17	QA	Queen Anne's
06	CL	Carroll	18	SM	St. Mary's
07	CE	Cecil	19	SO	Somerset
08	CH	Charles	20	TA	Talbot
09	DO	Dorchester	21	WA	Washington
10	FR	Frederick	22	WI	Wicomico
11	GA	Garrett	23	WO	Worcester
12	HA	Harford	24	BC	Baltimore City
			99	SW	Statewide

The individual drainage structures located within a system receive a unique three (3) digit identification number. For example, 1300140.007 is the seventh (.007) structure in the 140th drainage system in Howard County.

Numbering begins with the most downstream structure, usually the outfall, which is assigned the structure number of .001. Structures are then numbered as the system is traced upstream. For initial data collection or adding new systems, the most downstream structure in any system should be numbered .001. This is convention only, and structures may be numbered out of sequence in the existing geodatabase.

Each system that flows into a BMP is a separate system. The control structure and outfall for a stormwater BMP also starts a new system. Figures A-1 and A-2 show examples of system, structure, and BMP numbering.

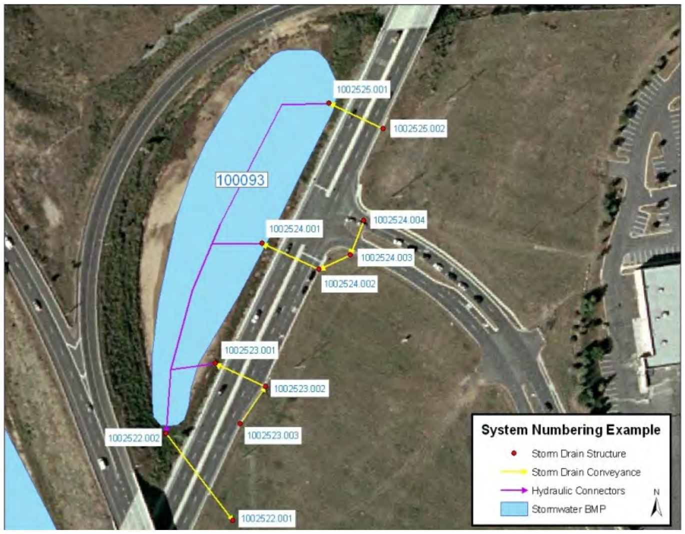


Figure A-1 System No. Ex. 1

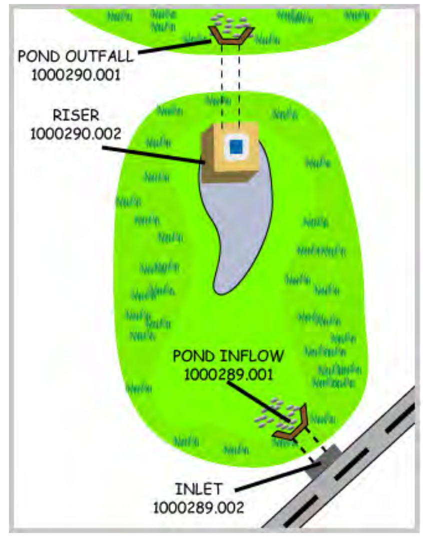


Figure A-2 System No. Ex. 2

The STRU_ID field definition in Attachment A tables requires a text field with a maximum length of 8 characters. MDE has requested that the STRU_ID number have the designation 'SHA' somewhere in the number. As defined above, SHA's unique STRU_ID values assigned are currently eight characters. SHA has added a field to the layers with Structure and BMP numbers called MDE_STRU_ID (text, 20) that has been processed to include the "SHA" prefix.

F Attachment A - Table Specifications Attribute Definitions

The following tables provide the table specifications for the layers in the SHA_AttachmentA_Geodatabase.gdb. In the database specification table below, SHA provides a *Double* number field type in compliance with the required number field designations.

TABLE_A_STORM_DRAIN_OUTFALLS:

The data (See Table A-3) provided is a point feature class representing all existing major outfalls statewide within SHA drainage systems. The drainage area layer is provided as a reference feature class layer in the SHA_NPDES_2013geodatabase.gdb named "DRAINAGE_STRUCTURE". The outfalls can be joined to this layer using the STRUCTURE_ID common field. The list of outfall type codes are provided below in Table A-4.

Table A-3. Storm Drain System Outfalls (Table A from Attachment A) - Attribute Structure
Feature Class Name: TABLE_A_STORM_DRAIN_OUTFALLS

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
OUTFALL_ID	TEXT	15	Unique outfall ID
MD_NORTH	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Northing
MD_EAST	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Easting
DIM_OUTFL	NUMBER	3	Outfall Dimensions in inches

Table A-3. Storm Drain System Outfalls (Table A from Attachment A) - Attribute Structure
Feature Class Name: TABLE_A_STORM_DRAIN_OUTFALLS

Column Name	Data Type	Length	Description
WATERSHED_CODE	NUMBER	20	Maryland 8 or 12-digit hydrologic unit code
TYPE_OUTFL	TEXT	3	Outfall Type (RCP, CMP, PVC, See Table A-4)
DRAIN_AREA	NUMBER	8	Drainage area to outfall (acres) [1]
LAND_USE	NUMBER	3	Predominant land use[2]
*MDE_OUTFALL_ID	TEXT	20	Unique outfall ID with the prefix of "SHA"

[1] GIS shapefile required
[2] Use attached Maryland Office of Planning land use codes
*Fields provided by SHA in addition to Attachment A

Table A-4 – Outfall Type Codes

Outfall Type Code	Description
PVC	Polyvinyl Chloride
RCP	Reinforced Concrete Pipe
HDPE	High Density Polyethylene
CONC	Concrete
SPP	Structural Plate Pipe
VC	Vitrified Clay
CMP	Corrugated Metal Pipe
CIP	Cast Iron Pipe
ACCMP	Asphalt Coated Corrugated Metal Pipe
BCCMP	Bituminous Coated Corrugated Metal Pipe
UNK	Unknown
OTHER	Other
ASRP	Aluminum Spiral Rib Pipe
TCP	Terracotta

***TABLE_B_URBAN_BMP_SWM_FACILITIES*:** The data (see Table A-5) provided is a polygon feature class representing all existing stormwater facilities statewide within SHA drainage systems. The drainage area layer is provided as a reference feature class layer in the SHA_NPDES_2013geodatabase.gdb named "DRAINAGE_SWMFACILITY". The stormwater facility BMPs can be joined to this layer using the FACILITY_ID common field. The impervious area information associated to the stormwater facilities is currently being updated to support the establishment of an accurate baseline. There are some facilities in the MS4 counties which do not have an impervious area acreage assigned due to limitations in the existing legacy data that is currently being processed with update improvements.

This layer includes the BASELINE_YEAR field which indicates if the facility is associated with the 2009 Baseline or the 2011 Current Capacity, or both due to a retrofit enhancement.

Table A-5 Urban Stormwater BMPs (Table B from Attachment A) - Attribute Structure Feature Class Name: TABLE_B_URBAN_BMP_SWM_FACILITIES

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
STRU_ID	TEXT	8	Unique structure ID[5]
PERMIT_NO	TEXT	10	Unique permit number
STRU_NAME	TEXT	60	Structure name
ADDRESS	TEXT	50	Structure address
CITY	TEXT	15	Structure address
STATE	TEXT	2	Structure address
ZIP	NUMBER	10	Structure address
MD_NORTH	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Northing
MD_EAST	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Easting
ADC_MAP	TEXT	15	ADC map book coordinate (optional if BMP has MD Northing\Easting)
WATERSHED_CODE	TEXT	20	Maryland 8 or 12-digit hydrologic unit code *Note: Provided in a text field with a 20 width to minimize data loss (truncated leading zero)*
STRU_TYPE	TEXT	10	Identify structure or BMP type[3]
LAND_USE	NUMBER	3	Predominant land use[2]
CON_PURPOSE	TEXT	4	New development (NEWD), Redevelopment (REDE), or Restoration (REST)
DRAIN_AREA	NUMBER	8	Structure drainage area (acres)[1]
IMP_ACRES	NUMBER	8	Structure impervious drainage area (acres)[1]
TOT_DRAIN	NUMBER	8	Total site area (acres)
WQ_VOLUME	NUMBER	8	Volume of rainfall depth in inches managed by the practice
RCN	NUMBER	5	Runoff curve number (weighted)
ON_OFF_SITE	TEXT	3	On or offsite structure
APPR_DATE	DATE/TIME	8	Permit approval date
BUILT_DATE	TEXT	8	Construction completion date *Note: Provided as a Text field due to constraints of source data.*

_Table A-5 Urban Stormwater BMPs (Table B from Attachment A) - Attribute Structure Feature Class Name: TABLE_B_URBAN_BMP_SWM_FACILITIES_

Column Name	Data Type	Length	Description
INSP_DATE	DATE/TIME	8	Record most recent inspection date
GEN_COMNT	TEXT	255	General comments *Note: Provided in a field width of 255 characters to minimize data loss.*
LAST_CHANGE	DATE/TIME	8	Date last change made to this record
*COUNTY	TEXT	2	Abbreviations for MD county.
*LOCATION	TEXT	255	Location descriptions
*BASELINE_YEAR	TEXT	8	2009 baseline or 2011 current capacity indicator, for MS4 counties only.
*MDE_STRU_ID	TEXT	20	Unique structure ID with the prefix of "SHA"

[1] GIS shapefile required
[2] Use attached Maryland Office of Planning land use codes
[3] Use attached urban BMP type code
[5] Use attached unique structure identification codes
*Fields provided by SHA in addition to Attachment A

***TABLE_C_IMPERVIOUS_SURFACES*:**
The data provided (see Table A-6) is a polygon feature class representing all existing impervious area with SHA right-of-way. The layer identifies the impervious area that is treated by SHA facilities. Within the dataset provided, the data for Baltimore, Washington and Cecil counties have been updated and represent current impervious and treatment conditions. The other MS4 counties in the layer were not compiled using the newest methods and are being updated currently to reflect the current conditions. The drainage area layer is provided as a reference feature class layer in the SHA_NPDES_2013geodatabase.gdb named "DRAINAGE_SWMFACILITY". The stormwater facility BMPs can be joined to this layer using the FACILITY_ID common field. The restoration fields are null at this point in time and will be prepared after the planned completion of the impervious data development updates.

In addition, there is a table provided in the geodatabase with the following name, TABLE_C1_IMPERVIOUS_WATERSHED_ACREAGES (table), which includes the summary of impervious acreage by watershed.

_Table A-6. Impervious Surfaces (Table C from Attachment A) – Attribute Structure Feature Class Name: TABLE_C_IMPERVIOUS_SURFACES_

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
WATERSHED_CODE	TEXT	20	Maryland 8 or 12-digit hydrologic unit code *Note: Provided in a text field with a 20 width to minimize data loss (truncated leading zero)*
IMP_ACREAGE	NUMBER	8	Total impervious acreage in watershed[1]
IMP_CONTROLLED	NUMBER	8	Impervious acreage controlled to the maximum extent practicable[1]
IMP_BASELINE	NUMBER	8	Impervious acreage not controlled to the maximum extent practicable [1, 2]

Table A-6. Impervious Surfaces (Table C from Attachment A) – Attribute Structure
Feature Class Name: TABLE_C_IMPERVIOUS_SURFACES

Column Name	Data Type	Length	Description
RESTORATION_P	NUMBER	8	Impervious acreage proposed for watershed restoration[1]
RESTORATION_UC	NUMBER	8	Impervious acreage under construction for watershed restoration[1]
RESTORATION_C	NUMBER	8	Impervious acreage completed (since program inception) [1]
*SHA_OWNED	TEXT	5	Impervious ownership by SHA (Yes or No)
*STATUS	TEXT	15	Determines if the impervious area is within a treatment drainage area (Inside or Outside)
*COUNTY	TEXT	50	County name
*SOURCE_DESC	TEXT	200	Identifies the imagery used to compile the impervious area (source year of aerial imagery)
*CAPTURE_METHOD	TEXT	50	Describes the capture method
*ACREAGE	NUMBER	8	Acreage of impervious surface

[1] GIS shapefile required
[2] Fixed baseline based on MDE Guidance and approval
*Fields provided by SHA in addition to Attachment A

TABLE_D_WATERQUALITY_IMPV_PROJECTS: The data (see Table A-7) provided is a polygon feature class representing the watershed restoration projects presented in the Table 1-19 - Watershed Restoration Projects. This layer references specifically the retrofit projects for stormwater facilities. There are six projects for stream restoration and stabilization that are not mapped yet, as these layers are under construction and the information has been provided in the Microsoft Excel file for those projects. The drainage area layer is provided as a reference feature class layer in the SHA_NPDES_2013geodatabase.gdb named "DRAINAGE_SWMFACILITY". The stormwater facility BMPs can be joined to this layer using the FACILITY_ID common field.

Table A-7. Water Quality Improvement Project Locations (Table D from Attachment A) – Attribute Structure
Feature Class Name: TABLE_D_WATERQUALITY_IMPV_PROJECTS

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
STRU_ID	TEXT	8	Unique structure ID[5]
STRU_NAME	TEXT	60	Structure name
MD_NORTH	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Northing
MD_EAST	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Easting
WATERSHED_CODE	TEXT	20	Maryland 8 or 12-digit hydrologic unit code *Note: Provided in a text field with a 20 width to minimize data loss (truncated leading zero)*
STRU_TYPE	TEXT	10	Identify structure or BMP type[3]
LAND_USE	NUMBER	3	Predominant land use[2]

Table A-7. Water Quality Improvement Project Locations (Table D from Attachment A) – Attribute Structure
Feature Class Name: TABLE_D_WATERQUALITY_IMPV_PROJECTS

Column Name	Data Type	Length	Description
DRAIN_AREA	NUMBER	8	Structure drainage area (acres)[1]
IMP_ACRES	NUMBER	8	Structure impervious drainage area (acres) [1]
WQ_VOLUME	NUMBER	8	Volume of rainfall depth in inches managed by the practice
LINEAR_FT	NUMBER	8	Use this field for stream restoration or shoreline protection
POUNDS_TN	NUMBER	8	Use this field for street sweeping or inlet cleaning
POUNDS_TP	NUMBER	8	Use this field for street sweeping or inlet cleaning
POUNDS_TSS	NUMBER	8	Use this field for street sweeping or inlet cleaning
APPR_DATE	DATE/TIME	8	Permit approval date
BUILT_DATE	TEXT	8	Construction completion date *Note: Provided as a Text field due to constraints of source data.*
INSP_DATE	DATE/TIME	8	Record most recent inspection date
GEN_COMNT	TEXT	255	General comments *Note: Provided in a field width of 255 characters to minimize data loss.*
LAST_CHANGE	DATE/TIME	8	Date last change made to this record
*COUNTY	TEXT	2	Abbreviations for MD county.
*LOCATION	TEXT	255	Location descriptions
*BASELINE_YEAR	TEXT	8	2009 baseline or 2011 current capacity indicator
*RESTORED_ACRES	NUMBER	8	Identifies the restored acreage for the project
*RETRO_COMPDATE	TEXT	8	Identifies the year the retrofit was completed.
*STATUS	TEXT	19	Determines the status of the restoration project
*RESTORATION_TYPE	TEXT	55	Identifies the type of restoration project
*MDE_STRU_ID	TEXT	20	Unique structure ID with the prefix of "SHA"

[1] GIS shapefile required
[2] Use attached Maryland Office of Planning land use codes
[3] Use attached urban BMP type code
[5] Use attached unique structure identification codes
*Fields provided by SHA in addition to Attachment A

TABLE_E_MONITORINGSITES_LOCATIONS: The data (see Table A-8) provided is a point feature class representing the monitoring site locations associated with projects from 1998 through 2009.

Table A-8. Monitoring Site Locations (Table E from Attachment A) – Attribute Structure Feature Class Name: TABLE_E_MONITORINGSITES_LOCATIONS

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
STATION	TEXT	30	Unique station ID
OUTFALL OR INSTREAM	TEXT	10	Outfall or instream station
WATERSHED_CODE	TEXT	20	Maryland 8 or 12-digit hydrologic unit code *Note: Provided in a text field with a 20 width to minimize data loss (truncated leading zero)*
MD_NORTH	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Northing
MD_EAST	NUMBER	8	Maryland grid coordinate (NAD 83 meters) Easting
DRAIN_AREA	NUMBER	8	Drainage area in acres[1]
*STUDY_YEARS	TEXT	30	Range of years for the study
[1] GIS shapefile required *Fields provided by SHA in addition to Attachment A			

TABLE_E1_MONITORINGSITES_LANDUSE: The data (see Table A-9) provided is a table of records representing the associated land use records for each specific monitoring site location during the period of 1998 through 2009. The STATION field can be used to associate the BMP records to the distinct monitoring site location.

Table A-9. Monitoring Site Locations – Multiple Land Use Values in Drainage Areas (Table E.1 from Attachment A) - Attribute Structure Table Name: TABLE_E1_MONITORINGSITES_LANDUSE

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
STATION	TEXT	30	Unique station ID (associated with unique station ID in section E)
LAND_USE_RANK	NUMBER	8	Ranking of land use from predominant to least
LAND_USE	NUMBER	4	Identify land use[2]
DRAIN_AREA	NUMBER	8	Drainage area in acres[1]
[1] GIS shapefile required [2] Use attached Maryland Office of Planning land use codes			

TABLE_E2_MONITORINGSITES_SWMBMP: The data (See Table A-10) provided is a table of records representing the associated stormwater BMPs for each specific monitoring site location during the period of 1998 through 2009. The STATION field can be used to associate the BMP records to the distinct monitoring site location.

Table A-10. Monitoring Site Locations – Multiple Stormwater BMPs in Drainage Areas (Table E.2 from Attachment A) - Attribute Structure
Table Name: TABLE_E2_MONITORINGSITES_SWMBMP

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
STATION	TEXT	30	Unique station ID
BMP_RANK	NUMBER	5	Ranking of BMPs from predominant to last
STRU_TYPE	TEXT	10	Identify structure of BMP type[3]
BMP_DESCRIPTION	TEXT	60	Brief description of BMP
DRAIN_AREA	NUMBER	8	Drainage area in acres[1]

[1] GIS shapefile required
[3] Use attached urban BMP type code

***TABLE_E3_MONITORINGSITES_DRAINAGE*:** The data (see Table A-11) provided is a feature class of records representing the associated drainage areas for the study area. The STATION field can be used to associate the drainage area to the distinct monitoring site location.

Table A-11. Feature Class Name: TABLE_E3_MONITORINGSITES_DRAINAGE

Column Name	Data Type	Length	Description
SHAPE_AREA	NUMBER	38	Determines the system generated area of the drainage extent.

***TABLE_F_CHEMICAL_MONITORING_RESULTS*:** The data (See Table A-12) provided is a table of records representing the chemical monitoring for events associated to the specific monitoring site location during the period of 1998 through 2009. The STATION field can be used to associate the chemical monitoring records to the distinct monitoring site location.

Table A-12. Chemical Monitoring (Table F from Attachment A) - Attribute Structure

Table Name: TABLE_F_CHEMICAL_MONITORING_RESULTS

Column Name	Data Type	Length	Description
JURISDICTION	TEXT	50	Monitoring jurisdiction name
EVENT_DATE	DATE/TIME	8	Date of storm event
EVENT_TIME	DATE/TIME	8	Time monitoring begins
STATION	TEXT	30	Station name (associated w/ unique station ID in section E.)
OUTFALL_OR_INSTREAM	TEXT	10	Outfall or instream station

Table A-12. Chemical Monitoring (Table F from Attachment A) - Attribute Structure

Table Name: TABLE_F_CHEMICAL_MONITORING_RESULTS

Column Name	Data Type	Length	Description
STORM_OR_BASEFLOW	TEXT	10	Storm or base flow sample
DEPTH	NUMBER	5	Depth of rain in inches
DURATION	NUMBER	5	Duration of event in hours and minutes
INTENSITY	NUMBER	5	Intensity = depth/duration
TOTAL_STORM_FLOW_VOLUME	NUMBER	5	Total storm flow volume in gallons
WATER_TEMP	NUMBER	5	Flow weighted average of water temperature (Fahrenheit)
pH	NUMBER	5	Flow weighted average of pH
BOD_dt	NUMBER	5	Biological Oxygen Demand detection limit used in analysis
BOD_EMC0	NUMBER	5	EMC for Biological Oxygen Demand in mg/l using (0)*
BOD_EMC_dt	NUMBER	5	EMC for Biological Oxygen Demand in mg/l using (dt)**
TKN_dt	NUMBER	5	Total Kjeldahl Nitrogen detection limit used in analysis
TKN_EMC0	NUMBER	5	EMC for Total Kjeldahl Nitrogen in mg/l using (0)*
TKN_EMC_dt	NUMBER	5	EMC for Total Kjeldahl Nitrogen in mg/l using (dt)**
NITRATE+NITRITE_dt	NUMBER	5	Record Nitrate + Nitrite detection limit used in analysis
NITRATE+NITRITE_EMC0	NUMBER	5	Enter EMC for Nitrate + Nitrite in mg/l using (0)*
NITRATE_EMC_dt	NUMBER	5	Enter EMC for Nitrate + Nitrite in mg/l using (dt)**
TOTAL_PHOSPHORUS_dt	NUMBER	5	Record Total Phosphorus detection limit used in analysis
TOTAL_PHOSPHORUS_EMC0	NUMBER	5	Enter EMC for Total Phosphorus in mg/l using (0)*
TOTAL_PHOSPHORUSEMC_dt	NUMBER	5	Enter EMC for Total Phosphorus in mg/l using (dt)**
TSS_dt	NUMBER	5	Total Suspended Solids detection limit used in analysis
TSS_EMC0	NUMBER	5	EMC for Total Suspended Solids in mg/l using (0)*
TSS_EMC_dt	NUMBER	5	EMC for Total Suspended Solids in mg/l using (dt)**
TOTAL_COPPER_dt	NUMBER	5	Record Total Copper detection limit used in analysis
TOTAL_COPPER_EMC0	NUMBER	5	Enter EMC for Total Copper in ug/l using (0)*
TOTAL_COPPER_EMC_dt	NUMBER	5	Enter EMC for Total Copper in ug/l using (dt)**
TOTAL_LEAD_dt	NUMBER	5	Record Total Lead detection limit used in analysis
TOTAL_LEAD_EMC0	NUMBER	5	Enter EMC for Total Lead in ug/l using (0)*
TOTAL_LEAD_EMC_dt	NUMBER	5	Enter EMC for Total Lead in ug/l using (dt)**
TOTAL_ZINC_dt	NUMBER	5	Record Total Zinc detection limit used in analysis
TOTAL_ZINC_EMC0	NUMBER	5	Enter EMC for Total Zinc in ug/l using (0)*
TOTAL_ZINC_EMC_dt	NUMBER	5	Enter EMC for Total Zinc in ug/l using (dt)**

Table A-12. Chemical Monitoring (Table F from Attachment A) - Attribute Structure

Table Name: TABLE_F_CHEMICAL_MONITORING_RESULTS

Column Name	Data Type	Length	Description
HARDNESS_dt	NUMBER	5	Record detection limit used in analysis
HARDNESS_EMC0	NUMBER	5	Enter EMC for Hardness in ug/l using (0)*
HARDNESS_EMC_dt	NUMBER	5	Enter EMC for Hardness in ug/l using (dt)**
TPH_dt	NUMBER	5	Record detection limit used in analysis
TPH_EMC0	NUMBER	5	EMC for Total Petroleum Hydrocarbons in mg/l using (0)*
TPH_EMC_dt	NUMBER	5	EMC for Total Petroleum Hydrocarbon in mg/l using (dt)**
ENTEROCOCCI_dt	NUMBER	5	Record detection limit used in analysis
ENTEROCOCCI_EMC0	NUMBER	5	EMC for enterococci in MPN/100 using (0)*
ENTEROCOCCI_EMC_dt	NUMBER	5	EMC for enterococci in MPN/100 using (dt)**
ECOLI_dt	NUMBER	5	Record E. Coli detection limit used in analysis
ECOLI_EMC0	NUMBER	5	Enter EMC for E. Coli in MPN/100ml using (0)*
ECOLI_EMC_dt	NUMBER	5	Enter EMC for E. Coli in MPN/100ml using (dt)**
*LOCAL_CONCERN1_CHEM_TYPE	TEXT	50	Type of Chemical for Local Concern
LOCAL_CONCERN1_dt	NUMBER	5	Record detection limit used in analysis
LOCAL_CONCERN1_EMC0	NUMBER	5	Enter EMC for in mg/l using (0)*
LOCAL_CONCERN1_EMC_dt	NUMBER	5	Enter EMC for in mg/l using (dt)**
*LOCAL_CONCERN2_CHEM_TYPE	TEXT	50	Type of Chemical for Local Concern
LOCAL_CONCERN2_dt	NUMBER	5	Record detection limit used in analysis
LOCAL_CONCERN2_EMC0	NUMBER	5	Enter EMC for in mg/l using (0)*
LOCAL_CONCERN2_EMC_dt	NUMBER	5	Enter EMC for in mg/l using (dt)**
*LOCAL_CONCERN3_CHEM_TYPE	TEXT	50	Type of Chemical for Local Concern
LOCAL_CONCERN3_dt	NUMBER	5	Record detection limit used in analysis
LOCAL_CONCERN3_EMC0	NUMBER	5	Enter EMC for in mg/l using (0)*
LOCAL_CONCERN3_EMC_dt	NUMBER	5	Enter EMC for in mg/l using (dt)**
*LOCAL_CONCERN4_CHEM_TYPE	TEXT	50	Type of Chemical for Local Concern
*LOCAL_CONCERN4_dt	NUMBER	5	Record detection limit used in analysis
*LOCAL_CONCERN4_EMC0	NUMBER	5	Enter EMC for in mg/l using (0)*
*LOCAL_CONCERN4_EMC_dt	NUMBER	5	Enter EMC for in mg/l using (dt)**
*LOCAL_CONCERN5_CHEM_TYPE	TEXT	50	Type of Chemical for Local Concern
*LOCAL_CONCERN5_dt	NUMBER	5	Record detection limit used in analysis
*LOCAL_CONCERN5_EMC0	NUMBER	5	Enter EMC for in mg/l using (0)*

Table A-12. Chemical Monitoring (Table F from Attachment A) - Attribute Structure

Table Name: TABLE_F_CHEMICAL_MONITORING_RESULTS

Column Name	Data Type	Length	Description
LOCAL_CONCERN5_EMC_dt	NUMBER	5	Enter EMC for in mg/l using (dt)**
GEN_COMNT	TEXT	50	Monitoring comments/documentation
*Fields provided by SHA in addition to Attachment A			

Table A-13. Pollutant Load Reductions (Table G from Attachment A)
Table Name: N/A (no data available)

This data is currently under construction and is not available at this time. The information will be provided with the next Annual Report submission.

Table A-14. Biological and Habitat Monitoring (Table H from Attachment A)
Table Name: N/A (no data available)

The monitoring studies performed during the period of 1998 through 2009 did not have any available biological and/or habitat monitoring information that corresponds with the information structure provided above. As a result, no database table was provided with this information.

***TABLE_I_IDDE*:**
The IDDE results provided cover the period of October 2012 through September 2013 and represent screenings and samplings performed on major outfalls throughout Charles, Carroll and Howard counties. See Table A-15 for data descriptions.

Table A-15. Illicit Discharge Detection and Elimination (Table I from Attachment A) – Attribute Structure
Table Name: TABLE_I_IDDE

Column Name	Data Type	Length	Description
YEAR	NUMBER	4	Annual report year
OUTFALL_ID	TEXT	15	Unique outfall ID used in Section A. database
SCREEN_DATE	DATE/TIME	8	Field screening date
TEST_NUM	NUMBER	5	Initial screening, follow-up test, 3rd, etc.
LAST_RAIN	DATE/TIME	8	Date of last rain > 0.10”
TIME	DATE/TIME	8	Field screening time
OBSERV_FLOW	TEXT	3	Was flow observed? (yes/no)
CFS_FLOW	NUMBER	5	Flow rate in cubic feet per second (CFS)
WATER_TEMP	NUMBER	5	Water temperature (Fahrenheit)
AIR_TEMP	NUMBER	5	Air temperature in (Fahrenheit)
CHEM_TEST	TEXT	3	Was chemical test performed? (yes/no)
pH	NUMBER	5	pH meter reading
PHENOL	NUMBER	5	Milligrams per Liter (mg/l)
CHLORINE	NUMBER	5	mg/l

Table A-15. Illicit Discharge Detection and Elimination (Table I from Attachment A) – Attribute Structure
Table Name: TABLE_I_IDDE

Column Name	Data Type	Length	Description
DETERGENTS	NUMBER	5	mg/l
COPPER	NUMBER	5	mg/l
ALGAEGROW	TEXT	3	Was algae growth observed? (yes/no)
ODOR	TEXT	2	Type of odor[4]
COLOR	TEXT	2	Discharge color[4]
CLARITY	TEXT	2	Discharge clarity [4]
FLOATABLES	TEXT	2	Floatables in discharge[4]
DEPOSITS	TEXT	2	Deposits in outfall area[4]
VEG_COND	TEXT	2	Vegetative condition in outfall area[4]
STRUCT_COND	TEXT	2	Structural condition of outfall[4]
EROSION	TEXT	2	Erosion in outfall area[4]
COMPLA_NUM	TEXT	3	Is screening complaint driven? (yes/no)
ILLICIT_Q	TEXT	3	Was illicit discharge found? (yes/no)
ILLICIT_ELIM	TEXT	3	Was illicit discharge eliminated? (yes/no)
[4] Use Attached Pollution Prevention Activities Codes			

Phase I&II National Pollutant Discharge Elimination System
Permit No. 99-DP-3313 MD0068276
Permit Term October 2005 to October 2010

APPENDIX B

EVALUATION OF TRANSITIONAL PERFORMANCE OF INFILTRATION BASIN (AUGUST 2012)

Final Report: Evaluation of Transitional Performance of an Infiltration Basin Managing Highway Runoff

Project Duration: June 2009 - August 2012

Project Sponsor:
Karuna Pujara, P.E.
Christie Minami, P.E.
Highway Hydraulics Division
Maryland State Highway Administration
707 North Calvert Street C-201
Baltimore, MD 21202

Project Coordinators:
Allen P. Davis, PhD, P.E.
Professor
Poornima Natarajan
Graduate Research Assistant
Department of Civil and Environmental Engineering
University of Maryland
College Park, MD 20742

Urban stormwater runoff is a recognized non-point source of pollution of surface waters in the United States. Stormwater runoff washes off pollutants such as suspended solids, nutrients, and heavy metals accumulated on roadways and parking lots which can degrade the water quality of the receiving water bodies. Not only is the water quality impacted, but also the increased runoff volume from impervious surfaces can alter stream hydrology. These modifications can result in the overall degradation of the stream ecosystem.

Onsite control of runoff through stormwater control measures (SCMs) have been increasingly adopted to slow and treat runoff before it reaches the streams. Infiltration basins are widely employed SCMs to manage and treat urban stormwater runoff.

While limited performance information is available for stormwater infiltration basins, high failure rates have been reported for these facilities. Over the years, inspections have shown that many infiltration basins constructed in Maryland exhibit inappropriate ponding of water, reduced infiltration rates, and thus experience progressive failure. The environmental functionality of such 'failed' infiltration basins in managing stormwater runoff is unknown.

The purpose of this research study was to systematically quantify through field-scale research, the hydrologic and water quality performances of a failed infiltration basin facility managing highway runoff in Maryland, U.S.A. Stormwater runoff flows were continuously monitored and representative runoff samples were collected during storm events and for time periods between events over a three-year research period. Runoff samples were analyzed for a suite of pollutants including total suspended solids, nitrogen species, phosphorus, heavy metals, and chloride, that are of greatest concern in roadway runoff. The hydrologic and water quality performances were quantified using appropriate performance metrics and compared to established goals.

The research study showed that the failed infiltration basin was naturally transforming into a wetland and/or wetpond-like practice and possessed both hydrologic management and water quality functions. Based on the 188 storm events monitored, the transforming infiltration basin effectively reduced the highway runoff flows by providing dynamic flow attenuation, and total volume and peak flow reductions. The infiltration basin assimilated the entire inflow volume and did not produce any outflow for 56 % of the monitored events. The overall volume reduction achieved through the infiltration basin for the entire monitoring duration was 18%. Flow delays and peak attenuation (median peak reduction= 44%) were observed during storm events that produced outflow from the infiltration basin.

Totally, 38 storm events and 54 dry-weather water quality samplings were performed. Water quality improvements were achieved through reductions in the mean pollutant concentrations and pollutant mass for all water quality parameters during both storm events and dry-weather periods. The discharge concentrations met the established water quality goals for all pollutants except total phosphorus. From a load perspective, pollutant mass reductions for all pollutants occurred during 35 of the 38 monitored storm events. The poorest performances were observed especially during winter events that exhibited export of nutrients and heavy metals. The overall pollutant mass removal efficiencies for the entire monitoring duration were 89% TSS, 61% TP, 78% NO_x-N, 79% nitrate-N, 53% nitrite-N, 51% TKN, 64% total N, 73% total copper, 63% total lead, 55% total zinc, and 45% chloride. A significant part of this mass removal is attributed to 30% volume reduction during the 38 monitored storm events.

Comprehensive analysis of various pollutant species, coupled with hydrologic analysis and characterization of environmental conditions in the infiltration basin during different seasons and storm characteristics, showed that sedimentation, adsorption, and denitrification were the main mechanisms controlling water quality at the facility.

The infiltration basin also provided ancillary benefits such as wildlife habitat, which added an overall ecological value to the facility. The vegetation at the infiltration basin site consisted of submerged and floating wetland species in the water, emergent wetland plants along the edges of the infiltration basin, and shrubs and trees upland of the infiltration basin site. The infiltration basin site provided food and habitat for amphibians, birds, ducks, and small animals.

The transforming infiltration basin, providing both hydrologic and water quality functions, must be considered as a functioning, innovative SCM. Results and research information obtained from this study are applicable for assessing similar SCM facilities and improve understanding of SCM performances and designs. Ultimately, the knowledge obtained will lead to widespread and reliable implementation of SCMs for improved environmental quality.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Land use changes induced by urbanization and highway construction have resulted in large scale replacement of pervious land cover by impervious areas. Consequently, increased stormwater runoff volumes, higher peak flows, frequent flooding, faster routing of the runoff, reduced infiltration and evapotranspiration, and lower dry weather flows in streams have been observed (Dunne and Leopold 1978; Walsh *et al.* 2005). Such hydrologic modifications in the rate, timing, and delivery of flow can deleteriously affect the physical, chemical, and biological conditions of the receiving waters (Paul and Meyer 2001; Wang *et al.* 2003; Konrad and Booth 2005).

Urban stormwater runoff is also a leading source of water quality impairment in surface waters (U.S. EPA 2005). The impervious surfaces (roads, driveways, parking lots, sidewalks, and rooftops) accumulate pollutants, including suspended solids, metals, nutrients, pesticides, pathogenic microorganisms, oil and grease, and deicing salts, which are washed off during storm events and eventually delivered to the streams (Barrett *et al.* 1998; Davis *et al.* 2001b; Paul and Meyer 2001; Davis and McCuen 2005; Kaushal *et al.* 2005). The term "urban stream syndrome" has been used to describe the consistently observed urban stormwater-induced ecological degradation of streams characterized by flashy hydrographs, decreased baseflow, channel instability, elevated levels of contaminants, stream warming, riparian deforestation, and decline in biodiversity (Walsh *et al.* 2005).

Stormwater control measures (SCMs) have been widely implemented to control the non-point pollution due to urban stormwater runoff. Infiltration basins and trenches, wetponds, rain gardens, vegetated filter strips, permeable pavements, and constructed wetlands are some examples of structural SCMs employed to reduce the post-development runoff flows and pollutant loadings in urban areas (U.S. EPA 2005). These SCMs provide on-site control and treatment of runoff before the runoff reaches the nearby water bodies.

Over the past few decades, a multitude of infiltration basin SCMs have been constructed for stormwater management. Infiltration basins are designed to capture, temporarily store, and infiltrate stormwater runoff into the underlying soil over a period of days (Ferguson 1990; PA DEP 2006). In addition to reducing the runoff volume leaving the site, these SCMs can remove pollutants through detention and filtration of runoff as the water percolates through the underlying soil (Ferguson 1990; U.S. EPA 1999; Birch *et al.* 2005; Dechesne *et al.* 2005; Barraud *et al.* 2005). Efficiency of infiltration basins in reducing stormwater runoff flows and treatment of pollutants such as total suspended solids, nutrients, metals, and fecal coliforms has been satisfactory (Birch *et al.* 2005; Barraud *et al.* 2005; Dechesne *et al.* 2005; Emerson *et al.* 2008; Emerson *et al.* 2010).

However, recent field inspections have shown that the infiltration basins may no longer be functioning as originally intended and designed. The original design of the infiltration basin is to facilitate complete infiltration of the incoming runoff and drying out of the facility over a period of time. An infiltration basin showing permanent ponding of the water suggests no active infiltration and thus the facility is considered to have 'failed' from an engineering perspective.

A two-part field survey conducted by Lindsey *et al.* (1992) in Maryland showed that stormwater infiltration basins (2-4 years old) exhibited inappropriate ponding of water, reduced infiltration rates, excessive sedimentation, clogging, and failure with time. About 51% of the infiltration basins were inappropriately ponded due to clogging by sediment input and needed rehabilitation. Although qualitative in nature, these site inspections showed that the longevity of infiltration basins could be compromised over time.

Decrease in infiltration ability of an infiltration trench due to deposition of sediments from urban stormwater runoff over a period of three years was reported by Emerson *et al.* (2010). In that study, the infiltration trench had an intentionally oversized impervious drainage area (160:1 drainage area to SCM footprint ratio vis-à-vis the recommended ratio of 5:1) in order to study the evolution and longevity of such infiltration SCMs. The excess areal suspended solids loading led to an exponential clogging process in the first two years that resulted in a corresponding exponential decay in infiltration performance. The study noted that the performance declined significantly over the first two years and only marginally in the third year. This was because as the infiltration trench aged, the solids captured clogged the bottom of the trench to a point where additional suspended solids input had minimal further impact on the infiltration performance of the facility.

Two research studies that focused on the long-term hydrology performances of infiltration basins, however, did not detect any systematic reduction in their performances (Dechesne *et al.* 2005; Emerson *et al.* 2008). In the study conducted by Emerson *et al.* (2008), the hydrology performance of two stormwater infiltration basins located in the Villanova University campus exhibited seasonal trends in performance driven by temperature, but no discernible systematic loss of performance with age over a period of 4.5 years. It must be noted that monitoring of these infiltration basins began 1.5 years after their inception and no performance data are available for the first 1.5 years. As noted earlier, the study conducted by Emerson *et al.* (2010) showed that an 'early start-up period characterized by a decrease in infiltration' can occur in infiltration-based SCMs. Hence, onset of monitoring relative to the duration of operation of the infiltration basin is an important consideration in interpreting the long-term performance of these SCMs.

Dechesne *et al.* (2005) studied the clogging and soil pollution in four infiltration basin facilities aged between 10 and 25 years, located in mixed urban land use area in Lyon, France. The study showed that, surprisingly, the facilities had similar hydraulic capacities and were still operating with good infiltration rates. The nutrient and metals pollution was contained in the top 30 *cm* depth of the infiltration basin. This study noted that infiltration basins of similar age but draining industrial regions exhibited permanent pooling. The operational condition or the lack thereof was justified by the nature of runoff pollutant loading from the watershed land use (heavily-used impervious area and industrial vis-à-vis less-developed) (Dechesne *et al.* 2005).

Thus, existing research on infiltration basin SCMs show that precluding pretreatment, improper and irregular maintenance of the infiltrating soil (removing debris and litter, and scraping off the sediment to restore the original infiltration rate), and disproportionate influent solids loading can negatively impact the sustainability of these SCMs and can lead to failure (Lindsey *et al.* 1992; Dechesne *et al.* 2005; SMRC 2008; Emerson *et al.* 2010).

Nevertheless, the environmental functionality of failed infiltration basins is not known. While the previous studies have focused on performances of infiltration basins under operation (Birch *et al.* 2005; Dechesne *et al.* 2005; Emerson *et al.* 2008), performances of failed infiltration facilities in mitigating stormwater runoff flows and treating the runoff have not been evaluated.

This research proposes that a separate ecological function may develop in the failed infiltration basin with time. The failed infiltration basin can gradually transform into or may possess qualities of a wetpond or wetland-like practice. Functions of stormwater wetponds and wetlands in providing hydrologic benefits and in reducing pollutant loads in runoff from impervious surfaces are well documented (Wu *et al.* 1996; U.S. EPA 1999; Carleton *et al.* 2000; Walker and Hurl 2002; German *et al.* 2003; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006; Yeh 2008; Wadzuk *et al.* 2010). Hence, it was hypothesized that a 'transitioning' infiltration basin can possess both hydrology management and water quality functions.

In addition to providing flood control and water quality improvements, wetland ecosystems are among the most productive habitats in the world (U.S. EPA 2001). Wetlands support abundant vegetation, provide vital habitats for fish, and wildlife, and serve as a breeding ground and nursery for numerous species (Tiner, 2009). Suitability of an infiltration basin, naturally evolving into a wetland-like practice, as a habitat for wildlife is also of interest.

The purpose of this research study was to investigate the overall performance of a 'transitioning' stormwater infiltration basin from a hydrology and water quality perspective. A stormwater infiltration basin, built along a highway in a suburban area in Maryland, was the focus of the study. This infiltration basin manages stormwater runoff from a section of this highway. The main objectives of this research were:

1. To determine the effectiveness of the transitioning infiltration basin in managing runoff flows

2. To determine the effectiveness of the transitioning infiltration basin in reducing pollutant loads and improving the water quality of runoff

3. To identify the controlling mechanisms for the water quality and hydrologic performances

4. To assess the ecological value of the infiltration basin site

The runoff flow and water quality characteristics at the infiltration basin were monitored during several storm events and for time periods directly subsequent to storm events, over a period of three years. The water quality parameters examined include total suspended solids (TSS), phosphorus, nitrogen species, heavy metals, and chloride. These pollutants are of the greatest concern in roadway runoff because their concentrations often exceed the limits set by anticipated total maximum daily loads (TMDL) requirements.

The hydrologic and water quality performances of the infiltration basin were systematically quantified based on appropriate performance metrics and goals. Ancillary benefits such as habitat for wildlife and supporting vegetation were evaluated. The ecological value of the facility in terms of providing hydrology, water quality, and habitat functions was assessed collectively. A set of 'indicators of functionality' that are applicable towards assessment of other failed infiltration basins was also developed.

Thus, this research was aimed to determine the functionality of a transitioning stormwater infiltration basin and utilize the information obtained to develop tools that are applicable to evaluate similar infiltration basins. The 'transitioning' infiltration basins that demonstrate adequate water quality improvement and control the hydrology, as they exist, need not be treated as 'failed'. Rather than failure, these transitioning SCMs should be reclassified as a functioning stormwater management practice and permitted to remain as they are. This can save the funds involved in rehabilitating these facilities to restore original conditions and/or reconstruction to a new detention basin. If these new wetland-like SCMs provide additional functions such as habitat for wildlife, these facilities can be considered valuable in terms of better site-control of stormwater runoff as well as beneficial to the fauna supported by these facilities in developed areas.

Chapter 2: Materials and Methods

2.1 Site Description

An infiltration basin, located along MD 175 East in Columbia, Howard County, Maryland (Figure 1 and Figure 2), was selected as the site for this research study. This infiltration basin has been classified as a 'failed' facility by the Maryland State Highway Administration (SHA). Table 1 summarizes the design characteristics of the infiltration basin, as extracted from the construction plans. Total drainage area to the basin is 7.19 *acres*, of which 33% is impervious. The infiltration basin has one inflow and one outflow point. The source of inflow is sheet flow from MD-175 and ramp to Snowden River Parkway south, along with culvert and swale flow; all of these flows concentrate within a vegetated swale as the input to the infiltration basin (Figure 2).

Figure 1. Photograph showing the infiltration basin located along MD 175 East. Photo, looking west, shows single concentrated inflow point to the infiltration basin.

Imagery Source: www.maps.bing.com

Imagery Source: www.maps.bing.com

Figure 2. Aerial map showing the location of the infiltration basin site along MD 175 East. Photograph on left shows a closer view of the infiltration basin site. (Source: <www.maps.bing.com>)

Table 1. Characteristics of the MD 175 infiltration basin site.

Characteristics	**Details**
Infiltration Basin Characteristics	
Year of construction	2002
Size	Length 232 *ft*, bottom width varying from 12 to 25 *ft*, depth 3 *ft* (from permanent bottom to outlet channel invert), side slope 4:1
Storage capacity	0.89 *acre-ft*
Bed material	1.0 *ft* of sand beneath the permanent bottom of the infiltration basin
Soil type around the facility	USDA Loam (mica note)
Native soil infiltration rate	0.52 $in\ hr^{-1}$
Vegetation planted upland	Black chokeberry, silky dogwood, and redosier dogwood
Drainage Area Characteristics	
Total drainage area	7.19 *acres* (impervious area = 2.38 *acres*)
Weighted curve number	75
Time of concentration	0.29 *hr*

2.2 Site Monitoring

2.2.1 Hydrology Monitoring

An input/output approach was employed to monitor the runoff hydrology and water quality at the infiltration basin. Runoff flows to and from the infiltration basin were directed through wooden V-notch weirs. Automated portable samplers (ISCO 6712, Teledyne ISCO, Lincoln, NE) with integrated flow meters (ISCO 730 bubbler flow module) recorded the runoff flows at the inlet and outlet of the infiltration basin (Figure 3). Rainfall depth measurements were taken using a tipping bucket rain gauge (ISCO 674) with 0.01 *inch* sensitivity, installed on top of the inlet sampler vault. Both flows and rainfall depths were continuously recorded on a 2-minute increment basis. A water level probe (Global Water Instrumentation, Gold River, CA) installed within the infiltration basin continuously recorded the water level at 10-minute intervals from March 2010 to August 2012. The accuracy of the water level measurements is ± 0.072 *inches* (per manufacturer specifications).

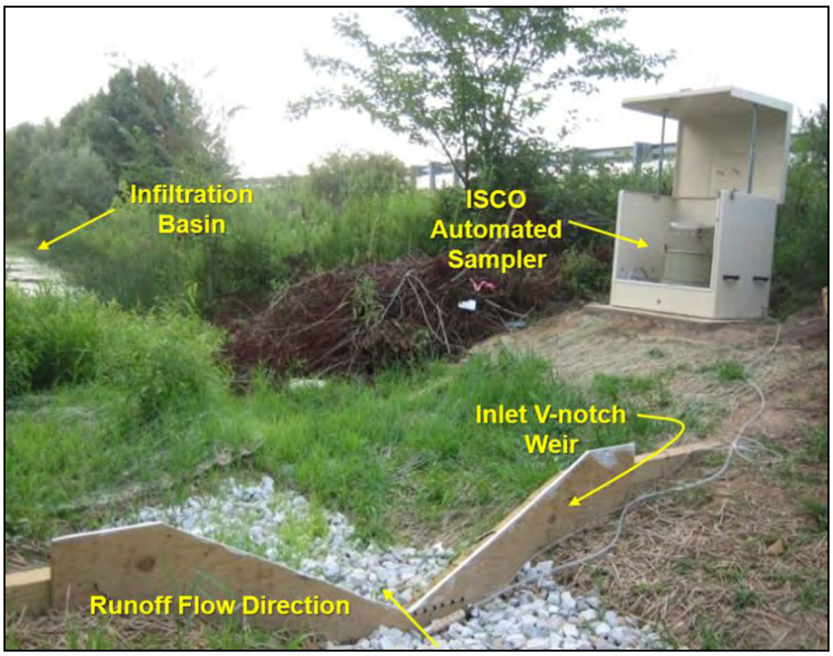


Figure 3. Photograph showing the sampler and weir installed at the inlet side of the infiltration basin.

2.2.2 Water Quality Monitoring

The ISCO portable samplers were used for water sample collection at the inlet and the outlet of the infiltration basin during storm events. Each sampler was programmed to collect 12 samples per event spread over the entire hydrograph (Figure 4). Based on the expected rainfall amount and duration from weather forecasts, a sampling program ranging from 6 up to 22-hour duration was employed in order to collect runoff samples representative of the rainfall event. Emphasis was placed on obtaining more samples in the early part of the rainfall event. The sampling program at the outlet was spread over a longer duration due to the expected flow attenuation through the infiltration basin facility. The multiple-sample collection method was adopted for 27 rainfall events. Flow-weighted composite samples were collected in a 10 L glass container during 11 rainfall events (Figure 5).

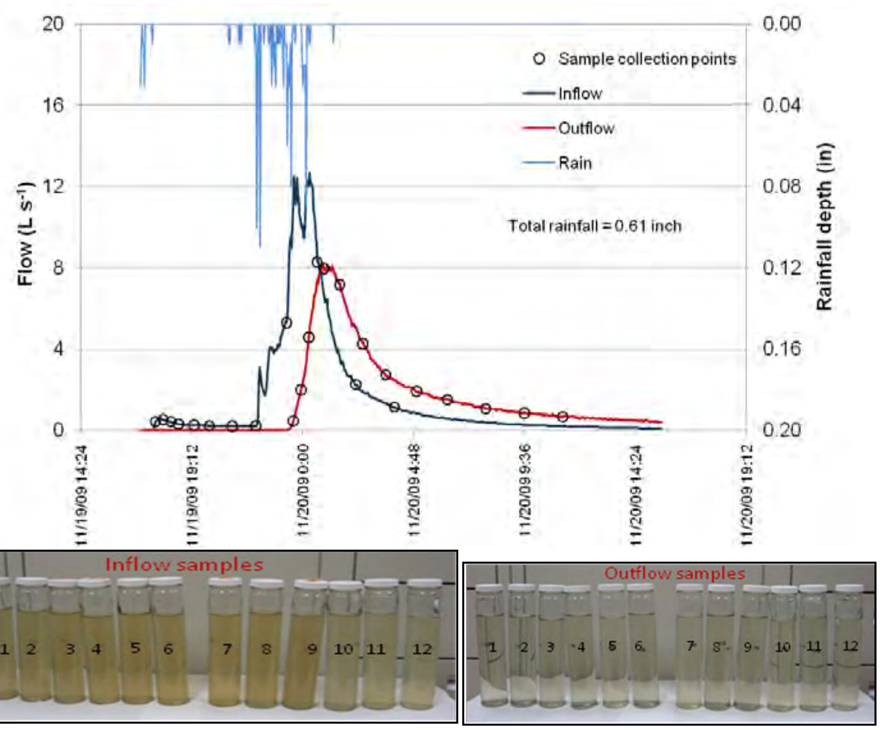


Figure 4. Inflow and outflow hydrographs recorded at the infiltration basin site during the Nov 19, 2009, rainfall event. Inlet sampling duration= 10 *hr* and outlet sampling duration= 12 *hr*. Photographs show the inflow and outflow samples collected for this rainfall event.

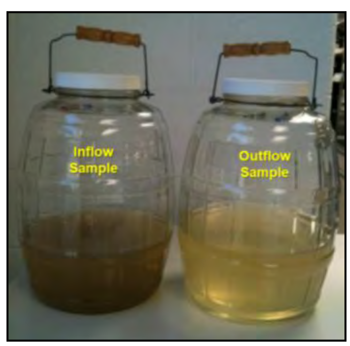


Figure 5. Photograph showing the inflow and outflow composite samples collected during the Feb 29, 2012, rainfall event.

The sample containers were cleaned with phosphorus-free soap, acid-washed, thoroughly rinsed with de-ionized water, and completely dried before placement in the samplers. Water samples collected were placed in an iced cooler, and transported to the Environmental Engineering Laboratory, University of Maryland College Park, MD within 12 hours after a rainfall event. Nitrile gloves were worn during handling of sample containers at all times. Attempts were made to monitor a distribution of rainfall events for water quality, consistent with those expected in Maryland.

In addition to sampling runoff during rainfall events, water samples were collected directly from the infiltration basin during selected dry-weather periods. These grab samples were collected from multiple locations in the infiltration basin using a swing sampler, prior to and following target events. As an example, Figure 6 shows the sampling locations and the grab samples collected on June 24, 2009.

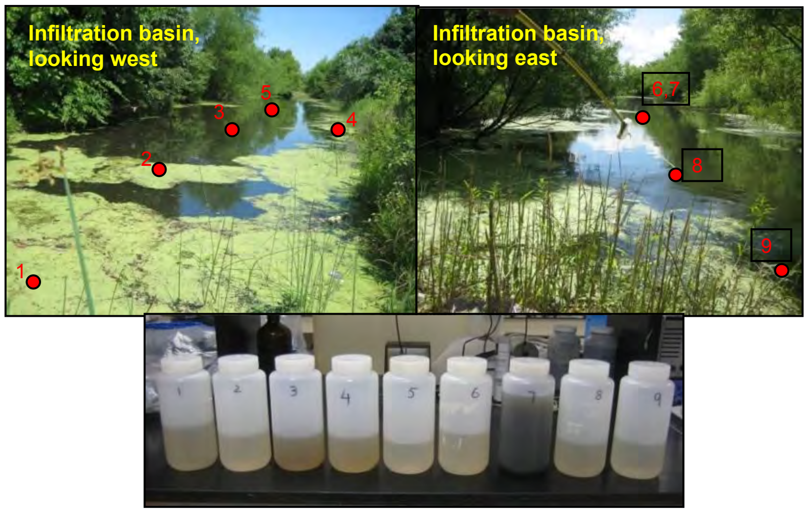


Figure 6. Sampling locations and samples collected during the 24 June, 2009, grab sampling. (Samples marked 1-6, 8, and 9 were water samples and sample 7 was a sediment sample)

At each location, samples were collected from the water column with efforts to not disturb the sediment bottom. Although care was taken to avoid plant material while taking a sample, some samples were found to have some plant material (fresh or decaying leaves). These were manually removed from the sample at the time of sample collection itself. The grab samples were analyzed for the target pollutants. The grab sample water quality data were utilized to support information obtained from stormwater runoff sampling and identify the mechanisms controlling pollutant transformations occurring in the infiltration basin.

In order to provide scientific justification to the environmental conditions facilitating pollutant transformations in the infiltration basin, additional water quality parameters were measured at the study site. Oxidation reduction potential (ORP), pH, temperature, and conductivity of the water column were continuously logged by sensors (Global Water Instrumentation, Gold River, CA) installed within the infiltration basin. Two ORP probes were installed, one close to the inlet side and one near the outlet side of the basin. The pH probe was installed near the ORP probe on the inlet side. The conductivity probe was installed near the ORP probe on the outlet side. The ORP, pH, and conductivity measurements were continuously taken in 20-minute increments for the period August 2011 to August 2012. Water temperature was continuously measured at 10-minute intervals from March 2010 through August 2012.

2.3 Analytical Methodology

The water samples were analyzed for total suspended solids (TSS), nitrate, nitrite, total Kjeldahl nitrogen (TKN), total phosphorus, total copper, total lead, total zinc, and chloride. In some cases, measurements for ammonium and dissolved phosphorus were additionally performed. All pollutant concentration determinations were based on *Standard Methods* (APHA *et al.* 1995). The laboratory analytical method for each pollutant and detection limit of each method are summarized in Table 2.

Table 2. Laboratory analytical methods for determination of pollutant concentrations.

Pollutant	Standard Method (APHA *et al.* 1995)	Detection limit ($mg\ L^{-1}$)
Total suspended solids	2540 D	1.0
Total phosphorus and dissolved phosphorus	4500-P	0.010
Total Kjeldahl nitrogen and ammonium	4500-N_{org} and 4500-NH_3	0.14 as N
Nitrite	4500-NO_2^- B	0.010 as N
Nitrate	Dionex DX-100 and ICS-1100 ion chromatograph	0.10 as N
Chloride	Dionex DX-100 and ICS-1100 ion chromatograph	2.0
Total Copper	3030, 3110	0.002
Total Lead	3030, 3110	0.005
Total Zinc	3030, 3111	0.025

Total suspended solids were determined by gravimetric method, following Standard Method 2540. Total phosphorus (TP) measurements were performed by persulfate digestion followed by colorimetric determination by the ascorbic acid method (Standard Method 4500-P) at 880 *nm* in a spectrophotometer (Shimadzu UV-160, Kyoto, Japan). Dissolved phosphorus measurements were performed on samples filtered through 0.2 μm membrane filters using the TP method. During TP analysis, runoff samples containing high TSS were observed to contain some suspended material after persulfate digestion. These digested samples were centrifuged or filtered to remove all suspended material before proceeding to the ascorbic method in order to avoid interferences during the spectrophotometric measurements.

TKN and ammonium analyses were performed by the macro-Kjeldahl method (Standard Methods 4500-N_{org} and 4500-NH_3). For nitrite analysis, samples were filtered through 0.2 μm filters and subjected to the colorimetric method (Standard Method 4500-NO_2^-

B) and measurements were made at 543 *nm* in the spectrophotometer. Nitrate and chloride measurements on samples filtered through 0.2 μm membrane filters were performed by ion chromatography in Dionex DX-100 (2009 - 2010 period) and ICS-1100 (2011 - 2012 period) systems. Analyses of total Pb and Cu were performed on the furnace module of a Perkin Elmer (Waltham, MA) 5100ZL Atomic Absorption Spectrophotometer (AAS) (Standard Method 3110), and total Zn on the flame module of the AAS (Standard Method 3111).

In cases where the concentration of a pollutant was below the laboratory analytical detection limit (Table 2), a value equal to one-half of the detection limit was assigned for calculation and statistical purposes.

Appropriate quality assurance/check procedures were adopted during all laboratory analyses. Laboratory blanks were subjected to the same analytical procedure as the field samples during each pollutant analysis. Standard calibration curves were validated by checking at least one standard during each pollutant analysis. For ion chromatography determinations of nitrate and chloride, at least two standards were checked in a sample set run. During metal analyses, at least one standard concentration was checked after every ten samples. In all cases, if the error in standard concentration check exceeded ±5%, a new standard calibration was performed.

2.4 Data Analyses and Performance Metrics

2.4.1 Hydrology Data Evaluation and Performance Metrics

2.4.1.1 Peak Flow and Volume Reduction

The hydrology data were evaluated based on selected hydrology performance metrics to determine the effectiveness of the infiltration basin in mitigating the runoff flows. For each rainfall event, the maximum inflow and outflow were compared using the peak flow ratio, R_{peak}, computed as:

$$R_{peak} = \frac{Q_{peak-out}}{Q_{peak-in}} \quad (1)$$

where, $Q_{peak-in}$ and $Q_{peak-out}$ are the measured peak stormwater flow rates at the inlet and outlet, respectively, during the rainfall event (Davis 2008).

The total flow volume was calculated by a simple numerical integration of the flow measurements over time:

$$V = \int_0^{T_d} Q\, dt \quad (2)$$

In Equation 2, Q is the measured stormwater flow rate, and T_d is the rainfall event duration. The interval between measurements is *dt*. The total inflow and outflow volumes during a rainfall event were obtained by substituting the measured inflow and outflow rates, respectively. The inflow and outflow volumes were compared to determine the volume reduction achieved through the infiltration basin during the event. A new rainfall event was defined as an event occurring six hours after the end of the preceding event. Occasionally, outflow from the infiltration basin continued for extended periods, overlapping the next rainfall event. In such cases, the flow volumes of the two events were combined during volume analyses.

2.4.1.2 Statistical Evaluation

Probability plots (Davis 2008; Li and Davis 2009) for peak flows and flow volumes were also developed. Statistical tests were performed to determine if the observed runoff and discharge volumes were significantly different. A non-parametric statistical method, the Wilcoxon matched-pairs signed-ranks test (McCuen 2005), was employed to determine if the outflow volumes were significantly lower than the inflow volumes. Runoff volumes measured during all 138 recorded storm events were compared, which included rainfall events with and without outflow. A value of zero was assigned for outflow volume for storm events that did not produce outflow. This test determined if the overall hydrologic performance of the infiltration basin was statistically significant. In a second test, data for only the 52 storm events with both inflow and outflow were tested. Two levels of significance (α), 5% and 1%, were used in these tests.

2.4.1.3 Flow Duration Curve

While efforts have been directed towards matching estimated pre- and post-development peak flows, the cumulative duration of discharge flows have increased due to the overall increase in urban runoff volume, which has implications on the stream hydraulics and delivery of pollutants to the streams (Booth and Jackson 1997). The cumulative duration of runoff flows at the infiltration basin site were illustrated using a flow duration curve. The flow rate time series recorded at 2-minute intervals were ranked from the highest to the lowest flow rate values for the duration of interest. The ranked series was plotted against time to develop the flow duration curve.

A study goal was to compare the flow durations at the infiltration basin site with that of a forested site to evaluate the effectiveness of the infiltration basin site in mitigating the highway runoff flows. Unlike traditional stormwater management designs of reducing peak flows, 'low-impact development' (LID) approaches are aimed to match post-development runoff flows to pre-development flow characteristics (Booth and Jackson 1997; Holman-Dobbs *et al.* 2003; Dietz and Clausen 2008). The LID technologies promote infiltration and evapotranspiration to compensate for the rainfall abstraction possible in grassed areas, and reduce the rapid concentration of excess runoff and slow the runoff (Holman-Dodds *et al.* 2003; Dietz and Clausen 2008). Therefore, the flow durations at the infiltration basin SCM and forested (pre-development) site were compared to examine the extent to which the infiltration basin mimicked the pre-development hydrologic regime.

Pond Branch, located in the Gunpowder Falls watershed in Baltimore County in Maryland, was selected as the reference site. The catchment area of Pond Branch is 94 *acres* and is 100% forested. Streamflow data for Pond Branch (in 15-minute intervals) were accessed at the U.S. Geological Survey (USGS) website <http://waterdata.usgs.gov/md/nwis/nwisman?site_no=01583570>.

Rainfall data for the reference site were obtained from a rain gauge station located at Oregon Ridge Park. This rain gauge station is located about 0.76 *miles* north of the Pond Branch flow gage and about 32 *miles* from the study site. The precipitation records for this station are managed by the Center for Urban Environmental Research and Education, University of Maryland Baltimore County, and are available at <http://hydro2.umbc.edu/Precip/>.

The rainfall distribution at the MD 175 infiltration basin site and Oregon Ridge Park were compared to determine if the rainfall depths and durations observed at the two sites were comparable. Figure 7 shows the rainfall depth-duration frequencies at the two sites for the monitoring duration. The two distributions were statistically compared using the hypothesis test on single proportions (McCuen 2005), where the equality of storm proportions in each depth-duration category was assessed at a 5% level of significance (α = 0.05).

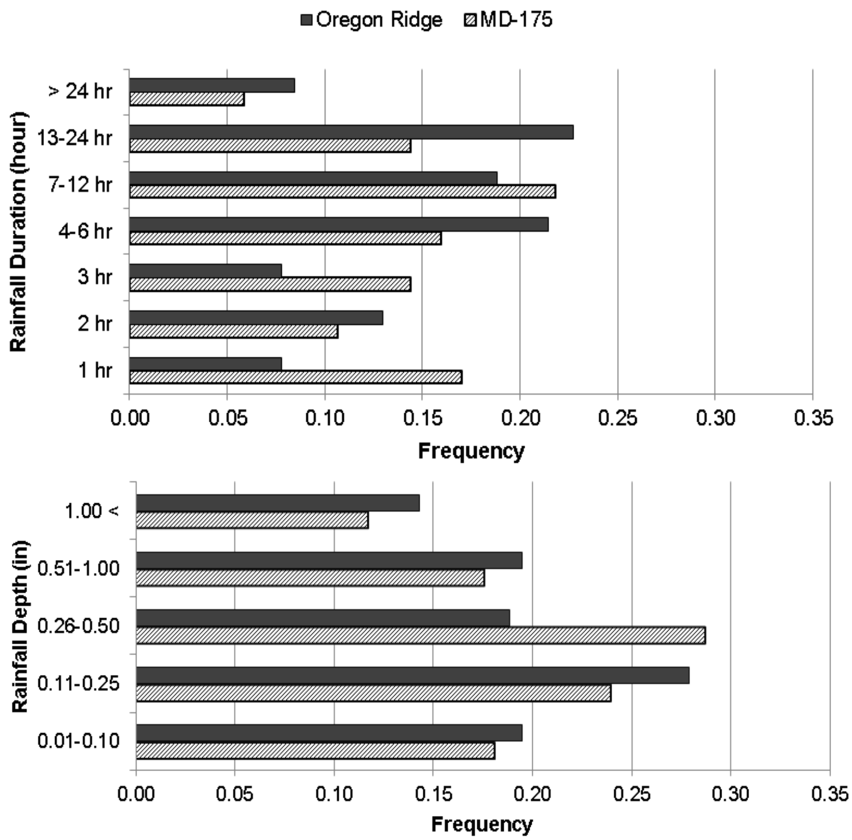


Figure 7. Rainfall depth-duration distributions for the MD 175 infiltration basin site and Oregon Ridge (reference site) for August 2009 to August 2012 period.

The test showed that the rainfall distributions at the two sites were statistically different for two (out of seven) duration categories in the (0.10 – 1.0 *in*) and three (out of seven) duration categories in the (0.25 – 0.50 *in*). The storm proportions were statistically similar for the (0.01 – 0.10 *in*), (0.51 – 1.0 *in*) and (> 1.0 *in*) depth-duration categories. Since the statistical test showed similar proportions for a majority of the depth-duration categories, the overall rainfall distributions at the study and reference site can be considered to be similar.

The flow magnitudes at the infiltration basin site and Pond Branch were normalized by their respective total drainage areas and were expressed in *in day*$^{-1}$. The Pond Branch stream maintains baseflow between storm events. The mode streamflow rate at Pond Branch was 0.0193 *in day*$^{-1}$ for the period Jan 2009 to August 2012. This mode value was selected as the baseflow and was subtracted from all recorded streamflow values. However, baseflow between storm events were not the same and this method of removing baseflow did not consistently eliminate baseflow. This resulted in very small flow values in the stream during dry periods. The flow durations at the Pond Branch stream were much longer compared to the infiltration basin site and these small flows were part of the tail end of the curve. Hence, this method was acceptable in the larger context. The reference flow duration curves were developed after removing baseflow from the streamflow data.

2.4.1.4 Estimation of Evapotranspiration

Evapotranspiration is a seasonal process and its effect on the water balance of the infiltration basin was examined. The evapotranspiration (ET) was estimated on a daily basis using the Blaney-Criddle formula (Blaney and Criddle 1962; Brouwer and Heibloem 1986):

$$ET_0 = p\,(0.46\,T_{mean} + 8) \quad (3)$$

where, ET_0 (*in day*$^{-1}$) is reference crop evapotranspiration, *p* is the mean daily percentage of annual daytime hours, and T_{mean} (°C) is the mean daily temperature. The mean daily temperature data were obtained from a weather station located 3 *miles* from the infiltration basin site. The data are accessible via web (<http://www.wunderground.com/cgi-bin/findweather/getForecast?query=21045>). The approximate values of *p* for the location of the study site are provided in Table 3.

Table 3. Mean daily percentage of annual daytime hours (*p*) for the study site location.

Latitude	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
39.24 N	0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21

(Source: Brouwer and Heibloem 1986)

The Blaney-Criddle formula is a simple temperature-based method. While the Blaney-Criddle method has been widely used to estimate evapotranspiration and crop irrigation needs, the reported reliability of this method has been mixed. Some research studies reported good correlation between predicted and measured ET values (or consumptive use) as well as predictions better than other temperature-based ET methods including Thornthwaite and Hargreaves Samani (Stephens and Stewart 1963; Hobbs and Krogman 1966; Cruff and Thompson 1967; Tabari *et al.* 2011; Xu and Singh 2011).

Tabari *et al.* (2011) reported 1.17% error of estimate (r^2 = 0.99; root mean square error of 0.0123 *in day*$^{-1}$) for the Blaney-Criddle predictions when compared to that of Penman-Monteith FAO 56 model for a mild-humid region in Iran, based on data for the period 1965 – 2005 for that region. Xu and Singh (2011) reported (-9) to (+20)% error of estimate for the monthly ET predictions (June to September for 10-year data set) using Blaney-Criddle when compared to pan evaporation data for a region in Ontario, Canada. The potential evapotranspiration computed by the Blaney-Criddle method at 15 sites in the subhumid and modified arid environments of Florida, yielded values within ±22% of the adjusted pan evaporation based on one-year data (Cruff and Thompson 1967).

Few other studies reported poor performance of Blaney-Criddle method with over-prediction of the ET (Tukimat *et al.* 2012) or underestimation of crop ET in semiarid, high-elevation environments (Juday *et al.* 2011). In general, radiation-based methods have been found to perform better in comparison to temperature-based methods. It has been suggested that the Blaney-Criddle method provides only a rough estimation of ET and can be highly inaccurate for extreme climatic conditions (windy, dry, and sunny (underestimated by 60%) vs. calm, humid, and clouded (overestimated by 40%)) (Brouwer and Heibloem 1986).

The Penman-Monteith method has been found to provide the most reliable predictions of ET close to field observations (Allen *et al.* 1996; Tukimat *et al.* 2012). However, this method requires extensive data and is not feasible for use in data scarce regions. The meteorological inputs for this method were unavailable for the study site. Hence, the scope of this research was limited to employ the Blaney-Criddle method for evapotranspiration estimation at the infiltration basin site.

2.4.2 Water Quality Data Evaluation and Performance Metrics

2.4.2.1 Pollutant Mass Removal and Event Mean Concentration

For each pollutant, the total mass (*M*) was calculated as:

$$M = \int_0^{T_d} Q\, C\, dt \qquad (4)$$

In Equation 3, *C* is the measured pollutant concentration in each sample. Substituting corresponding values of *Q* and *C* for inflow and outflow, the inflow and outflow mass loadings during an event were obtained, respectively.

During a few storm events, the runoff flows at the infiltration basin continued beyond the water quality sampling period. While performing pollutant mass loading calculations, concentration of the unsampled runoff volume was assumed to be equal to half the concentration of the last sample collected, as a conservative estimate. In the event that the sampling duration covered only a portion of the hydrograph, the water quality data collected was considered non-representative of the storm event and the water quality data was excluded from analysis.

Mass removal efficiency for a pollutant was calculated as:

$$M_R = \frac{(M_{in} - M_{out})}{M_{in}} \qquad (5)$$

where, M_{in} and M_{out} are the inflow and outflow pollutant mass loadings calculated using Equation 3. The total pollutant mass loadings and removals were evaluated for each storm event. In cases where the entire inflow volume was assimilated by the infiltration basin and no measurable outflow was produced, the removal efficiency for all target pollutants was 100% for that event.

The event mean concentration (EMC) was calculated as:

$$EMC = \frac{M}{V} = \frac{\int_0^{T_d} C\, Q\, dt}{\int_0^{T_d} Q\, dt} \qquad (6)$$

where, *V* is the stormwater runoff volume. Since EMC weights discrete concentrations with flow volumes, EMCs were used to compare pollutant concentrations of inflow and discharge for different events. For composite water sampling, the EMC was directly obtained as the measured concentration of a pollutant in the composite sample. When a composite sample was taken, the pollutant mass was obtained by multiplying the measured EMC with the total runoff volume for that storm event. For storm events without outflow, a value of zero was assigned for discharge EMC for statistical purposes.

2.4.2.2 Probability Exceedence and Water Quality Goals

Percent pollutant removal may not be an accurate representation of the performance of a SCM since it depends on the influent pollutant concentrations (Strecker *et al.* 2001). Therefore additional metrics were utilized to evaluate the water quality performance of the infiltration basin. The inflow and outflow concentrations were statistically characterized through probability exceedence distributions (Li and Davis 2009). The effluent pollutant concentrations were compared to appropriate water quality targets (Table 4).

Table 4. Criteria for various water quality parameters**.** All concentrations are in mg L^{-1}.

Pollutant	TSS	TP	Nitrate (as N)	Nitrite (as N)	TKN (as	TN (as	Lead	Copper	Zinc	Chloride
Water quality criterion	25[a]	0.05[a]	0.20[a]	1[c]	-	-	0.065[b]	0.013[b]	0.12[b]	250[c]

[a] Criterion for excellent water quality in the Potomac River Basin (Davis and McCuen 2005)
[b] Acute toxicity level (COMAR 2006)
[c] Secondary drinking water regulation (US EPA 2009)

The selected water quality criteria in Table 4 are based on the water quality goals outlined in the bioretention research study by Li and Davis (2009). The criteria were derived from various local, state, and federal regulations; threshold levels of TSS, TP, and nitrate are local quantitative water quality designations (Davis and McCuen 2005); total heavy metal criteria are acute toxicity levels for freshwaters in Maryland (Code of Maryland Regulations (COMAR) 2006); and the threshold nitrite and chloride levels are federal secondary drinking water regulation (US EPA 2009).

2.4.2.3 Pollutant Duration Curve

Pollutant duration curves (as in Stagge *et al.* 2012) were developed for each pollutant based on 27 discrete-sample monitored storm events. Composite sampling was performed during the 11 excluded storm events. The curves illustrate the cumulative duration of a pollutant concentration flowing into the infiltration basin, the maximum pollutant concentrations discharged, cumulative duration of concentrations discharged, and their exceedence in comparison to water quality targets.

2.4.2.4 Statistical Evaluation

A non-parametric statistical method, the Wilcoxon matched-pairs signed-ranks test (McCuen 2005), was used to determine if the outflow EMCs were significantly lower than the inflow EMCs ($EMC_{out} < EMC_{in}$) for all pollutants (TSS, TP, TKN, NO_x, Pb, Cu, Zn, and chloride). Two separate statistical tests were performed to determine the effectiveness of the infiltration basin in providing water quality benefit. In the first test, inflow and outflow EMCs of all 38 sampled storm events were compared to determine the overall water quality performance of the infiltration basin. For events with no outflow, an EMC value of zero was used. In the second test, EMCs of only the 15 storm events with both measurable inflow and outflow were compared. This test was performed to determine the effectiveness of the basin from a treatment perspective.

Both hydrology and water quality performances of the infiltration basin were evaluated on an event basis as well as on seasonal basis. The classification followed was: September to November as fall, December to February as winter, March to May as spring, and June to August as summer.

Chapter 3: Hydrologic Performance of the Infiltration Basin

A total of 188 rainfall events were recorded at the infiltration basin site for the period August 2009 to August 2012. Details of rainfall depth and duration, antecedent dry period, and runoff inflow and outflow volumes recorded during each storm event are summarized in Table A-1 in Appendix A. All rainfall events with 0.01 *in* rainfall depth were ignored from the data collected because 0.01 *in* rainfall depth corresponds to one rain gauge tip and this could occur due to moisture or wind conditions. Also, no hydrology data are available for select winter periods (late Dec 2009 through early Mar 2010; late Dec 2010 until early Feb 2011) when accumulation of snow and/or presence of ice cover at the weir rendered flow measurements impossible.

3.1 Characterization of Monitored Storm Events

Table 5 shows the rainfall depth-duration frequency distribution of the 188 rainfall events recorded at the MD 175 infiltration basin site. Also included in Table 5 is the historical rainfall distribution for Maryland (Kreeb 2003) for comparison. The two rainfall distributions were compared using the hypothesis test for single proportion (McCuen 2005). The equality of the proportions of rainfall events observed at the study site and that expected for Maryland for each depth-duration category were verified at a 5% level of significance ($\alpha = 0.05$).

Table 5. Rainfall distribution for the MD 175 infiltration basin site and historical data for Maryland (Kreeb 2003). 'MD175 Sum' represents the column or row total for each depth-duration category.

	Total Rainfall Depth (*in*)						
Rainfall Duration	**0.01 - 0.10**	**0.11 - 0.25**	**0.26 - 0.50**	**0.51 - 1.0**	**> 1.0**	**MD 175 Sum**	**Historical data**
0-2 hr	0.0479	0.0745	0.0266	0.0160	0.0053	**0.1702**	**0.3289**
2-3 hr	0.0479	0.0266	0.0160	0.0160	0.0000	**0.1064**	**0.0756**
3-4 hr	0.0266	0.0372	0.0532	0.0053	0.0160	**0.1383**	**0.0627**
4-6 hr	0.0319	0.0319	0.0798	0.0160	0.0000	**0.1596**	**0.1233**
7-12 hr	0.0266	0.0585	0.0638	0.0532	0.0213	**0.2234**	**0.1818**
13-24 hr	0.0000	0.0106	0.0426	0.0585	0.0319	**0.1436**	**0.1617**
24< hr	0.0000	0.0000	0.0053	0.0106	0.0426	**0.0585**	**0.0659**
MD 175 Sum	**0.1809**	**0.2394**	**0.2872**	**0.1755**	**0.1170**	**1.000**	**1.000**
Historical Data	**0.3287**	**0.1461**	**0.2130**	**0.1747**	**0.1374**	**1.000**	

The major differences in the two distributions were for the low rainfall depth (0.01 –0.10 and 0.11 – 0.25 *in*) and duration categories. These categories were under-represented at the

MD175 site and were statistically different from the MD distribution. As will be discussed later, all rainfall events of depth (< 0.11 *in*) and some events of depth (0.11 – 0.25 *in*) did not generate runoff to the site and were ignored for all volumetric analyses. The effect of these storms on the performance of the infiltration basin can thus be considered insignificant. The rainfall proportions were similar for rainfall depths (0.26 – 0.50 *in*) and larger (0.51 – 1.0 and >1.0 *in*) for most storm depth-duration categories (α = 0.05). These categories represent about 80% of the storm events that produced runoff to the infiltration basin. Therefore, the overall rainfall distribution at the study site was in good agreement with the historical data.

3.2 Results and Discussion

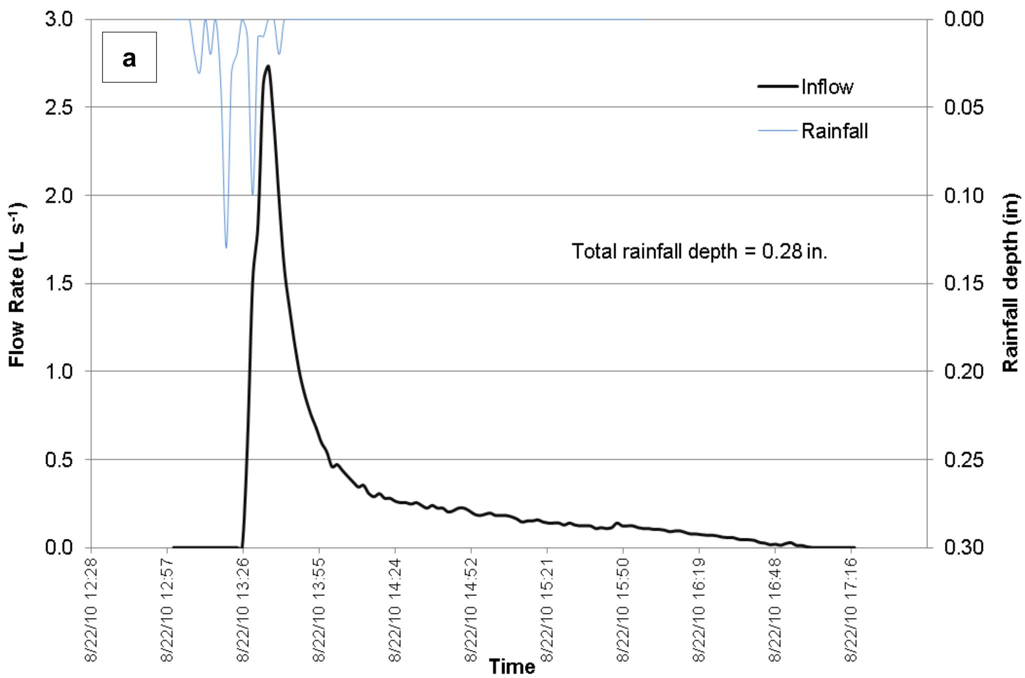
Of the total 188 monitored rainfall events, 54 events (mostly < 0.11 *in*) did not produce any inflow to the site. These events were excluded from all hydrologic performance analyses. After eliminating events which did not produce any inflow to the site and then combining events when flows overlapped, the sample size of rainfall events was reduced from 188 to 120 events. The hydrologic performance metrics were computed based on these 120 events.

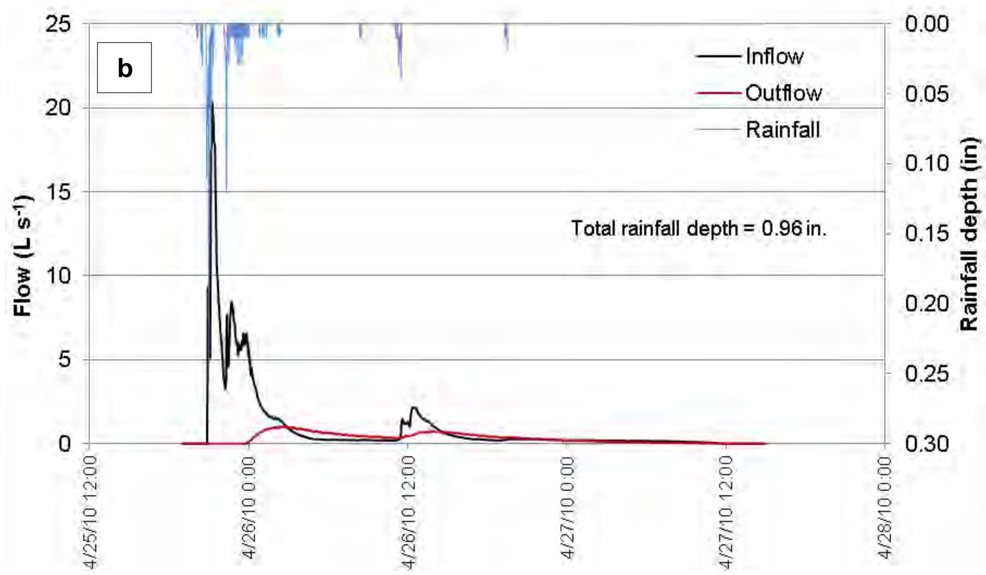
3.2.1 Hydrographs

Figure 8 shows sample inflow and outflow hydrographs recorded during rainfall events of different sizes and seasons. The inflow represents the rate of runoff flow from the drainage area to the infiltration basin based on the temporal variations in the rainfall intensity during that event. The outflow represents the dynamic response of the infiltration basin to the runoff inflow.

Figure 8a is hydrograph recorded in summer. During this event, the infiltration basin retained the entire inflow runoff and no discharge was observed (100% volume reduction). These observations were common to several small (25 events of <0.26 *in* rainfall depth) during all seasons and some moderate rainfall events (25 events of 0.26 – 0.50 *in* rainfall depth).

Figure 8b is a hydrograph recorded during a moderate rainfall event (rainfall depth = 0.96 *in*) in spring 2010. The reduction in peak flow, delayed outflow, reduced volume leaving the system (67% volume reduction), and longer outflow recession limb can be seen in the sample hydrograph presented in Figure 8b. For similar rainfall events during which outflow occurred, the infiltration basin was capable of delaying the discharge from the basin, ranging from one hour up to more than one day after the onset of inflow. The peak flow was reduced and the water was discharged at lower flow rates spread over several hours.


a
Inflow
Rainfall
Total rainfall depth = 0.28 in.
Flow Rate (L s-1)
Rainfall depth (in)
Time
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
8/22/10 12:28
8/22/10 12:57
8/22/10 13:26
8/22/10 13:55
8/22/10 14:24
8/22/10 14:52
8/22/10 15:21
8/22/10 15:50
8/22/10 16:19
8/22/10 16:48
8/22/10 17:16


b
Inflow
Outflow
Rainfall
Total rainfall depth = 0.96 in.
Flow (L s-1)
Rainfall depth (in)
25
20
15
10
5
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
4/25/10 12:00
4/26/10 0:00
4/26/10 12:00
4/27/10 0:00
4/27/10 12:00
4/28/10 0:00

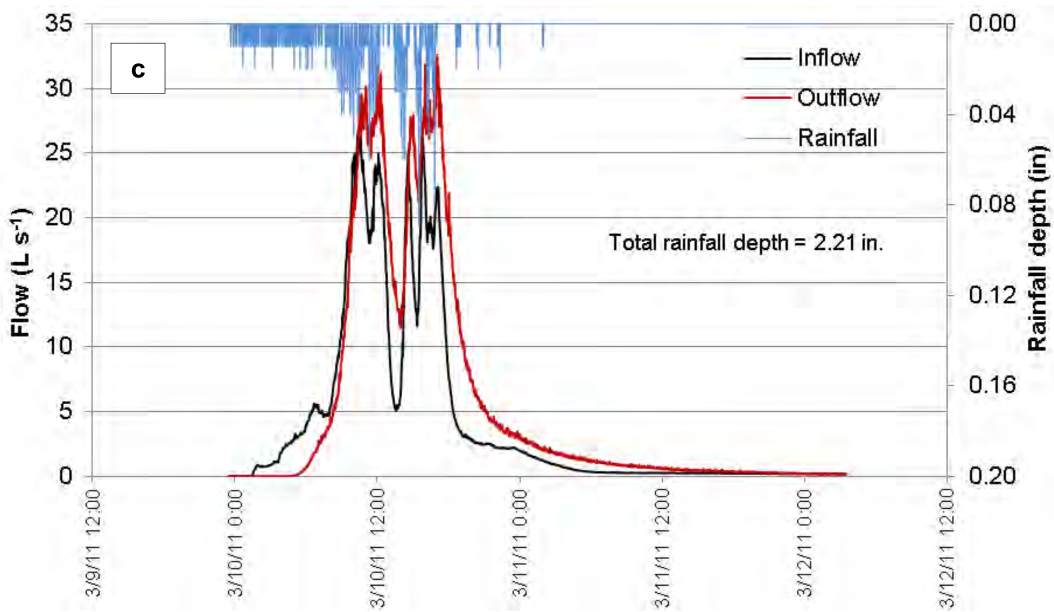


Figure 8. Hydrographs recorded during rainfall events on **a.** Aug 22, 2010 (no outflow) **b.** April 26, 2010 **c.** March 9, 2011 at the MD175 infiltration basin site.

The hydrograph in Figure 8c, recorded during a large rainfall event in spring 2011, shows no runoff volume reduction and no net peak flow attenuation. In fact, discharge volume in excess of the inflow volume was noted during this event. Similar observations were especially made during large and extreme rainfall events and extended wet periods at the site. The additional volume of water was possibly contributed by direct flow from the banks of the infiltration basin. Also direct input of rainfall to the infiltration basin could be significant during very large rainfall events.

3.2.2 Peak Flows and Peak Reduction Ratio

Since high runoff flow rates have implications in erosion and sediment transport, reduction of peak flows achieved through the infiltration basin was assessed. The peak inflows ranged between 1.9 and 272 L s^{-1} (median = 7 L s^{-1}). For the rainfall events producing outflow from the infiltration basin, the peak discharges ranged between 0.10 and 223 L s^{-1} (median = 4.8 L s^{-1}).

The probability plot for peak flows recorded during the entire monitoring duration is shown in Figure 9. The distribution of peak flows clearly depicts the attenuation of peak flows facilitated by the infiltration basin. While the median inflow peak flows was 7 L s^{-1}, the outflow peak flow was 0 L s^{-1} (no discharge).

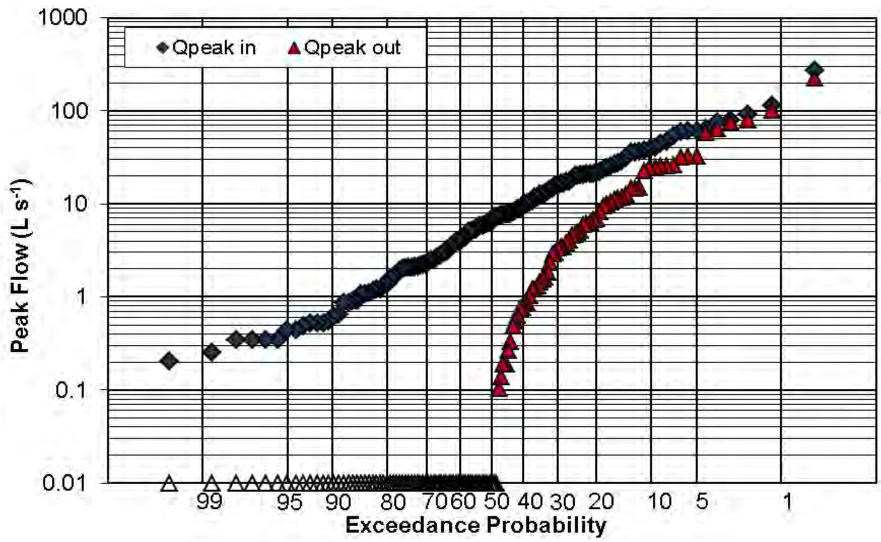


Figure 9. Probability plot for peak flows recorded at the MD175 infiltration basin site for the entire monitoring duration. Hollow points represent rainfall events with no discharge (complete capture of inflow).

For each rainfall event, the maximum inflow and outflow rates were compared using the peak flow ratio, R_{peak}, computed as:

$$R_{peak} = \frac{Q_{peak-out}}{Q_{peak-in}} \tag{7}$$

where, $Q_{peak-in}$ and $Q_{peak-out}$ are the measured peak stormwater runoff flow rates at the inlet and outlet, respectively, during the rainfall event. For the 53 events that produced outflow, the R_{peak} ranged between 0.01 and 1.2; the mean R_{peak} was 0.48 and the median was 0.44. Peak flow reductions were observed during all rainfall events of rainfall depth < 0.51 *in* and most moderate rainfall events (rainfall depth < 1.0 *in*). Negligible or no peak reduction ($R_{peak} \geq 1$) was characteristic of large and extreme events (rainfall depth > 1.8 *in*).

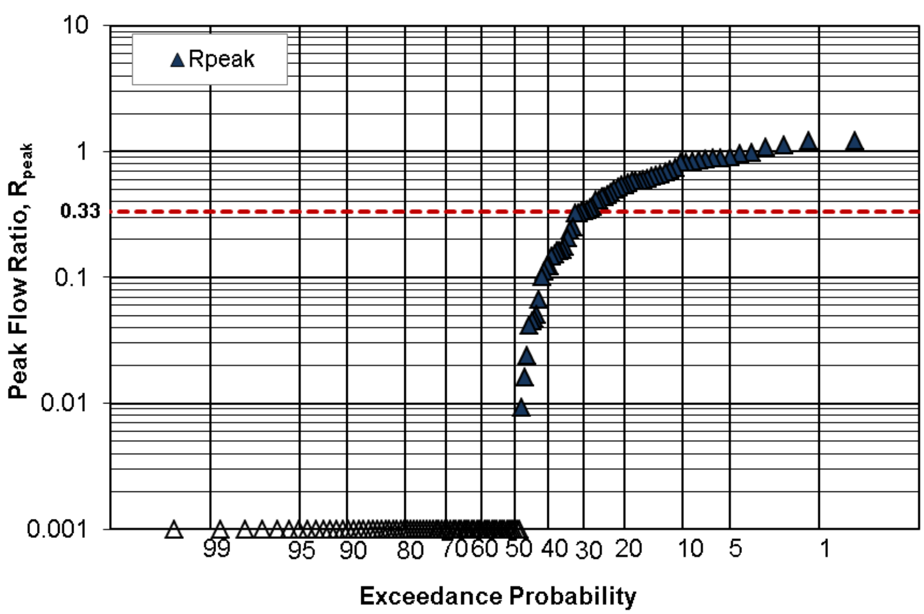


Figure 10. Probability plot for peak flow ratios (R_{peak}) for 120 rainfall events recorded at the MD175 infiltration basin site. Hollow points represent rainfall events with no discharge (complete capture of inflow).

The probability plot for R_{peak} for all 120 rainfall events is shown in Figure 10. The infiltration basin is expected to reduce the outflow peak ($R_{peak} < 1$) 96% of the time. A target peak ratio of 0.33 was used, which is simply the ratio of rational method coefficient (c) for undeveloped land ($c = 0.3$) and impervious area ($c = 0.9$) (Davis 2008). The R_{peak} criterion of 0.33 is expected to be met 69% of the time at the infiltration basin site.

3.2.3 Volumetric Performance

3.2.3.1 Runoff Volume Reductions

Of the 120 monitored rainfall events, outflow was produced during 53 events only. The infiltration basin assimilated the entire inflow volume and did not produce any outflow (100% volume reduction) for the remaining 67 events. For the 53 events during which outflow occurred, the outflow volumes were lower than the inflow volumes for 40 events. The reduction in volume ranged between 4 and 82% for these events; the median reduction in runoff volume was 28%.

Outflow volumes exceeding the inflow volumes (2 to 39%) were recorded during 13 rainfall events, four of which were large events (rainfall depth > 1.55 *in*), two were extreme events (Tropical Storm Lee and Hurricane Irene), and the remaining occurred in winter or followed extended wet days (rainfall depth 0.42 – 0.82 *in*). The source of additional volume of water was attributed to the direct flow from the banks of the infiltration basin and direct precipitation input, that can be significant during high rainfall volumes and extended wet periods.

The contribution of direct precipitation input was estimated for the range of rainfall depths recorded at the infiltration basin site. Although the pre-event storage volume varied prior to each event, the direct contribution of rainfall on to the surface of the infiltration basin was estimated assuming the infiltration was half-full, as a conservative estimate. The estimated contribution of direct rainfall input varied from 5,000 *L* (rainfall depth = 0.30 *in*) up to 47,000 *L* (rainfall depth = 2.87 *in*). For the 13 events producing higher outflow volumes (rainfall depths 0.63 to 8.66 *in*), the direct precipitation accounted for 13 to 100% of the observed excess outflow volume. The remaining unaccounted excess volume must be contributed by direct bank flow from area surrounding the infiltration basin.

Statistically, the discharge volumes observed for the 53 events were significantly lower than the inflow volume ($\alpha = 0.01$). The volume decreases observed for all 120 events were also significant at $\alpha = 0.01$, suggesting that the infiltration basin is effective in reducing runoff flow volumes.

The overall volumetric performance of the infiltration basin is shown in Figure 11. The data are differentiated with different colors and symbols based on seasons. A 1:1 line is also plotted in the figure. The plot shows that the small runoff volumes were completely captured within the basin. In Figure 11, flow volumes from eight large storm events are off the chart. Of these eight events, discharge volumes exceeding the inflow volumes were recorded during four events.

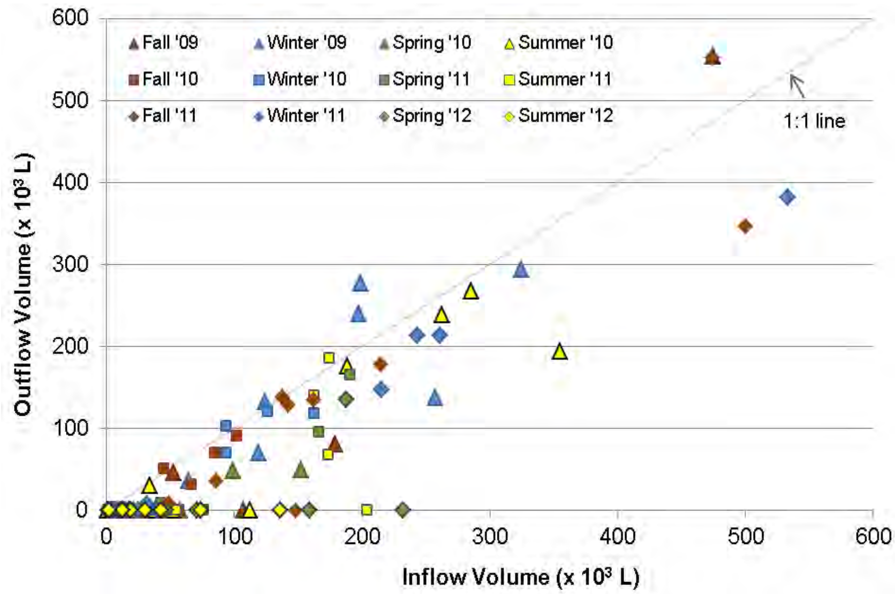


Figure 11. Inflow-outflow characteristics for 112 rainfall events recorded at the MD175 infiltration basin site from August 2009 to August 2012. (Eight large storm events were excluded to clearly show the distribution of the other data points).

In Figure 11, most of the data points lie below the 1:1 line suggesting that reduction in runoff volume was achieved for those events. The percent reductions, however, varied for different events and seasons. For the same inflow runoff volume, the volume reduction achieved in spring and summer was higher than that in late fall or winter. For instance, while 27% volume reduction was observed during a winter storm event (inflow volume = 163,000 L; rainfall depth = 0.77 *in*), 100% volume capture occurred for a similar rainfall event (inflow volume = 159,000 L; rainfall depth = 1.04 *in*) in summer. This can be attributed to the larger volume available for storing the incoming runoff during the warmer months compared to other months. Hence, greater volume reductions were observed in summer compared to other seasons. As noted earlier, discharge volumes greater than that of inflow were recorded when large events and extended wet periods occurred, represented by the points above the 1:1 line.

A probability plot for the inflow and outflow runoff volumes is shown in Figure 12. The probability plot clearly shows that the discharge volume was reduced by the infiltration basin, except for the largest flow volumes. The median discharge volume is zero, which corresponds to a volume reduction of 100% at the infiltration basin site.

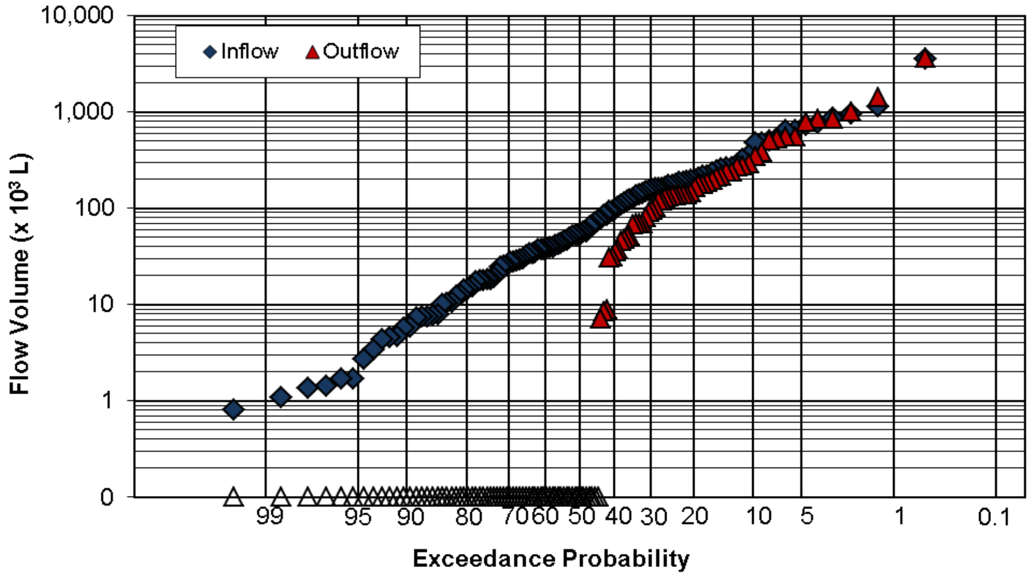


Figure 12. Probability plot for runoff flow volumes recorded during 120 rainfall events at the MD175 infiltration basin site from August 2009 to August 2012. Hollow points represent rainfall events with no discharge (complete capture of inflow).

The total inflow and outflow volumes recorded for 120 storm events were 5,315,820 gallons (20,123 x 10^3 L) and 4,338,955 gallons (16,425 x 10^3 L), respectively. Normalizing the volumes over the entire drainage area, this corresponds to total runoff depth of 27 inches input and 22 inches discharged from the infiltration basin. The cumulative runoff volume reduction was thus 18% for the three-year period.

3.2.3.2 Volume Reduction-Infiltration Basin Design Relationship

The volumetric performance was related to the existing design of the infiltration basin. The design storage capacity of the infiltration basin (S_T) is 171,712 gallons, as indicated in the original construction plans. The storage capacity of the infiltration basin estimated using the water level data is in agreement with this value as well. The ratio of measured inflow runoff volume at the site (V_{IN}) to the total design (S_T) was computed for each monitored storm event and their exceedence probabilities computed. The probability plot for this volume ratio ($\frac{V_{IN}}{S_T}$) is shown in Figure 13. The data are differentiated for storm events with outflow and without measurable outflow.

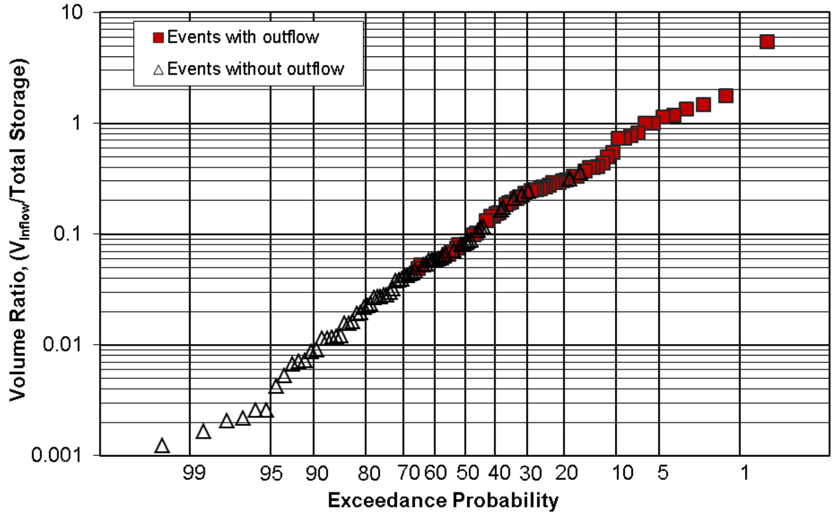


Figure 13. Probability plot for ratio of runoff inflow volume to design storage capacity of the infiltration basin for all rainfall events at the MD175 infiltration basin site. Data points are differentiated for rainfall events with and without outflow.

The probability plot shows that the rainfall events produced runoff volumes greater than the storage capacity of the infiltration basin about 7% of the time. As expected, discharge was produced for these events. Most runoff volumes lesser than 10% of the storage capacity were fully captured within the basin.

Variable performances were observed for volume ratios ranging between 0.25 and 0.09. As will be discussed later, the available storage in the infiltration basin varied during a year, influenced by rainfall characteristics and meteorological parameters. The available storage is likely to be higher in summer due to longer dry periods and higher water losses due to evapotranspiration when compared to cooler periods. This explains the response of the infiltration basin to differing runoff volume inputs during the year. This also explains the reason for a small runoff volume input to produce discharge from the infiltration basin on those occasions when the infiltration basin is already at its near-full capacity prior to the event, irrespective of the season.

3.2.3.3 Rainfall Size-Volume Reduction Relationship

The recorded hydrographs and flow volumes showed the varying volumetric performance of the infiltration basin based on the size of the storm event. Smaller runoff volumes were completely captured and no discharge occurred. Moderate to large rainfall events exhibited partial runoff capture resulting in some volume reduction. The largest events did not show net volume reductions. This relationship between rainfall and volumetric performance of the infiltration basin was examined in detail (Table 6). In Table 6, the number of rainfall events monitored in each rainfall depth-duration category is given. The number of monitored storms that were completely captured is indicated within brackets for each category. The cells have been shaded to show three categories: all storms completely captured, storm categories with a few events completely captured and with measurable discharge; storm categories with measurable discharge observed for all events.

Table 6. The relationship between rainfall depth-duration and volume reduction for the 120 rainfall events recorded at the MD 175 infiltration basin site. In each cell, total number of storms monitored in that category is given. The values within brackets represent the number of events completely captured in that category. Boxes are shaded as: storm categories completely captured (grey); storm categories with a few events completely captured and with outflow (white); storm categories with discharge observed for all events (shaded with dark outline).

	Total Rainfall Depth (*in*)					
Rainfall Duration	**0.01 -0.10**	**0.11-0.25**	**0.26-0.50**	**0.51-1.0**	**> 1.0**	**Sum**
0-2 hr	0 (0)	4 (4)	3 (3)	3 (2)	1 (1)	**11 (10)**
2-3 hr	2 (2)	2 (2)	2 (1)	3 (3)	0 (0)	**9 (8)**
3-4 hr	0 (0)	4 (3)	6 (5)	2 (2)	3 (1)	**14 (10)**
4-6 hr	1 (1)	2 (2)	7 (4)	2 (1)	1 (1)	**13 (9)**
7-12 hr	1 (1)	7 (7)	10 (7)	9 (1)	5 (0)	**31 (15)**
13-24 hr	0 (0)	3 (3)	7 (4)	10 (1)	5 (0)	**25 (8)**
24< hr	0 (0)	0 (0)	1 (1)	3 (2)	11 (2)	**15 (5)**
Sum	**4 (4)**	**22 (21)**	**36 (25)**	**32 (12)**	**26 (5)**	**120 (67)**

Based on Table 6, runoff produced by all smaller rainfall events of rainfall depth < 0.26 *in* of any duration can be expected to be completely captured (100% volume reduction) in the infiltration basin. In Table 6, one rainfall event in the (0.11 – 0.25 *in*) range produced outflow. This event followed three rainfall events (total rainfall depth = 1.21 *in;* antecedent dry period = 0.67 days) and runoff from all three events were fully captured by the infiltration basin. As supported by the water level data, the infiltration basin was at its near-full capacity after these three rainfall events. Hence, outflow was produced from the additional runoff input from the subsequent smaller event (rainfall depth = 0.24 *in* only).

Based on the rainfall data for the entire monitoring duration, events of rainfall depth (0.51 – 1.0 *in*) occur more frequently (68 events out of 120 total storm events). These rainfall events are expected to produce discharge on most occasions. However varying, reduction in runoff volumes (even up to 100%) can be expected to occur for these storm event categories. The large rainfall durations (rainfall depth > 1.0 *in*), which comprise 22% of rainfall events that occurred (26 events out of 120 total storm events), are likely to produce discharge for almost all events. This is supported by the previous volume reduction discussion.

The relationship between rainfall and hydrologic response of the infiltration basin was further investigated using a probability plot for the fraction of runoff volume produced per unit rainfall volume over the drainage area, as shown in Figure 14. The data are differentiated for events with outflow and without measurable outflow. The runoff-rainfall volume ratio ranged between 0.002 and 0.895, the median being 0.155. As expected, the maximum volume ratio was lower than one due to the initial abstraction of runoff from the drainage area during a storm event.

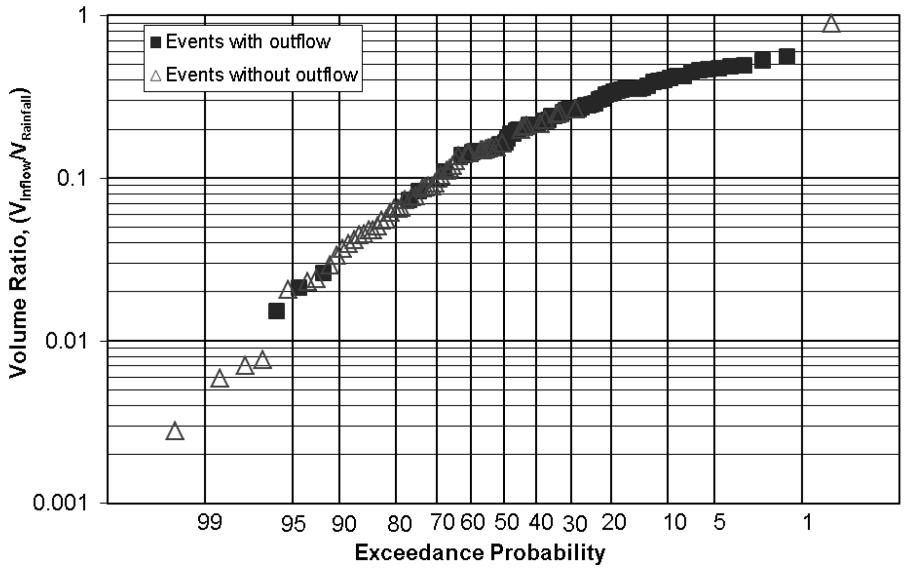


Figure 14. Probability plot for ratio of runoff flow volume to rainfall volume for 120 rainfall events recorded at the MD175 infiltration basin site. Hollow points represent rainfall events with no discharge (complete capture of inflow).

The effect of seasons was observable in the ratios; ratios lower than the median value were characteristic of several small (rainfall depths < 0.26 *in*) and moderate rainfall events (rainfall depth 0.26 – 0.50 *in*) in late spring and summer periods. During these warmer periods, relatively higher proportion of runoff was abstracted compared to cooler months. This was evident in the total runoff volume to the site for the same rainfall depth depending on the season. A large fraction of these rainfall events did not produce discharge from the infiltration basin. Figure 14 shows that a volume ratio of 0.27 and greater is likely to occur around 30% of the time and produce discharge from the infiltration basin. These observations are in agreement with the earlier results from analysis of rainfall and volume reduction characteristics.

The results suggest that the characteristics of the drainage area (percent pervious vis-à-vis impervious) and connectivity of the drainage area to the SCM facility can influence its hydrologic behavior. In the current study, the drainage area consisted of disconnected impervious surface (highway) and grassy area directly connected to the infiltration basin. Runoff from the entire drainage area concentrated into the grassy area and then flowed into the infiltration basin. The initial abstraction volume and the total runoff generated thus depended on the soil moisture conditions of the grassy area, which in turn influenced the hydrologic behavior of the infiltration basin. Different results may be produced for different drainage area characteristics. For instance, if the infiltration basin were to receive runoff only from impervious area, less variation and effect thereof of the inflow volumes would occur.

3.2.4 Water Balance for the Infiltration Basin

The hydrologic performance of the infiltration basin can be explained by its water balance. Figure 15 depicts the components of the hydrological inputs and outputs at the infiltration basin system. Water inputs to the infiltration basin are from runoff (weir flow and bank flow) and direct precipitation on the surface of the basin. Outflow occurs depending on the total volume of runoff received and the available storage in the infiltration basin. Water losses from the basin occur via evapotranspiration; evaporation driven by solar radiation and transpiration from vegetation in the infiltration basin, and by infiltration into the soil underneath.

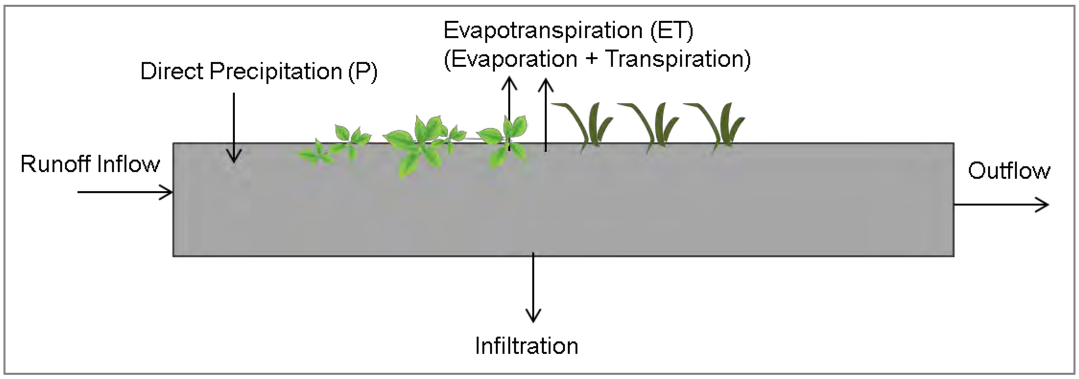


Figure 15. Schematic of water balance in the infiltration basin.

Accounting for all the water flows and losses in the infiltration basin, the water balance for the infiltration basin system (Figure 15) at any time *t* is:

$$\text{Change in storage}_{(t)} = \text{Inflow}_{(t)} + (PA)_{(t)} - \text{Outflow}_{(t)} - ET_{(t)} - \text{Infiltration}_{(t)} \quad (8)$$

where, *A* is the surface area of the infiltration basin.

The varying hydrologic behavior of the infiltration basin during different rainfall events can be explained by the combined influence of factors such as rainfall intensity and duration, antecedent dry period, and season, on the water balance of the infiltration basin. The antecedent dry period and season influenced the volume of runoff to the site. For instance, a few rainfall events, especially in summer (June and July 2010, 2011, and 2012), produced smaller or no runoff flows to the facility owing to long dry periods between the events. Depending on the pre-event storage volume and the input runoff volume, the infiltration basin was capable of reducing the discharge volume. While the entire runoff volume from most small rainfall events (rainfall depth < 0.26 *in*) was thus captured within the infiltration basin, varying volume reductions were observed during other moderate and large rainfall events.

The volume of water detained in the system was also influenced by the effects of evapotranspiration and infiltration from the system. Loss of water by evapotranspiration and infiltration can be important in summer (Lott and Hunt 2001; Braga *et al.* 2007). The existing vegetation also have an effect on the evapotranspiration from the basin (Lott and Hunt 2001). Braga *et al.* (2007) observed higher infiltration rates during warmer periods compared to other seasons in an infiltration trench which they attributed to temperature effects on the viscosity of water.

The water level in the infiltration basin was lowered significantly in summer (average water level in the basin < 1 *ft* only) owing to high air temperatures and scant rainfall. Therefore, the available storage in the infiltration basin was higher, resulting in higher volume reductions during warmer periods. In colder periods, the presence of ice cover changed the hydraulics of the infiltration basin by reducing the available storage. Water losses due to evapotranspiration were also lower during cold periods. These changes caused the infiltration basin to act as a flow-conveyance facility and offer negligible or no reduction of runoff flow volumes.

3.2.4.1 Water Levels and Water Losses at the Infiltration Basin

The water level in the infiltration basin was continuously monitored from April 2010 through August 2012. Data are unavailable for a brief period in June 2010 and June to July 2011 when the water level in the infiltration basin dropped below the probe until the probe was re-installed at a different location within the basin. Also, measurements made during winter periods when the surface of the infiltration basin was frozen were not utilized towards any calculations.

Based on the two-year continuous measurements, the water level in the infiltration basin ranged from ~ 0.59 *ft* (during dry-weather) up to 3.94 *ft* (during storm event). Figure 16 shows the water level recorded at the infiltration basin for Dec 2011. During a storm event, the water level increased due to runoff input and then decreased as outflow from the infiltration basin occurred. After the storm passed and discharge ceased, the water level continued to gradually decrease due to water losses by ET and infiltration from the infiltration basin.

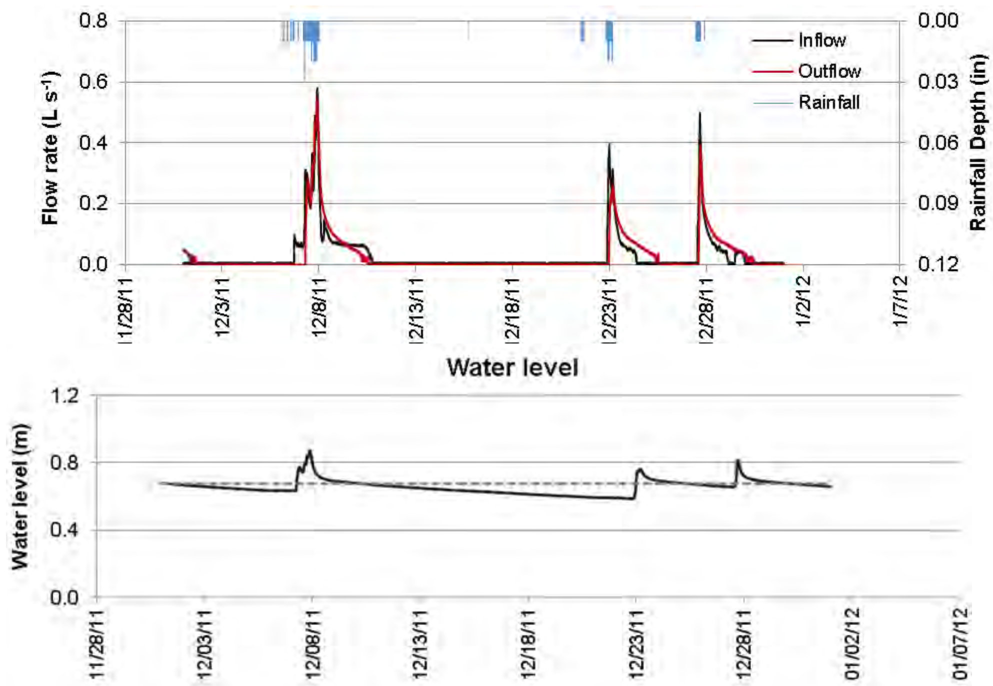


Figure 16. Water level in the infiltration basin in Dec 2011. Dashed line represents the invert of the outlet weir. Top figure shows the rainfall depth, inflow and outflow hydrographs for the month.

The water level data was used to estimate the water loss from the infiltration basin on each day. The daily water loss was calculated as the decrease in water level in 24 hours for a dry day. The water loss was not computed on a wet day if inflow and outflow occurred during a significant part of the day. The water loss was computed on a wet day only if the event occurred very early (midnight to 5 am) or very late (after 9 pm) in the day in some cases.

Figure 17 shows the water loss for April 2012 computed from the water level data collected. The estimated ET from Blaney-Criddle formula is also plotted in Figure 17. The water loss on a wet day has been differentiated from the dry days (darker square markers) in the plot. Figure 17 shows that the calculated daily water losses from the infiltration basin matched well with the estimated ET for the dry days for April 2012.

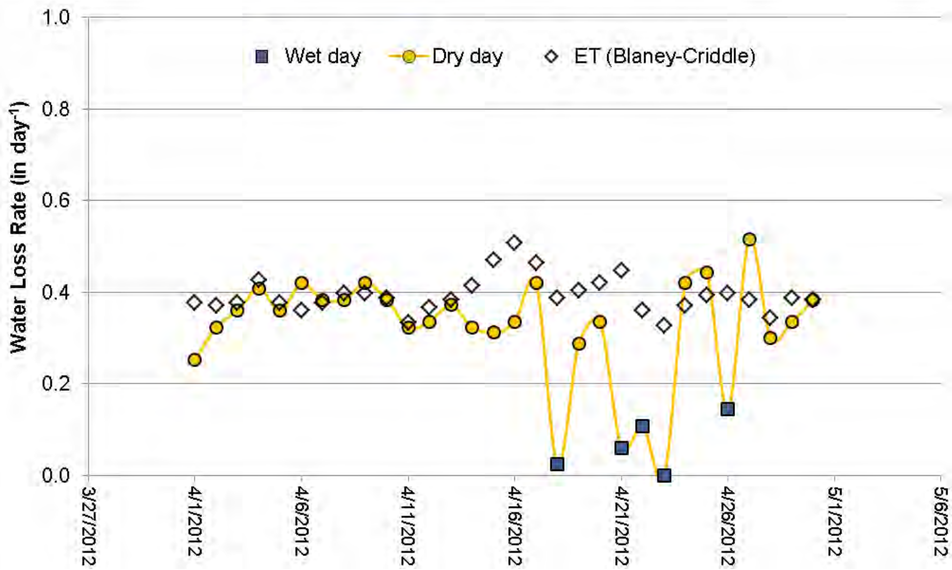


Figure 17. Measured and calculated water loss at the infiltration basin in April 2012. Estimated ET (based on Blaney-Criddle equation) has also been plotted.

The mean daily water loss rate, and monthly water loss and evapotranspiration totals for the dry days from April 2010 through August 2012 are summarized in Table 7. The water loss rate was highest in summer and decreased in the following months. This is expected since evaporation, infiltration, and transpiration rates increase during warmer periods compared to other seasons (Lott and Hunt 2001; Braga *et al.* 2007).

Table 7. Summary of water loss and evapotranspiration estimates at the infiltration basin site from April 2010 through August 2012.

Column (1)	*Column (2)*	*Column (3)*	*Column (4)*	*Column (5)*	*Col (5) /Col (4)*
Month of year	**Number of dry days**	**Mean dry day water loss rate (*in day^{-1}*)**	**Dry day water loss total (*in*)**	**Dry day ET* total (*in*)**	***ET/Water loss***
Apr-10	25	0.45	11.20 ± 0.6583	10.3	0.92
May-10	26	0.50	12.98 ± 0.6847	12.58	0.97
Jun-10	24	n/a	n/a	n/a	n/a
Jul-10	20	0.57	12.13 ± 0.5267	12.43	1.02
Aug-10	19	0.56	10.66 ± 0.5004	10.11	0.95
Sept-10	24	0.40	9.91 ± 0.6320	10.77	1.09
Oct-10	20	0.45	9.06 ± 0.5267	6.86	0.76
Nov-10	24	0.30	7.16 ± 0.6320	5.83	0.81
Dec-10	26	0.30	6.52 ± 0.6847	5.04	0.77
Feb-11	17	0.27	11.86 ± 0.4477	10.41	0.88
Mar-11	22	0.52	10.39 ± 0.5794	6.01	0.58

Apr-11	17	0.44	8.89 ± 0.4477	8.24	0.93
May-11	24	0.52	13.51 ± 0.6320	12.81	0.95
June+ 2011	22	0.48	9.61 ± 0.5794	5.03	0.52
July+ 2011	20	0.50	11.03 ± 0.5267	5.85	0.53
Aug-11	19	0.60	11.36 ± 0.5004	9.91	0.87
Sept-11	18	0.41	7.43 ± 0.4740	7.78	1.05
Oct-11	19	0.39	7.39 ± 0.5004	6.44	0.87
Nov-11	21	0.30	6.24 ± 0.5530	5.59	0.90
Dec-11	22	0.30	6.52 ± 0.5794	5.04	0.77
Jan-12	24	0.29	7.01 ± 0.6320	7.09	0.74
Feb-12	23	0.25	5.75 ± 0.6057	5.88	1.02
Mar-12	25	0.36	8.96 ± 0.6584	8.72	0.97
Apr-12	26	0.35	9.14 ± 0.6847	9.88	1.08
May-12	24	0.44	10.64 ± 0.6320	11.14	1.12
Jun-12	25	0.53	13.13 ± 0.6584	13.93	1.06
Jul-12	27	0.52	15.67 ± 0.7110	16.96	1.08
Aug-12	28	0.48	11.56 ± 0.7373	12.54	1.09
TOTAL			**254.2** ± 3.998	**230.6**	**0.92**

*ET estimated using Blaney-Criddle equation (Equation 8); n/a: no data; +excluding days on which data was unavailable

Table 7 shows that the estimated ET (using Blaney-Criddle equation) predicted 53 to 97% (although sometimes >100%) of the total water loss from the infiltration basin during the dry periods for the monitoring duration. The total estimated ET accounted for 92% of the total water loss from the infiltration basin for the dry periods considering the entire monitoring duration. Based on the reported accuracy of Blaney-Criddle method in literature, the error in predicted ET was assumed as ±20% in the current study. Using this error on the cumulative ET totals, the estimated ET still accounts for at least 73% of the cumulative water loss from the infiltration basin. Hence, it appears that evaporation is the major component of water loss from the infiltration basin and infiltration appears to be negligible.

The infiltration rate of the native soil at the infiltration basin site, as reported in the construction plans, is 0.52 $in\ hr^{-1}$. One foot of sand media was placed in the basin to infiltrate water into the underlying native soil. Assuming that the sand media has a high hydraulic conductivity and offers no resistance to flow through the media, the infiltration rate in the basin can be expected to be the same as that of the native soil (0.52 $in\ hr^{-1}$). Compared to the measured mean water loss of 0.43 $in\ day^{-1}$ over the research period, it can be deduced that the present infiltration rate at the infiltration basin is much lower than the expected original infiltration rate. Hence, it can be concluded that the infiltration is negligible at the infiltration basin, as predicted by the ET and water loss computations.

3.2.5 Flow Durations

The cumulative duration of runoff flows at the study site are illustrated using a flow duration curve. The flow durations show the magnitude of all flows, not just the peak flows, at the infiltration basin site for the entire monitoring duration.

Figure 18 shows the inflow and outflow durations at the infiltration basin for the three-year monitoring duration. Although the two curves show minimal differences overall, the infiltration basin reduced the flow magnitudes as wells as the durations. While the peak inflow was 32 *in day*$^{-1}$, the peak outflow was 26 *in day*$^{-1}$. The total discharge duration about 2.9 days shorter than the total inflow runoff duration, considering the entire three-year period.

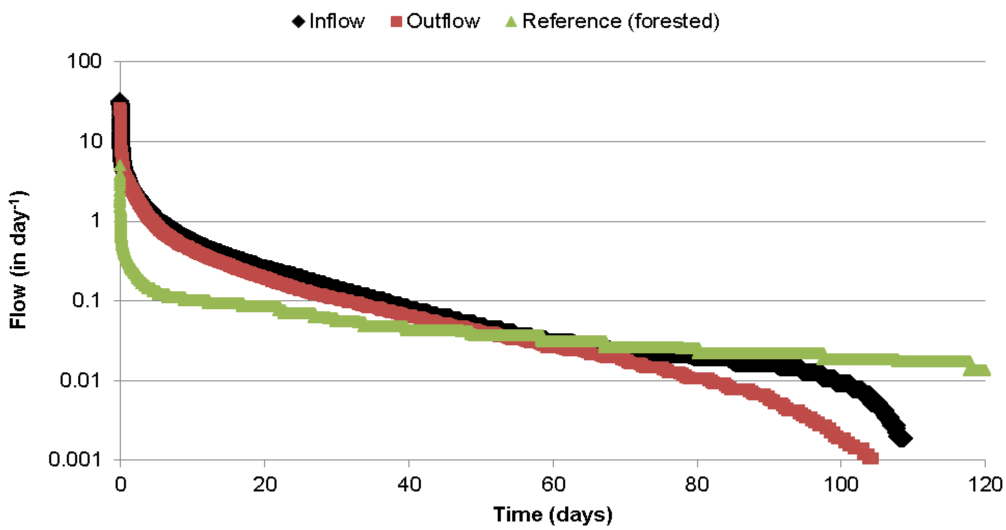


Figure 18. Flow duration curves at the MD 175 infiltration basin site for three-year monitoring duration. The plots also show the flow durations at the Pond Branch forested stream (reference site) only for the duration of flows at the MD 175 site.

The flow durations at Pond Branch, a 100% forested watershed located in Baltimore County, Maryland, was used as the reference in Figure 18. When compared to the forested site, the discharge flow magnitudes at the infiltration basin were higher throughout the three-year period. The discharge peak flow was much higher at the study site (4.8 *in day*$^{-1}$ at Pond Branch compared to 26 *in day*$^{-1}$ discharge at infiltration basin).

Shields *et al.* (2008) designated low- to moderate-flow conditions as < 0.039 *in day*$^{-1}$ (<1 *mm day*$^{-1}$) in their study on nitrogen export from urban and rural catchments and Pond Branch was used as the reference watershed in their study. For the total flow duration of 112 days at the infiltration basin, the discharge magnitudes were at the low-flow values for 61 days. For comparison, the flows at Pond Branch were above the low-flow values for about 49 days during the same period.

3.2.5.1 Seasonal Flow Durations

The flow durations exhibited strong differences when examined on a seasonal basis. Figure 19 illustrates the flow durations observed at the study site along with the reference flow durations for the four seasons. The flow data from the three-year research period were combined on a seasonal basis to derive the flow durations in Figure 19.

First, the inflow and outflow durations at the study site were compared (Figure 19). The magnitudes and durations of flows at the infiltration basin exhibited differences during all seasons. Reduction of peak flows and overall magnitude of flows occurred during all seasons. However, differences in flow magnitudes observed during fall and winter were moderate when compared to spring. Figure 19c shows that during winter, the inflow and outflow magnitudes were similar for most of the period until the flow magnitude fell below 0.0236 $in\ day^{-1}$. This observation was common to the wet periods in both fall and winter. During spring and summer, there were fewer storm events and long intermittent dry periods. Thus the infiltration basin was able to manage the runoff flows by assimilating most of the inflow, resulting in lower outflow magnitudes and much shorter flow duration (Figure 19d).

Occurrence of large and extreme storm events had an impact on the flow duration at the site. Large rainfall events (rainfall depth ~ 1.97 *in*) (Oct 2009, Sept 2010, March and Dec 2011 and Feb, June, and July 2012) and extreme events such as Hurricane Irene (Aug 2011) and Tropical Storm Lee (Sept 2011) were recorded during the monitoring period. Effects of these events are visible in Figure 19a and Figure 19b, which show high inflow and outflow magnitudes and long total flow durations. For instance, no discharge was observed during June and July 2011. The flows observed in summer 2011 were flows generated mostly from Hurricane Irene that occurred in Aug 2011. As discussed in the volumetric performance section, the infiltration basin provided only marginal control of high runoff flows during the largest storm events. Therefore, the largest flows were reduced only to a smaller extent. The infiltration basin, however, reduced the lower-magnitude flows and their durations.

Figure 19a and Figure 19b also show that the duration of outflow was higher than the duration of runoff to the site. Using the criterion of $< 0.039\ in\ day^{-1}$ for low- to moderate flow conditions (Shields *et al.* 2008), outflow magnitudes lower than this value at the infiltration basin site can be considered as low flows in Figure 19. Long duration of low flows is acceptable from a pre-development hydrology perspective, as suggested by DeBusk *et al.* (2011). DeBusk *et al.* (2011) compared the bioretention outflows with inter-event flows in a stream draining an undeveloped watershed located in North Carolina. The study results indicated that the bioretention outflow rates mimicked the shallow interflow to streams after a storm event, thereby suggesting that the low outflow rates from a bioretention need not be considered as 'runoff'. The same argument can be applied to the infiltration basin where low discharge flows are observed, even though the outflow occurs for extended time periods in comparison to the inflow durations.

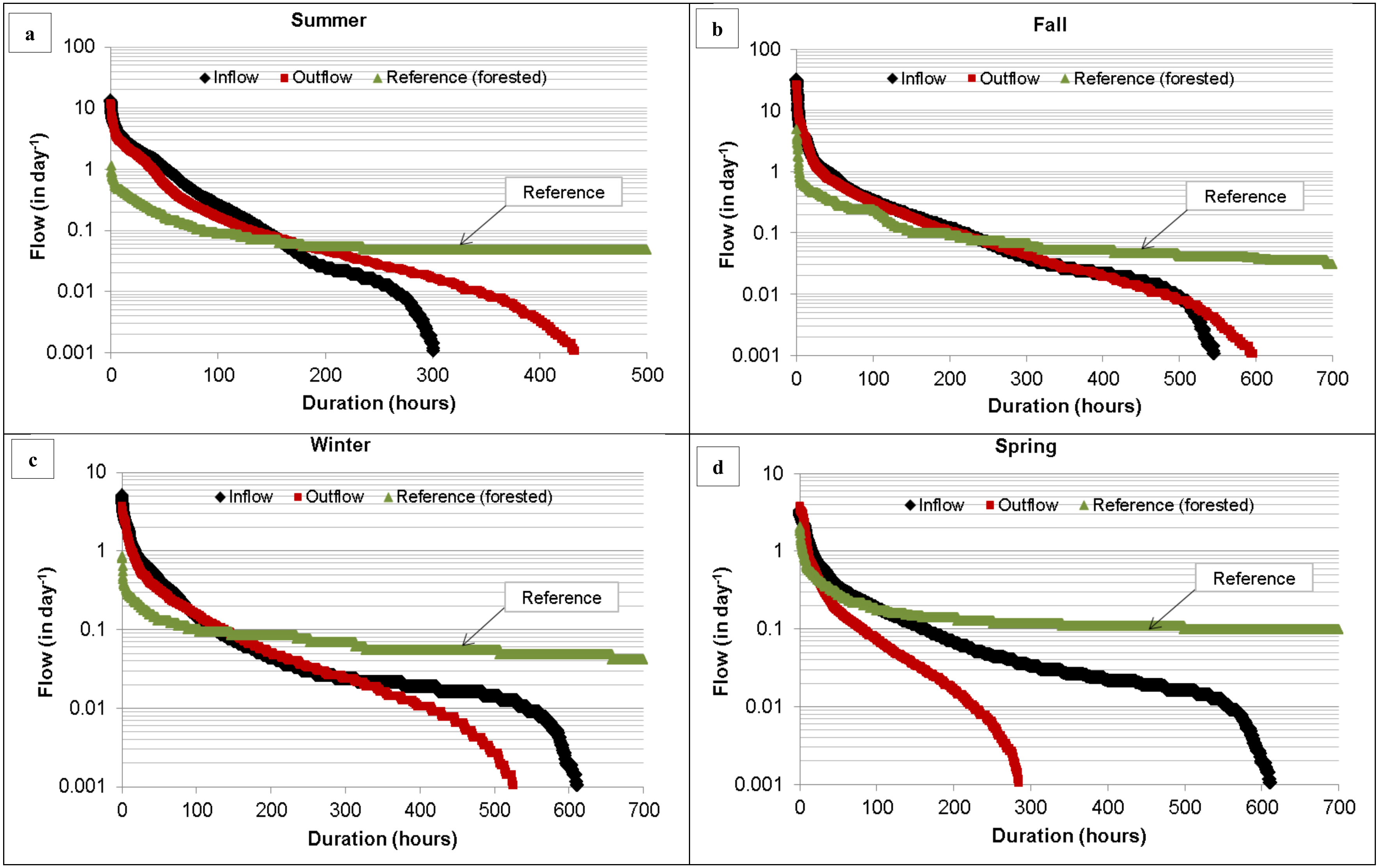


Figure 19. Flow duration curves for **a.** Summer (Jun to Aug) **b.** Fall (Sept to Nov) **c.** Winter (Dec to Feb) and **d.** Spring (Mar to May) at the MD 175 infiltration basin site for 2009 to 2012 period. Flow durations at the Pond Branch forested stream (reference site) are also included.

The infiltration basin outflow durations were compared with Pond Branch flow durations to determine the ability of the infiltration basin to mitigate urban runoff flows to forested (pre-development) conditions. Overall, the infiltration basin peak outflow magnitudes (normalized per drainage area) were much higher than the Pond Branch peak flows during all seasons. Pond Branch flows were at least one order magnitude lower than that of the infiltration basin discharges.

Given the difference in sizes of the drainage areas and absence of baseflow at the study site, the flow duration at Pond Branch was much longer compared to the flow duration at the study site. The forested watershed had an overall effect of dampening flows during storm events and maintained low flows for the most of the period. The streamflow was continuous for about 5914 hours at Pond Branch (PB) compared to 291 hours only for outflow from the infiltration basin in spring, for three years combined. While PB flow magnitudes were below 0.039 $in\ day^{-1}$ for 3324 hours, the infiltration basin outflow magnitudes remained lower than this low flow criterion (0.039 $in\ day^{-1}$) for 149 hours (out of 291 hours total duration) for this period.

Thus, it can be concluded that flow durations in forested streams, although very long, are in low- to moderate- flow condition for majority of the time periods. This is expected for a "natural" hydrologic condition. The infiltration basin was able to attenuate the runoff flows from the highway during storm periods and discharged water at lower rates that extended over a longer period of time. However, the discharge flow magnitudes at the infiltration basin were higher than that of Pond Branch which suggests that the infiltration basin may not be performing well in comparison to a forested site.

3.2.5.2 Flow Durations Based on Rainfall Characteristics

Results from rainfall and volumetric performance data were used to evaluate the flow duration patterns for different rainfall sizes. Smaller rainfall depth events were fully captured in the infiltration basin. In fact, all runoff inflows were detained within the infiltration basin for an entire month in summer (May 2010, June 2010, June 2011, July 2011, April 2012, May 2012, and August 2012). Hence, for smaller runoff flows, the flows are expected to be completely reduced and no discharge would occur.

It was observed that a higher proportion of moderate and all large rainfall events produced discharge from the infiltration basin (Table 6). Peak flow and volume attenuation were observed during most of these events due to some capture of runoff. Hence, smaller discharge magnitudes and shorter discharge durations are expected to be produced for moderate rainfall events.

However, the infiltration basin was unable to manage very high runoff volumes produced during the largest and extreme rainfall events (10 events measuring rainfall depths > 1.89 *in*). The large flows from these events resulted in high outflow magnitudes and durations longer than the inflow to the site. A research study on performance of grass swales by Stagge *et al.* (2012) also observed that the swales offered almost no protection against very high runoff flows. Therefore, it can be concluded that the infiltration basin cannot provide a significant impact during very large and extreme rainfall events which are, however, relatively rare in occurrence (10 out of 188 storms recorded).

3.3 Hydrologic Performance Summary

The effectiveness of a failed infiltration basin in mitigating stormwater runoff flows and volume from a highway area was evaluated over a three-year monitoring period. The runoff inflows and outflows were monitored during 188 rainfall events to quantify the hydrologic performance of the infiltration basin. Hydrographs and metrics such as peak reduction and total volume reduction, flow durations, and their statistical characterizations were used to evaluate the hydrologic performance. The rainfall depth-duration distribution monitored at the study site followed the expected distribution for Maryland.

Overall, the results indicate that the infiltration basin was capable of attenuating the hydrologic impacts of highway stormwater runoff. The infiltration basin attenuated peak flows, delayed outflow, and reduced the discharge volume during most rainfall events (101 out of 120 events). The observed volume reductions varied during different rainfall sizes and seasons. The smallest storm events were completely captured (100% volume reduction), the moderate events were attenuated to varying degree (4 to 100%), and the larger storm events were controlled to the least extent (-32 to 100%). For the same rainfall depth, the volume reductions achieved during warmer periods were higher than at other times.

The cumulative flow magnitudes and their durations at the infiltration basin were evaluated and compared to a forested site. The infiltration basin attenuated the peak flows from the highway and discharged water at lower flow rates. The duration of flows were reduced due to capture of runoff within the infiltration basin. The infiltration basin was more effective in reducing runoff flow magnitudes and minimizing flow durations for smallest and moderate rainfall events compared to the largest events. On a seasonal basis, the flow magnitudes and durations were attenuated more effectively in summer compared to the wetter periods in other seasons. However, the discharge flow magnitudes were higher compared to the forested site suggesting that the infiltration basin was unable to reduce the urban runoff flows to pre-development forested conditions.

Rainfall size, antecedent dry period, and meteorological factors influenced the hydrologic responses of the infiltration basin. Warmer months were characterized by longer dry periods and significant water loss via evapotranspiration and, to a lesser extent, infiltration. During colder periods, the presence of snow and ice cover modified the hydraulics of the infiltration basin and water losses were low. Hence, the infiltration basin provided the least hydrologic benefits during colder months compared to other periods.

Based on the hydrologic analyses, it can be concluded that the failed infiltration basin effectively controls the runoff flows, as it exists. The existing infiltration basin configuration allows for significant reduction of runoff volumes during most storm events, except the largest and extreme events. The occurrence of extreme events is relatively infrequent and hence management of very high flows during these events need not be considered critical. Therefore, the infiltration basin is hydrologically functional from a stormwater management perspective.

Chapter 4: Water Quality Performance of the Infiltration Basin

The second objective of this research study was to quantify the water quality performance of the transitioning infiltration basin. Since several research studies demonstrated the water quality benefits provided by stormwater infiltration basins, wetlands, and wetponds, this research hypothesized that a failed infiltration basin, naturally transforming into a wetland or wetpond, can provide functions of pollutant removal and enhancement of the quality of runoff.

The performance of the infiltration basin in removing total suspended solids (TSS), nitrate, nitrite, total Kjeldahl nitrogen (TKN), total phosphorus, total copper, total lead, total zinc, and chloride from the highway runoff was evaluated over a three-year period.

In total, 38 storm events were monitored and sampled for water quality. For 27 storm events, the sampling program was designed to collect multiple samples spread over the entire hydrograph. Flow-weighted composite samples were collected during the remaining 11 storm events. Also, 54 dry-weather sampling excursions were performed for the entire monitoring duration. Of the 38 storm events sampled for water quality, only 14 events produced measurable outflows. Runoff inflow to the infiltration basin was completely captured within the basin for the remaining 24 events. The pollutant mass removal efficiencies for these 24 storm events were, hence, 100%.

The comprehensive data of event mean concentrations (EMCs) and percent pollutant mass removals for each storm event are presented in Table B-1 in the Appendix B. For the dry-weather samples, average concentration in the collected samples, along with the standard deviation are reported in Table B-1. Water quality data for individual storm event are presented in Table B-2 in the Appendix B. The hydrology data (rainfall depth and flow volumes) for the storm events sampled for water quality are included in Table A-1 in the Appendix A. No hydrology and water quality data are available for winter periods (late Dec 2009 through early Mar 2010; late Dec 2010 until early Feb 2011) when flow measurements were impossible due to snow and/or ice cover on the weirs at the study site. Also, grab samples were not collected when the water in the infiltration basin was frozen during colder periods.

4.1 Characterization of Storm Events Monitored for Water Quality

A detailed analysis on the rainfall depth-duration distribution of the 38 storm events sampled for water quality at the infiltration basin site was conducted and is presented in Table 8. The depth-duration frequencies of all 188 storm events recorded at the study site and the historic distribution for Maryland (Kreeb 2003) are also included in Table 8.

Table 8. Rainfall depth-duration distribution of 38 storm events sampled for water quality at the MD 175 infiltration basin site. Distribution of all 188 storm events recorded at the infiltration basin site and historical data for Maryland (Kreeb 2003) are also included.

	Total Rainfall Depth (*in*)							
Rainfall Duration	**0.01-0.10**	**0.11-0.25**	**0.26-0.50**	**0.51-1.0**	**> 1.0**	**Sum**	**MD 175**	**Historical Data**
0-2 hr	0.0000	0.0000	0.0000	0.0526	0.0263	**0.0789**	**0.1702**	**0.3289**
2-3 hr	0.0263	0.0000	0.0000	0.0263	0.0000	**0.0526**	**0.1064**	**0.0756**
3-4 hr	0.0263	0.0000	0.0526	0.0000	0.0263	**0.1053**	**0.1383**	**0.0627**
4-6 hr	0.0000	0.0000	0.0526	0.0000	0.0000	**0.0526**	**0.1596**	**0.1233**
7-12 hr	0.0000	0.0526	0.0526	0.1316	0.0263	**0.2632**	**0.2234**	**0.1818**
13-24 hr	0.0000	0.0263	0.1316	0.1053	0.1053	**0.3684**	**0.1436**	**0.1617**
24< hr	0.0000	0.0000	0.0000	0.0263	0.0526	**0.0789**	**0.0585**	**0.0659**
Sum	**0.0526**	**0.0789**	**0.2895**	**0.3421**	**0.2368**	**1.000**		
MD 175	**0.1809**	**0.2394**	**0.2872**	**0.1755**	**0.1170**		**1.000**	**1.000**
Historical Data	**0.3287**	**0.1461**	**0.2130**	**0.1747**	**0.1374**		**1.000**	

The proportion of sampled events in the rainfall depth categories (0.01 – 0.10 and 0.11 – 0.25 *in*) were under-represented compared to the overall MD 175 site and historic MD frequencies. Correspondingly, frequencies of rainfall depth categories (0.51 – 1.0 and > 1.0 *in*) sampled for water quality were higher compared to the site data as well as the expected MD data. The frequencies in the duration categories were well representative of both MD175 site and expected distributions.

As discussed in the hydrologic performance chapter, response of the infiltration basin to a storm event with respect to stormwater runoff capture and discharge characteristics, varied during different storm sizes and seasons. Most storm events of very small rainfall depths (< 0.26 *in*) did not produce runoff to the infiltration basin. Therefore, these smaller storm events were less likely to be sampled for water quality, apparent by the under-represented categories in Table 8. Also, it took storm events of greater rainfall depths (> 0.50 *in*) to produce outflow from the infiltration basin, especially during warmer months. Therefore, such larger storm events were more likely to be targeted in order to collect both inflow and discharge samples.

For the 38 storm events sampled for water quality, only 14 events produced outflow from the infiltration basin. This represents 37% storm events with outflow that were sampled for water quality in comparison to 47% of storm events producing outflows from the infiltration basin, based on the overall hydrology data for the MD 175 study site. In Table 8, distribution of these 15 sampled events with outflow is indicated by shaded cells. The overall distribution of storm events that produced outflow from the infiltration basin for the entire monitoring period was presented in Table 6 in the chapter 3 on 'Hydrologic Performance'. From Table 6 it was evident that most of the smaller events (< 0.26 *in*) were fully captured. The likelihood of storm events producing outflows was higher in the 0.51 - 1.0 *in* range and much higher in the > 1.0 *in* category. Therefore, the overall distribution of the water quality events can be considered to be representative of the storm event characteristics recorded at the infiltration basin site.

The water quality results are presented and discussed in two sections: the first section is on TSS, metals, and chloride and the second section is on nutrients phosphorus and nitrogen.

4.2 Water Quality Performance for TSS, Metals, and Chloride

4.2.1 Introduction and Background

Urban storm water runoff contains pollutants like suspended solids, heavy metals copper, lead, and zinc, and chloride. Suspended solids in road runoff originate from pavement wear, vehicles, atmospheric deposition, maintenance activities, and wash off from local soils (Sansalone *et al.* 1998). The expected concentration of total suspended solids (TSS) in highway runoff is 10 – 500 mg L^{-1} (Wu *et al.* 1998). The particle size distribution of solids in highway runoff is of hetero-disperse nature, with particle sizes ranging from 1 μm to greater than 24,500 μm (Kim and Sansalone 2008). High levels of suspended solids in runoff are attributed to coarser fractions (Furumai *et al.* 2002). While suspended solids are pollutants themselves, nutrients and heavy metals can be associated with the particles (Guo 1997; Herngren *et al.* 2005).

Heavy metals such as copper, lead, and zinc are introduced into runoff from vehicles, tires, brake wear, and by atmospheric deposition (Davis *et al.* 2001a). Heavy metal concentrations in runoff are of concern since their bioavailability can impart toxicity (Herngren *et al.* 2005). In general, the metal concentrations in urban runoff are: copper 5 – 200 µg L^{-1}, lead 5 – 200 µg L^{-1}, and zinc 20 – 5000 µg L^{-1} (Davis *et al.* 2001a). The metals can be present in both dissolved and particulate forms in stormwater runoff. A study conducted by Furumai *et al.* (2002) observed higher particle-bound fractions of Zn, Pb, and Cu than their dissolved forms in runoff from a highway in Switzerland. Particle-size distribution studies of highway runoff found that most metals have a greater affinity for smaller particles and hence metal concentrations generally increase with decreasing particle size (Furumai *et al.* 2002; Herngren *et al.* 2005).

Chloride in urban runoff is mainly introduced from the use of deicing salts for road maintenance during winter (Marsalek 2003; Semadeni-Davies 2006). Research by Kaushal *et al.* (2005) showed long-term increase in chloride concentrations in urban streams of the northeastern U.S. due to use of road salts. The streams draining urban and suburban areas contained chloride concentrations 100 times greater than streams draining forested and agricultural watersheds. Peak stream chloride concentration as high as 5 g L^{-1} (25% of sea water concentration) was reported in this research study.

Chloride pollution can have several human and ecological implications including potential threats to availability of freshwater for consumption, degradation of aquatic habitat, and alteration of ecosystem structure in wetlands and detention ponds (Marsalek 2003; Kaushal *et al.* 2005; Semadeni-Davies 2006; Van Meter *et al.* 2011a; Van Meter *et al.* 2011b). For instance, elevated chloride levels (650 mg L^{-1}) can induce changes in the composition of algae and zooplankton grazers, by negatively impacting zooplanktons (Van Meter *et al.* 2011a). Under elevated chloride concentrations in stormwater ponds, metamorphed amphibians such as American toads were favored and detrimental effects on gray tree frogs and wood frogs were observed in a study conducted by Van Meter *et al.* (2011b) in Baltimore, Maryland.

Good removal efficiencies of suspended solids and metals have been reported for infiltration basins, wetponds and wetlands. Birch *et al.* (2005) studied the efficiency of an infiltration basin, located in Sydney (Australia), in removing pollutants from urban stormwater runoff and reported reductions in TSS (50%), and trace metals Cu (68%), Pb (93%) and Zn (52%), respectively. Removal efficiencies of metals in wetponds and wetlands were reported as (80-90%) TSS, (45-65%) Cu, (33%-75%) Pb, and (31-61%) Zn (Wu *et al.* 1996; Carleton *et al.* 2000; Shutes *et al.* 2001; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006). These studies on wetponds and wetlands were conducted in the U.S. (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002), Canada (Brydon *et al.* 2006), Australia (Birch *et al.* 2004), and U.K. (Shutes *et al.* 2001). Chloride retention up to 80% was observed in a stormwater pond during winter periods in Sweden (Semadeni-Davies 2006). The chloride retention was, however, temporary and flushing of chloride was observed in baseflow and subsequent storm events.

Figure 20 illustrates the possible removal mechanisms of suspended solids, metals, and chloride in infiltration facilities, wetponds, and wetlands. The primary removal mechanism of suspended solids in runoff is by sedimentation in detention basins, wetlands, and wetponds (Kadlec and Knight 1996; Wu *et al.* 1996). Removal mechanisms of heavy metals include sedimentation, filtration, chemical precipitation and adsorption, microbial interactions, and uptake by vegetation (Walker and Hurl 2002; Yeh 2008). The chloride ion is extremely mobile and since it is a conservative dissolved parameter, its mobility is based on physical processes such as transport and dilution (Marsalek 2003). Therefore, reduction in chloride can be due to dilution and wash out after input of new water, and release into the ground via infiltration.

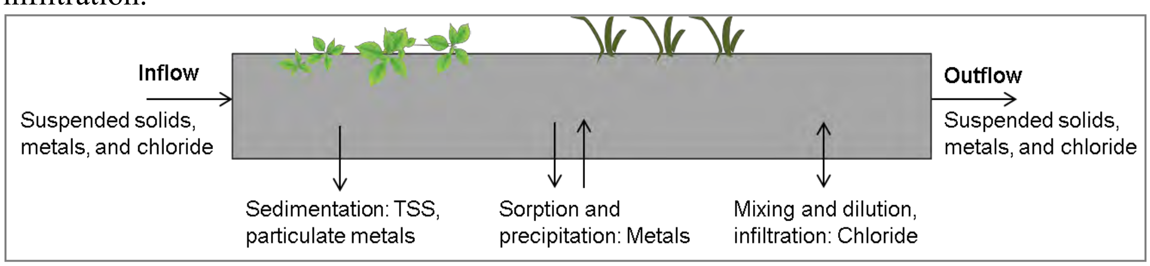


Figure 20. Schematic of expected pollutant (TSS, metals, and chloride) removal mechanisms in stormwater infiltration basins, wetponds, and wetlands.

Factors such as residence time, presence and type of vegetation, and surface area can influence the removal of pollutants in these stormwater treatment systems. Longer residence time provides opportunity for constituents to be acted upon either chemically or biologically (Wadzuk *et al.* 2010). Presence of vegetated regions increases the residence time and promotes sedimentation (Nepf 1999; Serra *et al.* 2004; Wadzuk *et al.* 2010). A study by Wu *et al.* (1996) showed that in wet detention ponds, a surface area ratio (ratio of pond area to drainage area) of 1-2% can provide adequate area for high removal of total suspended solids and other pollutants like metals associated with the solids via sedimentation.

4.2.2 Results and Discussion

The summary statistics (mean, median, and range) of event mean concentrations (EMCs) of TSS, total Cu, Pb, Zn, and chloride for 38 storm events monitored for water quality at the infiltration basin site are shown in Table 9. The water quality criteria (from Table 4 in 'Materials and Methods' chapter) for each pollutant are also included in the table. In Table 9, statistically significant EMCs for the 14 storm events with both inflow and outflow have also been indicated. Table 10 shows the summary statistics (mean, median, and range) of pollutant mass observed during the 38 sampled storm events.

Table 9. Mean, median, and range of pollutant event mean concentrations (EMCs) for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012.

Pollutant	Water quality criteria	n	EMCin			EMCout		
			Mean	Median	Range	Mean	Median	Range
TSS * (mg L^{-1})	25	37	89	49	13 –510	5	NF	NF – 32
Total Copper * (μg L^{-1})	13	38	10	9	(< 2) –26	< 2	NF	NF – 6
Total Lead ** (μg L^{-1})	65	38	5	4	(< 5) – 22	< 5	NF	NF – 7
Total Zinc * (μg L^{-1})	120	37	40	41	(< 25) – 103	< 25	NF	NF – 43
Chloride (μg L^{-1})	250	37	434	52	5 – 6423	57	NF	NF – 702

n = number of events sampled; **NF** = no flow

* a = 0.01; ** a = 0.05 (where, a = level of significance)

Table 10. Mean, median, and range of pollutant mass for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012. Negative values indicate export of pollutant.

Pollutant	n	Mass in (*lb*)			Mass out (*lb*)			Mass removal (%)	
		Mean	Median	Range	Mean	Median	Range	Mean	Range
TSS	37	40	11	0.75 – 600	4.2	NF	NF – 71	95	67 – 100
Total Copper	38	~3.1	~0.15	~0.039 – 29	~0.90	NF	NF – 7.3	86	(-8) – 100
Total Lead	38	~1.5	~0.79	~0.059 – 13	~0.64	NF	NF – 4.2	76	(-62) – 100
Total Zinc	37	~14	~5.3	~0.53 – 108	~6.2	NF	NF – 82	81	(-13) – 100
Chloride	37	51	6.6	0.57 – 344	29	NF	NF – 304	65	(-253) – 100

n = number of events sampled; **NF** = no flow

4.2.2.1 Total Suspended Solids (TSS)

A first flush phenomenon was observed in a majority of the rainfall events where high inflow TSS concentrations were recorded in the beginning of the event. Also, the TSS concentration and the rainfall intensity profiles correlated (Figure 21). The suspended solids concentrations flushed into the infiltration basin increased when the rainfall intensity and runoff flow rates increased. However, no notable flushing trends were observed in the discharge from the infiltration basin; the TSS concentrations were mostly similar in all discharge samples for a storm event.

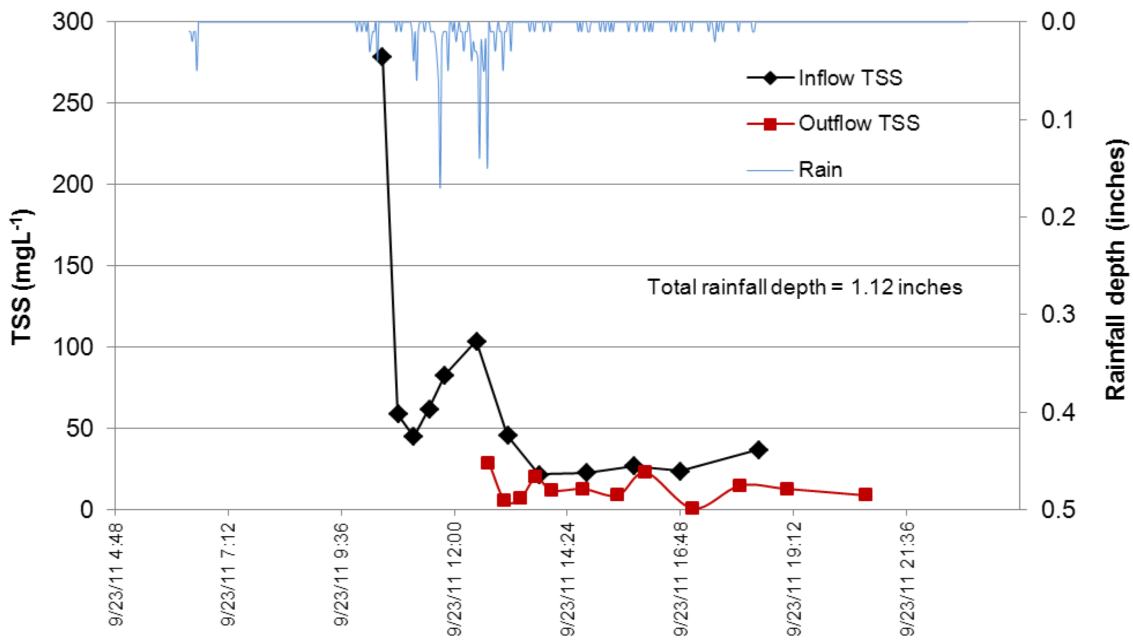


Figure 21. Pollutograph of inflow and outflow total suspended solids (TSS) recorded during the Sept 23, 2011, rainfall event at the infiltration basin.

A typical pollutograph recorded during a storm event on Sept 23, 2011 is depicted in Figure 21. During this rainfall event, the EMC of the inflow was 50 mg L^{-1} and the outflow EMC was 10 mg L^{-1}. Outflow occurred two hours after the onset of inflow and during this period most of the solids in the inflow runoff apparently settled, resulting in a total mass removal efficiency of 82% for this event. Similar observations were made during other storm events, with no particular seasonal patterns associated with TSS loadings and removals during the monitoring period.

The infiltration basin exhibited large removal of TSS from the stormwater runoff, both with respect to event mean concentration (EMC) (Table 9) and total mass (Table 10). The inflow EMCs ranged between 800 and 30 mg L^{-1} (median EMC = 49 mg L^{-1}). The discharge EMCs ranged between 32 and 2 mg L^{-1} (median EMC = 0 mg L^{-1}; no discharge) and were lower than the inflow EMCs for all storm events. The decrease in EMC was statistically significant (level of significance α = 0.01), considering all 38 events as well as for the 14 events with outflow.

High TSS mass reductions ranging between 67 and 100% (median = 100%) were observed for the 38 storm events. These values are comparable to the observed 50 to 90% TSS mass removal efficiencies in infiltration basins, wetponds, and wetlands (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Birch *et al.* 2005, Brydon *et al.* 2006).

The excellent TSS removals are supported by the probability exceedence plot (Figure 22) and pollutant duration plot (Figure 23) for the infiltration basin. The probability plot was developed using TSS EMC data of all sampled storm events. The water quality target level of 25 mg L^{-1} was used for comparison.

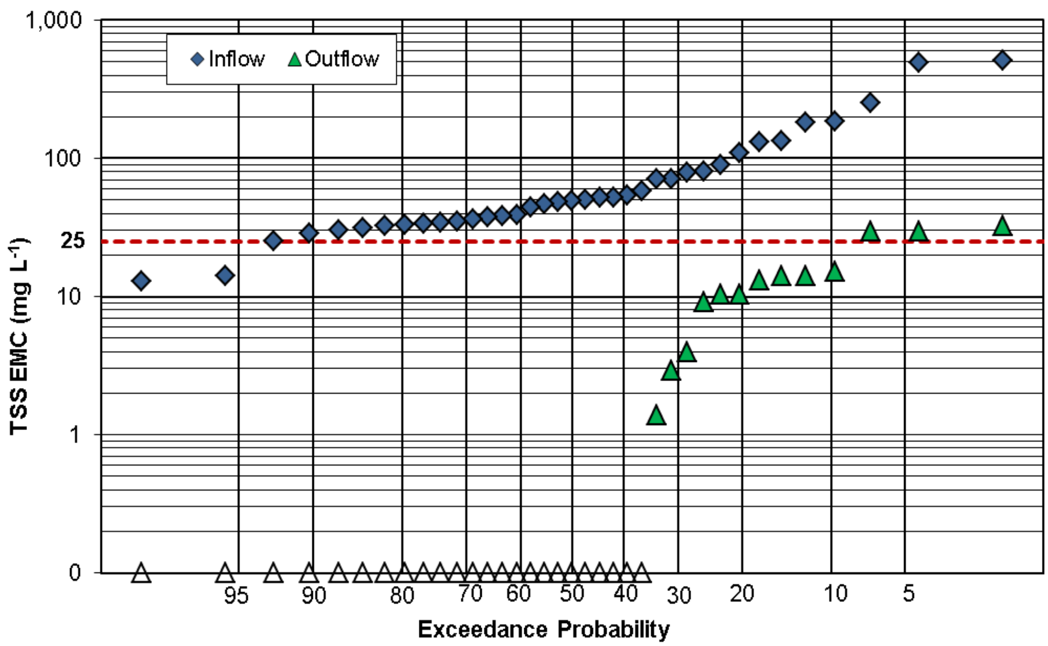


Figure 22. Probability plot for total suspended solids (TSS) EMCs at the infiltration basin. Open symbols represent storm events with no outflow. Dashed line represents the TSS water quality target criterion (25 mg L^{-1}).

Figure 22 shows that the median discharge TSS value is zero mg L^{-1}, resulting from no discharge. The discharge TSS concentrations were consistently lower than the influent for the remaining events as well as the water quality goal. About 90% of the discharge TSS concentrations are expected to meet the target value of 25 mg L^{-1}.

The instantaneous TSS inputs to and discharges from the infiltration basin are illustrated by the TSS pollutant duration in Figure 23. While the highest measured instantaneous inflow TSS concentration was 1771 mg L^{-1}, the peak discharge concentration was 48 mg L^{-1}. Also, the duration of TSS discharged was shorter owing to capture of runoff volume during 63% of the sampled events. The inflow exceeded the water quality criterion of 25 mg L^{-1} for 199 hours compared to 28 hours only for the discharge from the infiltration basin.

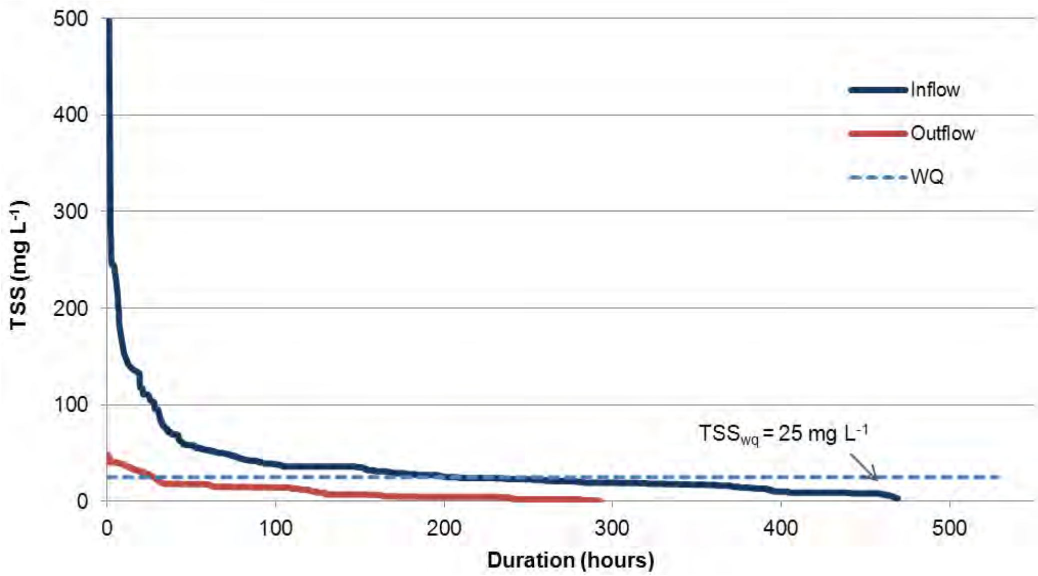


Figure 23. Pollutant duration curve for total suspended solids (TSS) at the infiltration basin for the monitoring duration. Dashed line represents the TSS water quality criterion (25 mg L^{-1}). The y-axis has been truncated at 500 mg L^{-1} in order to show the outflow pollutant duration clearly; the maximum value is 1771 mg L^{-1}.

4.2.2.1.1 TSS Removal Mechanism

Based on the TSS water quality data, it can be deduced that the suspended solids are primarily removed through sedimentation. Several other research studies have identified sedimentation as the primary removal mechanism for solids in infiltration basins, wetponds, and wetlands (Wu *et al.* 1996; Kadlec and Knight 1996; Guo 1997; Reddy and D'Angelo 1997; Comings *et al.* 2000; Mallin *et al.* 2002; Herngren *et al.* 2005). The pollutographs and observed flow delays suggest that detention (and or retention) of runoff enabled the suspended solids to settle within the infiltration basin, resulting in reduced discharge TSS concentrations and high TSS mass removals.

A simple analysis was performed to estimate the theoretical detention time during a storm event. A set of runoff flows consisting of highest, moderate, and low inflows recorded at the site, ranging from 272 to 0.52 $L\ s^{-1}$, was chosen. This corresponds to runoff depths of 0.021 to 34 $mm\ hr^{-1}$ over the total drainage area to the infiltration basin. Given the volume of the infiltration basin (V), these flows (Q) were used to derive a distribution of detention times (t). As examples, the detention times in the infiltration basin were distributed between 347 hours for very small flow rates (0.52 $L\ s^{-1}$), 36 hours for low flow rates (5 $L\ s^{-1}$); 4 hours for moderate flow rates (40 $L\ s^{-1}$), and 0.6 hours for the highest flow rate values (272 $L\ s^{-1}$).

The theoretical detention times were used to compute particle settling velocities as the ratio of depth of the infiltration basin to detention time. These settling velocities were in turn used to estimate the range of particle sizes that are expected to settle in the basin. For the detention times estimated for the different detention times, the settling velocities were: (0.209 x 10^{-4}) $in\ s^{-1}$ for 347 hours detention (very small flow rates); (0.202 x 10^{-3}) $in\ s^{-1}$ for 36 hours detention (low flow rates); (1.61 x 10^{-3}) *in* s^{-1} for 4 hours detention (moderate flow rates); and 0.0109 *in* s^{-1} for 0.6 hours detention (very high flow rate values). The corresponding particle sizes were: 31 μm (silt particle range) for very small flow rates; 96 μm (very fine sand particle range) for low flow rates; 270 μm (medium sand particle range) for moderate flow rates, and 705 μm (medium sand particle range) for the highest flow rate values.

Therefore, particle sizes ranging between medium sand and silt particles (0.5 *mm* to 3.9 μm) can be expected to settle for the flow rates observed at the infiltration basin. The solid particle sizes range from 1 μm to greater than 24,500 μm in highway runoff (Kim and Sansalone 2008). This suggests that the infiltration basin is large enough to provide a detention period that will allow most of the suspended solid particles in typical roadway runoff to be removed via sedimentation during flow periods.

The removal of suspended solids from the runoff by sedimentation is also supported by the TSS levels in the grab samples collected during the inter-storm periods. Based on the data collected, water stored in the infiltration basin for a relatively long dry period (~10 days) contained a TSS concentration between 10 and 20 mg L^{-1} (Table B-1 in Appendix B). As an example, an inflow EMC of 185 mg L^{-1} was recorded during the April 25, 2010 event. Grab samples were taken one day prior to the storm (pre-event) and one week after the storm (post-event). Comparing the pre-event (16 mg L^{-1}), outflow EMC (29 mg L^{-1}), and post-event (9 mg L^{-1}) TSS levels, it can be deduced that some mixing and settling occurred during the event and given enough detention time (one week), the solids settled within the infiltration basin.

In wet detention ponds, a surface area ratio (ratio of pond area to drainage area) of 1 to 2% is expected to provide high mass removal efficiencies of total suspended solids (up to 80%) (Wu *et al.* 1996). In the current study, the surface area of the infiltration basin is about 3% of the total drainage area and high removals of TSS (67 – 100%) were achieved. This suggests that the sizing of the infiltration basin is adequate for achieving high mass removals of suspended solids.

The cumulative TSS mass input to and output from the infiltration basin for the 38 monitored events were 1446 and 157 *lb*, respectively. This corresponds to a TSS mass removal efficiency of 89% for the three-year period. While part of this removal is attributed to 30% volume reduction during the 38 monitored storm events, sedimentation of suspended solids during the storm events contributed to the high removal efficiency.

The long-term effect of sedimentation of solids on the depth of the infiltration basin was assessed. For the three-year research period, the total sediment mass captured was 1289 *lb*, which corresponds to 287 $lb\ ac^{-1}\ yr^{-1}$, normalized by drainage area. Assuming a dry bulk density of 94 $lb\ ft^{-3}$ for the sediment, the infiltration basin would have accumulated approximately 14 ft^3 of sediments. For the bottom surface area of 4844 ft^2, this corresponds to a sediment accretion rate of 0.0449 $in\ yr^{-1}$ in the infiltration basin. Decrease in infiltration abilities of infiltration facilities due to deposition of sediments from urban stormwater runoff have been reported in several studies (Dechesne *et al.* 2005; Emerson *et al.* 2010). The estimated accumulation rate should not impact the depth of the infiltration basin over the course of the study. However, in the long-term, the sediment accumulation in the infiltration basin may have an effect on the structure of the basin.

4.2.2.2 Heavy Metals: Copper, Lead, and Zinc

The levels of total copper, lead, and zinc in the runoff were measured for 38 storm event samples and 54 grab samples collected during dry periods. In general, the heavy metal concentrations were low in the roadway runoff (inflow EMCs of total Cu < 26 μg L^{-1}; total Pb < 22 μg L^{-1}; total Zn < 103 μg L^{-1}). The average metal concentrations in the grab samples were also low (total Cu < 6 μg L^{-1}; total Pb < 7 μg L^{-1}; total Zn < 45 μg L^{-1}).

4.2.2.3 Copper

The EMCs of inflow total copper ranged between (< 2) and 26 μg L^{-1} (median EMC = 9 μg L^{-1}) and that of outflow between (< 2) and 6 μg L^{-1} (median EMC = 0 μg L^{-1}; no discharge). The non-exceedence probability for total copper above the target water quality (13 μg L^{-1}) is thus > 99% (Figure 24). The outflow EMCs were significantly lower than that of the inflow (a = 0.01) for all 38 events as well as for the 14 events with outflow. The total copper mass removals ranged between -8 and 100% (median = 100%) for the 38 sampled storm events (Table 10). The mass export of copper occurred during one winter event (8% for January 2010 event).

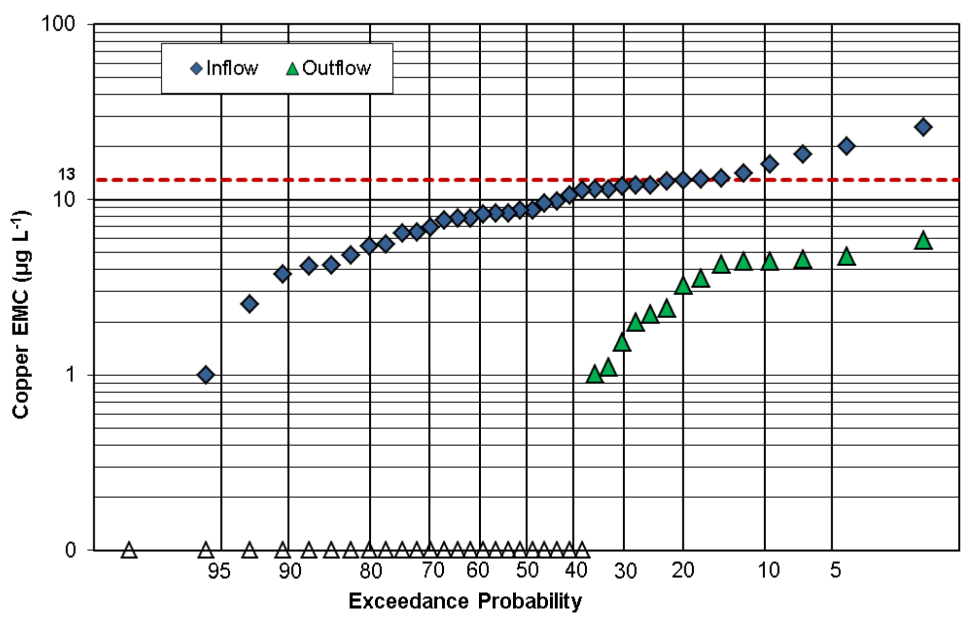


Figure 24. Probability plot for total copper EMCs at the infiltration basin. Open symbols represent storm events with no outflow. Dashed line represents the copper water quality target criterion (13 μg L^{-1}).

4.2.2.4 Lead

Total lead concentrations in the influent runoff were also very low. The inflow EMCs ranged between <5 μg L^{-1} and 22 μg L^{-1} (median EMC < 5 μg L^{-1}) (Table 10). The discharge samples contained Pb levels usually around or below their detection limits (median EMC = 0 μg L^{-1}; no discharge). Although the discharge EMC was higher than that of influent for one storm event, the discharge concentrations were much lower than the 65 μg L^{-1} target for all storm events. The exceedence probability of discharge Pb concentrations above the water quality goal of 65 μg L^{-1} is, thus, < 0.1%. Statistically, the outflow EMCs were significantly lower than the inflow EMCs both from a treatment (14 events; a = 0.05) and performance perspective (38 events; a = 0.01). The total Pb mass removal efficiencies ranged between -28 and 100% (median = 100%) for 38 events (Table 10). Mass export of Pb was observed during three storm events, two of which were during winter (28% on January 2010 and 13% on Dec 2011 events).

4.2.2.5 Zinc

Sample zinc concentrations were above detection limit in influent samples more frequently compared to Pb and Cu. The influent EMCs ranged between < 25 and103 μg L^{-1} (median = 41 μg L^{-1}) (Figure 25). The discharge EMCs ranged between < 25 and 43 μg L^{-1} (median EMC = 0 μg L^{-1}; no discharge). The discharge EMCs were statistically significantly lower than the inflow EMCs (a = 0.01).

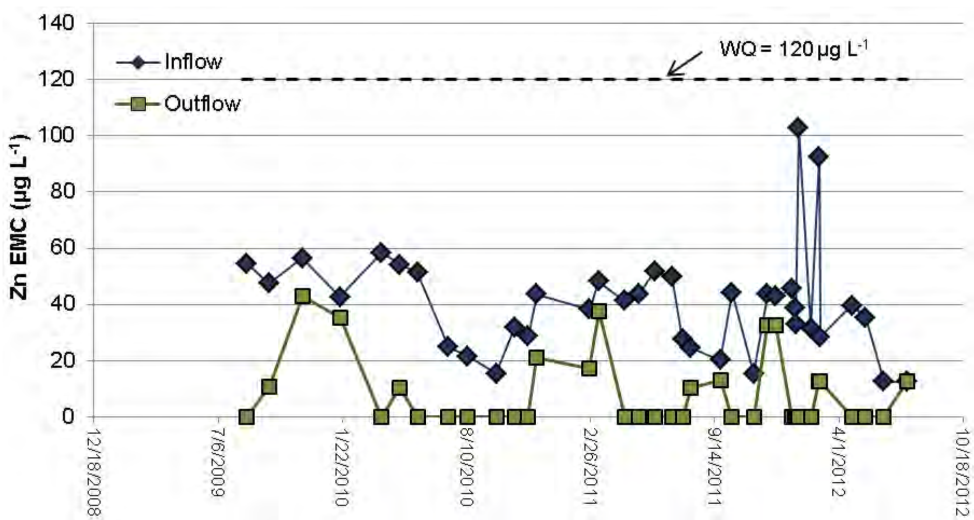


Figure 25. Event mean concentrations of zinc in the inflow and outflow at the infiltration basin during the three-year monitoring period. Open squares denote storm events with no outflow. Dashed line represents the zinc water quality target criterion (120 μg L^{-1}).

Similar to other heavy metals, non-exceedence probability for discharge Zn to be higher than the target water quality level is > 99%. The Zn mass removal efficiencies ranged between (-13) and 100%; the median being 100% (Table 10). The mass export of Zn occurred during two events (13% on January 2010 and 1% on March 2011 events).

Since the concentrations of all three heavy metals were low in the highway runoff for most periods, the instantaneous outflow pollutant concentrations at the study site were also much lower than the water quality goals for all there heavy metals for the entire duration.

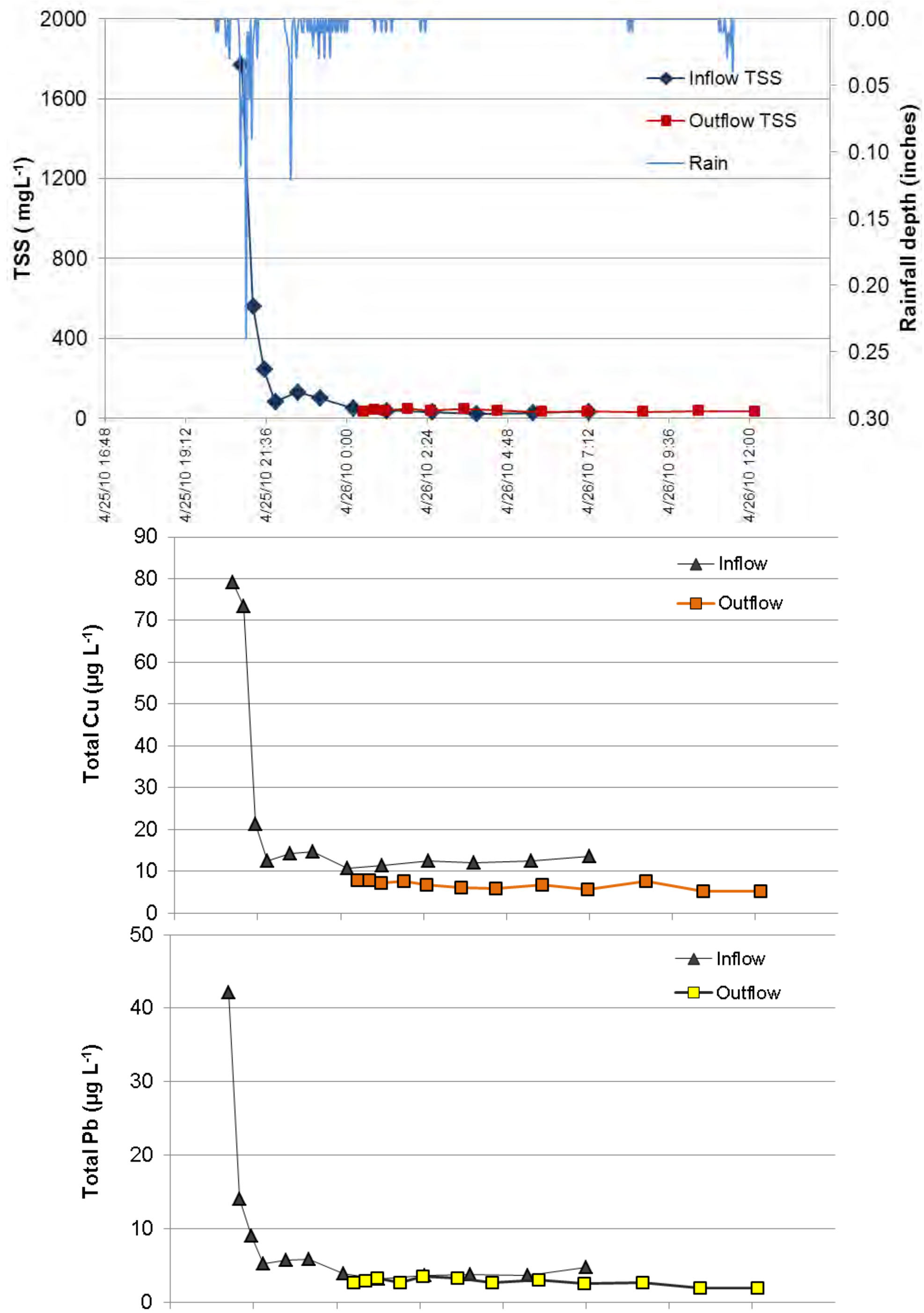
Although no particular trend was associated with heavy metal loading to the infiltration basin, the highest inflow EMCs for all three metals were recorded during a winter storm in 2012. Accumulation of metals in snow and subsequent introduction of high pollutant loads through snowmelt from urban highway have been reported (Sansalone and Glenn 2002; Glenn and Sansalone 2002; Vollertsen *et al.* 2009). The inflow EMC measurements showed mixed levels during the other seasons.

However, a seasonal trend was evident with respect to metal mass removal efficiency. As discussed earlier, two winter storm events showed export of pollutant mass for all three heavy metals. This can be attributed to minimal treatment provided by the infiltration basin during winter periods. The presence of ice-cover on the surface of the infiltration basin modified the hydraulics of the infiltration basin. Also, the ice cover prevented active removal of pollutants through sedimentation or adsorption. Poor performance of stormwater detention ponds during winter compared to other seasons have been reported by other studies as well for the same reasons (German *et al.* 2003; Semadeni-Davies 2006; Vollertsen *et al.* 2009).

The cumulative pollutant mass into and out of the infiltration basin were calculated for the 38 monitored events. For Cu, the mass input was 0.12 *lb* and output was 0.031 *lb*. For Pb, the mass input was 0.059 *lb* and output was 0.022 *lb*. For Zn, the mass input was 0.51 *lb* and output was 0.22 *lb*. This shows that the input pollutant loads were reduced by the infiltration basin for all the metal pollutants. The metal mass removal efficiency for the entire monitoring duration was: 73% total Cu, 63% total Pb, and 55% total Zn. Part of this removal is attributed to 30% runoff volume reduction during the 38 monitored storm events

4.2.2.5.1 Heavy Metals Removal Mechanism

One observation noticeable during several storm events was that the inflow concentration profiles of total copper, lead, and zinc correlated with that of TSS, exhibiting a first flush behavior. As an example, Figure 26 shows the pollutographs of TSS, Cu, Pb, and Zn for the April 26, 2010, storm event. The inflow TSS and metal concentration profiles exhibited a similar trend with high initial concentration (first-flush) and decrease in concentrations afterwards. Similar to outflow TSS, the outflow metal concentrations did not exhibit any first-flush trend and remained more or less uniform throughout the storm event.


TSS (mgL-1)
Rainfall depth (inches)
Inflow TSS
Outflow TSS
Rain
4/25/10 16:48
4/25/10 19:12
4/25/10 21:36
4/26/10 0:00
4/26/10 2:24
4/26/10 4:48
4/26/10 7:12
4/26/10 9:36
4/26/10 12:00
Total Cu (µg L-1)
Inflow
Outflow
Total Pb (µg L-1)
Inflow
Outflow

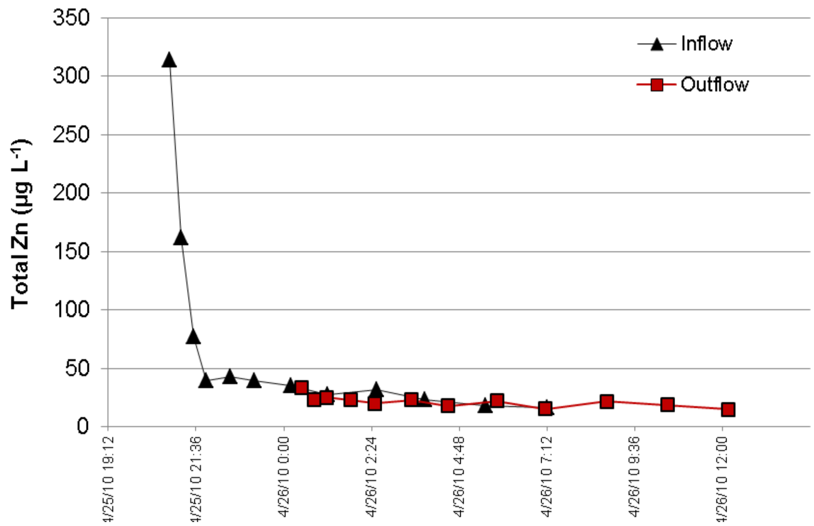


Figure 26. Pollutographs of inflow and outflow total suspended solids (TSS), total copper, lead, and zinc recorded during the April 25, 2010, rainfall event at the infiltration basin.

Based on the observed similarity in the TSS and heavy metals pollutographs (Figure 26), the correlations between TSS and metal concentration trends were examined (Figure 27). The concentrations of TSS and metals measured in the individual water samples collected during each storm event were used to develop the plot. Correlation between pollutant mass load and EMC was not performed. This is because both mass load and EMC quantities involve the volume term in their computation and regression between two quantities involving the same parameter may yield high linear correlation, leading to erroneous conclusions.

In the case of inflow concentrations, the TSS and metal concentrations exhibited very good linear correlations (Pb: 0.59; Cu: 0.60; and Zn: 0.64) (Figure 27). This suggests that a higher fraction of the total metal was in the particulate form in the inflow runoff for all three heavy metals. This is in agreement with research studies by Guo (1997), Pettersson (1998), and Herngren *et al.* (2005), who found that metals were mostly associated with particulates. Also, a study conducted by Furumai *et al.* (2002) observed higher particle-bound fractions of Zn, Pb, and Cu than their dissolved forms in runoff from a highway in Switzerland.

However, the outflow TSS and metal concentrations showed poor linear correlations (Pb: 0.019; Cu: 0.19; and Zn: 0.0005) (Figure 27). As discussed earlier, the total metal concentrations in the outflow samples were often below detection limits for Cu, Pb, and Zn. Also, assuming most of the inflow particulate metals were removed via sedimentation, most of the outflow metals must be in the dissolved form. Thus, no linear trend was detectable between outflow TSS and metal concentrations.

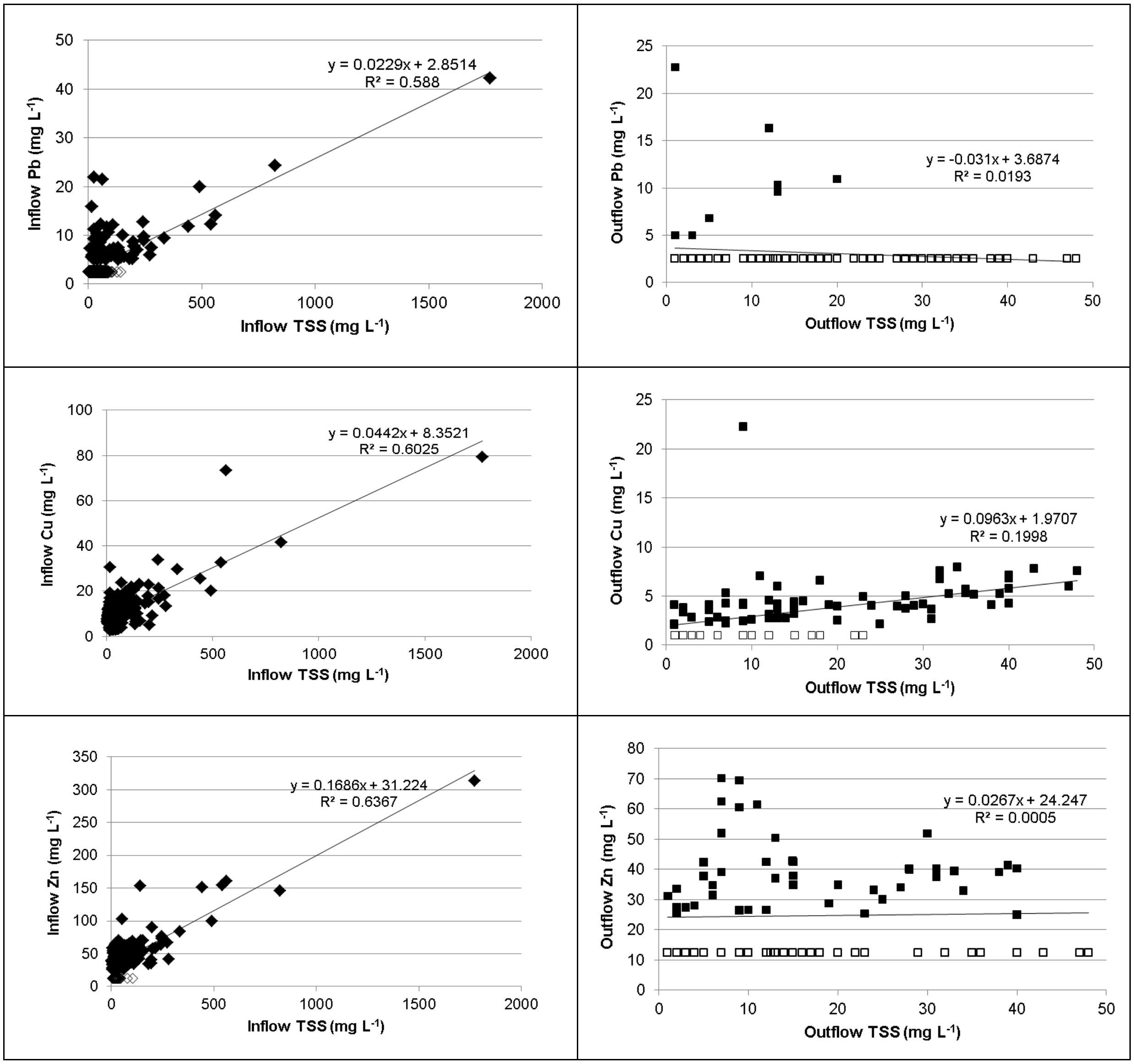


Figure 27. Correlations between TSS and metal concentrations in inflow and outflow for all storm events sampled for water quality at the infiltration basin site. Open symbol represents sample concentration measured below the analytical detection limit and assigned a value of half the detection limit.

Since speciation of metal (particulate vis-à-vis dissolved) was not performed, the fraction of metal associated with particulates in the inflow and outflow could not be quantified. However, based on the inflow and outflow metals concentrations and their respective linear relationship with the TSS concentrations, it can be deduced that the particulate metals in the inflow runoff settle out with solids. The high TSS mass removals (67 – 100%) via sedimentation and high mass removal efficiencies for the three metals during storm events are in support of the hypothesis.

Removal of metals by sedimentation is supported by the low water column concentrations of total Cu, Pb, and Zn in the grab samples (Table B-1 in Appendix B). The average concentration of total Cu ranged between < 2 and 7 µg L^{-1}; total Pb < 5 and 7 µg L^{-1}; and total Zn < 25 and 45 µg L^{-1} in the grab samples, based on54 dry-weather samplings Copper and lead levels were mostly below or around detection limit in the grab samples. Average zinc concentration was above detection in only 10 out of the 54 grab sample sets. Therefore, it can be deduced that the removal of particulate metal species occurred via sedimentation during the inter-event periods. The dissolved metal species could have been removed via adsorption, thereby resulting in overall low water column concentrations for all three metals.

4.2.2.6 Chloride

Chloride concentrations in the roadway runoff exhibited strong seasonal trends during the three-year research period. The highway runoff contained high levels of chloride during winter storm events when application of road salts for deicing was common. Chloride pollutograph and photographs of the ice-covered infiltration basin and the adjoining highway with road salt applied one day prior to the Jan 18, 2010, rainfall event are shown in Figure 28. Stormwater runoff sample contained chloride concentration as high as 2445 mg L^{-1} in this event. The inflow and outflow EMCs were 766 and 631 mg L^{-1}, respectively, for this event. The chloride mass removal efficiency for this event was -18% (mass export).

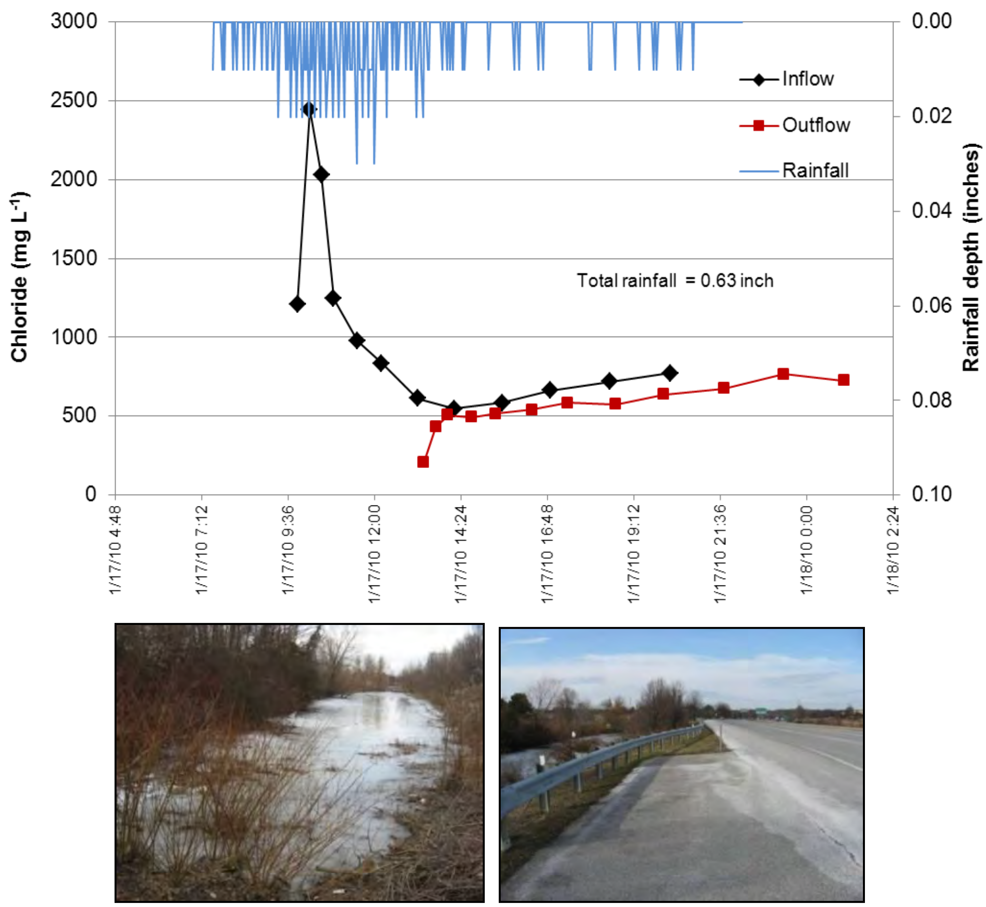


Figure 28. Pollutographs of inflow and outflow chloride during the Jan 17, 2010, rainfall event at the infiltration basin site. Photographs show the ice-covered infiltration basin (left) and the adjoining highway (right), one day prior to the event.

Figure 29 shows the inflow and discharge chloride EMCs observed at the infiltration basin for the entire monitoring duration. The inflow EMCs ranged from 5 to 6423 mg L^{-1} (median = 52 mg L^{-1}). The outflow EMCs varied between 6 and 702 mg L^{-1} (median = 0 mg L^{-1}; no discharge). As seen in Figure 29, the highest inflow EMCs were recorded during winter storm events. The maximum inflow EMC of 6423 mg L^{-1} was observed during the Jan 21, 2012, storm event. Correspondingly, the outflow EMCs were higher in winter and spring compared to other seasons. The inflow chloride EMC levels gradually decreased during the following seasons. In Figure 29, four inflow EMCs greater than 1000 mg L^{-1} are off the chart (1251 mg L^{-1} on Feb 24, 2011, 6423 mg L^{-1} on Jan 21, 2012 , 3126 mg L^{-1} on Jan 23, 2012, and 1326 mg L^{-1} on Feb 16, 2012 storm events).

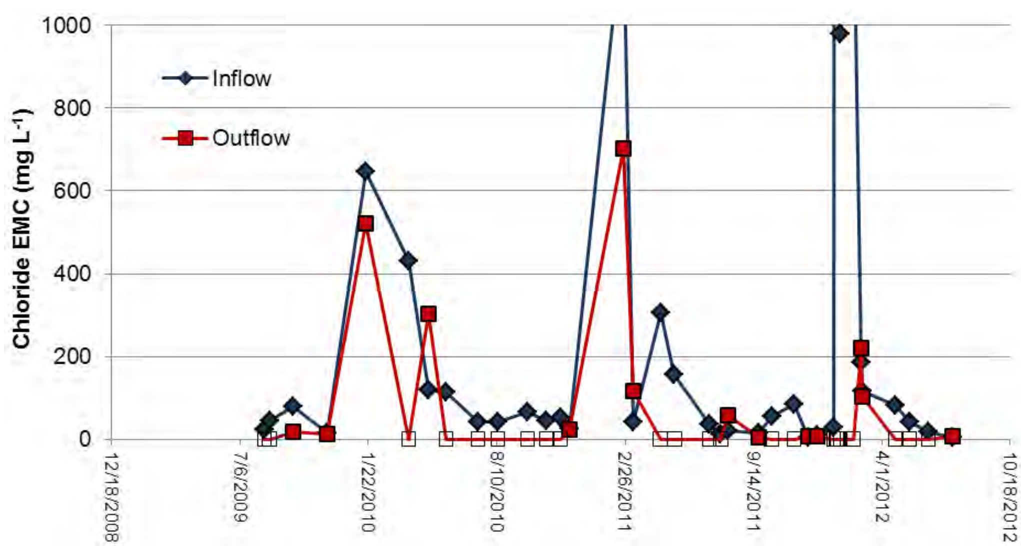


Figure 29. Event mean concentrations of chloride in the inflow and outflow observed at the MD175 infiltration basin site during the monitoring period. Open squares denote storm events with no outflow. In this plot, four inflow EMCs greater than 1000 mg L^{-1} are off the chart (1251 mg L^{-1} on Feb 24, 2011; 6423 mg L^{-1} on Jan 21, 2012; 3126 mg L^{-1} on Jan 23, 2012; and 1326 mg L^{-1} on Feb 16, 2012, storm events).

The large chloride inputs from winter storms resulted in elevated chloride levels in the water stored within the infiltration basin which is supported by the grab samples data (Figure 29). The grab samples collected after winter storm events showed high levels of chloride, ranging between 286 and 825 mg L^{-1} and remained elevated through spring (101 to 408 mg L^{-1}) (Figure 30).

The conductivity values measured within the infiltration basin also fluctuated throughout the year due to chloride input and subsequent wash out (Figure 30). The conductivity values increased from ~30 $\mu S\ cm^{-1}$ in Fall 2011 to up to 1000 $\mu S\ cm^{-1}$ in Feb 2012. The conductivity values remained in the 600 – 300 $\mu S\ cm^{-1}$ range in spring 2012 and decreased ~150 $\mu S\ cm^{-1}$ by end of summer 2012. As a comparison, the conductivity measured in runoff samples collected during winter and spring seasons ranged from 17.6 to 438 $mS\ cm^{-1}$ at two stormwater wet detention ponds treating runoff from a commercial/residential area in Bellevue, Washington (Comings *et al.* 2000).

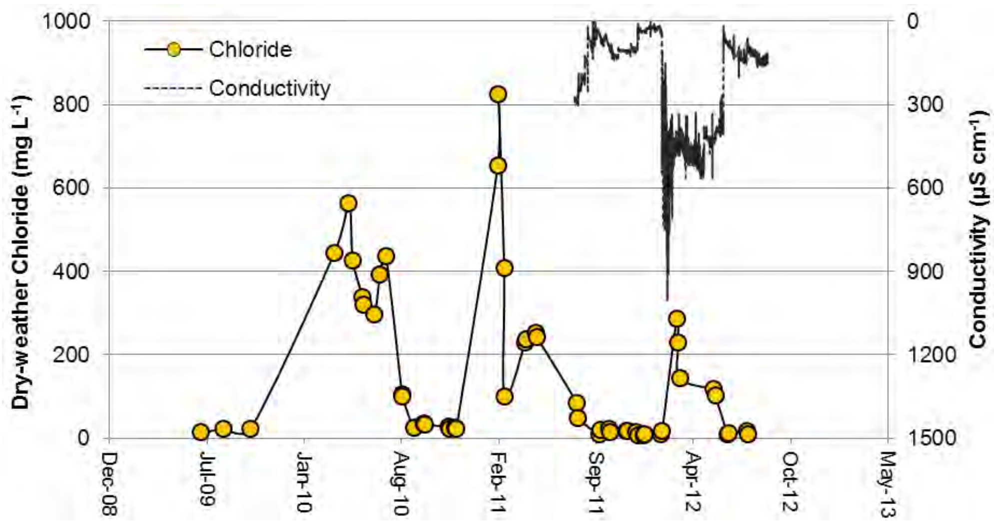


Figure 30. Concentration of chloride in the infiltration basin during dry-weather periods from June 2009 to Aug 2012. Conductivity measured in the infiltration basin during the period Aug 2011 to Aug 2012 is also shown.

As a conservative dissolved pollutant, chloride concentrations are expected to decrease through dilution and wash out during subsequent storm events (Semadeni-Davies 2006). As can be seen in Figure 30, the chloride concentration (and conductivity) in the water stored in the infiltration basin gradually decreased during summer and fall after input of new runoff during subsequent storm events.

As the chloride retained in the infiltration basin was diluted by runoff input and flushed out during subsequent storm events, it sometimes resulted in increased discharge EMC and/or export of chloride mass during storm events in early spring, that immediately followed winter periods. Five storm events in spring recorded discharge EMCs higher than the inflow EMCs (Figure 29) and three of these events showed chloride mass exports (from 10 up to 253%) (Table B-1 in Appendix B). Export of chloride mass (11 to12%) was observed during two other large events (rainfall depth > 1.0 *in*) in summer.

Reductions in influent chloride EMCs and masses were observed during the remaining nine events that had measurable outflow. This reduction in concentration can be attributed largely to dilution. The chloride mass removals ranged between 13 and 100% for these nine events. However, the outflow EMCs were not significantly lower than inflow EMC for the 14 storm events with measured outflow (rejection probability > 95%). The outflow EMCs were statistically lower than the inflow EMCs (α = 0.01) considering the EMCs of all 38 events, where 63% events did not have outflows.

Based on the chloride pollutant duration at the site, the inflow chloride concentrations exceeded the water quality criterion of 250 mg L^{-1} for 130 hours out of 529 hours total inflow duration. The peak discharge concentration (942 mg L^{-1}) was much lower than the inflow (3398 mg L^{-1}). The cumulative discharge duration was 176 hours shorter than the inflow duration. However, the discharge concentrations exceeded the water quality goal for about 124 hours out of the 353 hours of total discharge duration.

The probability exceedence for chloride is shown in Figure 31. The median concentration is zero mg L^{-1} owing to no discharge. The discharge chloride concentrations exceeded the water quality criterion of 250 mg L^{-1} for about 10% of the time.

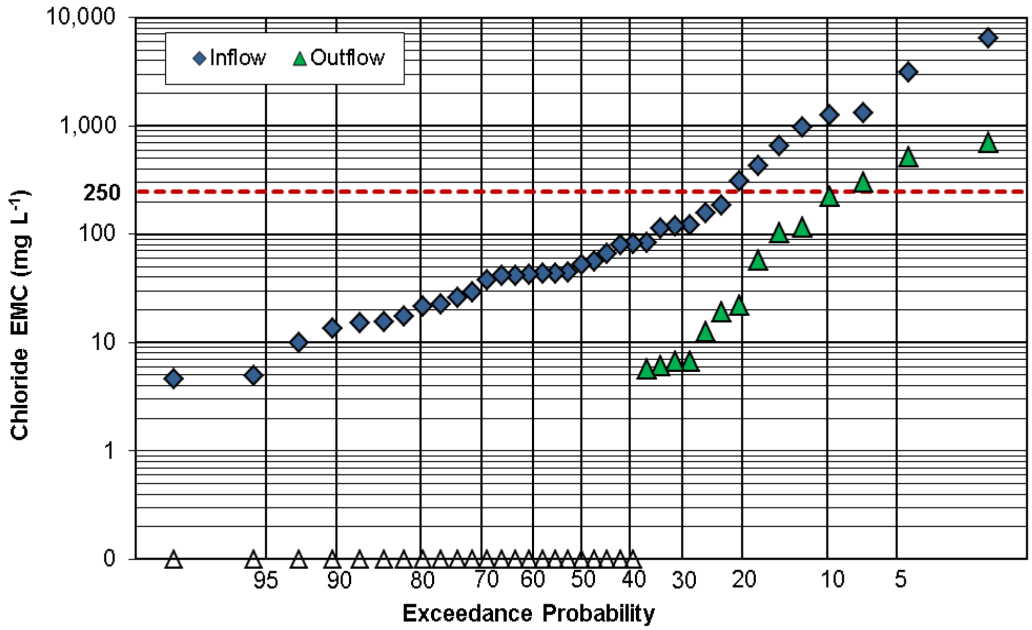


Figure 31. Probability plot for chloride EMCs at the infiltration basin site. Open symbols represent storm events with no outflow. Dashed line represents the chloride water quality target criterion (250 mg L^{-1}).

The observed chloride concentration trend is supported by a research study conducted by Kaushal *et al.* (2005) that showed long-term increase in chloride concentrations in urban and sub-urban streams of the northeastern US, due to the application of deicing salts during winter. Also, the study noted that the chloride concentrations remained elevated through spring, summer, and autumn in urban streams when compared to un-impacted forested streams.

In the current study, although the residence time of chloride was not estimated, flushing out of chloride was observed from winter through summer. As a comparison, Shaw *et al.* (2012) studied the steady, decades-long (1972 to 2003) increase in stream chloride concentration in Fall Creek near Ithaca, New York, due to road salt application. The average residence time of road salt in the watershed was estimated to be approximately 50 years (40 to 70 years considering uncertainty), suggesting that the stream chloride concentrations may not level out for decades. Several research studies have highlighted that high salinity levels caused by road salts can indirectly induce stress and alter the structure of the primary producer and consumer communities in the stormwater ponds, wetland ecosystems, and streams (Marsalek 2003; Kaushal *et al.* 2005; Semadeni-Davies 2006; Van Meter *et al.* 2011a; Van Meter *et al.* 2011b). Chloride concentration of 650 mg L^{-1} caused mortality of zooplankton grazers (copepods) and this concentration was sub-lethal to gray tree frog larvae in a pond mesocosm study conducted by Van Meter *et al.* (2011a) in Baltimore, MD.

In another field study, the relationship between specific conductance levels (99 to 19,320 µS cm^{-1}) and assemblages of zooplankton grazers and algae producers were studied in eight stormwater ponds receiving road salt deicers in Baltimore, MD (Van Meter *et al.* 2011b). The algal biomass and zooplankton community composition changed with salinity, with declining zooplankton grazers and thus increasing algal biomass in high specific conductance waters and the vice-versa in low to medium specific conductance ponds. These research studies suggest that the observed high chloride levels at the infiltration basin may have ecological implications on the invertebrate and amphibian populations in the infiltration basin.

The cumulative chloride mass input and output during the 38 monitored events were 1874 and 1030 *lb*, respectively, which corresponds to a chloride mass removal efficiency of 45% for the entire monitoring duration. The 30% volume reduction achieved during the 38 monitored storm events contributed to this mass removal. Thus, the chloride water quality data suggest that the overall performance of the infiltration basin in reducing chloride levels in the highway runoff was moderate. Since dilution is the only mechanism of decrease in concentration, the runoff capture and volume reduction during storm events influenced the chloride removal efficiencies.

4.2.2.7 Annual Pollutant Mass Loads

Annual pollutant mass load per unit drainage area is an important parameter employed towards design of a SCM in a watershed (Li and Davis 2009). The annual pollutant mass load per unit drainage area (L, in *lb* ac^{-1} yr^{-1}) was estimated using Equation 9:

$$\boldsymbol{L} = \frac{\boldsymbol{M}}{\boldsymbol{A}} \times \frac{\boldsymbol{P_{average}}}{\boldsymbol{P_{observed}}} \qquad (9)$$

In Equation 9, M_{in} is the overall pollutant mass (in *lb*), A is the drainage area of the infiltration basin (in *acres*), $P_{average}$ is the average annual precipitation [42 *in* yr^{-1} for the State of Maryland; MDE 2000], and $P_{observed}$ is the observed cumulative precipitation during the monitoring duration (in *inches*). $P_{observed}$ for the 38 monitored events was 30 *in*. The annual pollutant mass input L_{in} and discharge L_{out} from the infiltration basin were obtained using the input (M_{in}) and output (M_{out}) masses, respectively.

Table 11 shows the annual pollutant mass input and discharge load at the infiltration basin for the entire monitoring period. The difference between annual input and output masses ($L_{in} - L_{out}$) is the effect of the infiltration basin in reducing the annual pollutant loads. Table 11 shows that the annual pollutant mass discharged from the infiltration basin was much lower than the annual pollutant input load for all pollutants. The mass removals were 89% TSS, 73% copper, 63% lead, 55% zinc, and 45% chloride. The infiltration basin was, thus, effective in reducing pollutant mass loads and thus improving the discharge water quality.

Table 11. Annual pollutant mass input and discharge load of TSS, metals, and chloride for 38 storm events recorded at the infiltration basin from August 2009 to August 2012. Annual pollutant mass input and discharge values for a bioretention, as reported by Li and Davis (2009), are also included.

Pollutant	Annual Pollutant Mass Load (*lb ac*$^{-1}$ *yr*$^{-1}$)			
	MD 175 Infiltration Basin		Bioretention[a]	
	Input (L_{in})	Output (L_{out})	Input	Output
TSS	288	31	509	34
Total Lead	0.011	~ 0.004	0.027	0.013
Total Copper	0.023	~ 0.006	0.11	0.040
Total Zinc	0.103	~ 0.046	0.32	0.015
Chloride	365	200	286	22

[a] Li and Davis (2009)

The annual pollutant input loads at the infiltration basin were compared to the values published for a bioretention facility by Li and Davis (2009) (Table 11). The bioretention facility, managing parking lot runoff, is located in Silver Spring, MD, and has a drainage area of 2.2 *acres* (90% impervious). This is in comparison to the 7.2 *acres* (33% impervious) drainage area to the infiltration basin. While the annual TSS and metal loads to the infiltration basin were relatively lower than at the bioretention, the chloride load at the infiltration basin was greater than the bioretention. The difference in pollutant loadings to the two SCMs is attributed to the land use of the contributing drainage areas.

On a performance perspective, the efficacy of the infiltration basin in removing the annual pollutant loads was quite comparable to that of the bioretention facility. The annual mass load removal efficiencies of the bioretention were 93% TSS, 50% copper, 63% lead, 95% zinc, and 92% chloride and this is comparable to the performance data for the infiltration basin: 89% TSS, 73% copper, 63% lead, 55% zinc, and 45% chloride removals.

4.2.3 Performance Summary for TSS, Metals, and Chloride

Performance of the infiltration basin in removing TSS, metals (Cu, Pb, Zn), and chloride from the runoff was evaluated for 38 storm events. Also, grab samples were collected from the infiltration basin during the dry periods before and after a storm event. The water quality data, collected over a three-year period, suggest overall improvements in the runoff water quality during both storm events and dry-weather periods.

The discharge event mean concentrations (EMCs) of TSS and metals (copper, lead, and zinc) were significantly lower ($\alpha = 0.01$) than those of inflow for the 14 storm events which produced outflow and considering all 38 storm events. The discharge EMCs of TSS exceeded the selected water quality criteria during three storm events (90% non-exceedence probability). The discharge EMCs of copper, lead and zinc satisfied the selected water quality criterion for all the events monitored (> 99% non-exceedence probability).

High mass removal efficiencies were observed for TSS and metals. The mean mass removal efficiencies were 95% TSS, 86% copper, 76% lead, and 81% zinc at the infiltration basin. The TSS and metals mass removal efficiencies of the infiltration basin were comparable to other SCMs. Removal efficiencies of 50 – 90% TSS, (45 – 65%) Cu, (33% – 75%) Pb, and (31 – 61%) Zn have been reported for infiltration basins, wetponds, and wetlands by other research studies (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Birch *et al.* 2005; Brydon *et al.* 2006).

Pollutant removal efficiencies for metals were poorest in winter compared to other seasons. Export of pollutant mass was observed for Pb (13 – 28%), Cu (8%), and Zn (1 – 13%) during two winter storm events. This observation is consistent with the poor metal removal performance of stormwater ponds during winter than in summer (German *et al.* 2003; Semadeni-Davies 2006; Vollertsen *et al.* 2009).

While no particular seasonal trends were visible for TSS and metal input loadings to the infiltration basin, chloride concentrations exhibited very strong seasonal patterns. The highest inflow EMCs (up to 6423 mg L^{-1}) were recorded during winter storm events. Correspondingly, the grab samples showed higher chloride levels in winter and spring periods due to the large chloride input. Discharge EMCs (up to 702 mg L^{-1}) recorded during winter and spring storm events were higher than the EMCs for storm events occurring in other seasons.

The high mass loads of chloride washed into the infiltration basin were gradually flushed out during subsequent storm events in spring, sometimes resulting in export of chloride mass (up to 253%) during these events. Reductions in chloride concentrations and masses were observed during the remaining nine storm events, largely due to dilution. However, the discharge EMC was not statistically lower than the inflow EMC for the 14 storm events with outflow, but significant ($\alpha = 0.01$) considering all 38 storm events. The discharge EMCs exceeded the chloride water quality target during 10% of the time.

Based on the wet- and dry-weather TSS water quality data for the infiltration basin, sedimentation was identified as the main removal mechanism. The detention time during a storm event and inter-event periods allowed the suspended solids to be removed via settling.

The good linear correlation between TSS and metal mass loads suggested that most of the metals were attached to particulates. Higher fractions of particle-bound Zn, Pb, and Cu compared to their dissolved forms in highway runoff have been observed in other studies (Furumai *et al.* 2002). The grab samples also contained very low metal concentrations. This explained the observed high mass removals for heavy metals during storm events and dry-periods mainly via sedimentation. In the case of chloride, reduction in EMC observed during storm events and inter-event periods should occur largely by dilution of chloride concentration.

The pollutant removal efficiencies for chloride and metals were poorest in winter compared to other seasons. During colder periods, the surface of the infiltration basin was frozen. The formation of ice cover changed the conditions in the infiltration basin by reducing the available detention volume and deterring sedimentation. Based on the hydrologic performance data for the infiltration basin, the infiltration basin acted as a flow-through facility during colder periods due to the presence of ice-cover. The water losses were also lower (at least 45%) in winter compared to warmer months. Since volumetric reduction is an important consideration for pollutant mass removal, the overall pollutant removal efficiency of the infiltration basin can be expected to be worse during colder periods compared to other seasons

4.3 Water Quality Performance for Nitrogen and Phosphorus

4.3.1 Introduction and Background

Nutrients (nitrogen and phosphorus) are introduced into urban runoff through decomposing organic matter, human and pet wastes, fertilizers, and atmospheric deposition. Urban runoff containing elevated levels of nutrients can enrich and cause hypoxia in the receiving waters. The resulting conditions degrade the water quality and other ecosystem services of the streams (Kaushal *et al.* 2008). In particular, excess nutrients have been identified as the main issue in the decline of the Chesapeake Bay (Boesch *et al.* 2001; Shields *et al.* 2008).

Nitrogen in runoff is speciated into various forms: ammonium, nitrate, nitrite, and organic nitrogen. Taylor *et al.* (2005) characterized the composition of nitrogen in urban stormwater runoff in a study conducted in Australia and found that total dissolved nitrogen is a larger portion (~80%) of total nitrogen (TN) of the runoff. The study also revealed that organic nitrogen is the major (> 50%) and ammonia is the least-abundant (~11%) constituent of TN in stormwater runoff. Phosphorus occurs in both organic and inorganic forms that can be either dissolved or particulate in nature. The typical concentrations of the various nitrogen and phosphorus species in urban stormwater runoff are: nitrate 0.01 – 5 mg L^{-1}; TKN 1 – 50 mg L^{-1}; and total phosphorus 0.5 – 20 mg L^{-1} (Lee *et al.* 2003; Stagge 2006).

Figure 32 illustrates the possible fate and transformations of nutrients in a wetpond or wetland-like environment. The biochemical reactions are governed by the presence of aerobic or anaerobic conditions in the system, which create redox gradients in the soil and water columns. Redox conditions are influenced by hydrological fluctuations, the presence of electron acceptors (O_2, NO_3^- SO_4^{2-}), and transport of oxygen by plants into the root zones (Reddy and D'Angelo 1997). Since nutrients can be associated with suspended solids, removal mechanism of suspended solids is also included in Figure 32.

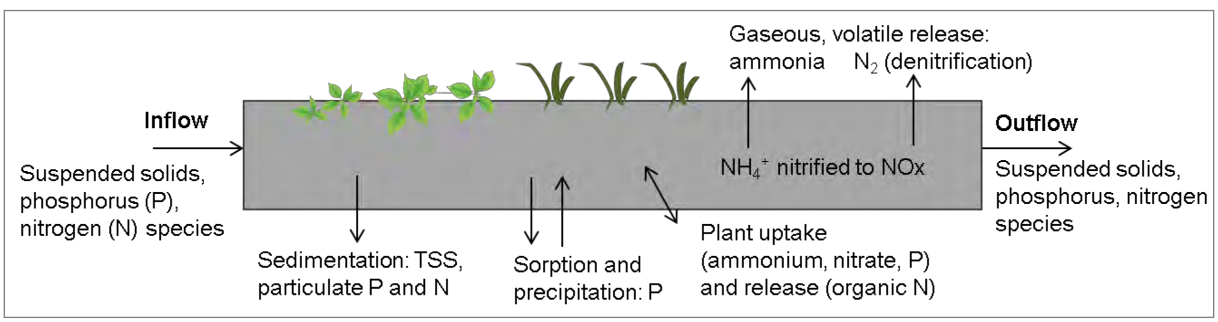


Figure 32. Schematic of possible pollutant (TSS, nitrogen, and phosphorus) removal mechanisms in stormwater infiltration basins, wetponds, and wetlands.

In a wetpond or wetland environment, nitrogen and phosphorus are utilized via complex biogeochemical cycling, which involves many pathways, sinks and sources (Kadlec and Knight 1996). The species are partitioned into particulates, dissolved in water, sorbed, and exist in biomass phases. The nitrogen species transform from organic to inorganic and vice-versa via chemical and biologically-mediated transformations, as shown in Figure 32. Ammonium nitrogen (NH_4^+-N) is transformed into oxidized nitrogen (NO_x) by nitrifying bacteria. Some NH_4^+-N is lost through volatilization. Under saturated conditions, reducing (anoxic) conditions likely develop in the soil and diffusion of the water into the anoxic soil zone favors denitrification to convert NO_x species to N_2 or NH_4^+-N (Reddy and D'Angelo 1997; Galloway *et al.* 2003; Vymazal 2007). Additionally, microbes can take up N for carrying out energy-generating reactions. Plants can assimilate N into their tissues and their senescence can release nitrogen back to the water column (Vymazal 2007; Fennessey *et al.* 2008). Temperature can significantly affect mineralization, nitrification, and denitrification processes (Kadlec and Knight 1996).

Phosphorus is regulated via various abiotic and biotic processes such as sedimentation, adsorption, plant uptake, and microbial reactions. Mineralization of plant litter and soil organic-P can release P into the water. Precipitation and dissolution of the nitrogen and phosphorus species are influenced by factors such as redox potential, temperature of the sediment and water, and pH (Reddy and D'Angelo 1997).

The removal of pollutants in a wetpond, wetland, or detention basin is a function of residence time, which is defined as the mean time spent by a flow parcel in the basin (Walker 1998; Wang *et al.* 2004; Wadzuk *et al.* 2010). Extended residence time provides opportunity for components to be acted upon either biologically or chemically. Presence of vegetated regions can impart a baffle-effect that can increase the residence time and promote sedimentation and other biological reactions (Nepf 1999; Serra *et al.* 2004). Wind and submerged vegetation can also play a role in the mixing of water in free water surface wetland (Kadlec 2003).

Birch *et al.* (2005) studied the efficiency of an infiltration basin, located in Sydney (Australia), in removing pollutants from urban stormwater runoff and reported reduction in total suspended solids (TSS) (50%), total phosphorus (TP) (51%), and total Kjeldahl nitrogen (TKN) (65%). But increased NO_x levels were observed in the outflow due to presence of aerobic conditions in the sand filter of the infiltration basin, facilitating oxidation of organic nitrogen to ammonia and subsequently to nitrate.

Both wetponds and wetlands have been found to be effective in removing pollutants from urban stormwater runoff. Removals in the range of 80 – 90% for TSS, 21 – 50% TKN, 22 – 58% NO_x, 16 – 48% TN, and 19 – 65% TP were reported (Wu *et al.* 1996; Carleton *et al.* 2000; Comings *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006; Vymazal 2007). These research studies were conducted in the U.S. (Wu *et al.* 1996; Comings *et al.* 2000; Carleton *et al.* 2000; Mallin *et al.* 2002), Canada (Brydon *et al.* 2006), and Australia (Birch *et al.* 2004). In the research studies on wetponds, highly variable removal efficiencies were reported for phosphorus, generally <50%, sometimes exhibiting phosphorus export. Also, wetponds performed poorly when removing dissolved constituents, whose removals occur via adsorption to sediments or biological uptake (Comings *et al.* 2000).

The previous research studies on stormwater infiltration basins, wetlands, and wetponds demonstrate abilities of these systems to transform and remove phosphorus and nitrogen species. Thus, it was hypothesized that a 'transforming' infiltration basin with characteristics of wetland or wetpond will provide an environment for pollutants to undergo transformations and thus enhance the quality of the stormwater runoff.

As a second objective of this research, performance of the transitioning infiltration basin in removing nutrients from the roadway runoff was quantified. Concentrations of various nitrogen and phosphorus species in the inflow runoff and discharge were monitored for several storm events and for periods between storm events. The quality of the water discharged from the facility was evaluated based on established water quality goals and various performance metrics. Trends in water quality performances associated with season and rainfall characteristics were also determined.

4.3.2 Results and Discussion

In total, 38 storm events were monitored and sampled for water quality at the infiltration basin from August 2009 to August 2012. The distribution of the storm events sampled for water quality was representative of the overall rainfall distribution at the infiltration basin site. Also, 54 dry-weather samplings were performed during the entire monitoring duration.

All water samples were analyzed for total phosphorus, nitrate, nitrite, and TKN. In some cases, measurements for ammonium and dissolved phosphorus were additionally performed. Mean, median, and range of EMCs and masses of phosphorus (total and dissolved), and nitrogen species (nitrate, nitrite, TKN, and ammonium) for the sampled storm events have been summarized in Table 12 and Table 13, respectively. The water quality criteria (from Table 4 in "Materials and Methods" chapter) for each pollutant are also included in the table. In Table 12, statistically significant EMCs for the 14 storm events with both inflow and outflow have been indicated.

Table 12. Mean, median, and range of pollutant event mean concentrations (EMCs) for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012.

Pollutant	Water quality criteria (mg L^{-1})	n	EMCin (mg L^{-1})			EMCout (mg L^{-1})		
			Mean	Median	Range	Mean	Median	Range
Total phosphorus*	0.05	38	0.31	0.29	0.050 – 0.60	0.046	NF	NF – 0.21
Total dissolved phosphorus *	0.05	15	0.15	0.12	0.039 – 0.45	0.032	0.01	NF – 0.11
Nitrate (as N) *	0.2	32	0.46	0.38	(< 0.10) – 1.2	< 0.10	NF	NF – 0.30
Nitrite (as N) *	1.0	36	~0.016	~0.014	(< 0.01) – 0.042	< 0.01	NF	NF – 0.032
TKN (as N) *	-	37	1.6	1.5	0.96 – 3.2	0.34	NF	NF – 1.2
Ammonium (as N) **	-	9	0.45	0.28	0.05 – 1.2	< 0.14	< 0.14	NF – 0.28
Total N[b]	-	32	2.1	1.9	1.2 – 4.1	0.40	NF	NF – 1.3

n = number of events sampled; **NF** = no flow; *a = 0.01; **a = 0.05 (a = level of significance)
[b]Total N = (Nitrate + Nitrite + TKN)

Table 13. Mean, median, and range of pollutant mass for storm events monitored for water quality at the infiltration basin from August 2009 to August 2012. Negative values indicate export of pollutant.

Pollutant	n	Mass in (*lb*)			Mass out (*lb*)			Mass removal (%)	
		Mean	Median	Range	Mean	Median	Range	Mean	Range
Total phosphorus	38	0.088	0.12	0.002 – 0.057	0.077	NF	NF – 0.39	82	(-16) – 100
Total dissolved phosphorus	15	0.049	0.04	0.002 – 0.17	0.024	0.002	NF – 0.14	76	(-18) –100
Nitrate (as N)	32	0.016	0.062	0.004– 1.6	0.033	NF	NF – 0.39	88	20 – 100
Nitrite (as N)	36	~0.004	~0.002	~($2.2x10^{-3}$) – 0.019	~0.002	NF	NF – 0.019	77	(-25) – 100
TKN (as N)	37	0.46	0.24	0.033 – 2.9	0.22	NF	NF – 1.9	77	(-13) – 100
Ammonium (as N)	9	0.13	0.086	0.033 – 0.42	0.071	0.033	NF – 0.26	63	(-13) – 100
Total N	32	0.62	0.33	0.055 – 3.8	0.22	NF	NF – 2.4	82	6 – 100

n = number of events sampled; **NF** = no flow

4.3.2.1 Phosphorus

The infiltration basin exhibited good removal of phosphorus (Table 12 and Table 12). In the 38 sampled storm events, the total phosphorus (TP) EMC levels in the inflow runoff were between 0.10 and 0.60 mg L^{-1} (median = 0.29 mg L^{-1}). The outflow EMCs ranged between 0.06 and 0.21 mg L^{1} (median = 0 mg L^{-1}; no discharge). Although the outflow EMCs were significantly lower than inflow EMCs during all 14 events ($\alpha = 0.01$), the discharge TP concentrations exceeded the stringent water quality criterion of 0.05 mg L^{-1} during all 15 storm events with outflow.

Figure 33 shows the probability exceedence plot for TP based on EMC data of 38 sampled storm events.

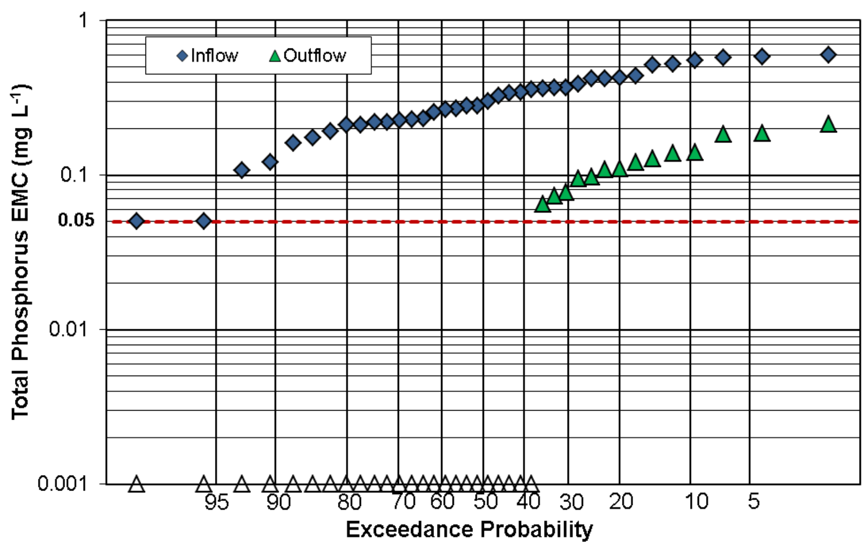


Figure 33. Probability plot for total phosphorus EMCs at the MD175 infiltration basin site. Open symbols represent storm events with no outflow. Dashed line represents the water quality target criterion (0.05 mg L^{-1}).

The inflow TP levels exceeded the water quality target value of 0.05 mg L^{-1} greater than 95% of the time. Although all measured discharge TP EMC values were greater than the water quality goal, the median discharge TP value is zero mg L^{-1} resulting from no discharge. About 40% of the discharge TP EMCs are expected to exceed the stringent target value of 0.05 mg L^{-1}.

Figure 34 shows the duration of instantaneous total phosphorus input and discharge from the infiltration basin. Both inflow and outflow TP levels exceeded the stringent water quality criterion of 0.05 mg L^{-1} during most of the period. While the inflow concentration exceeded the water quality criterion for 466 hours, the discharge exceeded the water quality criterion for 284 hours.

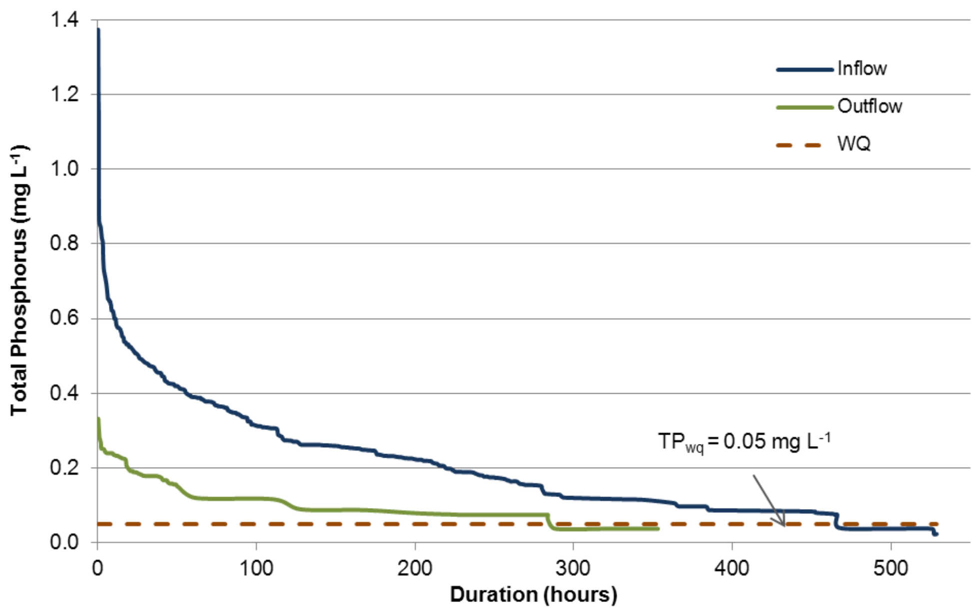


Figure 34. Pollutant duration curve for total phosphorus (TP) at the infiltration basin for the entire monitoring duration. Dashed line represents the water quality criterion (0.05 mg L^{-1}).

Efficiency of the infiltration basin in removing the TP mass varied between (-16) and 100% (median = 100%) during the 38 sampled storm events (Table 12). Phosphorus mass export occurred during a winter storm event (Jan 18, 2010) and a large storm event (rainfall depth = 2.21 *in*) in spring (March 9, 2011). Both these events recorded outflow volumes in excess of the inflow volumes (32 and 39%, respectively). Also, these storm events recorded high outflow EMCs of 0.19 mg L^{-1} and 0.18 mg L^{-1}, respectively.

The cumulative total phosphorus mass input and output for the 38 monitored events were 3.3 and 1.3 *lb*, respectively. This shows that the total input TP mass reduction achieved through the infiltration basin was 61% for the monitoring duration. Since the cumulative volume reduction (31%) was observed for the 38 monitored storm events, a part of the cumulative TP mass removal can be attributed to the water volume reduction.

4.3.2.1.1 Phosphorus Speciation

In order to understand the phosphorus removal mechanism in the infiltration basin, selected samples were analyzed for dissolved phosphorus (DP) in addition to total phosphorus (TP). Particulate phosphorus (PP) levels were determined as the difference between total and dissolved phosphorus levels. A total of 15 storm events were tested for DP, of which eight storm events produced outflow.

Figure 35 shows the particulate (PP) and dissolved phosphorus (DP) pollutographs for the Sept 23, 2011, rainfall event. The inflow and outflow PP EMCs were 0.097 and 0.056 mg L^{-1}, respectively. The inflow and outflow DP EMCs were 0.168 and 0.072 mg L^{-1}, respectively. The PP and DP mass removal efficiencies for this event were 52% and 64%, respectively. For this event, most of the phosphorus in the inflow was in the dissolved form (63% by mass). In the outflow, 56% of total P was in dissolved form.

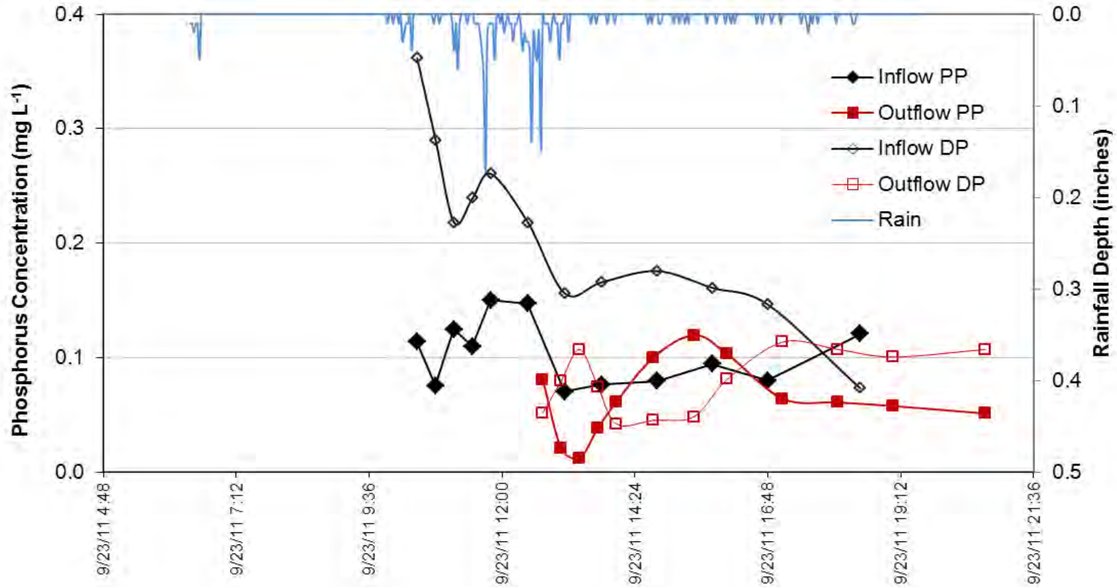


Figure 35. Concentrations of inflow and outflow particulate phosphorus (PP) and dissolved phosphorus (DP) recorded during the Sept 23, 2011 rainfall event.

For the 15 sampled events, the inflow particulate phosphorus (PP) EMCs ranged between 0.067 and 0.33 mg L^{-1} (median = 0.12 mg L^{-1}). This corresponds to 22 to 86% of inflow TP levels (median = 46%). The outflow PP EMCs ranged between 0.040 and 0.103 mg L^{-1}(median = 0.07 mg L^{-1}), which is 41 to 87% of outflow TP levels (median = 46%) for the eight events with outflow data. The discharge PP EMCs were less than the inflow PP EMCs for all eight events. The mass removals of PP ranged between 14 and 100% (median = 77%).

The inflow DP event mean concentrations ranged between 0.039 and 0.45 mg L^{-1} (median = 0.12 mg L^{-1}); which is 14 to 78% of inflow TP levels (median = 54%) for the 15 sampled storm events. The outflow DP EMCs ranged between 0.010 and 0.11 mg L^{-1} (median = 0.01 mg L^{-1}); which corresponds to 13 to 59% of outflow TP levels (median = 54%) for the eight events with outflow data. Although no export of PP mass was observed during any storm event, export of dissolved phosphorus mass (18%) occurred during one winter storm event (Dec 8, 2011). Also, the discharge DP EMC (0.08 mg L^{-1}) was higher than the inflow DP EMC (0.07 mg L^{-1}) for this event. Export of dissolved phosphorus from two wetponds in fall and winter was noted in a study conducted by Comings *et al.* (2000). The DP mass removals in the infiltration basin ranged between 22 to 90% for the remaining seven events. The DP EMCs exceeded the selected water quality criterion of 0.05 mg L^{-1} during five storm events.

While the DP and PP EMCs showed the variability involved in the nature and removal of the phosphorus species loading to the infiltration basin, the analysis of the individual sample concentrations of dissolved and particulate phosphorus in the inflow and outflow samples presented some interesting results. The sample concentrations of inflow dissolved phosphorus ranged between 0.04 – 0.65 mg L^{-1} (median = 0.17 mg L^{-1}) and that of outflow dissolved phosphorus ranged between 0.01 – 0.11 mg L^{-1} (median = 0.08 mg L^{-1}). The inflow particulate phosphorus sample concentrations ranged between 0.05 – 0.59 mg L^{-1} (median = 0.11 mg L^{-1}). The outflow particulate phosphorus sample concentrations ranged between 0.01 – 0.20 mg L^{-1} (median = 0.09 mg L^{-1}). These data suggest that both PP and DP levels in the inflow runoff were variable. However, the variability associated with the outflow DP concentrations was less when compared to the outflow PP levels. Comparison of the storm event DP and PP data with the grab sample data yielded more information on the possible removal mechanism of phosphorus in the infiltration basin.

4.3.2.1.2 Grab Sample Water Quality

Figure 36 shows the average total phosphorus levels in the grab samples collected during the inter-event periods at the infiltration basin. The TP concentrations ranged between 0.06 and 0.45 mg L^{-1}(median = 0.14 mg L^{-1}). Speciation of phosphorus into particulate and dissolved forms was performed for 21 grab sample sets. The particulate phosphorus concentration ranged between 0.01 – 0.19 mg L^{-1} (median = 0.06 mg L^{-1}) and the dissolved phosphorus concentrations ranged between 0.01 – 0.09 mg L^{-1} (median = 0.05 mg L^{-1}) in these 21 sample sets.

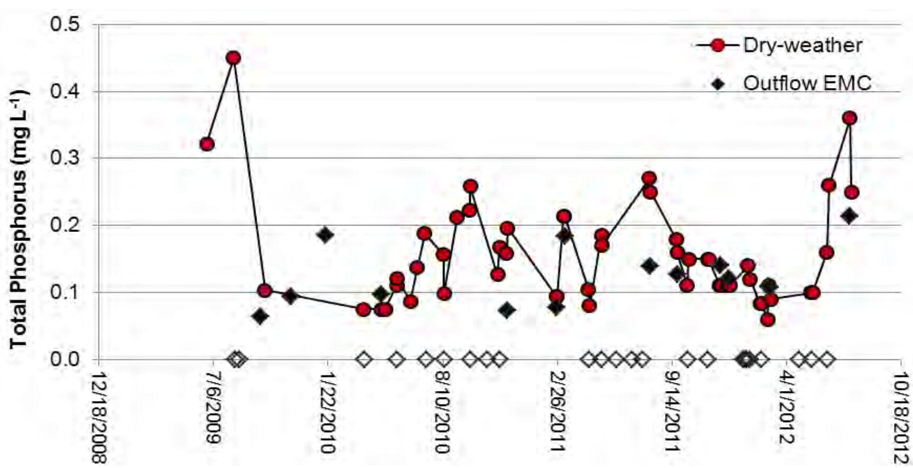


Figure 36. Concentrations of total phosphorus in the dry-weather samples collected at the infiltration basin site from June 2009 to Aug 2012. The outflow EMCs for the storm events are also plotted. Open symbols represent storm events with no outflow.

Interestingly, the grab sample DP levels are similar to the DP concentrations in the outflow samples (0.01 – 0.11 mg L^{-1}; median = 0.08 mg L^{-1}). Based on the concentration ranges, it can be deduced that while the dissolved P levels were more uniform in the grab samples, the particulate P levels in the grab samples were mixed. The more or less uniform DP levels in the stored water suggest that this DP must be recalcitrant or represents a background phosphorus level, as observed in treatment and vegetated wetlands (Kadlec and Knight 1996; Juston and DeBusk 2011).

4.3.2.1.3 Phosphorus Removal Mechanism

Figure 37 shows the inflow pollutographs of TSS and TP during a sample storm event. Similar to TSS, a first flush phenomenon was observed in the inflow runoff and the concentration profiles of the two pollutants matched for the majority of the storm events. The similarity in profiles suggests a strong relation between TSS and phosphorus that could be associated with the suspended solids.

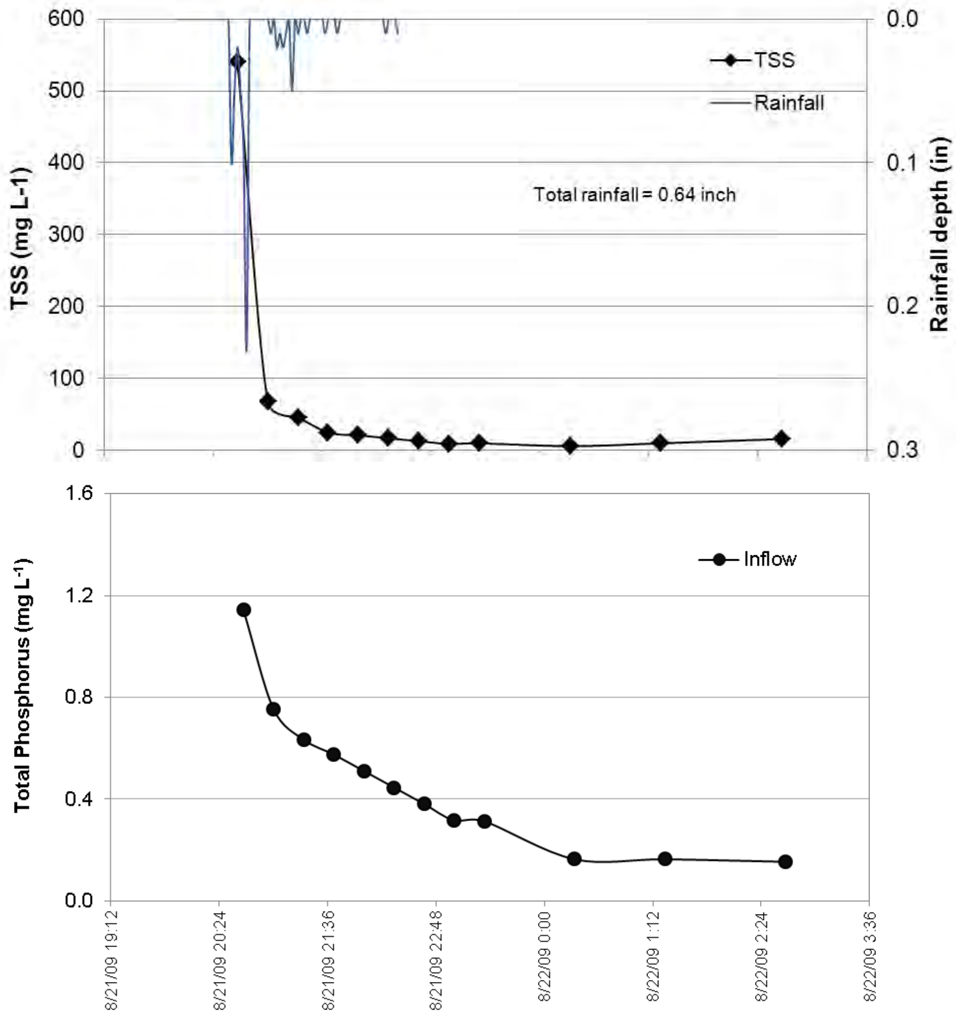


Figure 37. Inflow total suspended solids (TSS) and total phosphorus (TP) concentration profiles recorded during the Aug 21, 2009, rainfall event.

The relationship between TSS and phosphorus constituents was further analyzed by determining the correlation between TSS and particulate phosphorus (PP) concentrations (Figure 38). The individual sample concentrations of TSS and PP measured for all storm events were used in this plot. As expected, a good linear correlation (R^2 = 0.49) between the inflow TSS-PP concentrations was observed. Positive correlations between TSS and phosphorus levels in stormwater runoff have been observed in other research studies (Wu *et* *al.* 1996; Mallin *et al.* 2002). The linear correlation between the outflow TSS and PP was, however, poor (R^2 = 0.098).

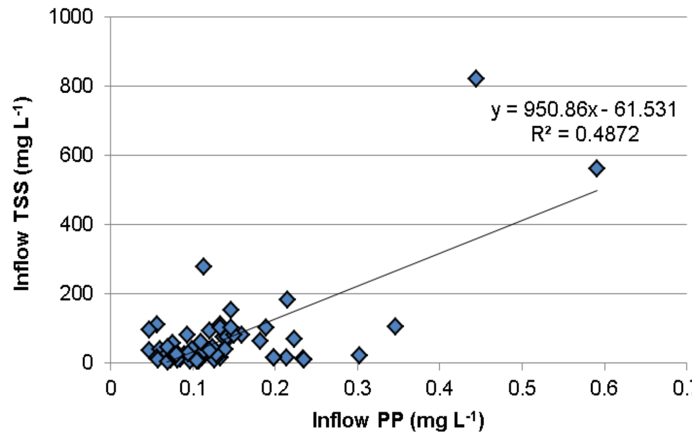


Figure 38. Correlations of TSS and particulate phosphorus concentrations in inflow runoff to the infiltration basin site.

The phosphorus removal mechanisms can be deduced based on the concentration of particulate and dissolved P in the inflow, outflow, and grab samples and the relationship between TSS and PP. The decrease in TP concentration through the infiltration basin can be partly attributed to settling of particulate phosphorus during the course of the storm event. Removal of the TSS by sedimentation during the detention period will contribute to the removal of the any phosphorus associated with the settling solids. Removal of particulate phosphorus by sedimentation has been reported by other studies as well (Wu *et al.* 1996; Reddy and D'Angelo 1997). The dissolved P can be removed via adsorption to sediments or biological uptake or simply by dilution. The similarity in the dissolved P levels in the outflow samples (median = 0.08 mg L^{-1}) and grab samples (median = 0.05 mg L^{-1})suggest that while a portion of the inflow DP could be removed via adsorption/biological uptake during a storm event, a part of the DP in the outflow is the recalcitrant DP flushed out from the infiltration basin.

There is no evidence of internal loading of phosphorus from sediments between storm events since the inter-event grab samples showed small variation in the phosphorus levels. The average total phosphorus level in the 54 grab sample sets was 0.16 ± 0.07 mg L^{-1}. The mean inter-event dissolved phosphorus level was 0.05 ± 0.02 mg L^{-1}. This suggests that the water in the infiltration basin contains a background phosphorus concentration which can consist of both bioavailable and recalcitrant compounds (Kadlec and Knight 1996; Juston and DeBusk 2011).

4.3.2.2 Nitrogen

Nitrogen species nitrate, nitrite, and total Kjeldahl nitrogen (TKN) were analyzed for all water quality samplings. Nine composite sample sets collected were analyzed for ammonium-N in addition to other nitrogen species. Due to equipment failure, nitrate-N data are unavailable for the period February through July 2011. Samples collected during this period were analyzed for nitrite-N and TKN only.

4.3.2.2.1 Nitrite

In general, nitrite-N concentrations were low in the water samples collected during storm events. In the inflow, individual sample concentrations of nitrite-N ranged between (< 0.01) and 0.09 mg L^{-1}. Sample outflow nitrite-N levels were around or below the laboratory detection limit of 0.01 mg L^{-1}. The inflow nitrite-N EMCs ranged between (< 0.01) and 0.042 mg L^{-1}. The discharge nitrite-N EMCs ranged between (< 0.01) and 0.032 mg L^{-1}. The discharge nitrite-N EMCs were always lower than the inflow EMCs during all storm events. The discharge EMCs of nitrite-N were much lower than the water quality criterion of 1 mg L^{-1} in all 15 events that produced outflow. The nitrite mass removals varied between (-25) and 100%, with mass exports occurring during two winter events (Jan 18, 2010, and Dec 8, 2011). The median mass removal efficiency was 100% for 36 sampled storm events.

4.3.2.2.2 Nitrate

EMCs of nitrate-N ranged between (<0.10) and 1.2 mg L^{-1} in the influent (median = 0.38 mg L^{-1}) and between (<0.10) and 0.30 mg L^{-1} in the outflow (median = 0 mg L^{-1}; no discharge) (Table 12). The discharge EMC levels were less than that of influent in all events. The discharge nitrate EMCs exceeded the water quality criterion of 0.20 mg L^{-1} during 3 winter events (Jan 18, 2010, Dec 8, 2011, and Feb 29, 2012). The highest outflow EMC of 0.30 mg L^{-1} NO_x-N was recorded during the Jan 18, 2010 storm event. The nitrate mass removals varied between 20 and 100% (median = 100%) for 32 sampled events (Table 12). Although no net export of nitrogen mass was observed during any storm event, reduced mass removals were observed during winter periods.

The discharge NO_x (nitrate + nitrite) EMCs were lower than that of inflow in all 32 sampled events. The statistics tests showed that the outflow NO_x EMCs were significantly lower than the inflow EMCs both from an overall performance (32 storm events) and treatment (14 storm events) perspectives ($\alpha = 0.01$).

4.3.2.2.3 TKN

The inflow TKN EMCs ranged between 0.96 and 3.2 mg L^{-1} and the outflow EMC levels were between 0.43 and 1 mg L^{-1} (Table 12). The TKN outflow EMCs were lower than the inflow EMCs during 36 storm events, the exception being one winter event (Feb 24, 2011). Based on all 14 sampled events with outflow, the outflow EMC values were significantly lower than inflow EMCs ($\alpha = 0.01$).

As noted for nitrate and nitrite, the worst removal of TKN was observed during the winter rainfall events (Jan 18, 2010, Feb 24, 2011, and Dec 8, 2011) and during a large storm event (rainfall depth = 2.21 *in*) on March 9, 2011. During these events, export of TKN mass was observed (13 to 0.37%). Excluding these four storm events, the TKN mass removal efficiencies ranged between 5 and 100% (Table 12).

The pollutant duration curves for TKN and NO_x-N species are shown in Figure 39. With respect to the water quality criterion for NO_x-N (1.2 mg L^{-1}), the runoff flowing into the infiltration basin contained NO_x levels greater than 1.2 mg L^{-1} for a duration of 15 hours. However, the runoff discharged met the 1.2 mg L^{-1} water quality criterion for NO_x the entire duration.

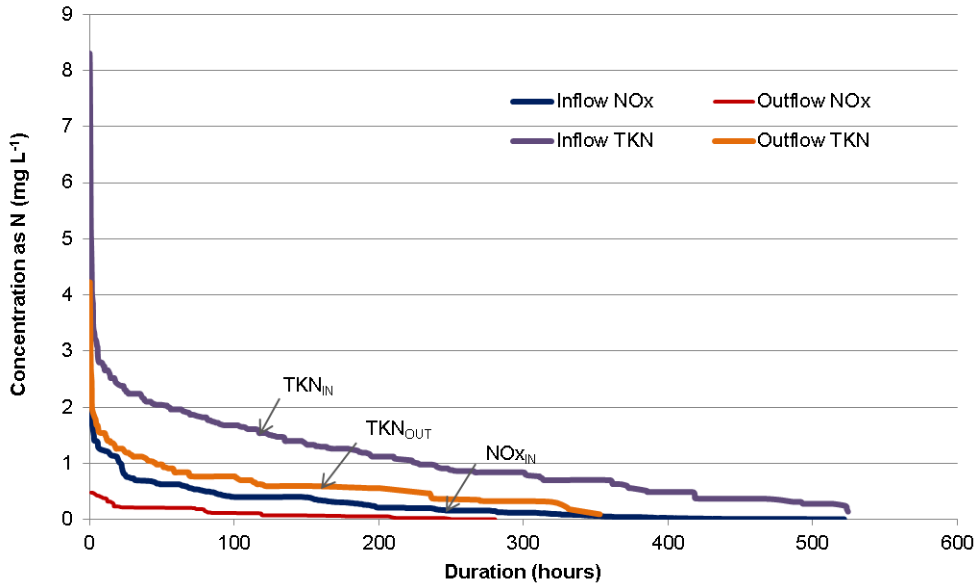


Figure 39. Pollutant duration curves for nitrogen species (TKN and NO_x-N) at the infiltration basin site for the entire monitoring duration.

Total nitrogen (TN) was determined as the sum of nitrogen species: nitrate, nitrite, and TKN (TN = NO_3-N + NO_2-N + TKN-N). Based on data available for all nitrogen species, the TN event mean concentrations in the runoff to the infiltration basin ranged between 1.2 and 4.1 mg L^{-1} during 32 storm events (Table 12). The discharge TN EMCs ranged between 0.59 and 1.3 mg L^{-1}. The mass removal efficiency for TN varied between 6 and 100% (median = 100%) for the 32 storm events. Thus, the infiltration basin exhibited good removal of TN from the highway runoff.

4.3.2.2.4 Nitrogen Speciation

In order to analyze the characteristics of nitrogen in the runoff and to understand the nitrogen dynamics in the infiltration basin, a comprehensive analysis was performed to speciate the runoff samples into the various nitrogen species (nitrate, nitrite, TKN, and ammonium) for selected rainfall events.

Excluding six storm events with no nitrate data, TKN was found to be the largest portion of TN in both inflow (median = 81%; 32 storm events) and outflow (median = 87%; 12 storm events). This observation is in agreement with the study by Taylor *et al.* (2005) in which TKN was found to be the major constituent (~70%) of total nitrogen in urban stormwater runoff.

Ammonium-N concentrations were determined for nine storm events. Organic nitrogen level was obtained as the difference between TKN and ammonium levels. Comparing the organic nitrogen and ammonium-N concentrations in these samples, organic nitrogen was the dominant fraction of TKN in both inflow and outflow samples. While organic nitrogen (ON) concentrations were 54 – 96% of TKN in inflow, outflow TKN consisted of 70 – 92% organic-N. The median ON concentrations in the inflow and discharge were 1.2 and 0.65 mg

L^{-1}, respectively. For comparison, the median organic-N (ON) concentrations in the inflows and discharges were 1.09 and 0.78mg L^{-1}, respectively, at seven stormwater wetlands in North Carolina (Moore *et al.* 2011). The median ON:TN ratios for inflow and outflow at the infiltration basin facility were 0.82 and 0.89, respectively. This is in comparison to the median ON:TN ratios of 0.66 and 0.75 in the inflow and discharge, respectively, in stormwater wetlands (Moore *et al.* (2011).

Overall, the concentrations of nitrogen species observed at the infiltration basin are in agreement with the median concentrations of various nitrogen species observed in stormwater runoff from a variety of urban land uses (Taylor *et al.* 2005; Collins *et al.* 2010, and Moore *et al.* 2011).

The cumulative pollutant mass inputs and outputs (in *lb*) for all nitrogen species measured for the 38 events are summarized in Table 14. These correspond to mass removal efficiencies of 79% nitrate-N, 52% nitrite-N, 79% NOx-N (nitrate + nitrite), 51% TKN, and 64% total N, for the entire monitoring duration. This shows that the nutrient input pollutant loads were reduced by the infiltration basin. The 30% volume reduction observed during the 38 monitored storm events partially contribute towards the mass removals.

Table 14. Total pollutant mass input and output at the infiltration basin for 38 monitored rainfall events from August 2009 to August 2012.

Pollutant	Mass Input (*lb*)	Mass Output (*lb*)
Nitrate (as N)	5.1	1.04
Nitrite (as N)	0.167	0.066
NOx (as N)	5.3	1.1
TKN (as N)	16.8	8.16
Total N	19.8	7.1

4.3.2.2.5 Nitrogen Removal Mechanisms

For the 38 storm events sampled for water quality, the volume reductions ranged between 6 and 100% during 34 storm events (as discussed in the 'Hydrologic Performance' chapter). While a part of the removal of nitrogen mass can be attributed to the observed volume reductions during these storm events, the physical and biological processes aiding N removal in the infiltration basin were specifically identified based on the concentrations of various nitrogen species in the water. Nitrate and nitrite are primarily dissolved components in the water (Taylor *et al.* 2005). Removal of NO_x must occur through conversion of nitrite to nitrate and denitrification of nitrate to N_2 for complete removal of NO_x (Reddy and D'Angelo 1997).

The nitrate and nitrite levels in the grab samples collected between storm events were usually around or below their respective detection limits (Table B-1 in Appendix B) (nitrite detection limit = 0.01 mg L^{-1}; nitrate detection limit = 0.1 mg L^{-1}). The NO_x concentrations ranged between (< 0.06) and 0.21 mg L^{-1} in the grab samples collected. The NO_x levels in the samples collected before and after a storm event were usually less than 0.06 mg L^{-1}. This suggests that the conditions in the infiltration basin enabled removal of NO_x during inter-storm periods.

The oxidation-reduction potential (ORP) measurements of the water in the infiltration basin support processing of NO_x through denitrification during storm events and dry periods. Figure 40 shows the ORP measurements taken during December 2011.

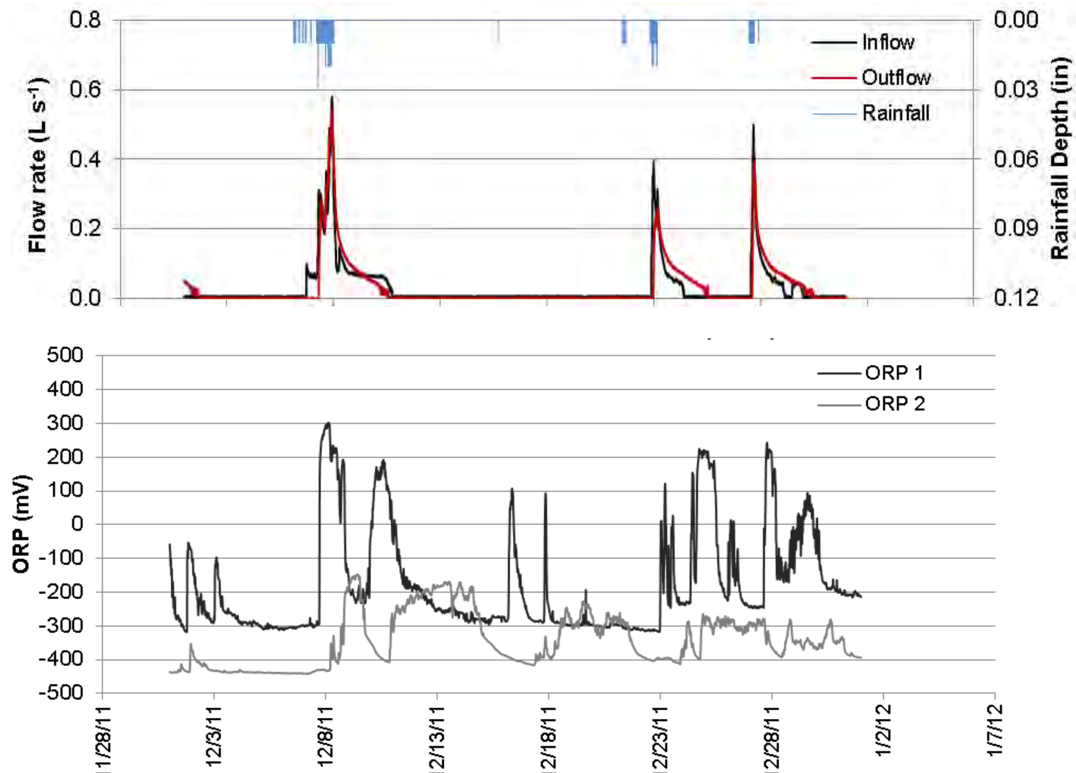


Figure 40. Oxidation-reduction potential measured in the infiltration basin during Dec 2011. ORP 1 and ORP 2 were recorded near the inlet and outlet sides of the infiltration basin, respectively. Also included are the inflow and outflow hydrographs for the month (top figure).

The ORP of the water column remained largely negative (-100 to -400 *mV*) during dry periods. During a storm event, ORP increased to more positive values due to fresh input of runoff into the infiltration basin.

As can be seen in Figure 40, the ORP values measured by the two probes were different. One reason could be because probes were installed in two different locations in the infiltration basin. The second reason could be due to the fluctuation observed in the overall accuracy of ORP probes (50 – 100 *mV* margin), in general.

Based on the one-year continuous measurements, the ORP of the water column remained low positive to large negative (-400 to 200 *mV*) in the anoxic/anaerobic range during most dry periods. The presence of anoxic conditions within the infiltration basin is conducive for nitrate removal through denitrification during inter-storm periods (Kadlec and Knight 1996; Reddy and D'Angelo 1997). The pH of the water remained within the 6 to 8 range for most periods, which falls within the optimal pH range of 7 to 8.5 for denitrification (Kadlec and Knight 1996).

The existing vegetation at the infiltration basin also provided evidence of prevalence of wetland-like conditions at the site. The emergent vegetation (softstem bulrush) established at the fringe of the infiltration basin, and floating vegetation (floating primrose-willow) were identified as 'obligate' wetland plants that are found in wetlands only. The wetland conditions support the hypothesized nitrate removal mechanism via denitrification. The details on all vegetation types identified at the infiltration basin are presented in the 'Ecological Value of the Infiltration Basin' chapter. Removal of nitrate during a storm event could largely be due to dilution and volume reduction.

While NO_x removals were very good, removal of TKN was moderate and mixed in the infiltration basin. This can be attributed to the removal mechanisms governing each component of TKN in the runoff. TKN primarily consists of dissolved and particulate organic-N and a small portion of dissolved ammonium in urban stormwater runoff (Taylor *et al.* 2005). Although the ammonium concentrations were found to low in the water samples, removal of ammonium must occur through nitrification and plant uptake (Reddy and D'Angelo 1997).

The dry-weather monitoring showed that the TKN concentration ranged between 0.30 and 3.7 mg L^{-1} (median = 1.1 mg L^{-1}) in the inter-storm periods. Speciation of TKN was not performed for the grab samples. However, the TKN levels in the water stored in the infiltration basin in between storm events were around the same concentration (~1 mg L^{-1}).

Based on the concentrations of TKN in the inflow, outflow, and dry-weather samples, it was deduced that most of the TKN in the infiltration basin water was organic nitrogen. Given the location of the infiltration basin, the source of organic-N in the runoff must be from plants in the upstream swale area. The recorded pollutographs of inflow TKN showed stronger first flush behavior compared to nitrate and nitrite during several storm events. If the particulate organic-N can be assumed to follow the TSS trend, some removal of TKN can be expected to occur by sedimentation of the particulate organic-N component.

The dissolved organic-N (DON) in marine and aquatic systems was historically considered to consist of refractory compounds that are resistant to biological degradation and unavailable as N source to organisms (Berman and Bronk 2003). However, several studies have recognized that DON can provide a source of nitrogen to phytoplanktons and bacteria in aquatic ecosystems (Stepanauskas *et al.*, 1999; Berman and Bronk 2003; Seitzinger *et al.* 2002; Kaushal and Lewis 2005; Wiegner *et al.* 2009). The bioavailability of dissolved organic-N varies depending on the source. For instance, research by Seitzinger *et al.* (2002) showed that about 59 ± 11% of org-N was bioavailable in stormwater runoff from urban watersheds compared to 30 ± 14% for agricultural and 23 ± 19% for forested watersheds.

Moderate removal of TKN, consistent TKN levels (~1 mg L^{-1}) in the water stored in the infiltration basin during inter-storm periods, and predominance of organic-N in the inflow and outflow, suggest the organic-N in the discharge from the infiltration basin consists of both recalcitrant and bioavailable portions. Similar to a natural wetland, stormwater wetlands were found to contain a consistent background organic-N concentration and limited organic-N removal, likely attributed to internal loading from plants (Moore *et al.* 2011). In the current study, plants growing within the infiltration basin can assimilate N into their tissues and their senescence can release nitrogen back to the water column (Fennessey *et al.* 2008).

4.3.2.3 Annual Pollutant Mass Loads

Annual pollutant mass load per unit drainage area are important parameters employed towards design of a SCM in a watershed (Li and Davis 2009). The annual pollutant mass load per unit drainage area (L, in *lb* ac^{-1} yr^{-1}) was estimated for each pollutant using Equation 10:

$$L = \frac{M}{A} \times \frac{P_{average}}{P_{observed}} \qquad (10)$$

In Equation 10, M_{in} is the overall input pollutant mass (in *lb*), A is the drainage area of the infiltration basin (in *acres*), $P_{average}$ is the average annual precipitation [42 *in* yr^{-1} for the State of Maryland; MDE 2000], and $P_{observed}$ is the observed cumulative precipitation during the monitoring period (in *inches*). $P_{observed}$ for the 38 monitored events was 30 *in*.

The annual pollutant mass input (L_{in}) and discharge (L_{out}) at the infiltration basin are summarized in Table 15. The annual pollutant mass discharged from the infiltration basin was lower than the annual pollutant input load for both phosphorus and nitrogen. The annual mass removals were 61% TP, 79% nitrate, 53% nitrite, 78% NO_x, 51% TKN, and 64% total N. This suggests that the infiltration basin effectively reduced pollutant loads and provided an overall improvement in water quality of the water discharged from the facility.

Table 15. Annual pollutant mass input and discharge load of phosphorus and nitrogen based on 38 storm events recorded at the infiltration basin from August 2009 to August 2012. Annual pollutant mass input and discharge values for a bioretention, as reported by Li and Davis (2009), are also included.

Pollutant	Annual Pollutant Mass Load (*lb* ac^{-1} yr^{-1})			
	MD 175 Infiltration Basin		Bioretention[a]	
	Input (L_{in})	Output (L_{out})	Input	Output
Total Phosphorus	0.65	0.26	0.8	0.34
Nitrate (as N)	1.16	~ 0.24	3.3	~ 0.17
Nitrite (as N)	~ 0.034	~ 0.013	0.18	~ 0.05
NO_x (as N)	1.19	~ 0.25		

TKN (as N)	3.36	1.64	5.4	3.2
Total Nitrogen	4.53	1.63	8.6	3.2

[a] Li and Davis (2009)

The annual pollutant input loads at the infiltration basin were compared to values for a bioretention facility located in Silver Spring, MD (Li and Davis 2009) (Table 14). The bioretention has a drainage area of 2.2 *acres* (90% impervious) and manages runoff from a parking lot. Comparing the annual pollutant loads at the two SCMs, the mass loads to the bioretention were greater than those to the infiltration basin for nitrogen. Phosphorus loadings were similar at the two sites.

Although the infiltration basin and bioretention SCMs are structurally different and operate on different science, the performances of the two facilities were compared. Based on the annual loading and removal, the annual mass load removal efficiencies of the bioretention were 53% TP, 98% nitrate, 70% nitrite, 40% TKN, and 63% TN. The performance data of the infiltration basin are comparable to the bioretention data: 61% TP, 79% nitrate, 53% nitrite, 51% TKN, and 64% total N removals. Since annual mass loads are important parameters for TMDL models, the infiltration basin research data contribute towards the determination of loads for these models.

4.3.3 Performance Summary for Nutrients

Water quality data from 38 storm events and 54 dry-weather samplings showed overall improvements in the runoff water quality for nutrients. The event mean concentrations (EMCs) of the measured pollutants in the outflow were significantly lower ($\alpha = 0.01$) than those of inflow in all events for both phosphorus and nitrogen species. The outflow EMCs of nitrite-N satisfied the water quality target during all 14 events. The discharge nitrate-N EMC exceeded the selected water quality criteria for 3 out of the 12 monitored events. However, the discharge TP EMCs exceeded the stringent water quality goal of 0.05 mg L^{-1} during all events.

Average mass removal efficiencies of 82% TP, 77% TKN, and 86% NO_x-N 86% were observed at the infiltration basin. This is in comparison to mass removals in the range of 35 – 65% TP, 21 – 50% TKN, 22 – 58% NO_x, and16 – 48% TN, that have been reported for wetponds and wetlands (Wu *et al.* 1996; Carleton *et al.* 2000; Mallin *et al.* 2002; Birch *et al.* 2004; Brydon *et al.* 2006). As observed in the other research studies (Comings *et al.* 2000; Birch *et al.* 2005), highly variable removal efficiencies of nitrogen and phosphorus, sometimes exhibiting phosphorus and nitrogen exports were observed.

Speciation analyses of phosphorus (dissolved vis-à-vis particulate) showed that the particulate P ranged between 22 and 86% of inflow TP levels and 41 to 87% of outflow TP levels. While removal of particulate P ranged between 14 and 100%, export (18%) of dissolved P was observed during one winter storm event. The PP and DP levels were more variable in the inflow runoff than in the outflow.

The speciation analysis and good linear correlation between TSS and particulate P mass loads, along with the grab sampling data, showed that most of the phosphorus removal occurred via sedimentation of particulate P in the infiltration basin. Removal of dissolved P should occur via adsorption and biological uptake. There is no evidence of phosphorus release from the sediments during inter-event periods.

The nitrogen water quality data showed that the infiltration basin is effective in removing the oxidized nitrogen species (NO_x) through denitrification. This is supported by the low oxidation-reduction potential measured in the water column of the infiltration basin and NO_x concentrations below detection limit especially during the dry periods between storm events. The presence of wetland plants also confirm the presence of wetland conditions at the infiltration basin.

TKN (ammonium-N + organic-N) was only partially removed. The speciation analyses showed that majority of the TKN was in the form of organic-N in both inflow and outflow samples. Based on the inter-event TKN levels (~1 mg L^{-1}) and predominance of organic N in discharge (70-90% of TKN), it was deduced that the majority of the TKN was in the organic N form in the water stored between events. While the particulate fraction of organic-N is expected to settle with the solids, a fraction of the dissolved organic-N (DON) may be available for biological uptake. The presence of organic-N in the discharge (median = 0.65 mg L^{-1}) suggests that a background concentration of organic-N will persist in the water, likely due to recalcitrant DON and/or contribution from plants in the basin, as observed in natural wetlands and constructed stormwater wetlands (Seitzinger *et al.* 2002; Moore *et al.* 2011).

With respect to overall performance, the treatment efficiency of the infiltration basin showed seasonal differences. The mass removals ranged between 17 – 100% for total phosphorus, 23 – 100% for TKN and 20 – 100% for NO_x during storm events in spring, summer, and early fall. The poorest nutrient removal performance was observed during the coldest months and this trend repeated each seasonal year. Export of total phosphorus (3 – 16%), nitrite (13 – 25%) and, TKN (0.32 – 13%) masses and low nitrate mass removals (23%) were observed during winter storm events. Similar observations were made in other research studies where performances of wetpond, wetland, and infiltration basin SCMs were observed to be worse during winter than in summer (Oberts 1994; Marsalek 2003; German *et al.* 2003; Semadeni-Davies 2006; Emerson and Traver 2008; Vollertsen *et al.* 2009; Wadzuk *et al.* 2010).

During colder periods, water in the infiltration basin was frozen forming a sheet of ice on the surface which reduced the available detention volume. Also, water losses through evapotranspiration and infiltration were lower during winter (at least 45%) compared to warmer months. The hydrology data indicated that the infiltration basin provided least water quantity control during colder periods due to presence of ice cover. Also, cold temperatures arrest biological activity which affects the water quality performance of the system. Runoff volume reduction is an important consideration for pollutant mass reduction. Changes in the physical and biological processes within the infiltration basin, combined with changes in hydraulic behavior, can impact the overall water quality performance of the infiltration basin. Hence, during the coldest temperatures, the infiltration basin is expected to act as a flow-through system and provide the least benefits, as evident by the poor nutrient removal performance.

Chapter 5: Ecological Value of the Infiltration Basin

The third objective of this research study was to evaluate the ecological value of the infiltration basin. In addition to monitoring hydrology and water quality functions, the vegetation and wildlife at the infiltration basin were recorded throughout the three-year monitoring period. The goal was to collectively qualify the hydrologic, water quality, and habitat conditions at the infiltration basin site in terms of their ecological significance.

5.1 Vegetation and Animals Observed at the Infiltration Basin Site

First, the plants and animals occurring at the MD175 infiltration basin site are described. Figure 41 and Figure 42 show the various species of flora and fauna observed at the infiltration basin site during the three-year research period.

The *2012 National Wetland Plant List* (PLANTS, USDA 2012) of the U.S. Department of Agriculture (USDA) for wetland indicator statuses was utilized to characterize the plants identified at the infiltration basin site. The USDA 2012 PLANTS database replaced the 1988 U.S. Fish and Wildlife Service's National list of plant species that occur in wetlands (Reed 1988) for use under the Clean Water Act, Swamp Buster, and National Wetland Inventory programs. The plant species are classified into five indicator categories based on their preference for occurrence in wetland or upland: *obligate wetland* (occur almost always in wetlands; estimated probability (p) > 99%), *facultative wetland* (usually occur in wetlands, p = 67 - 99%, but occasionally found in nonwetlands), *facultative* (equally likely to occur in wetlands or nonwetlands; p = 34 - 66%), *facultative upland* (usually occur in nonwetlands, p = 67 - 99%, but occasionally found in nonwetlands), and *obligate upland* (occur almost always under natural conditions in nonwetlands; p > 99%) (Reed 1988).

Figure 41. Photographs showing the vegetation at the MD175 infiltration basin site for the period 2009 to 2012. (Plants not labeled were not identified)

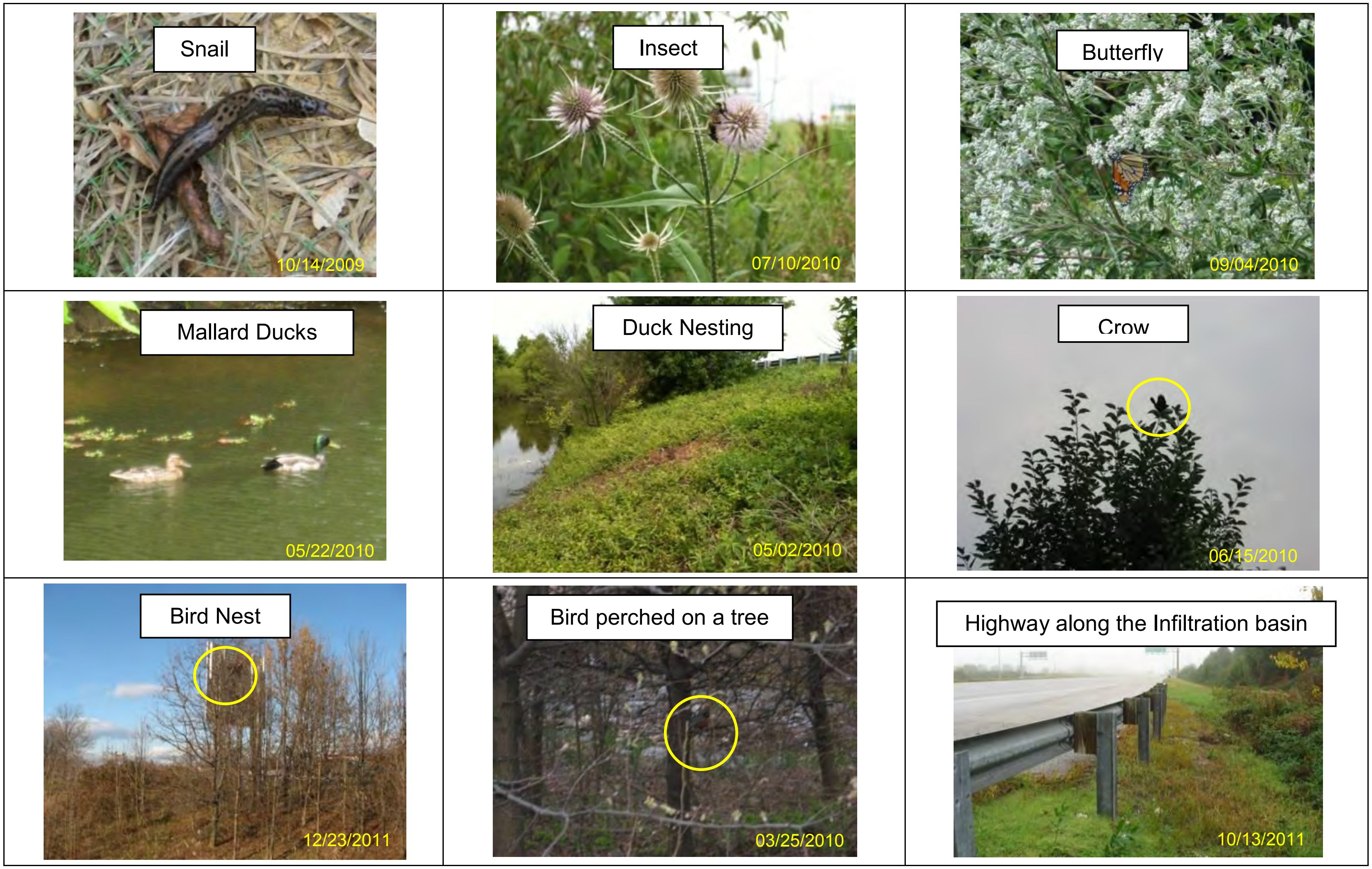


Figure 42. Photographs showing the wildlife observed at the MD175 infiltration basin site during the period 2009 to 2012.

The vegetation at the infiltration basin site consisted of submerged and floating species in the water, emergent plants along the edges of the infiltration basin, and shrubs and trees upland of the infiltration basin site. Some of the plants were identified with the help of Dr. Andrew Baldwin of University of Maryland (personal communication).

The submerged aquatic vegetation was identified as water-nymph (*Najas* spp.), an obligate wetland plant that can tolerate anaerobic conditions (PLANTS, USDA 2012). This plant was found to be actively growing and blooming in the spring and summer of 2009 and 2010 (Figure 41).

The floating macrophyte, floating primrose-willow (*Ludwigia peploides*), was observed to be growing in the infiltration basin water (Figure 41). This perennial aquatic weed is also an obligate wetland species that has been deemed as an invasive plant displacing native species in wetland ecosystems (Tiner 2009; PLANTS, USDA 2012). Known to grow and spread very fast, this plant covered nearly 70% of the water surface in spring, summer, and fall of 2010 to 2012. It was observed that floating primrose-willow displaced the water-nymph plants in 2011. Another obligate floating wetland plant, duckweed (*Lemna spp.)*, was observed in the shallow water regions on both inlet and outlet sides of the infiltration basin.

The emergent vegetation at the site consisted of colonies of softstem bulrush (*Schoenoplectus tabernaemontani*), established in shallow water along the edges of the infiltration basin (Figure 41). The softstem bulrush is an obligate wetland plant belonging to the sedge family (Tiner 2009; PLANTS, USDA 2012) and the plants were actively growing in spring, summer, and fall seasons throughout the research period.

Some of the upland shrubs and trees at the site include oxeye daisy (*Chrysanthemum leucanthemum*), blackberry, honeysuckle, black chokeberry, and dogwood (Figure 41). These plants and trees followed their growing and blooming cycle from spring through fall. Several other upland weed plants, shrubs, and trees were growing at the infiltration basin site but were not identified by their names. The upland weeds and shrubs provided a continuous cover of vegetation in the area surrounding the infiltration basin in the growing season.

The fauna spotted at the infiltration basin site ranged from macroinvertebrates, frogs, toads, terrestrial insects and butterflies, and terrestrial animals such as raccoons, mice, ducks, and birds (Figure 42). The presence of water and vegetation cover provided a potential source of food, water, and shelter for these animals belonging to different trophic levels.

The water in the infiltration basin contained a few macroinvertebrates. The only macroinvertebrate identified at the infiltration basin site was snail. Although, benthic macroinvertebrates and amphibians are indicator organisms of the environmental condition of the water in an ecosystem (Micacchion 2004), biotic sampling was not performed in this research study.

The infiltration basin provided habitat for amphibians and rodents, which are animals with limited mobility and small home ranges (Micacchion 2004). Presence of both open water and vegetation is important for amphibians (toads and frogs) for breeding, feeding, and shelter. Although the stagnant water is a breeding ground for mosquitoes, which is a prevalent problem in in wetlands (Dale and Knight 2008), the amphibians feed on mosquito and their larvae, and other invertebrates in the water. Although the upland weeds growing at the infiltration basin site hold limited value as a habitat, they provided food and cover for terrestrial species such as raccoons and rodents. The vegetation cover continuity at the site provided a hiding and resting site for these animals.

Mallard ducks were often spotted swimming in the infiltration basin water. The vegetation cover around the basin also provided a nesting habitat for the ducks (Figure 42). The upland trees and woody vegetation provided a nesting habitat for birds and acted as perch sites for small birds (crows, others not identified) (Figure 42). The abundance of insects, amphibians, and plants is a source of food for the ducks and birds. As an example, the hard coated fruits of softstem bulrush growing at the site are food for ducks and raccoons (Neill and Cornwell 1992; Dick *et al.* 2004; PLANTS, USDA 2012).

Since the infiltration basin is located along a highway in a suburban area (Figure 42), the habitat value of the infiltration basin site is expected to be limited. The increased level of human activity in the area including automobiles on the highway, surrounding developed areas (shopping mall and hotel), and the noise associated with all these activities limit the use of the infiltration basin site as a habitat for small animals, birds, amphibians, and invertebrates. However, the infiltration basin site must be considered a valuable habitat to these animals in an urban setting.

5.2 Assessment of the Ecological Value of the Infiltration Basin Site

5.2.1 Wetland Assessment Methods

Under the U.S. Environmental Protection Agency's (EPA) National Wetland Program, wetland monitoring and assessment programs have been developed to evaluate the ecological conditions of wetlands (U.S. EPA 2002; U.S. EPA 2003). The purpose of these programs is to assess the ambient wetland resources, for regulatory purposes, and for assessing mitigation and restoration project success. These monitoring and assessment methods vary in scale and intensity, ranging from broad landscape-level assessment (level 1), rapid field methods (level 2) to rigorous physico-chemical and biological measurements (level 3).

The wetland assessment methods embed the classification of wetlands so that scores for two wetlands in the same class can be compared. Two wetland classification systems are widely accepted: The U.S. Fish and Wildlife Service's wetland classification system, in which wetlands are defined by plants (hydrophytes), soils (hydric soils), and frequency of flooding (Cowardin *et al.* 1979); and the hydrogeomorphic (HGM) classification of wetlands which is based on the wetland hydrogeomorphic properties of geomorphic setting, water source, and hydrodynamics (Brinson 1993).

Smith *et al.* (1995) proposed an approach for assessing wetland functions based on HGM classification, centered on the fact that the interdependency of geomorphic setting, water source, and hydrodynamics reveal the functions that the wetlands are likely to perform. The overall wetland assessment approach is to identify the functions of the wetland based on its existing condition (taking into consideration all the disturbances), recognize a reference wetland (least disturbed wetland) belonging to the same HGM class, assign scores to the identified functional values in comparison to the reference wetland and develop the functional capacity index for the wetland (Bartoldus 1994; Smith *et al.* 1995).

The wetland assessment methods are comprised of various indicators and metrics related to hydrology, soils, and biotic communities for evaluating the wetland condition and functions. Some methods employ the index of biotic integrity (IBI) that utilize fish, amphibians, invertebrates, and vegetation assemblages as indicators of the overall biological condition of a wetland (Mack 2004; Micacchion 2004).

Rapid assessment methods have been widely used for wetland assessment and monitoring projects since they provide sound quantitative information on wetland conditions for the small amount of time and effort invested (Fennessey *et al.* 2004). Fennessey *et al.* (2004) reviewed the existing rapid assessment methods developed by various U.S. State programs and summarized the strongest metrics related to hydrology, soil conditions, vegetation, and landscape setting that measure and provide quantitative information of the wetland resources.

5.2.2 Site Assessment Plan for the Infiltration Basin

The rapid assessment method is a tool applicable towards evaluating the condition of stormwater control measures (SCMs) as well (Fennessey *et al.* 2004). A rapid assessment plan was designed to evaluate the ecological value of the infiltration basin site. For the current research study, scope of the rapid assessment plan was limited to identifying and describing the hydrologic, water quality, and habitat functions observed at the site. Although no overall scoring and comparisons to reference wetland conditions were performed, the existing conditions and identified functions were qualified in terms of the ecosystem services provided by the infiltration basin.

Table 16 shows the hydrology, water quality, and habitat criteria/indicators for the rapid assessment of the MD 175 infiltration basin. The selected criteria/indicators were derived from several wetland assessment methods from literature (Fennessey *et al.* 2004; Smith *et al.* 1995). The hydrology criteria include stormwater control, source of water to the infiltration basin, and hydroperiod and water level fluctuations, which influence the soil and vegetation conditions at the site. For water quality, reduction and removal of pollutants (solids, nutrients, and metals) were mainly considered. Under habitat characteristics, maintenance of representative vegetation and wildlife habitat at the infiltration basin site were evaluated. The monitoring method, and functions and benefits corresponding to each criterion are summarized in Table 16.

Table 16. Assessment plan for evaluating the ecological value of the infiltration basin site.

Characteristics	Criteria/Indicator	Measurement/ Monitoring	Observations	Functions/Benefits/Ecosystem Services
Hydrology	Source of water		Surface runoff from impervious and grassy areas; direct precipitation	Stormwater runoff management
Hydrology	Stormwater runoff control	Continuous rainfall depth, runoff inflow and outflow measurements; Continuous water level monitoring	• Runoff flow and volume attenuation • Peak flow attenuation • Short-term and long-term storage of runoff	• Slow runoff flows • Reduced discharge volumes and peak flows • Flood attenuation • Flood storage potential • Erosion control • Possible improved downstream water quality • Maintenance of habitat
Maintenance of hydrologic regime	Hydroperiod	Continuous water level monitoring	• Permanently flooded (water present in all seasons) • Open water and partially vegetated water surface (spring to fall seasons)	• Increased evapotranspiration • Maintenance of vegetation • Maintenance of habitat • Groundwater recharge through infiltration
Maintenance of hydrologic regime	Water level fluctuation	Continuous water level monitoring	• Up to 1.97 *ft*	• Storage of runoff
Water Quality	Removal of pollutants on a short- and long-term basis	Water quality sampling during 38 storm events; Grab sampling during inter-event periods; Continuous water temperature, pH, redox potential monitoring	• Removal of suspended solids, nitrogen, phosphorus, heavy metals (copper, lead, and zinc) through physical, chemical, and biochemical processes • Retention of particulate pollutants • Improved discharge water quality	• Reduced downstream particulate loading • Reduced pollutant concentrations (solids, nutrients, and metals) Transformation of pollutant species to innocuous forms • Reduced downstream pollutant mass loading • Possible improved downstream water quality • Nutrient cycling • Maintenance of habitat

Characteristics	Criteria/Indicator	Measurement/ Monitoring	Observations	Functions/Benefits/Ecosystem Services
Water Quality	Presence of algae (or signs of eutrophication)	Visual inspection year-round	None	• Nutrient cycling • Reduced downstream nutrient loading • Possible improved downstream water quality
Habitat	Maintenance of plant communities	Visual inspection year-round	• Obligate wetland plants (submerged, floating, and emergent hydrophytes) • Upland weeds, shrubs, and trees	• Habitat for wildlife (invertebrates, amphibians, ducks, birds) • Nest, shade and food for wildlife
Habitat	Maintenance of animal communities	Visual inspection year-round	• Presence of invertebrates, amphibians, insects, ducks, and birds	• Habitat for wildlife
Habitat	Vegetation alterations (mowing, toxicity)	Visual inspection year-round	None	
Other – SCM facility settings	Sensitivity to stormwater/urban development		• Ratio of facility area to drainage area = 3% • Land use of watershed = sub-urban (buildings, highway, and roads) • Position of the facility in the watershed = along a highway • Connectivity and proximity to surface water = outflow from facility discharged into a storm drain	
Other	Aesthetics, recreation, education, cultural uses		• Education uses	• Provide research opportunities

The runoff flow and water level data collected over the three-year research period were utilized to assess the hydrology characteristics. Results from water quality samplings performed during storm events and dry-weather period were utilized for water quality characteristics. The detailed methodology of measurements and samplings were presented in the ‘Materials and Methods’ chapter. The results of the hydrology and water quality analyses were presented in the ‘Hydrology Performance’ and ‘Water Quality Performance’ chapters.

For the biota (vegetation and animals) category, biosurveys or any other intensive field samplings were beyond the scope of this research work. Hence, measures such as number of species, richness, and diversity were not employed to evaluate the biota composition and condition at the site. As a simple approach, the plants and animals occurring at the infiltration basin site were identified and the potential for wildlife habitat (nests, shade, and open water) was assessed.

The infiltration basin facility is expected to provide stormwater runoff flow and volume control, and reduce the runoff pollutant loads to improve the discharge water quality. The assessment of the hydrology, water quality, and habitat conditions at the infiltration basin site show that the infiltration basin provides these ecosystem services. Also, the infiltration basin site supports vegetation and provides habitat for amphibians, birds, and small animals. Several of these functions of the infiltration basin site are similar to the ecosystem services provided by natural and constructed wetlands that include flood control, groundwater recharge, water quality regulation, nutrient cycling, habitat for plants, animals and micro-organisms, wildlife conservation, and recreational opportunities (Kadlec and Knight 1996; Fisher and Acreman 2004; Vymazal 2007; Blackwell and Pilgrim 2011).

As indicated earlier, the infiltration basin is located in a suburban setting and can be considered to have a high degree of human disturbance. It is important to recognize that the infiltration basin holds a high value as a stormwater quantity and quality control structure as well as value as a habitat for the animals. Van Meter *et al.* (2011) have noted that stormwater detention ponds have emerged as important manmade aquatic ecosystems that support birds, amphibians, small mammals, and invertebrates, in urban areas which are heavily influenced by anthropogenic factors. Given the limited number of wetlands in urban areas, location of the infiltration basin in a disturbed area makes it a valuable habitat to the different organisms living at the site.

5.3 Indicators of Functionality of the Infiltration Basin

The hydrology and water quality performance monitoring and evaluation showed that the transitioning infiltration basin facility is effective in managing runoff flows and improving the runoff water quality. In addition to providing water quantity and quality benefits, the infiltration basin provides ancillary benefits such as wildlife habitat.

The research information obtained from this three-year research study was utilized to identify the ‘indicators of functionality’ of the infiltration basin under investigation. The aim of this task was to select indicators that can predict the existence of conditions that allow the desired functions to be performed by the transitioning infiltration basin. Ultimately, the goal is employ the derived set of indicators of functionality to evaluate similar failed and transitioning infiltration basins.

The wetland classification systems and assessment methods are based on the idea that the ecological conditions and functions of a wetland are a consequence of the ecosystem processes governed by the factors of geomorphic setting, hydrodynamics, soils, and vegetation (Smith *et al.* 1995). Since vegetation provides important clues of the hydrogeomorphic forces at work in a wetland ecosystem, vegetation-based assessment tools have been used for assessing wetland conditions (Brinson 1993; Tiner 1993a; Tiner 1993b; Mack 2004). In fact, the U.S. Fish and Wildlife Service's wetland classification system (Cowardin *et al.* 1979) relies largely on vegetative cover for determining the wetland type.

The aquatic plants or hydrophytes found in wetlands are adapted to the conditions of prolonged inundation/soil saturation (classified as obligate, facultative, facultative wetland; PLANTS, USDA 2012). The plants supported by the hydric soils in wetlands are characterized by the presence of aerenchyma tissue, which are internal spaces in the stems and rhizomes that allow atmospheric oxygen to be transported to the root zones (Kadlec and Knight 1996). Hydric soils develop under 'conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part' (U.S. Army Corps of Engineers Environmental Laboratory 1987). An area with hydric soils, wetland-adapted plants, and the presence of water for at least a portion of the year is considered to be a wetland.

In the current research study, at least three obligate wetland plants namely, softstem bulrush, floating primrose willow, and water nymph, were observed at the infiltration basin site. The wetland plant softstem bulrush belongs to the sedge family of plants that thrive in hydric soil conditions. These observations strongly suggest that wetland conditions prevail at the infiltration basin.

Given that wetland conditions exist at the infiltration basin, the environmental conditions must facilitate biogeochemical processes like nutrient cycling. The nitrogen water quality data along with the oxidation-reduction potential trends support that conditions favoring denitrification exist at the infiltration basin. The water level data and hydrology data also showed that the infiltration basin remained inundated throughout the year, which support the presence of hydric soils and hydrophytic vegetation onsite. Thus, there is sufficient evidence to support the research hypothesis that the failed infiltration basin is evolving into a wetland-like practice.

This knowledge gained was utilized to develop a simple method to assess a failed and transitioning infiltration basin SCM facility (Table 17).

Table 17. Indicators of functionality for evaluating a failed stormwater infiltration basin facility.

Indicator	Measure	Monitoring/Measurement
Source of water	Runoff/precipitation/baseflow	Visual inspection
Hydroperiod	Permanent inundation/seasonal/saturated/drained	Visual inspection (watermarks, sediment

		deposition, wetness of soil)
Water level	Standing water (percent area inundated)	Visual inspection (watermarks, sediment deposition, wetness of soil)
Vegetation	Maintenance of plant community characteristic of wetlands • floating leaved community dominated by: • submerged aquatic community dominated by: • emergent community dominated by: • upland vegetation:	Refer 2012 PLANTS database (PLANTS, USDA 2012)
Soil conditions	Presence of hydric soil	Visual inspection (rotten-egg odor, organic material accumulation). Refer NRCS hydric soil field guide (USDA NRCS 2010)
Habitat	• Vegetation cover (aquatic, emergent, upland shrub and woody vegetation) • Animals supported	Visual inspection
Design features	• Size relative to drainage area • Location in watershed • Watershed characteristics	Visual inspection

The indicators presented in Table 17 are simple visual measures that can be employed during a field-scale inspection of the facility. For an intensive assessment, physical and chemical measurements must be taken at the site in addition to the field inspection. Although a detailed procedure for an intensive assessment method is not presented in this section, the research methodology described in the 'Materials and Methods' chapter can be used a reference for conducting rigorous physico-chemical monitoring and measurements at the site.

For the indicators presented in Table 17, the visual inspection must be carried out seasonally. This is because periods immediately after a storm event may cause temporary inundation at the site, whereas the water conditions might be different a few days after the storm event which can lead to different set of conclusions about hydroperiod and water level criteria.

Presence of saturated soil conditions and hydrophytic vegetation are strong indicators of the presence of wetland condition. Therefore, the type of the vegetation in terms of probability of occurrence in wetlands or upland (obligate and/or facultative) must be determined (PLANTS, USDA 2012). Based on the adaptation and tolerance of the plants (pH, alkalinity, soil type, water levels), it can be confirmed if wetland conditions prevail. Subsequently, functions typically associated with wetlands, like nutrient cycling and other pollutant removals, can be expected to occur.

Hydric soils that are usually associated with wetland areas are strongly influenced by the presence of water (U.S. Army Corps of Engineers Environmental Laboratory 1987). A simple visual inspection of the soil can reveal if hydric soil conditions are present. As an example, hydrogen sulfide is formed under reducing conditions due to prolonged inundation/soil saturation, which yields a rotten-egg odor to the soil. Presence of organic material represented by a darker color surface layer is a sign of hydric soil (U.S. Army Corps of Engineers Environmental Laboratory 1987). For detailed information, the NRCS field guide for hydric soils (USDA NRCS 2010) must be used for hydric soil identification.

Ancillary benefits like wildlife habitat can be assessed based on the vegetation structure and composition. The vegetation plays a fundamental role in providing habitat for birds, mammals, and other groups. The wildlife present at the site can be determined by visual inspection. It must be reiterated that SCM facilities are typically located in urban areas that feature roads and large areas of development. The presence of these urban features creates limited but valuable vegetation and habitat conditions that can be associated with urban SCM facilities.

5.4 Summary

Some plants and animals occurring at the infiltration basin site were identified and recorded over the three-year research period. The plants were established in the various regions of the site: submerged, floating and emergent plants in the wetter areas, and shrubs and woody vegetation in the upland areas. The submerged, floating, and emergent species were hydrophytes, the majority of which were identified as obligate wetland plants that occur in wetlands only. This confirmed the presence of wetland conditions at the infiltration basin site. The upland vegetation consisted of weedy species, shrubs, and trees. The water and vegetation at the infiltration basin site provided a foraging and nesting habitat for animals such as invertebrates, amphibians (frogs and toads), insects, raccoons, mice, ducks, and birds.

The ecological value of the infiltration basin was assessed based on the hydrologic, water quality, and ancillary benefits provided by the facility using a simple assessment plan. The infiltration basin was capable of slowing runoff, reducing the peak flows and total runoff volumes, and reducing the pollutant concentrations and loads. Some of the benefits associated with these functions are flood attenuation and control, erosion control, improved discharge water quality, and thus possible improved downstream water quality. The maintenance of plant and animal communities presented a potential habitat for small animals at the infiltration basin site.

The research information obtained from the hydrology, water quality, and field observations were utilized to identify existing conditions favoring the functional performance of the infiltration basin, especially pollutant removal functions of the facility. The indicators of functionality were developed based on the hydroperiod, soil, and vegetation characteristics at the facility. Since vegetation characteristics are dependent on both water and soil conditions, presence of vegetation native to wetlands is a strong biotic indicator of wetland-like conditions and hence the associated beneficial functions. A simple visual assessment plan was devised using these indicators for use with any failed infiltration basin evaluation.

Chapter 6: Conclusions and Recommendations

This research study fully monitored, researched, and documented the functionality of a failed stormwater infiltration basin managing highway runoff. The research hypothesis was that a separate ecological function may develop in the failed infiltration basin with time. The failed infiltration basin can gradually transform into or may possess qualities of a wetland or wetpond-like practice.

The hydrology and water quality at the infiltration basin were monitored during many storm events and for periods between storm events, over a period of three years. Trends in hydrology and water quality performances associated with season and rainfall characteristics, and the controlling mechanisms were determined. Ancillary benefits such as wildlife habitat were also recorded. The rainfall distribution monitored at the infiltration basin site was well-representative of the historical rainfall distribution for Maryland.

6.1 Hydrologic Performance

The effectiveness of the infiltration basin in mitigating runoff flows and volumes was evaluated based on the flow responses, i.e., hydrographs, and performance metrics such as total volume reduction, peak flow attenuation, and flow duration for the 120 monitored rainfall events. Dynamic reduction in flow magnitudes, decrease in peak flows, delay in discharge of runoff, and net reduction in total volume were observed during the majority of storm events. Overall, the total volume reductions ranged between 4 and 100% (median = 100%) and peak flow reductions ranged between 1 and 100% (median = 100%), excluding a few large events that produced higher peak flows and no net volume reductions. The decrease in runoff volume achieved was statistically significant for the entire monitoring duration ($\alpha = 0.01$).

The hydrologic performance of the infiltration basin showed distinct trends based on the rainfall characteristics. The smallest storm events (rainfall depth < 0.26 *in*) were fully captured within the infiltration basin, resulting in 100% volume reduction. For moderate rainfall events (rainfall depth < 1.0 *in*), significant reduction in total volume discharged and dynamic flow attenuation were observed. The hydrographs indicated that the infiltration basin detained the inflow runoff initially thereby delaying the discharge, and subsequently discharged water at reduced flow rates, resulting in overall total volume reduction (1 – 100%) as well as peak flow reduction for these events (5 – 100%).

The hydrologic performance of the infiltration basin was less efficient for the large storm events (rainfall depths > 1.0 *in*). The higher runoff volumes from these large rainfall events overwhelmed the storage capacity of the infiltration basin, resulting in only small reduction of the total runoff volume and flow magnitudes. Negligible volume reductions and no net peak flow reductions were observed for the largest and extreme storm events (rainfall depths > 1.96 *in*), during which the infiltration basin acted merely as a flow-conveyance facility.

The rainfall size, evapotranspiration, infiltration, and antecedent dry period produced a combined effect on the volume capture/attenuation through the infiltration basin. Assessment of the influence of these factors on a seasonal basis showed some interesting observations about the hydrologic behavior of the infiltration basin. During warmer months, the inter-event dry periods were longer compared to other seasons. The rainfall events thus contributed lesser runoff volume to the infiltration basin due to higher initial abstraction. Loss of water through evapotranspiration and infiltration was also higher due to warm temperatures. As a result, the effective volume available in the infiltration basin was higher and this allowed capture of inflow runoff more effectively. During winter periods, the smaller water loss and periodic ice cover modified the hydraulics of the infiltration basin. Therefore, for the same inflow runoff volume, the volume reductions achieved during warm periods were higher than that during colder months. The runoff volume reductions directly contributed to total pollutant mass reductions through the facility.

The overall magnitude and total duration of discharge were reduced by the infiltration basin with a strong seasonal pattern associated with this performance. The effectiveness of the infiltration basin was strongest for the smaller to moderate flows, when runoff retention/capture and flow attenuation allowed discharge flows of smaller magnitude and shorter flow durations. The highest flows were partially reduced, explained by the hydrologic response of the infiltration basin to large and intense rainfall events during any season. In terms of matching the hydrologic regime to pre-development conditions, the effect of the infiltration basin was less effective when compared to a forested condition, as expected. Matching flows at the infiltration basin to forested condition is an ambitious target and consideration must be given to the overall impact of the infiltration basin in attenuating runoff flows from the highway area.

It can be concluded that the infiltration basin is effective as a stormwater runoff control practice as it exists, providing significant runoff flow attenuation, volume reduction, and reduced flow durations. The size of the facility is adequate to provide substantial hydrologic benefits for the more frequent smaller and moderate rainfall events, and least hydrologic benefits during the occasional largest and extreme rainfall events. No modifications to the existing design of the facility are necessary.

6.2 Water Quality Performance

The effectiveness of the infiltration basin in improving the water quality of the highway runoff was quantified based on 38 storm event and 54 dry-weather samplings. Water quality of the runoff inflow and discharge were monitored for a suite of pollutants: total suspended solids (TSS), total phosphorus (TP), nitrate, nitrite, TKN, total lead, copper, zinc, and chloride. Measurements for ammonium and dissolved phosphorus were additionally performed on some occasions. Performance efficiency for the infiltration basin was evaluated based on pollutant mass removal efficiency, effluent pollutant concentrations, pollutant durations, and probability exceedence distributions with appropriate water quality targets.

Overall, the infiltration basin reduced the mean pollutant concentrations and pollutant mass for all water quality parameters. The discharge event mean concentrations (EMCs) of TSS, metals (copper, lead, and zinc), total phosphorus (TP), TKN, NO_x-N (nitrate + nitrite), and chloride were statistically significantly lower than those of inflow considering all 38 storm events (α = 0.01). The discharge EMCs of TSS, metals, and NO_x-N satisfied their respective water quality criterion for all the events monitored, except for total phosphorus.

Excellent reductions in TSS mass were observed during all storm events. Metal mass removals were also high for most storm events, except for three winter events that showed export for all three metals. The removal of nitrogen and phosphorus was mixed, effective for the majority of storm events and showing export during certain winter events. The inorganic nitrogen mass (nitrite and nitrate) was consistently removed and TKN removal was moderate. Chloride mass removal and discharge concentration decrease were partial, with increased discharge concentrations and mass export during winter and spring storm events due to the high input chloride pulses during winter.

The cumulative mass removal efficiencies were 89% TSS, 61% TP, 79% NO_x-N, 51% TKN, 64% total nitrogen, 73% total Cu, 63% total Pb, 55% total Zn, and 45% chloride. The annual mass load input and discharge from the infiltration basin were determined, which are critical input parameters for TMDL models. The annual pollutant mass data showed that the infiltration basin reduced the input loads for all water quality parameters.

6.2.1 Controlling Mechanisms

The water quality data from storm event and inter-event periods were utilized to determine the controlling mechanisms in the infiltration basin. Figure 43 exemplifies the physical, chemical, and biological mechanisms governing the pollutant removals and transformations in the infiltration basin.

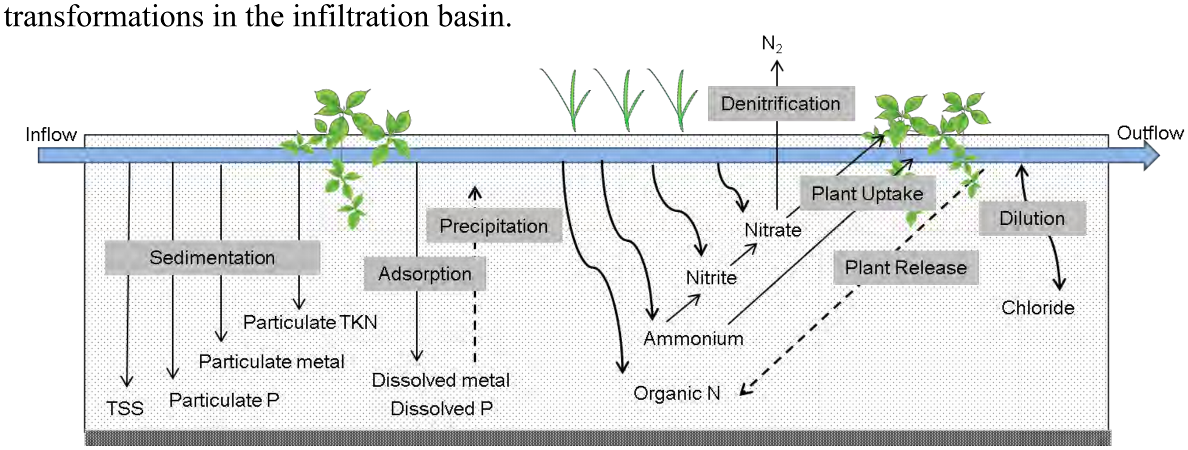


Figure 43. Schematic of controlling mechanisms in the transforming infiltration basin.

The infiltration basin acted as a sedimentation basin to effectively remove the suspended solids in the runoff. The particulate fractions of phosphorus, TKN, metals also settled with the solids. This behavior of the infiltration basin is similar to that of a stormwater detention pond.

In a research study on performance of stormwater wet detention ponds, utilizing 1-2% of the watershed area for the development of the ponds was recommended to achieve high pollutant mass removal efficiencies for TSS, TP, and metals (Wu *et al.* 1996). In the current study, the surface area of the infiltration basin was 3% of the total drainage area and high removals of TSS, TP, and metals were achieved. Although mass removal efficiency is not a good measure of performance, this suggests that the sizing of the infiltration basin is adequate for achieving high mass removals of suspended solids and pollutants associated with the solids.

The infiltration basin provided very good removals of inorganic nitrogen, which is not typically expected in detention ponds. The nitrogen processing ability is attributed to the separate wetland-like ecological function developed in the transitioning infiltration basin facility. Several floating and emergent macrophytes were observed within and at the periphery of the infiltration basin during the growing season. All of these established hydrophytes were identified as 'obligate' wetlands plants that occur in wetlands only (> 99% probability of occurrence). The oxidation reduction potential measurements in the water column confirmed the existence of anoxic/anaerobic conditions, especially during inter-event periods. The wetland environmental conditions thus favored denitrification to occur to effectively process nitrogen.

The presence of vegetation in the basin also aided in slowing the water and increasing sedimentation. The removal of dissolved phosphorus and metal components was possibly through adsorption or biological uptake. Chloride reduction occurred largely through mixing and dilution.

Figure 44 shows the year-round view of the infiltration basin, starting spring 2009 through summer next year. As can be seen in Figure 44, productivity of the infiltration basin changed as the seasons changed, which had implications for both hydrology and water quality at the site. The basin consisted of both open water, and transpiring floating and emergent vegetation during the growing season, which enabled loss of water by evapotranspiration. This contributed to the water balance in the basin by increasing the volume available for runoff retention. Correspondingly, good pollutant removals occurred, supported by the active physico-chemical and biological processes during the warm periods.

As fall progressed, the plants began to perish, decreasing transpiration but evaporation continued to occur from the open water. During winter, the water surface was completely frozen and was devoid of any transpiring plants. The ice cover resulted in minimal volume reduction and jointly influenced by the reduced biological activity in cold temperatures, resulted in poor removals of nitrogen, phosphorus, and heavy metals during winter storm events.

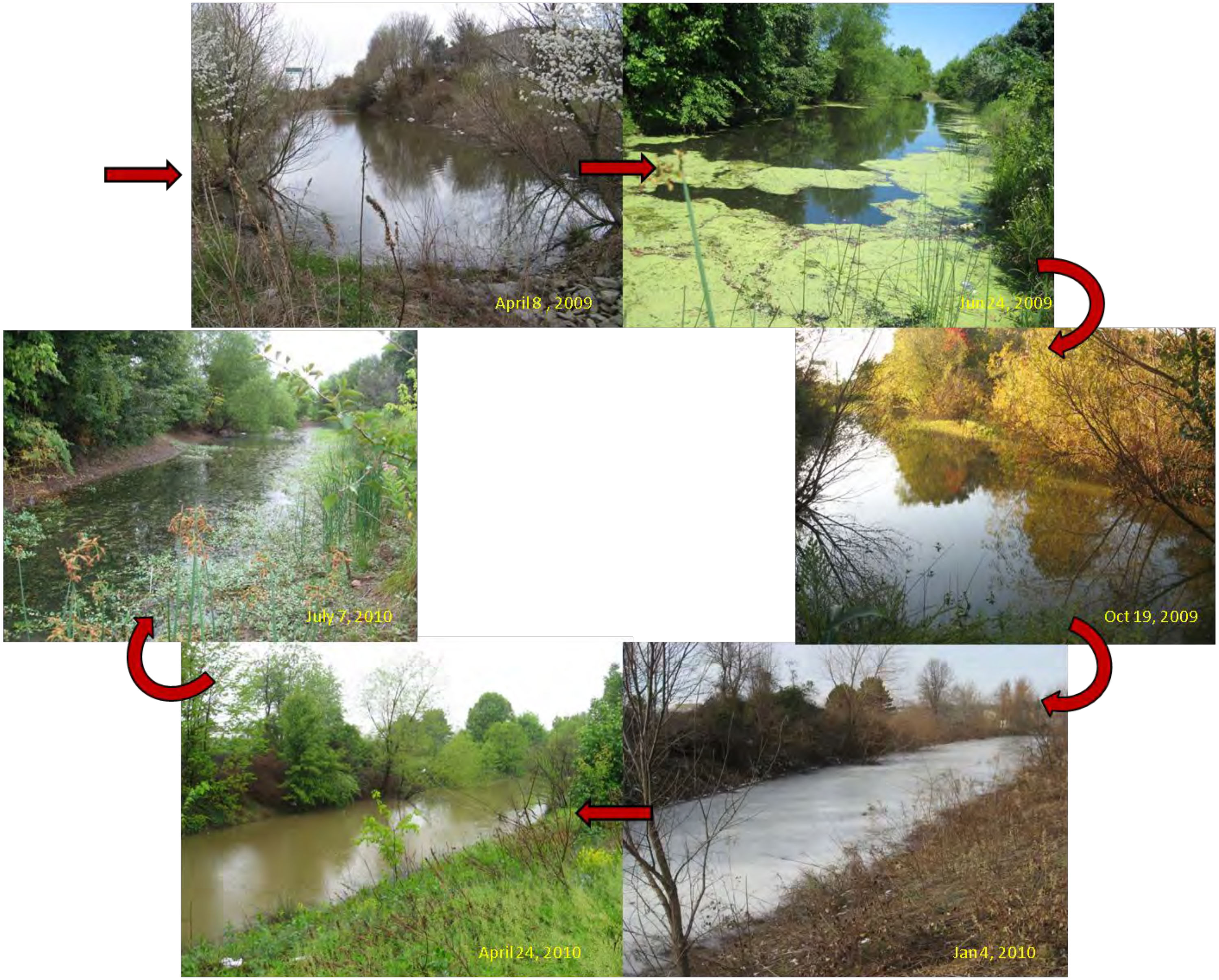


Figure 44. Photographs showing the infiltration basin from April 2009 through July 2010.

6.3 Recommendations and Future Work

This research study clearly showed that a failed stormwater infiltration basin can naturally transform into a wetlands/wetpond site, possessing both hydrologic management and water quality functions. Additionally, the site can provide ancillary benefits such as habitat for wildlife. In the current study, the presence of water and vegetation cover presented a potential source of water, food, and shelter for animals such as invertebrates, amphibians, mice, raccoons, ducks, and birds, which added an overall ecological value to the infiltration basin site. Therefore, rather than failure, such transforming infiltration basins must be considered as innovative stormwater management practices that provide valuable habitat for animals in the urban areas.

Research results obtained from this study are directly applicable to similar failed infiltration basins. A failed infiltration basin is primarily characterized by inappropriate ponding of water. In the current study, the water level in the infiltration basin fluctuated between partially to completely full (0.98 to 3 *ft*), but a pool of water persisted throughout a year. The soil in the shallower areas of the basin remained moist, if not completely wet. The prolonged inundation likely developed anaerobic conditions and formed hydric soils, which are characteristic of wetlands, over a period of time. Although the original infiltration capacity may be lost over time, the inundation of water due to reduced infiltration can potentially create wetland and/or wetpond conditions in the meanwhile, which together add functionality to an otherwise failed infiltration facility. Also, the ponding of water increases evaporation/transpiration (ET). This is only a modification to the original hydrologic cycle at the infiltration basin; water loss to the atmosphere via ET instead of groundwater recharge via infiltration.

It is recommended that such transforming infiltration basins be permitted to remain on site. These new wetland-like SCMs may in fact provide better functionality than the original infiltration basin by providing stormwater control and treatment in urban areas as well as providing habitat to wildlife. By allowing these SCMs to remain, the cost required to remove these facilities or restore the SCM to the original infiltration basin can be avoided.

The set of indicators of functionality developed in this research can be utilized as a guide to evaluate the existence of functional conditions in a hypothetically transforming infiltration basin. However, it must be pointed out the evolution of an infiltration basin facility into a wetland/wetpond involves time and the effectiveness of the facility during the transitioning period may or may not satisfy all stormwater management goals, especially water quality targets.

As an extension of this research, a water budget model for the infiltration basin can be developed. One application of the model could be to predict the hydrologic behavior/efficacy of the infiltration basin for different storm event characteristics given a geographical region and then assess the likely impact on the hydrologic and water quality performances of the infiltration basin. This model is also important in light of the fact that rainfall patterns are expected to be altered due to climate change and this can have implications on the hydrologic and water quality behaviors and thus the design of a SCM facility (Pyke *et al.* 2011).

With respect to water quality, phosphorus reduction achieved through the infiltration basin was moderate and the discharge phosphorus concentrations did not satisfy the water quality goal. As a future work, research on enhanced phosphorus removal within a transforming infiltration basin can be conducted. Research on bioretention soil mixture amended with water treatment residual has shown promising results of increased phosphorus adsorption (O'Neill and Davis 2012). Similarly, the soil media can be amended in selected locations within the infiltration basin and its effect on phosphorus removals can be explored.

The scope of incorporating a infiltration basin, naturally transforming into a new wetland/wetpond facility, as a part of a stormwater treatment train can be investigated. Since the transitioning infiltration basin was successful in removing TSS, nitrogen and metals, the discharge from the infiltration basin can be subsequently treated in a SCM facility such as a bioretention amended for enhanced phosphorus removal. Alternatively, discharge from a SCM such as a wetpond that has inferior inorganic nitrogen removal capability, can be introduced into the transitioning infiltration basin with wetland features so that complete removal of nitrogen through denitrification can be achieved.

Research on these areas can provide improved understanding of SCM designs and contribute towards novel stormwater management technologies. With improved understanding, more widespread and reliable implementation of SCM facilities can be exercised to mitigate the negative impacts of urban stormwater runoff and hence protect the surface waters and the health of natural ecosystems.

Appendices

Appendix A

Table A-1. Hydrology data recorded at the MD 175 infiltration basin site from August 2009 to August 2012.

Event date	Antecedent dry period (days)	Rainfall depth (in)	Rainfall duration (hours)	Inflow volume (x 10^3 L)	Outflow volume (x 10^3 L)
8/13/2009[a]	2	0.94	1.1	107	0
8/21/2009[a]	2	0.64	15.0	41	0
9/26/2009[a]	1	1.28	16.6	179	81
10/15/2009[a]	17	2.87	71.6	649	502
10/24/2009	6.3	0.40	8.1	52	46
10/27/2009	2.1	1.82	33.4	475	554
11/1/2009	3.4	0.45	12.3	119	70
11/11/2009	10.3	1.12	36.6	257	137
11/13/2009	0.7	0.36	1.9	64	37
11/19/2009[a]	6	0.61	8.5	124	133
11/23/2009	3	0.83	22.1	325^{++}	294^{++}
11/25/2009	0.7	0.17	10.8		
11/26/2009	0.9	0.12	5.0		
11/30/2009	3.3	0.22	7.1	34	0
12/2/2009	1	0.82	19.3	197	240
12/5/2009	2	0.14	6.2	0	0
12/7/2009	1	0.16	4.4	0	0
1/17/2010[a]	16	0.63	13.4	199	277
3/25/2010	3.3	0.30	11.13	35	0
3/28/2010[a]	2.4	0.50	10.97	99	48
3/30/2010[a]	1.3	0.10	3.5	18	0
4/21/2010	7.0	0.30	3.0	3	0
4/25/2010	4	0.96	15.4	152	50
5/3/2010	6	0.23	2.70	8	0
5/11/2010	7	0.27	8.03	0	0
5/12/2010	1	0.47	1.60	57	0
5/18/2010	0.5	0.18	9.83	7	0
5/23/2010[a]	4	0.40	3.47	28	0

Event date	Antecedent dry period (days)	Rainfall depth (in)	Rainfall duration (hours)	Inflow volume (x 10^3 L)	Outflow volume (x 10^3 L)
5/27/2010	4	0.37	2.30	21	0
6/3/2010	2	0.25	0.90	1	0
6/6/2010	2	0.12	0.53	0	0
6/9/2010	2	0.09	1.83	0	0
6/28/2010	19	0.48	0.53	0	0
7/10/2010	10	0.32	5.37	0	0
7/12/2010	2	0.55	0.80	11	0
7/12/2010	0.25	0.96	1.57	52	0
7/13/2010	0.75	1.70	7.27	355[++]	194[++]
7/14/2010	0.29	0.11	1.17		
7/18/2010	4.5	0.17	0.67	0	0
7/25/2010	6.5	0.39	0.33	1	0
8/4/2010	9.6	0.71	1.77	39	0
8/5/2010	0.83	0.08	3.67	0	0
8/12/2010[a]	8.1	1.06	0.93	113	0
8/13/2010	0.67	1.04	6.37	262	238
8/15/2010	2.2	0.33	3.13	34	31
8/18/2010	2.6	0.96	6.47	189	176
8/22/2010	4.1	0.28	0.47	4	0
8/23/2010	0.79	1.16	2.67	285	268
9/12/2010	19	0.42	11.97	0	0
9/16/2010[a]	4	0.29	14.13	0	0
9/26/2010	9.8	0.92	25.63	57	0
9/29/2010	2	3.70	25.30	958	845
10/14/2010	9	0.89	6.23	102	91
10/19/2010	4	0.42	5.13	45	51
10/27/2010	7	0.61	12.00	66	31
11/3/2010	5	1.09	17.43	0	0
11/15/2010	10	0.78	31.67	85	70
11/25/2010	7	0.05	2.57	0	0
11/30/2010	4	0.06	4.40	0	0
12/1/2010	12	0.56	6.20	94	70
12/11/2010[a]	10	0.77	22.53	163	119
12/18/2010	6	0.03	1.87	0	0
2/24/2011[a]	1	0.43	14.17	126	121
2/28/2011	2	0.45	18.73	94	103
3/9/2011[a]	2	2.21	26.33	770	1013

Event date	Antecedent dry period (days)	Rainfall depth (in)	Rainfall duration (hours)	Inflow volume (x 10^3 L)	Outflow volume (x 10^3 L)
4/5/2011	3	0.28	7.37	29	0
4/8/2011	2	0.33	12.13	52	0
4/12/2011	3	0.31	6.87	37	0
4/13/2011	0.5	0.18	11.33	38	0
4/16/2011	2	0.90	12.73	191	165
4/19/2011	2	0.11	5.00	0	0
4/22/2011[a]	2	0.33	23.53	24	0
4/24/2011	1	0.63	10.23	166	95
4/28/2011	3.3	0.11	1.63	2	0
5/1/2011	3	0.05	1.60	0	0
5/4/2011	8	0.34	11.03	37	0
5/14/2011[a]	9	0.38	3.17	17	0
5/16/2011	1.7	0.35	0.50	29	0
5/17/2011	0.5	0.27	5.63	76[++]	0
5/17/2011	0.25	0.17	1.60		
5/18/2011	0.42	0.04	1.07		
5/18/2011	0.67	0.24	2.60	43	9
5/19/2011	0.79	0.14	2.87	15	0
6/9/2011[a]	20	0.83	0.67	55	0
6/10/2011	0.75	0.21	0.50	8	0
6/12/2011	1	0.13	0.17	0	0
6/16/2011	5	0.11	0.37	0	0
6/18/2011	1.4	0.09	0.67	0	0
6/20/2011	1	0.10	4.90	0	0
6/21/2011	1.5	0.04	0.17	0	0
7/3/2011	13	0.31	2.87	0	0
7/3/2011	0.46	0.22	0.30	0	0
7/7/2011[a]	3	0.34	2.03	7	0
7/8/2011	0.67	0.44	2.23	39	0
7/11/2011	2	0.08	0.17	0	0
7/19/2011	5	0.16	0.57	0	0
7/25/2011[a]	5	1.82	2.33	204	0
8/1/2011	6	0.10	0.27	0	0
8/3/2011	1	0.35	0.70	0	0
8/6/2011[a]	2	0.94	6.43	174[++]	68[++]
8/7/2011	0.67	0.16	0.27		
8/9/2011	1	0.14	0.17	0	0
8/13/2011	3	0.35	3.53	10	0

Event date	Antecedent dry period (days)	Rainfall depth (in)	Rainfall duration (hours)	Inflow volume (x 10^3 L)	Outflow volume (x 10^3 L)
8/14/2011	0.54	0.62	4.37	162++	140++
8/14/2011	0.39	0.41	3.53		
8/15/2011	0.45	0.13	4.87		
8/21/2011	5.3	0.24	0.30	1	0
8/21/2011	5	0.90	0.90	174	186
8/25/2011	3	0.16	2.03	3	0
8/27/2011	1	3.16	28.87	1148	1429
9/5/2011	7	8.53	91.10	3507	3674
9/11/2011	1	1.55	9.03	474	553
9/20/2011	8	0.07	4.07	0	0
9/22/2011	1.7	0.16	0.23	0	0
9/23/2011[a]	11.3	1.12	12.00	162	135
9/28/2011	4	0.41	1.73	137	139
9/28/2011	0.44	0.40	2.13		
10/1/2011	2	0.31	10.13	49	9
10/3/2011	0.8	0.06	7.40	0	0
10/12/2011[a]	8	0.53	21.20	148++	0
10/13/2011	0.45	0.13	0.40		
10/14/2011	0.34	0.34	4.07		
10/19/2011	4	0.45	5.53	142	129
10/19/2011	0.29	0.30	7.70		
10/26/2011	6	0.06	0.63	0	0
10/27/2011	0.5	0.16	4.50	0	0
10/28/2011	9	0.84	19.73	215	178
11/16/2011	17	0.11	1.70	0	0
11/16/2011[a]	17	0.36	21.90	28	0
11/22/2011	5	1.38	20.80	500	347
11/29/2011	5	0.32	5.63	85	36
12/6/2011	6	0.13	18.57	8	0
12/7/2011[a]	0.5	2.14	19.53	736	834
12/22/2011[a]	14	0.82	7.87	215	147
12/27/2011	3	0.73	10.73	243	213
1/11/2012	10	0.96	16.77	261	214
1/16/2012[a]	3	0.15	16.27	25	0
1/21/2012[a]	3	0.22	9.00	18	0
1/23/2012[a]	1	0.06	1.80	40	0
1/27/2012[a]	3	0.26	2.40	32	7

Event date	Antecedent dry period (days)	Rainfall depth (in)	Rainfall duration (hours)	Inflow volume (x 10^3 L)	Outflow volume (x 10^3 L)
2/4/2012	7	0.11	2.73	15[++]	0
2/5/2012	0.26	0.12	9.57		
2/8/2012	3	0.09	8.43	6	0
2/10/2012	2	0.07	2.60	25[++]	0
2/11/2012	0.29	0.16	2.43		
2/16/2012[a]	5	0.15	9.03	14	0
2/24/2012	7	0.16	6.83	6	0
2/29/2012[a]	4	1.79	15.40	533	381
3/2/2012[a]	1	0.55	15.63	188	135
3/19/2012	16.8	0.04	6.10	0	0
3/24/2012	4	0.37	26.40	18	0
4/1/2012	7	0.08	5.47	0	0
4/18/2012	16.5	0.19	10.60	0	0
4/21/2012	2	0.26	3.73	0	0
4/22/2012[a]	0.42	1.10	15.47	232[++]	0
4/23/2012	0.28	0.08	12.00		
4/26/2012	3	0.14	1.13	5	0
4/28/2012	1	0.08	9.37	0	0
5/2/2012	3	0.21	0.30	10	0
5/3/2012	1.7	0.05	0.77	0	0
5/8/2012	7.5	0.09	1.63	0	0
5/8/2012	0.29	0.17	6.23	5	0
5/9/2012	0.5	0.41	8.07	46	0
5/14/2012[a]	4	1.04	24.67	159	0
5/20/2012	5.9	0.43	15.20	18	0
5/24/2012	3	0.08	0.47	0	0
5/27/2012	3.8	0.12	2.17	0	0
5/29/2012	1.8	0.36	3.73	13	0
6/1/2012	2	2.24	8.08	873	789
6/12/2012[a]	10	0.62	11.47	19	0
6/22/2012	10	0.05	0.60	0	0
6/25/2012	3	0.05	0.27	0	0
6/29/2012	4	0.47	2.47	0	0
7/2/2012	1	0.03	2.90	0	0
7/9/2012	6	0.47	5.03	0	0
7/14/2012	4.5	0.84	2.23	71	0
7/15/2012	0.7	0.06	0.47	0	0
7/19/2012	4	1.34	3.50	136	0

Event date	Antecedent dry period (days)	Rainfall depth (in)	Rainfall duration (hours)	Inflow volume (x 10^3 L)	Outflow volume (x 10^3 L)
7/20/2012[a]	0.83	2.08	24.17	651	522
7/26/2012	6	0.23	4.27	43	0
8/5/2012	9.63	0.37	4.57	0	0
8/9/2012	3.67	0.50	2.30	12	0
8/10/2012	0.29	0.51	4.77	74	0
8/11/2012	0.75	0.08	1.17	1	0
8/12/2012	0.75	0.06	2.97	0	0
8/14/2012	0.67	0.07	1.33	0	0
8/18/2012	3.5	0.32	11.50	2	0
8/20/2012	1.5	0.61	2.08	30	0

[a] Rainfall event sampled for water quality

[++]Flow volumes have been combined since continuous flow occurred during this period.

Appendix B

Table B-1. Water quality data of the 38 sampled rainfall events and 54 dry-weather samplings at the MD 175 infiltration basin site from June 2009 to August 2012.

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
6/24/2009 Dry-weather	65 ± 75			0.32 ± 0.23			2.5 ± 1.7			0.06 ± 0.0		
8/10/2009 Dry-weather	126 ± 107			0.45 ± 0.16			6.6 ± 4.1			0.08 ± 0.06		
8/13/2009 Storm event	181	0*	100	0.52	0*	100	1.5	0*	100	0.58	0*	100
8/21/2009 Storm event	44	0*	100	0.42	0*	100	2.6	0*	100	0.38	0*	100
9/26/2009 Storm event	39	1	98	0.43	0.06	93	1.5	0.93	72	0.96	0.05	97
10/04/2009 Dry-weather	7.6 ± 2.1			0.10 ± 0.06			1.5 ± 0.3			0.06 ± 0.0		
11/19/2009 Storm event	110	9	91	0.25	0.09	60	1.2	0.70	38	0.26	0.06	76
01/18/2010 Storm event	n/a~	n/a~		0.22	0.19	-16	1.3	0.92	-0.32	0.58	0.34	20
3/25/2010 Dry-weather	14 ± 2.1			0.08 ± 0.0			1.19 ± 0.10			0.07 ± 0.02		
3/26/2010 Storm event	72	0*	100	0.22	0*	100	2.1	0*	100	0.46	0*	100
4/24/2010 Dry-weather	16 ± 3.6			0.08 ± 0.0			1.4 ± 0.14			0.11 ± 0.03		
4/25/2010 Storm event	185	29	95	0.28	0.10	91	1.9	1.1	83	0.29	0.14	85
5/2/2010 Dry-weather	9 ± 1.5			0.08 ± 0.0			1.2 ± 0.3			0.22 ± 0.03		
5/22/2010 Dry-weather	15 ± 11			0.11 ± 0.06			0.49 ± 0.3			0.07 ± 0.03		
5/23/2010 Storm event	52	0*	100	0.34	0*	100	1.3	0*	100	0.18	0*	100
5/23/2010 Dry-weather	11 ± 6.6			0.12 ± 0.05			0.98 ± 0.2			0.06 ± 0.0		
6/15/2010 Dry-weather	6 ± 2.5			0.09 ± 0.01			0.89 ± 0.08			0.10 ± 0.05		
6/27/2010 Dry-weather	17 ± 3.3			0.14± 0.03			1.1 ± 0.06			0.06 ± 0.0		
7/9/2010 Dry-weather	44 ± 48			0.19 ± 0.07			2.1 ± 0.43			0.06 ± 0.0		
7/12/2010 Storm event	54	0*	100	0.58	0*	100	0.99	0*	100	0.86	0*	100

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
8/11/2010 Dry-weather	49 ± 30			0.16 ± 0.09			2.03 ± 0.89			0.06 ± 0.0		
8/12/2010 Storm event	47	0*	100	0.58	0*	100	1.39	0*	100	0.47	0*	100
8/12/2010 Dry-weather	9 ± 6			0.10 ± 0.04			1.33 ± 0.10			0.06 ± 0.0		
9/4/2010 Dry-weather	45 ± 28			0.21 ± 0.05			1.96 ± 0.0			0.05 ± 0.0		
9/26/2010 Dry-weather	45 ± 29			0.22 ± 0.14			2.08 ± 0.93			0.06 ± 0.0		
9/27/2010 Storm event	31	0*	100	0.44	0*	100	1.54	0*	100	0.32	0*	100
9/27/2010 Dry-weather	49 ± 23			0.26 ± 0.10			3.66 ± 0.34			0.06 ± 0.0		
10/27/2010 Storm event	35	0*	100	0.42	0*	100	1.57	0*	100	0.12	0*	100
11/14/2010 Dry-weather	2 ± 0.71			0.13 ± 0.05			0.52 ± 0.05			0.06 ± 0.0		
11/17/2010 Storm event	14	0*	100	0.37	0*	100	1.2	0*	100	0.18	0*	100
11/17/2010 Dry-weather	9 ± 6.8			0.17 ± 0.10			0.98 ± 0.40			0.06 ± 0.0		
11/29/2010 Dry-weather	10			0.16 ± 0.06			0.49 ± 0.30			0.06 ± 0.00		
12/1/2010 Storm event	25	3	92	0.34	0.07	85	1.25	0.64	65	0.08	0.05	60
12/1/2010 Dry-weather	4			0.20 ± 0.10			0.7 ± 0. 0			0.06 ± 0.00		
2/24/2011 Dry-weather	22			0.09			0.98			0.01 ± 0.00$^+$		
2/24/2011 Storm event	58	13	79	0.12	0.08	40	0.97	0.98	5	0.03$^+$	0.004$^+$	87
2/25/2011 Dry-weather	22 ± 19			0.06 ± 0.01			0.77 ± 0.10			0.01 ± 0.00$^+$		
3/9/2011 Dry-weather	23 ± 2.7			0.15 ± 0.10			1.26			0.01 ± 0.00$^+$		
3/9/2011 Storm event	130	32	68	0.23	0.18	-3	1.01	0.86	-11	0.011$^+$	0.009$^+$	-0.37
3/11/2011 Dry-weather	75			0.19 ± 0.03			0.98			0.01 ± 0.00$^+$		
4/21/2011 Dry-weather	13 ± 3.5			0.10 ± 0.02			0.98			0.01 ± 0.00$^+$		
4/22/2011 Storm event	28	0*	100	0.21	0*	100	1.93	0*	100	0.03$^+$	0*	100
4/23/2011 Dry-weather	12 ± 6.2			0.08 ± 0.07			1.12			0.01 ± 0.00$^+$		
5/14/2011 Dry-weather	20 ± 14			0.19 ± 0.02			1.68			0.01 ± 0.00$^+$		
5/14/2011 Storm event	34	0*	100	0.36	0*	100	2.28	0*	100	0.02$^+$	0*	100

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
5/15/2011 Dry-weather	25 ± 9.9			0.17 ± 0.04			1.82			0.01 ± 0.00^{+}		
6/9/2011 Storm event	134	0*	100	0.60	0*	100	n/a~			n/a~		
7/7/2011 Storm event	48	0*	100	0.55	0*	100	2.18	0*	100	n/a~		
7/25/2011 Storm event	30	0*	100	0.37	0*	100	1.46	0*	100	0.03^{+}	0*	100
8/5/2011 Dry-weather	14 ± 2.8			0.27 ± 0.03			1.49			0.01 ± 0.00^{+}		
8/6/2011 Storm event	38	10	90	0.36	0.14	85	1.6	0.47	89	0.93	0.16	93
8/7/2011 Dry-weather	16 ± 4.9			0.25 ± 0.08			1.68			0.01 ± 0.00^{+}		
9/21/2011 Dry-weather	60 ± 29			0.18 ± 0.03			0.91 ± 0.1			0.13 ± 0.00^{+}		
9/21/2011 Storm event	58	9	91	0.27	0.11	76	1.4	0.81	67	0.4	0.2	58
9/23/2011 Dry-weather	11 ± 1.1			0.16 ± 0.03			0.98 ± 0.0			0.08 ± 0.00		
10/10/2011 Dry-weather	15 ± 4.2			0.11 ± 0.02			0.98			0.06 ± 0.00		
10/12/2011 Storm event	52	0*	100	0.32	0*	100	1.5	0*	100	0.32	0*	100
10/13/2011 Dry-weather	55 ± 27			0.15 ± 0.07			1.82			0.06 ± 0.00		
11/15/2011 Dry-weather	6 ± 3.1			0.15 ± 0.07			0.93			0.06 ± 0.00		
11/16/2011 Storm event	36	0*	100	0.51	0*	100	1.88	0*	100	0.07	0*	100
11/17/2011 Dry-weather	8 ± 1.2			0.15 ± 0.03			1.12			0.06 ± 0.00		
12/06/2011 Dry-weather	8			0.11 ± 0.07			1.31			0.06 ± 0.00		
12/07/2011 Storm event	90	14	82	0.19	0.14	17	1.23	1.22	-13	1.01	0.22	85
12/09/2011 Dry-weather	5 ± 1.5			0.11 ± 0.004			2.24			0.21 ± 0.11		
12/20/2011 Dry-weather	5 ± 2.5			0.11 ± 0.01			0.84 ± 0.2			0.06 ± 0.00		
12/22/2011 Storm event	49	4	94	0.17	0.12	52	1.28	1.00	46	0.25	0.05	85
12/23/2011 Dry-weather	8 ± 2.3			0.11 ± 0.02			0.84 ± 0.2			0.06 ± 0.00		
01/16/2012 Storm event	40	0*	100	0.24	0*	100	1.47	0*	100	1.03	0*	100
01/21/2012 Storm event	33	0*	100	0.04	0*	100	1.26	0*	100	0.65	0*	100
01/23/2012 Storm event	13	0*	100	0.08	0*	100	1.26	0*	100	1.18	0*	100

Event	TSS			TP			TKN (as N)			Nitrite + Nitrate (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
01/24/2012 Dry-weather	92			0.14			1.12			0.13		
01/27/2012 Storm event	490	0*	100	0.14	0*	100	3.16	0*	100	0.89	0*	100
01/28/2012 Dry-weather	6 ± 1.1			0.12 ± 0.01			0.75			0.08 ± 0.00		
02/14/2012 Dry-weather	10			0.08			0.93			0.06		
02/16/2012 Storm event	252	0*	100	0.11	0*	100	2.45	0*	100	0.58	0*	100
02/17/2012 Dry-weather	7 ± 3.2			0.08 ± 0.04			1.1 ± 0.05			0.26 ± 0.02		
02/27/2012 Dry-weather	7 ± 1.1			0.06 ± 0.02			0.56			0.06 ± 0.00		
02/29/2012 Storm event	510	30	96	0.39	0.11	80	2.43	0.93	72	0.77	0.28	73
03/1/2012 Dry-weather	24 ± 3.5			0.11 ± 0.01			0.75			0.06 ± 0.00		
03/2/2012 Storm event	80	15	86	0.16	0.11	52	1.49	0.93	55	0.24	0.15	55
03/4/2012 Dry-weather	13 ± 0.76			0.09 ± 0.00			0.93			0.08 ± 0.04		
04/22/2012 Storm event	79	0*	100	0.27	0*	100	1.03	0*	100	0.29	0*	100
05/13/2012 Dry-weather	17			0.10			0.56			0.06		
05/14/2012 Storm event	71	0*	100	0.23	0*	100	1.11	0*	100	0.13	0*	100
05/16/2012 Dry-weather	11 ± 0.71			0.10 ± 0.02			0.75			0.06 ± 0.00		
06/10/2012 Dry-weather	21 ± 3.5			0.16 ± 0.05			0.75			0.06 ± 0.00		
06/12/2012 Storm event	32	0*	100	0.30	0*	100	2.37	0*	100	0.15	0*	100
06/13/2012 Dry-weather	23 ± 13			0.26 ± 0.12			1.68			0.06 ± 0.00		
07/20/2012 Dry-weather	41 ± 46			0.36 ± 0.15			2.61			0.08 ± 0.03		
07/20/2012 Storm event	34	14	67	0.21	0.21	18	1.21	1.17	23	0.06	0.06	20
07/23/2012 Dry-weather	11 ± 11			0.25 ± 0.01			1.31			0.06 ± 0.00		

Table B-1. (Continued) Water quality data of the 38 sampled rainfall events and 54 dry-weather samplings at the MD 175 infiltration basin site from June 2009 to August 2012.

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
6/24/2009 Dry-weather	7 ± 2.7			6 ± 4			23 ± 13			13 ± 0.1		
8/10/2009 Dry-weather	4 ± 2.1			2 ± 2.8			13 ± 0.0			21 ± 0.14		
8/13/2009 Storm event	7	0*	100	11	0*	100	n/a~	0*		22	0*	100
8/21/2009 Storm event	5	0*	100	13	0*	100	55	0*	100	44	0*	100
9/26/2009 Storm event	2	2	48	10	2	93	47	11	90	79	19	89
10/04/2009 Dry-weather	3 ± 0.0			2 ± 0.0			n/a~			22 ± 0.55		
11/19/2009 Storm event	6	4	29	11	4	64	56	43	18	15	12	10
01/18/2010 Storm event	2	2	-28	5	4	-8	43	35	-13	647	522	-10
3/25/2010 Dry-weather	3 ± 0.0			3 ± 0.72			17 ± 9.1			444 ± 19		
3/26/2010 Storm event	6	0*	100	13	0*	100	58	0*	100	449	0*	100
4/24/2010 Dry-weather	3 ± 0.0			1 ± 0.7			13 ± 0.0			562 ± 86		
4/25/2010 Storm event	6	2	90	20	5	93	54	10	94	120	303	21
5/2/2010 Dry-weather	3 ± 0.0			1 ± 0.7			13 ± 0.0			427 ± 33		
5/22/2010 Dry-weather	3 ± 0.0			1 ± 0.93			21 ± 16			339 ± 14		
5/23/2010 Storm event	3	0*	100	16	0*	100	51	0*	100	113	0*	100
5/23/2010 Dry-weather	3 ± 0.0			1 ± 0.6			13 ± 0.0			320 ± 20		
6/15/2010 Dry-weather	3 ± 0.0			1 ± 0.7			13 ± 0.0			297 ± 6		
6/27/2010 Dry-weather	3 ± 0.0			2 ± 1.1			13 ± 0.0			392 ± 10		
7/9/2010 Dry-weather	5 ± 3.1			5 ± 3.5			13 ± 0.0			436 ± 13		
7/12/2010 Storm event	4	0*	100	13	0*	100	25	0*	100	42	0*	100
8/11/2010 Dry-weather	3 ± 0.0			3 ± 0.46			13 ± 0.0			106 ± 6		
8/12/2010 Storm event	4	0*	100	12	0*	100	22	0*	100	42	0*	100
8/12/2010 Dry-weather	3 ± 0.0			1 ± 0.67			13 ± 0.0			100 ± 11		
9/4/2010 Dry-weather	3 ± 0.0			3 ± 0.42			13 ± 0.0			25 ± 2.3		

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_{R}$ (%)	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_{R}$ (%)	EMC$_{in}$ (µg L^{-1})	EMC$_{out}$ (µg L^{-1})	M$_{R}$ (%)	EMC$_{in}$ (mg L^{-1})	EMC$_{out}$ (mg L^{-1})	M$_{R}$ (%)
9/26/2010 Dry-weather	3 ± 0.0			3 ± 1.9			13 ± 0.0			35 ± 4.1		
9/27/2010 Storm event	3	0*	100	11	0*	100	15	0*	100	66	0*	100
9/27/2010 Dry-weather	3 ± 0.0			3 ± 1.4			13 ± 0.0			33 ± 6.7		
10/27/2010 Storm event	3	0*	100	8	0*	100	32	0*	100	43	0*	100
11/14/2010 Dry-weather	4 ± 1.9			1.7 ± 1.0			17 ± 8.5			26 ± 0.66		
11/17/2010 Storm event	2	0*	100	7	0*	100	29	0*	100	52	0*	100
11/17/2010 Dry-weather	5 ± 1.9			3 ± 1.6			42 ± 4.9			23 ± 1.7		
11/29/2010 Dry-weather	3 ± 0.0			1.3 ± 0.64			38 ± 7.6			25 ± 1.1		
12/1/2010 Storm event	3	2	39	4	1	82	44	21	67	26	22	42
12/1/2010 Dry-weather	3 ± 0.0			1.7 ± 1.3			34 ± 4.8			23 ± 1.9		
2/24/2011 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			655		
2/24/2011 Storm event	3	2	32	6	1	83	38	17	58	1251	702	47
2/25/2011 Dry-weather	3 ± 0.0			1 ± 0.67			26 ± 11			825 ± 51		
3/9/2011 Dry-weather	3 ± 0.0			5 ± 0.63			31 ± 4.4			408 ± 74		
3/9/2011 Storm event	5	2	37	6	4	11	48	38	-1	43	117	-253
3/11/2011 Dry-weather	3 ± 0.0			5 ± 0.83			40 ± 5.9			101 ± 15		
4/21/2011 Dry-weather	3 ± 0.0			1 ± 0.59			13 ± 0.0			229 ± 3.7		
4/22/2011 Storm event	4	0*	100	11	0*	100	41	0*	100	307	0*	100
4/23/2011 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			238 ± 3.0		
5/14/2011 Dry-weather	3 ± 0.0			1 ± 0.0			27 ± 0.33			252 ± 12.5		
5/14/2011 Storm event	3	0*	100	13	0*	100	44	0*	100	157	0*	100
5/15/2011 Dry-weather	3 ± 0.0			2 ± 1.3			13 ± 0.0			243 ± 3.8		
6/9/2011 Storm event	4	0*	100	18	0*	100	52	0*	100	n/a~		
7/7/2011 Storm event	4	0*	100	14	0*	100	50	0*	100	37	0*	100
7/25/2011 Storm event	3	0*	100	8	0*	100	28	0*	100	14	0*	100
8/5/2011 Dry-weather	4 ± 2.01			3 ± 0.01			13 ± 0.0			84 ± 5.2		

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (µg L^{-1})	EMC_{out} (µg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} (mg L^{-1})	M_R (%)
8/6/2011 Storm event	4	2	80	9	3	89	25	11	84	21	58	-12
8/7/2011 Dry-weather	4 ± 2.2			7 ± 5.3			13 ± 0.0			49 ± 32		
9/21/2011 Dry-weather	4 ± 2.5			6 ± 0.69			13 ± 0.0			8 ± 0.36		
9/21/2011 Storm event	5	6	28	8	3	77	19	12	63	15	6	68
9/23/2011 Dry-weather	3 ± 0.0			5 ± 1.3			13 ± 0.0			19 ± 10		
10/10/2011 Dry-weather	3 ± 0.0			1 ± 0.0			41 ± 0.1			23 ± 0.79		
10/12/2011 Storm event	2	0*	100	8	0*	100	44	0*	100	56	0*	100
10/13/2011 Dry-weather	3 ± 0.0			1 ± 0.0			45 ± 1.7			15 ± 2		
11/15/2011 Dry-weather	3 ± 0.0			2 ± 1.7			13 ± 0.0			18 ± 0.39		
11/16/2011 Storm event	5	0*	100	9	0*	100	15	0*	100	73	0*	100
11/17/2011 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			18 ± 2.1		
12/06/2011 Dry-weather	3 ± 0.0			4 ± 1.7			13 ± 0.0			15 ± 1.5		
12/07/2011 Storm event	2	1	-13	5	2	48	44	33	16	5	6	-50
12/09/2011 Dry-weather	3 ± 0.0			2 ± 1.1			30 ± 2.6			7 ± 5.2		
12/20/2011 Dry-weather	3 ± 0.0			1 ± 0.0			18 ± 8.6			6 ± 3.1		
12/22/2011 Storm event	3	3	32	4	2	67	43	33	48	10	7	54
12/23/2011 Dry-weather	3 ± 0.0			2 ± 0.84			33 ± 3.4			8 ± 1.4		
01/16/2012 Storm event	9	0*	100	4	0*	100	46	0*	100	30	0*	100
01/21/2012 Storm event	3	0*	100	1	0*	100	39	0*	100	6423	0*	100
01/23/2012 Storm event	3	0*	100	1	0*	100	33	0*	100	3126	0*	100
01/24/2012 Dry-weather	6			3			13			8		
01/27/2012 Storm event	13	0*	100	6	0*	100	103	0*	100	979	0*	100
01/28/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			18 ± 4.8		
02/14/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0					
02/16/2012 Storm event	3	0*	100	3	0*	100	32	0*	100	1326	0*	100
02/17/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			172 ± 31		

Event	Total Pb			Total Cu			Total Zn			Chloride		
	EMC_{in} ($\mu g\ L^{-1}$)	EMC_{out} ($\mu g\ L^{-1}$)	M_R (%)	EMC_{in} ($\mu g\ L^{-1}$)	EMC_{out} ($\mu g\ L^{-1}$)	M_R (%)	EMC_{in} ($\mu g\ L^{-1}$)	EMC_{out} ($\mu g\ L^{-1}$)	M_R (%)	EMC_{in} ($mg\ L^{-1}$)	EMC_{out} ($mg\ L^{-1}$)	M_R (%)
02/27/2012 Dry-weather	3 ± 0.0			1 ± 0.0			13 ± 0.0			286 ± 39		
02/29/2012 Storm event	11	3	84	26	6	84	93	13	90	185	220	15
03/1/2012 Dry-weather	3 ± 1.6			5 ± 0.74			17 ± 8.3			229 ± 41		
03/2/2012 Storm event	7	3	72	8	4	62	28	13	68	118	104	37
03/4/2012 Dry-weather	3 ± 0.0			4 ± 0.27			13 ± 0.0			143 ± 9.1		
04/22/2012 Storm event	9	0*	100	10	0*	100	40	0*	100	81	0*	100
05/13/2012 Dry-weather	5			7			13			117		
05/14/2012 Storm event	8	0*	100	12	0*	100	35	0*	100	42	0*	100
05/16/2012 Dry-weather	4 ± 2.1			3 ± 2.3			20 ± 10			103 ± 8		
06/10/2012 Dry-weather	3 ± 0.0			3 ± 0.56			13 ± 0.0			10 ± 1.9		
06/12/2012 Storm event	22	0*	100	12	0*	100	13	0*	100	18	0*	100
06/13/2012 Dry-weather	3 ± 0.0			2 ± 1.2			13 ± 0.0			11 ± 1.1		
07/20/2012 Dry-weather	7 ± 5.7			5 ± 3.7			23 ± 14			17 ± 3.5		
07/20/2012 Storm event	3	3	20	8	5	52	13	13	20	5	7	-11
07/23/2012 Dry-weather	4 ± 2.1			4 ± 0.43			21 ± 11			8 ± 0.88		

EMC = Event mean concentration (as defined in Equation 5); $\mathbf{M_R}$ = Mass removal efficiency (as defined in Equation 4);
*****Entire inflow runoff volume assimilated
[+] Nitrite only
n/a Not applicable
n/a~ No data due to lab accident and/or equipment failure

Table B-1. (Continued) Water quality data of the 38 sampled rainfall events and 54 dry-weather samples at the MD 175 infiltration basin site from June 2009 to August 2012.

Event	Dissolved P			Ammonium (as N)		
	EMC_{in} (mg L^{-1})	EMC_{out} mg L^{-1})	M_R (%)	EMC_{in} (mg L^{-1})	EMC_{out} mg L^{-1})	M_R (%)
3/25/2010 Dry-weather	0.01 ± 0.0			n/a		
3/26/2010 Storm event	0.12	0*	100	n/a		
4/24/2010 Dry-weather	0.018 ± 0.002			n/a		
5/23/2010 Storm event	0.15	0.057	89	n/a	n/a	
5/22/2010 Dry-weather	0.038 ± 0.006			n/a		
5/23/2010 Storm event	0.16	0*	100	n/a		
5/23/2010 Dry-weather	0.041 ± 0.008			n/a		
6/15/2010 Dry-weather	0.083 ± 0.002			n/a		
6/27/2010 Dry-weather	0.087 ± 0.033			n/a		
7/9/2010 Dry-weather	0.079 ± 0.012			n/a		
9/26/2010 Dry-weather	0.078 ± 0.016			n/a		
9/27/2010 Storm event	0.32	0*	100	n/a		
9/27/2010 Dry-weather	0.067 ± 0.009			n/a		
8/06/2011 Storm event	0.23	0.053	90	n/a		
9/23/2011 Storm event	0.17	0.072	64	n/a		
12/06/2011 Dry-weather	0.094 ± 0.005			n/a		
12/07/2011 Storm event	0.074	0.077	-18	0.14	0.14	-13
12/09/2011 Dry-weather	0.064 ± 0.006			n/a		
12/20/2011 Dry-weather	0.041 ± 0.011			n/a		
12/22/2011 Storm event	0.093	0.070	48	0.17	0.10	59
12/23/2011 Dry-weather	0.074 ± 0.008			n/a		
01/23/2012 Storm event	n/a			0.56	0*	100
01/24/2012 Dry-weather	0.080			n/a		
01/27/2012 Storm event	0.061	0*	100	1.21	0*	100
01/28/2012 Dry-weather	0.067 ± 0.014			n/a		
02/14/2012 Dry-weather	0.035			n/a		
02/16/2012 Storm event	0.039	0*	100	1.12	0*	100
02/17/2012 Dry-weather	0.030 ± 0.008			n/a		
02/27/2012 Dry-weather	0.016 ± 0.001			n/a		
02/29/2012 Storm event	0.054	0.023	70	0.37	0.19	64
03/1/2012 Dry-weather	0.033 ± 0.010			n/a		
03/2/2012 Storm event	0.040	0.014	74	0.28	0.28	28
03/4/2012 Dry-weather	0.019 ± 0.005			n/a		
04/22/2012 Storm event	0.14	0*	100	0.19	0*	100
07/20/2012 Storm event	0.12	0.11	22	0.047	0.093	30

Table B-2. Water quality data of measured sample pollutant concentrations for the 38 storm events sampled at the infiltration basin site from August 2009 to August 2012.

WATER QUALITY DATA FOR STORM EVENT ON 08/13/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO2-N**	**NO3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
8/13/09 0:42	0	5.73	443	0.47	3.45	0.05	0.86	12	26	152	43
8/13/09 1:02	20	23.67	492	0.82	2.01	0.03	0.82	20	20	99	18
8/13/09 1:22	20	26.88	78	0.51	0.70	0.02	0.44	< 5	8	39	16
8/13/09 1:42	20	14.69	43	0.41	1.33	0.02	0.42	< 5	7	38	19
8/13/09 2:02	20	7.73	9	0.31	1.96	0.03	0.40	< 5	6	38	23
8/13/09 2:22	20	4.12	10	0.34	1.27	0.03	0.41	< 5	6	38	27
8/13/09 2:42	20	2.38	11	0.36	0.59	0.03	0.42	< 5	6	37	30
8/13/09 3:02	20	1.56	8	0.37	0.75	0.04	0.43	< 5	6	37	35
8/13/09 3:22	20	0.90	5	0.37	0.91	0.04	0.43	< 5	6	37	40
8/13/09 4:22	60	0.25	4	0.38	1.30	0.06	0.47	< 5	7	38	53
8/13/09 5:22	60	0.15	3	0.39	1.68	0.08	0.51	< 5	8	40	55
8/13/09 6:42	80	0.05	6	0.38	0.28	0.03	1.04	< 5	9	33	60

WATER QUALITY DATA FOR STORM EVENT ON 08/21/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
8/21/09 20:46	0	1.38	540	1.14	3.35	0.03	1.19	12	33	154	38
8/21/09 21:06	20	3.54	68	0.75	2.44	0.02	0.71	< 5	13	62	47
8/21/09 21:26	20	5.31	46	0.63	6.87	0.02	0.52	< 5	10	67	30
8/21/09 21:46	20	4.10	25	0.58	1.70	0.01	0.38	< 5	10	62	35
8/21/09 22:06	20	2.86	21	0.51	2.23	0.02	0.35	< 5	10	59	42
8/21/09 22:26	20	2.06	17	0.45	2.76	0.02	0.33	< 5	10	56	49
8/21/09 22:46	20	0.30	13	0.38	3.29	0.03	0.30	< 5	10	53	57
8/21/09 23:06	20	0.97	9	0.32	3.82	0.03	0.27	< 5	9	51	64
8/21/09 23:26	20	0.63	10	0.31	2.78	0.03	0.27	< 5	9	40	67
8/22/09 0:26	60	0.24	6	0.16	1.74	0.01	0.25	< 5	12	59	80
8/22/09 1:26	60	0.16	10	0.16	1.93	0.01	0.28	< 5	11	54	88
8/22/09 2:46	80	0.27	16	0.15	2.11	0.01	0.23	16	31	58	81

WATER QUALITY DATA FOR STORM EVENT ON 09/26/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
9/26/09 19:48	0	0.59	36	0.53	2.36	0.030	0.72	< 5	13	54	109
9/26/09 20:08	20	1.09	36	0.53	2.04	0.028	0.65	< 5	11	58	35
9/26/09 20:28	20	0.85	42	0.52	1.72	0.033	0.52	< 5	10	65	35
9/26/09 20:48	20	1.05	40	0.52	1.74	0.038	0.51	< 5	9	60	31
9/26/09 21:08	20	1.49	54	0.43	1.77	0.031	0.49	< 5	9	103	27
9/26/09 21:28	20	2.34	25	0.27	1.39	0.027	0.18	< 5	7	62	23
9/26/09 21:48	20	2.74	18	0.34	1.02	0.014	0.32	< 5	7	63	88
9/26/09 22:08	20	3.42	28	0.31	2.10	0.014	0.17	< 5	7	61	35
9/26/09 22:28	20	4.93	142	0.65	3.18	0.089	1.31	< 5	16	153	68
9/26/09 23:28	60	8.94	44	0.60	2.61	< 0.01	1.13	< 5	11	58	107
9/27/09 0:28	60	6.48	19	0.53	2.04	< 0.01	1.39	< 5	12	48	112
9/27/09 1:48	80	4.19	45	0.52	1.02	< 0.01	1.36	< 5	13	34	117
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
9/27/2009 1:46	0	0.46	7	0.11	1.56	< 0.01	< 0.10	< 5	5	39	22
9/27/2009 2:06	20	0.75	5	0.10	1.37	< 0.01	< 0.10	7	4	< 25	22
9/27/2009 2:26	20	1.18	3	0.10	1.18	< 0.01	< 0.10	5	3	< 25	22
9/27/2009 2:46	20	1.62	1	0.11	1.94	< 0.01	< 0.10	5	< 2	< 25	22
9/27/2009 3:06	20	2.05	2	0.09	2.70	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 3:26	20	2.30	1	0.10	3.46	< 0.01	< 0.10	< 5	2	< 25	22
9/27/2009 3:46	20	2.51	3	0.10	4.23	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 4:06	20	2.70	2	0.11	2.55	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 4:26	20	2.97	2	0.10	0.87	< 0.01	< 0.10	< 5	< 2	< 25	22
9/27/2009 5:26	60	3.33	2	0.11	0.77	< 0.01	< 0.10	< 5	3	< 25	22
9/27/2009 6:26	60	3.03	1	0.11	0.66	< 0.01	< 0.10	< 5	2	< 25	22
9/27/2009 7:46	80	2.28	1	0.11	0.33	< 0.01	< 0.10	< 5	< 2	< 25	22

WATER QUALITY DATA FOR STORM EVENT ON 11/19/2009											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/19/2009 17:38	0	0.34	88	0.39	2.66	0.044	0.54	6	14	65	57
11/19/2009 17:58	20	0.52	55	0.38	2.87	0.055	0.50	5	13	56	43
11/19/2009 18:18	20	0.41	36	0.35	3.08	0.031	0.47	< 5	12	71	43
11/19/2009 18:38	20	0.32	27	0.35	2.52	0.028	0.42	6	12	57	45
11/19/2009 19:18	40	0.26	23	0.32	1.96	0.024	0.39	< 5	13	66	48
11/19/2009 19:58	40	0.24	22	0.27	1.54	0.025	0.37	< 5	11	48	49
11/19/2009 20:58	60	0.21	19	0.27	1.12	0.024	0.30	< 5	12	32	52
11/19/2009 21:58	60	1.03	25	0.23	1.26	0.025	0.26	11	17	56	51
11/19/2009 23:18	80	7.13	245	0.37	1.40	0.027	0.23	10	17	73	16
11/20/2009 0:38	80	8.77	117	0.22	1.33	0.032	0.16	7	9	59	7
11/20/2009 2:18	100	2.36	50	0.25	1.26	0.021	0.30	< 5	7	54	9
11/20/2009 3:58	100	1.15	41	0.21	0.63	0.019	0.40	5	6	48	12
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/19/2009 23:36	0	0.53	11	0.13	0.70	< 0.01	< 0.10	< 5	7	62	13
11/19/2009 23:56	20	2.00	9	0.13	0.77	< 0.01	< 0.10	< 5	22	70	14
11/20/2009 0:16	20	4.50	7	0.11	0.84	< 0.01	< 0.10	< 5	2	70	14
11/20/2009 0:56	40	7.86	5	0.12	0.91	< 0.01	< 0.10	< 5	2	38	14
11/20/2009 1:36	40	7.10	7	0.09	0.98	< 0.01	< 0.10	< 5	2	52	13
11/20/2009 2:36	60	4.34	12	0.11	0.77	< 0.01	< 0.10	< 5	5	42	13
11/20/2009 3:36	60	2.79	15	0.13	0.56	< 0.01	< 0.10	< 5	4	38	14
11/20/2009 4:56	80	1.96	15	0.14	0.66	< 0.01	< 0.10	< 5	3	43	13
11/20/2009 6:16	80	1.49	7	0.14	0.70	< 0.01	< 0.10	< 5	4	62	14
11/20/2009 7:56	100	1.11	15	0.17	0.77	< 0.01	< 0.10	< 5	4	43	13
11/20/2009 9:36	100	0.86	5	0.18	0.84	< 0.01	< 0.10	< 5	4	42	13
11/20/2009 11:16	100	0.68	13	0.24	0.42	< 0.01	0.12	< 5	4	37	13

WATER QUALITY DATA FOR STORM EVENT ON 01/17/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
1/17/2010 9:52	0	0.46	n/a	0.08	4.62	0.097	1.84	9	12	90	1211
1/17/2010 10:12	20	1.51	n/a	0.19	3.92	0.112	0.55	< 5	15	63	2445
1/17/2010 10:32	20	1.75	n/a	0.28	3.22	0.099	1.31	< 5	9	55	2030
1/17/2010 10:52	20	3.15	n/a	0.42	2.73	0.068	0.97	< 5	11	72	1245
1/17/2010 11:32	40	5.04	n/a	0.42	2.24	0.071	0.57	< 5	12	71	976
1/17/2010 12:12	40	6.96	n/a	0.42	1.93	0.062	0.48	< 5	11	66	835
1/17/2010 13:12	60	6.94	n/a	0.25	1.61	0.043	0.56	< 5	8	52	612
1/17/2010 14:12	60	5.30	n/a	0.24	1.37	0.038	0.50	< 5	7	48	546
1/17/2010 15:32	80	3.07	n/a	0.22	1.12	0.033	0.57	< 5	4	43	586
1/17/2010 16:52	80	2.20	n/a	0.23	1.30	0.029	0.64	< 5	4	59	663
1/17/2010 18:32	100	1.76	n/a	0.17	1.47	0.025	0.71	< 5	3	34	718
1/17/2010 20:12	100	1.88	n/a	0.17	0.74	0.024	0.78	< 5	3	36	774
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
1/17/2010 13:22	0	0.44	n/a	0.06	0.84	0.021	0.29	< 5	5	57	210
1/17/2010 13:42	20	1.04	n/a	0.16	1.26	0.037	0.35	< 5	5	40	432
1/17/2010 14:02	20	1.69	n/a	0.15	1.68	0.043	0.32	< 5	5	51	508
1/17/2010 14:42	40	2.51	n/a	0.24	1.40	0.042	0.34	< 5	7	50	496
1/17/2010 15:22	40	3.29	n/a	0.24	1.12	0.040	0.36	< 5	6	45	515
1/17/2010 16:22	60	3.96	n/a	0.24	1.16	0.040	0.39	< 5	5	48	542
1/17/2010 17:22	60	3.97	n/a	0.25	1.19	0.040	0.44	< 5	5	44	584
1/17/2010 18:42	80	4.10	n/a	0.23	1.37	0.055	0.42	< 5	7	43	577
1/17/2010 20:02	80	4.12	n/a	0.23	1.82	0.040	0.41	< 5	6	46	638
1/17/2010 21:42	100	4.38	n/a	0.24	1.54	0.040	0.38	< 5	6	47	675
1/17/2010 23:22	100	4.29	n/a	0.23	1.26	0.038	0.34	< 5	6	45	768
1/18/2010 1:02	100	3.91	n/a	0.23	0.63	0.038	0.37	< 5	4	41	725

WATER QUALITY DATA FOR STORM EVENT ON 03/26/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
3/26/2010 1:42	0	0.45	823	0.58	0.14	2.52	0.023	0.60	24	41	146	682
3/26/2010 2:02	20	0.57	154	0.28	0.14	2.56	0.025	0.54	10	23	70	569
3/26/2010 2:22	20	0.68	111	0.19	0.13	2.59	0.029	0.48	7	20	63	504
3/26/2010 2:42	20	0.51	72	0.27	0.13	2.03	0.047	0.46	5	18	56	499
3/26/2010 3:22	40	0.68	111	0.27	0.13	1.47	0.027	0.43	6	18	57	420
3/26/2010 4:02	40	0.81	77	0.27	0.14	2.07	0.027	0.42	6	17	62	368
3/26/2010 5:02	60	2.05	102	0.31	0.13	2.66	0.020	0.57	< 5	15	64	365
3/26/2010 6:02	60	1.40	37	0.16	0.11	2.17	0.018	0.47	< 5	10	55	431
3/26/2010 7:22	80	0.68	32	0.18	0.10	1.68	0.016	0.41	< 5	8	48	510
3/26/2010 8:42	80	0.36	28	0.16	0.08	2.04	0.016	0.40	< 5	10	49	560
3/26/2010 10:22	100	0.49	95	0.18	0.06	2.40	0.027	0.28	7	13	66	362
3/26/2010 12:02	100	0.55	27	0.17	0.04	1.20	0.016	0.32	< 5	9	48	571

WATER QUALITY DATA FOR STORM EVENT ON 04/25/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
4/25/2010 20:52	0	3.22	1771	1.37		8.30	0.028	0.35	42	79	313	172
4/25/2010 21:12	20	14.65	562	0.72	0.08	4.85	0.015	0.34	14	73	161	42
4/25/2010 21:32	20	13.83	246	0.40		1.40	0.014	0.33	9	21	77	54
4/25/2010 21:52	20	6.92	83	0.21	0.05	1.61	0.015	0.28	5	13	39	68
4/25/2010 22:32	40	6.31	133	0.26		1.82	0.016	0.27	6	14	43	82
4/25/2010 23:12	40	6.13	103	0.25	0.08	1.61	0.016	0.34	6	15	39	79
4/26/2010 0:12	60	4.52	51	0.18		1.40	0.015	0.32	< 5	11	35	80
4/26/2010 1:12	60	1.99	39	0.18	0.08	1.51	0.016	0.26	< 5	11	27	125
4/26/2010 2:32	80	1.23	32	0.20		1.61	0.011	0.28	< 5	12	32	143
4/26/2010 3:52	80	0.52	23	0.17	0.08	1.65	0.017	0.29	< 5	12	< 25	191
4/26/2010 5:32	100	0.24	28	0.15		1.68	0.018	0.32	< 5	12	< 25	315
4/26/2010 7:12	100	0.22	34	0.06	0.07	1.68	0.016	0.30	< 5	14	< 25	441
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
4/26/2010 0:30	0	0.45	34	0.09		1.40	< 0.01	0.23	< 5	8	33	379
4/26/2010 0:50	20	0.64	43	0.13	0.00	1.52	< 0.01	0.19	< 5	8	< 25	381
4/26/2010 1:10	20	0.79	40	0.14		1.59	< 0.01	0.21	< 5	7	25	379
4/26/2010 1:50	20	0.93	48	0.11	0.01	1.65	< 0.01	0.17	< 5	8	< 25	380
4/26/2010 2:30	40	0.98	40	0.14		1.40	< 0.01	0.22	< 5	7	< 25	382
4/26/2010 3:30	40	0.92	47	0.11	0.00	1.26	< 0.01	0.18	< 5	6	< 25	381
4/26/2010 4:30	60	0.79	40	0.11		1.12	< 0.01	0.21	< 5	6	< 25	386
4/26/2010 5:50	60	0.65	32	0.12	0.01	1.12	< 0.01	0.18	< 5	7	< 25	389
4/26/2010 7:10	80	0.53	35	0.04		1.12	< 0.01	0.18	< 5	6	< 25	397
4/26/2010 8:50	80	0.44	32	0.11	0.02	1.33	< 0.01	0.18	< 5	8	< 25	393
4/26/2010 10:30	100	0.36	36	0.13		1.54	< 0.01	0.12	< 5	5	< 25	404
4/26/2010 12:10	100	0.49	35	0.15	0.01	1.54	< 0.01	0.14	< 5	5	< 25	385

WATER QUALITY DATA FOR STORM EVENT ON 05/23/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
5/23/2010 4:30	0	0.54	69	0.40	0.18	1.39	0.042	0.27	< 5	24	47	231
5/23/2010 5:30	60	3.13	105	0.51	0.17	1.32	0.017	0.22	< 5	20	69	45
5/23/2010 6:30	60	2.18	24	0.25	0.16	1.26	0.012	0.11	< 5	12	40	84
5/23/2010 7:30	60	0.84	14	0.23	0.15	1.30	0.015	0.10	< 5	12	53	121
5/23/2010 8:30	60	0.32	16	0.19	0.13	1.33	0.016	0.08	< 5	13	34	148
5/23/2010 9:30	60	0.19	15	0.25	0.11	1.67	0.017	0.08	5	14	36	203
5/23/2010 10:30	60	0.15	16	0.21	0.10	2.00	0.016	0.09	< 5	14	42	264
5/23/2010 11:30	60	0.11	14	0.20	0.09	1.98	0.015	0.09	< 5	15	58	300
5/23/2010 12:30	60	0.07	29	0.19	0.09	1.96	0.016	0.11	< 5	14	44	350
5/23/2010 13:30	60	0.02	33	0.18	0.05	0.98	0.015	0.16	< 5	15	39	409

WATER QUALITY DATA FOR STORM EVENT ON 07/12/2010												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
7/12/2010 16:08	0	0.33	96	0.50	0.45	2.30	0.042	0.55	6	16	37	73
7/12/2010 16:28	20	3.99	76	0.60	0.46	1.26	0.025	0.73	5	16	42	27
7/12/2010 16:48	20	2.47	40	0.60	0.46	1.46	0.031	0.99	< 5	12	< 25	34
7/12/2010 17:08	20	1.10	27	0.57	0.47	1.66	0.039	0.88	< 5	11	< 25	46
7/12/2010 17:28	20	0.46	20	0.58	0.47	1.68	0.042	0.83	6	11	< 25	59
7/12/2010 18:08	20	0.09	21	0.54	0.24	1.71	0.046	1.07	< 5	13	< 25	72

WATER QUALITY DATA FOR STORM EVENT ON 08/12/2010											
Sampling Time	Duration	Inflow	TSS	TP	TKN-N	NO_2-N	NO_3-N	Total Pb	Total Cu	Total Zn	Chloride
INFLOW	minutes	L s^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	mg L^{-1}
8/12/2010 7:14	0	4.81	196	0.84	1.96	0.032	0.65	5	18	35	51
8/12/2010 7:34	20	32.40	53	0.73	1.58	0.037	0.54	6	17	38	34
8/12/2010 7:54	20	26.61	31	0.50	1.19	0.052	0.35	< 5	10	< 25	36
8/12/2010 8:14	20	13.62	17	0.47	1.16	0.038	0.34	< 5	8	< 25	43
8/12/2010 8:34	20	7.20	6	0.42	1.12	0.046	0.38	< 5	9	< 25	45
8/12/2010 8:54	20	3.87	8	0.48	1.40	0.044	0.33	< 5	8	< 25	50
8/12/2010 9:14	20	2.13	9	0.49	1.68	0.041	0.31	< 5	11	< 25	58
8/12/2010 9:34	20	1.22	7	0.46	1.68	0.040	0.32	< 5	9	< 25	67
8/12/2010 9:54	20	0.65	8	0.42	1.68	0.036	0.31	< 5	9	< 25	75
8/12/2010 10:54	60	0.13	24	0.38	0.84	0.031	0.28	< 5	11	< 25	100

WATER QUALITY DATA FOR STORM EVENT ON 09/27/2010												
Sampling Time	Duration	Inflow	TSS	TP	DP	TKN-N	NO_2-N	NO_3-N	Total Pb	Total Cu	Total Zn	Chloride
INFLOW	minutes	L s^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	mg L^{-1}
9/27/2010 4:58	0	1.44	182	0.86	0.65	2.28	0.019	0.61	5	15	34	52
9/27/2010 5:16	20	4.95	78	0.51		1.53	0.018	0.34	< 5	10	< 25	33
9/27/2010 5:36	20	8.99	41	0.47	0.37	0.79	0.013	0.37	< 5	12	< 25	27
9/27/2010 5:56	20	5.51	14	0.51	0.27	1.13	0.016	0.29	< 5	8	< 25	32
9/27/2010 6:36	40	2.68	17	0.43	0.23	1.47	0.010	0.24	< 5	13	< 25	50
9/27/2010 7:16	40	1.27	10	0.31	0.18	1.77	0.009	0.25	< 5	9	< 25	85
9/27/2010 8:16	60	0.96	15	0.46	0.24	2.07	0.013	0.29	< 5	13	< 25	100
9/27/2010 9:16	60	0.79	17	0.47	0.27	2.15	0.010	0.29	< 5	13	47	103
9/27/2010 10:36	80	0.24	10	0.36	0.31	2.24	0.009	0.38	< 5	13	< 25	161
9/27/2010 11:56	80	0.16	24	0.48	0.35	2.52	0.010	0.49	< 5	12	26	220
9/27/2010 13:36	100	0.25	25	0.49	0.38	2.80	0.019	0.49	6	18	35	217
9/27/2010 15:16	100	0.79	17	0.31		2.45	0.021	0.22	< 5	17	< 25	108

WATER QUALITY DATA FOR STORM EVENT ON 10/27/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
10/27/2010 3:58	0	0.30	133	0.43	8.07	0.020	0.43	7	12	41	95
10/27/2010 4:18	20	0.57	52	0.46	5.22	0.016	0.34	< 5	11	63	87
10/27/2010 4:38	20	0.41	35	0.30	2.38	0.013	0.27	< 5	9	34	90
10/27/2010 4:58	20	1.00	133	0.50	2.12	< 0.01	0.21	8	13	62	55
10/27/2010 5:18	20	1.39	71	0.48	1.87	< 0.01	0.20	< 5	9	39	45
10/27/2010 5:58	40	2.83	53	0.56	1.73	< 0.01	0.11	< 5	8	30	24
10/27/2010 6:38	40	3.32	28	0.43	1.58	0.014	0.07	< 5	7	30	33
10/27/2010 7:18	40	2.25	15	0.39	1.19	< 0.01	0.08	< 5	6	32	38
10/27/2010 8:18	60	1.19	10	0.31	0.80	< 0.01	0.09	< 5	10	< 25	45
10/27/2010 9:18	60	0.65	23	0.31	1.20	0.010	0.10	< 5	7	41	54
10/27/2010 10:18	60	0.33	14	0.35	1.60	0.010	0.09	< 5	7	33	69
10/27/2010 11:58	100	0.20	20	0.32	1.73	0.010	0.09	< 5	8	37	124

WATER QUALITY DATA FOR STORM EVENT ON 11/16/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/16/2010 10:34	0	0.32	59	0.40	1.54	0.016	0.35	< 5	8	36	88
11/16/2010 10:54	20	0.44	17	0.31	1.51	0.016	0.37	< 5	8	32	80
11/16/2010 11:14	20	0.38	11	0.29	1.47	0.013	0.30	< 5	7	13	81
11/16/2010 11:34	20	0.32	7	0.33	1.09	0.012	0.25	< 5	6	28	82
11/16/2010 12:14	40	0.25	13	0.34	0.70	0.011	0.19	< 5	7	27	85
11/16/2010 12:54	40	0.21	10	0.35	1.05	0.011	0.15	< 5	7	13	89
11/16/2010 13:54	60	0.22	8	0.35	1.40	0.011	0.12	< 5	8	36	92
11/16/2010 14:54	60	0.22	13	0.31	1.40	0.011	0.10	< 5	8	29	91
11/16/2010 16:14	80	0.77	10	0.25	1.40	0.012	0.20	< 5	7	29	58
11/16/2010 17:34	80	1.36	22	0.48	1.33	0.014	0.29	< 5	7	42	28
11/16/2010 19:14	100	1.02	13	0.37	1.30	0.010	0.15	< 5	8	28	57
11/16/2010 20:54	100	0.61	16	0.52	1.26	0.010	< 0.10	< 5	8	27	57

WATER QUALITY DATA FOR STORM EVENT ON 12/01/2010											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
12/1/2010 5:46	0	0.69	132	0.83	2.33	< 0.01	0.22	5	11	62	83
12/1/2010 6:16	30	1.22	42	0.34	1.87	< 0.01	0.19	< 5	6	36	55
12/1/2010 6:56	40	0.99	31	0.35	1.40	< 0.01	0.16	< 5	5	34	45
12/1/2010 7:36	40	2.01	58	0.62	1.19	0.010	0.10	< 5	7	46	26
12/1/2010 8:36	60	2.88	31	0.55	0.98	< 0.01	< 0.10	< 5	6	44	30
12/1/2010 9:36	60	3.79	17	0.38	1.19	< 0.01	< 0.10	< 5	4	46	28
12/1/2010 11:06	90	5.87	25	0.23	1.40	< 0.01	< 0.10	< 5	4	47	12
12/1/2010 13:06	120	1.35	15	0.25	1.26	< 0.01	< 0.10	< 5	3	39	22
12/1/2010 15:06	120	0.39	16	0.21	0.84	< 0.01	< 0.10	< 5	3	36	35
12/1/2010 17:06	120	0.19	16	0.21	0.91	0.010	0.10	< 5	3	42	64
12/1/2010 19:36	150	0.07	14	0.18	0.98	0.010	< 0.10	< 5	4	45	127
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
12/1/2010 10:46	0	0.57	9	0.10	0.70	< 0.01	< 0.10	< 5	< 2	61	24
12/1/2010 11:16	30	1.35	4	0.21	0.72	< 0.01	< 0.10	< 5	< 2	< 25	24
12/1/2010 11:56	40	1.67	2	0.06	0.56	< 0.01	< 0.10	< 5	< 2	26	24
12/1/2010 12:36	40	1.75	1	0.06	0.74	< 0.01	< 0.10	< 5	< 2	31	24
12/1/2010 13:36	60	0.17	3	0.02	1.26	< 0.01	< 0.10	< 5	< 2	27	25
12/1/2010 15:06	90	1.30	4	0.14	0.93	< 0.01	< 0.10	< 5	< 2	< 25	24
12/1/2010 16:36	90	1.05	6	0.09	0.56	< 0.01	< 0.10	< 5	< 2	32	24
12/1/2010 18:36	120	0.86	1	0.02	0.59	< 0.01	< 0.10	< 5	< 2	< 25	24
12/1/2010 20:36	120	0.69	2	0.08	0.56	< 0.01	< 0.10	< 5	< 2	27	24
12/1/2010 23:06	150	0.54	4	0.09	0.63	< 0.01	< 0.10	< 5	< 2	28	24
12/2/2010 1:36	180	0.45	2	0.08	0.70	< 0.01	< 0.10	< 5	4	34	24
12/2/2010 4:36	180	0.36	4	0.08	0.70	< 0.01	< 0.10	< 5	< 2	< 25	24

WATER QUALITY DATA FOR STORM EVENT ON 02/25/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
2/25/2011 0:44	0	0.47	53	0.14	0.63	0.011	n/a	< 5	8	41	1072
2/25/2011 1:14	30	0.82	42	0.13	0.94	0.012	n/a	< 5	7	36	1057
2/25/2011 1:54	40	0.79	33	0.13	1.25	0.047	n/a	< 5	5	31	1933
2/25/2011 2:34	40	1.47	29	0.09	0.77	0.094	n/a	< 5	5	30	3398
2/25/2011 3:34	60	1.21	22	0.04	0.29	0.043	n/a	< 5	5	41	2204
2/25/2011 4:34	60	0.95	20	0.02	0.65	0.037	n/a	< 5	6	39	2378
2/25/2011 6:04	90	1.26	19	0.02	1.01	0.029	n/a	< 5	4	< 25	2350
2/25/2011 8:04	120	6.54	145	0.22	1.26	0.032	n/a	5	10	70	797
2/25/2011 10:04	120	2.67	49	0.15	1.12	0.022	n/a	< 5	5	42	801
2/25/2011 12:04	120	1.49	25	0.12	0.91	0.021	n/a	< 5	4	33	931
2/25/2011 14:34	150	0.80	38	0.10	0.70	0.018	n/a	< 5	4	29	1021
2/25/2011 17:34	180	0.38	18	0.05	0.98	0.016	n/a	< 5	3	< 25	1254
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
2/25/2011 7:40	0	0.46	31	0.25	2.43	< 0.01	n/a	< 5	3	40	472
2/25/2011 8:10	30	1.49	22	0.24	1.79	< 0.01	n/a	< 5	< 2	< 25	515
2/25/2011 8:50	40	2.47	23	0.19	1.26	< 0.01	n/a	< 5	< 2	25	552
2/25/2011 9:30	40	3.11	10	0.11	1.15	< 0.01	n/a	< 5	< 2	< 25	619
2/25/2011 10:30	60	3.01	17	0.08	1.05	< 0.01	n/a	< 5	< 2	< 25	730
2/25/2011 12:00	90	2.38	9	0.02	1.04	< 0.01	n/a	< 5	< 2	< 25	725
2/25/2011 13:30	90	1.85	18	0.07	0.98	< 0.01	n/a	< 5	< 2	< 25	911
2/25/2011 15:30	120	1.38	25	0.22	1.03	< 0.01	n/a	< 5	< 2	30	942
2/25/2011 17:30	120	1.08	15	0.09	0.98	< 0.01	n/a	< 5	< 2	< 25	906
2/25/2011 20:00	150	0.84	12	0.06	1.09	< 0.01	n/a	< 5	< 2	27	857
2/25/2011 22:30	150	0.67	10	0.04	0.77	< 0.01	n/a	< 5	< 2	27	883
2/26/2011 1:30	180	0.53	9	0.03	1.19	< 0.01	n/a	< 5	< 2	27	783

WATER QUALITY DATA FOR STORM EVENT ON 03/10/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
3/10/2011 1:36	0	0.41	95	0.41	1.68	0.014	n/a	< 5	9	59	762
3/10/2011 2:06	30	0.77	58	0.26	1.75	0.026	n/a	5	10	43	399
3/10/2011 2:46	40	0.80	31	0.23	1.82	0.022	n/a	< 5	9	51	392
3/10/2011 3:46	60	1.69	62	0.23	1.47	0.017	n/a	< 5	8	44	336
3/10/2011 4:46	60	2.71	44	0.14	1.12	0.014	n/a	< 5	8	41	227
3/10/2011 6:16	90	4.45	57	0.22	1.12	0.012	n/a	< 5	5	44	136
3/10/2011 8:16	90	7.58	58	0.20	1.12	0.013	n/a	< 5	5	46	86
3/10/2011 10:16	120	22.02	215	0.31	1.12	0.012	n/a	7	9	58	26
3/10/2011 12:46	120	14.50	158	0.25	0.98	0.011	n/a	6	7	54	20
3/10/2011 15:16	150	18.30	137	0.25	0.84	0.012	n/a	6	7	48	20
3/10/2011 17:46	150	11.93	134	0.18	0.98	0.010	n/a	6	5	48	16
3/10/2011 20:46	180	2.59	72	0.23	1.40	0.010	n/a	< 5	6	42	0
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
3/10/2011 5:46	0	0.46	30	0.33	1.68	< 0.01	n/a	< 5	4	52	365
3/10/2011 6:16	30	1.09	27	0.29	1.47	< 0.01	n/a	< 5	4	34	353
3/10/2011 6:56	40	2.18	20	0.25	1.68	< 0.01	n/a	< 5	4	35	348
3/10/2011 7:56	40	3.94	24	0.27	1.26	< 0.01	n/a	< 5	4	33	332
3/10/2011 9:26	60	14.13	19	0.19	1.12	< 0.01	n/a	< 5	4	29	310
3/10/2011 10:56	90	26.76	28	0.19	0.84	< 0.01	n/a	< 5	5	40	154
3/10/2011 12:56	90	20.58	38	0.20	0.84	< 0.01	n/a	< 5	4	39	83
3/10/2011 14:56	120	22.11	33	0.19	0.84	< 0.01	n/a	< 5	5	39	78
3/10/2011 17:26	120	23.87	40	0.18	0.84	< 0.01	n/a	< 5	4	40	74
3/10/2011 19:56	150	7.95	39	0.18	0.70	< 0.01	n/a	< 5	5	41	72
3/10/2011 22:56	180	3.50	31	0.18	0.91	0.012	n/a	< 5	4	38	83
3/11/2011 1:56	180	2.15	28	0.18	1.12	< 0.01	n/a	< 5	4	40	104

WATER QUALITY DATA FOR STORM EVENT ON 04/22/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
4/22/2011 20:16	0	0.43	40	0.24	2.66	0.036	n/a	< 5	15	41	0
4/22/2011 20:46	30	0.42	25	0.25	2.73	0.031	n/a	< 5	14	37	0
4/22/2011 21:26	40	0.37	31	0.25	2.80	0.028	n/a	< 5	12	39	0
4/22/2011 22:06	40	0.34	35	0.21	2.31	0.029	n/a	< 5	12	39	0
4/22/2011 23:06	60	0.36	39	0.22	1.82	0.029	n/a	< 5	13	42	0
4/23/2011 0:36	90	0.29	27	0.23	2.03	0.029	n/a	< 5	12	36	0
4/23/2011 2:06	90	0.28	30	0.23	2.24	0.029	n/a	< 5	13	46	0
4/23/2011 4:06	120	0.39	29	0.22	2.38	0.026	n/a	6	12	40	0
4/23/2011 6:06	120	0.48	24	0.19	1.96	0.034	n/a	< 5	8	41	0
4/23/2011 8:36	150	0.31	18	0.15	1.61	0.017	n/a	< 5	9	41	0
4/23/2011 11:06	150	0.20	24	0.22	1.26	0.012	n/a	6	10	43	0
4/23/2011 14:06	180	0.25	54	0.23	0.63	0.022	n/a	6	16	50	0

WATER QUALITY DATA FOR STORM EVENT ON 05/14/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
5/14/2011 22:56	0	0.54	118	0.57	4.34	0.042	n/a	6	22	64	207
5/14/2011 23:16	20	1.26	63	0.45	3.36	0.030	n/a	< 5	15	47	220
5/14/2011 23:36	20	1.53	33	0.42	2.38	0.027	n/a	< 5	14	40	224
5/15/2011 0:16	40	2.04	30	0.38	2.24	0.024	n/a	< 5	13	41	108
5/15/2011 0:56	40	1.32	30	0.34	1.82	0.022	n/a	< 5	12	50	118
5/15/2011 1:56	60	0.55	20	0.27	2.04	0.017	n/a	< 5	10	39	134
5/15/2011 2:56	60	0.23	24	0.26	2.27	0.017	n/a	< 5	12	44	197
5/15/2011 4:16	80	0.04	27	0.21	1.13	0.018	n/a	< 5	10	31	278

WATER QUALITY DATA FOR STORM EVENT ON 06/09/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
6/9/2011 20:16	0	7.68	335	0.58	n/a	n/a	n/a	9	30	83	n/a
6/9/2011 21:16	60	5.90	75	0.65	n/a	n/a	n/a	< 5	13	44	n/a
6/9/2011 22:16	60	1.61	22	0.54	n/a	n/a	n/a	< 5	14	30	n/a
6/9/2011 23:16	60	0.52	19	0.50	n/a	n/a	n/a	< 5	15	33	n/a
6/10/2011 0:16	60	0.10	17	0.65	n/a	n/a	n/a	< 5	19	43	n/a

WATER QUALITY DATA FOR STORM EVENT ON 07/07/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
7/7/2011 19:52	0	0.53	127	0.55	3.22	n/a	n/a	< 5	20	59	69
7/7/2011 20:12	20	0.52	81	0.41	2.24	n/a	n/a	< 5	18	44	90
7/7/2011 20:32	20	2.25	50	0.58	1.96	n/a	n/a	7	13	57	20
7/7/2011 20:52	20	1.31	41	0.57	2.10	n/a	n/a	< 5	13	51	25
7/7/2011 21:12	20	0.70	24	0.64	2.24	n/a	n/a	< 5	12	46	26
7/7/2011 21:32	20	0.39	18	0.57	2.38	n/a	n/a	< 5	13	50	34
7/7/2011 21:52	20	0.24	18	0.56	2.52	n/a	n/a	< 5	13	38	36
7/7/2011 22:12	20	0.14	38	0.62	2.38	n/a	n/a	< 5	14	44	29
7/7/2011 22:32	20	0.04	27	0.46	1.19	n/a	n/a	< 5	14	42	23

WATER QUALITY DATA FOR STORM EVENT ON 07/25/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
7/25/2011 15:16	0	15.19	54	0.54	1.82	0.028	0.74	< 5	8	29	18
7/25/2011 15:36	20	63.26	32	0.36	1.40	0.016	0.46	< 5	10	34	7
7/25/2011 15:56	20	35.93	31	0.31	1.26	0.022	0.35	< 5	8	30	11
7/25/2011 16:16	20	22.27	35	0.33	1.33	0.026	0.39	< 5	8	31	12
7/25/2011 16:36	20	13.59	13	0.34	1.40	0.031	0.30	< 5	7	< 25	14
7/25/2011 16:56	20	7.96	12	0.41	1.75	0.039	0.48	< 5	7	< 25	20
7/25/2011 17:16	20	4.76	10	0.38	2.10	0.045	0.48	< 5	9	< 25	33
7/25/2011 17:36	20	2.90	6	0.43	1.89	0.044	0.62	< 5	8	< 25	24
7/25/2011 17:56	20	1.71	7	0.39	1.68	0.043	0.66	< 5	9	26	38
7/25/2011 18:56	60	0.48	9	0.36	1.68	0.030	0.37	< 5	10	27	53
7/25/2011 19:56	60	0.08	12	0.36	1.68	0.023	0.29	< 5	11	< 25	57
7/25/2011 21:16	80	0.00	16	0.41	0.84	0.019	0.16	< 5	13	26	70

WATER QUALITY DATA FOR STORM EVENT ON 08/06/2011												
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
8/6/2011 18:18	0	11.23	83	0.53	0.37	2.05	0.014	1.11	< 5	13	35	37
8/6/2011 18:38	20	53.36	64	0.39	0.21	1.87	< 0.01	1.22	< 5	12	46	12
8/6/2011 18:58	20	30.11	26	0.29	0.18	1.49	< 0.01	0.78	5	7	< 25	16
8/6/2011 19:18	20	16.68	11	0.28	0.21	1.40	0.011	0.74	7	6	< 25	26
8/6/2011 19:38	20	10.27	6	0.33	0.24	1.31	0.011	0.79	< 5	6	< 25	24
8/6/2011 19:58	20	6.09	9	0.35	0.27	1.31	0.010	0.65	< 5	7	< 25	27
8/6/2011 20:18	20	3.71	5	0.36	0.30	1.31	0.010	0.73	< 5	7	< 25	33
8/6/2011 20:38	20	1.98	8	0.37	0.27	1.03	0.010	0.62	< 5	6	< 25	29
8/6/2011 20:58	20	0.98	7	0.34	0.24	0.75	0.010	0.42	< 5	7	< 25	35
8/6/2011 21:58	60	0.12	11	0.35	0.12	0.37	0.011	0.48	< 5	9	< 25	41
8/6/2011 22:58	60	0.00										
8/7/2011 0:18	80	0.00										
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
8/6/2011 19:08	0	0.51	13	0.28	0.09	1.49	< 0.01	0.31	< 5	6	50	75
8/6/2011 19:28	20	1.32	18	0.24	0.08	1.40	< 0.01	0.23	< 5	7	< 25	76
8/6/2011 19:48	20	1.84	12	0.24	0.08	1.31	< 0.01	0.39	< 5	3	< 25	73
8/6/2011 20:08	20	2.28	9	0.19	0.08	1.12	< 0.01	0.23	< 5	2	< 25	73
8/6/2011 20:28	20	2.17	12	0.16	0.08	0.93	< 0.01	0.31	< 5	3	< 25	73
8/6/2011 20:48	20	2.09	12.5	0.16	0.08	0.84	< 0.01	0.37	< 5	3	< 25	78
8/6/2011 21:08	20	2.24	13	0.18	0.07	0.75	< 0.01	0.29	< 5	3	< 25	75
8/6/2011 21:28	20	2.03	10	0.16	0.07	0.65	< 0.01	0.15	< 5	3	< 25	74
8/6/2011 21:48	20	1.79	16	0.17	0.08	0.56	< 0.01	0.18	< 5	4	< 25	73
8/6/2011 22:48	60	1.71	13	0.16	0.08	0.47	< 0.01	0.11	< 5	3	< 25	73
8/6/2011 23:48	60	1.49	12	0.16	0.08	0.37	< 0.01	0.23	< 5	3	< 25	73
8/7/2011 1:08	80	1.32	14	0.18	0.04	0.19	< 0.01	0.13	< 5	3	< 25	73

WATER QUALITY DATA FOR STORM EVENT ON 09/23/2011

Sampling Time	Duration	Inflow	TSS	TP	DP	TKN-N	NO_2-N	NO_3-N	Total Pb	Total Cu	Total Zn	Chloride
INFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
9/23/2011 10:28	0	0.36	279	0.48	0.36	4.03	0.017	0.73	7	13	41	90
9/23/2011 10:48	20	0.52	59	0.37	0.29	3.13	0.013	0.81	< 5	13	27	107
9/23/2011 11:08	20	0.80	45	0.34	0.22	2.24	< 0.01	0.56	< 5	12	< 25	106
9/23/2011 11:28	20	1.22	62	0.35	0.24	1.77	< 0.01	0.27	21	11	26	84
9/23/2011 11:48	20	6.24	83	0.41	0.26	1.54	< 0.01	0.48	12	9	33	18
9/23/2011 12:28	40	12.61	104	0.37	0.22	1.31	< 0.01	0.34	< 5	13	< 25	16
9/23/2011 13:08	40	16.50	46	0.23	0.16	0.71	< 0.01	0.27	< 5	7	< 25	7
9/23/2011 13:48	40	7.70	22	0.24	0.17	0.80	< 0.01	0.52	< 5	5	49	8
9/23/2011 14:48	60	2.57	23	0.26	0.18	0.89	< 0.01	0.63	< 5	6	< 25	12
9/23/2011 15:48	60	1.87	27	0.26	0.16	1.00	< 0.01	0.63	< 5	7	25	21
9/23/2011 16:48	60	2.14	24	0.23	0.15	1.12	< 0.01	0.30	< 5	7	< 25	8
9/23/2011 18:28	100	2.11	37	0.19	0.07	0.56	< 0.01	0.40	< 5	6	< 25	28
Sampling Time	**Duration**	**Outflow**	**TSS**	**TP**	**DP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
OUTFLOW	**minutes**	**L s^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**
9/23/2011 12:44	0	0.67	29	0.13	0.05	2.02	< 0.01	0.32	< 5	4	< 25	6
9/23/2011 13:04	20	4.19	6	0.10	0.08	1.43	< 0.01	0.23	< 5	3	35	5
9/23/2011 13:24	20	8.88	7	0.12	0.11	0.83	< 0.01	0.05	< 5	2	< 25	5
9/23/2011 13:44	20	8.60	20	0.11	0.07	0.73	< 0.01	0.18	11	3	< 25	6
9/23/2011 14:04	20	7.69	12	0.10	0.04	0.62	< 0.01	0.18	16	3	< 25	6
9/23/2011 14:44	40	5.16	13	0.15	0.05	1.01	< 0.01	0.21	10	4	< 25	7
9/23/2011 15:28	40	3.52	9	0.17	0.05	1.40	< 0.01	0.29	< 5	4	< 25	5
9/23/2011 16:04	40	2.71	23	0.18	0.08	1.01	0.013	0.26	< 5	5	< 25	8
9/23/2011 17:04	60	2.26	1	0.18	0.11	0.62	< 0.01	0.32	23	4	< 25	6
9/23/2011 18:04	60	2.08	15	0.17	0.11	0.92	< 0.01	0.31	< 5	4	35	7
9/23/2011 19:04	60	1.92	13	0.16	0.10	1.21	< 0.01	0.23	10	4	< 25	7
9/23/2011 20:44	100	1.51	9	0.16	0.11	0.93	< 0.01	0.21	< 5	4	< 25	7

WATER QUALITY DATA FOR STORM EVENT ON 10/12/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
10/12/2011 16:34	0	0.50	197	0.65	1.68	0.020	0.71	6	15	41	60
10/12/2011 16:54	20	1.15	199	0.24	1.68	0.021	0.55	9	23	91	54
10/12/2011 17:14	20	0.85	59	0.45	2.10	0.015	0.44	< 5	9	43	65
10/12/2011 17:34	20	1.27	90	0.32	2.52	0.014	0.37	< 5	10	48	63
10/12/2011 17:54	20	1.41	41	0.43	1.96	0.017	0.48	< 5	9	48	24
10/12/2011 18:34	40	0.83	40	0.39	1.40	0.018	0.54	< 5	8	49	33
10/12/2011 19:14	40	0.45	39	0.38	1.47	0.016	0.55	< 5	9	48	44
10/12/2011 19:54	40	0.27	49	0.39	1.54	0.011	0.48	< 5	12	49	56
10/12/2011 20:54	60	0.19	47	0.40	2.10	0.013	0.48	< 5	9	47	73
10/12/2011 21:54	60	0.20	42	0.44	2.66	0.010	0.39	< 5	10	54	94
10/12/2011 22:54	60	0.28	58	0.41	2.10	0.010	0.25	< 5	10	63	109
10/13/2011 0:34	100	0.44	47	0.38	1.54	0.011	0.12	< 5	9	55	99

WATER QUALITY DATA FOR STORM EVENT ON 11/16/2011											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
11/16/2011 12:20	0	0.81	272	1.19	3.08	0.026	0.23	6	18	67	57
11/16/2011 12:50	30	0.97	59	0.80	2.24	0.015	0.17	5	10	34	72
11/16/2011 13:30	40	0.66	31	0.43	2.05	< 0.001	< 0.10	< 5	9	< 25	76
11/16/2011 14:30	60	0.90	23	0.85	1.87	0.017	0.13	< 5	8	< 25	29
11/16/2011 15:30	60	0.57	18	0.69	1.91	0.010	< 0.10	< 5	7	< 25	42
11/16/2011 17:00	90	0.37	28	0.47	1.96	< 0.001	< 0.10	6	8	< 25	60
11/16/2011 19:00	120	0.30	31	0.45	1.90	< 0.001	< 0.10	7	8	< 25	80
11/16/2011 21:00	120	0.31	39	0.43	1.84	0.010	< 0.10	5	10	< 25	96
11/16/2011 23:30	150	0.27	27	0.39	2.04	0.010	< 0.10	5	8	< 25	109
11/17/2011 2:00	150	0.22	22	0.33	2.24	0.010	< 0.10	5	8	< 25	122
11/17/2011 4:30	150	0.20	19	0.26	1.12	0.011	< 0.10	6	9	< 25	143
11/17/2011 7:30	180	0.18	26	0.23	0.56	< 0.001	< 0.10	5	8	< 25	174

WATER QUALITY DATA FOR STORM EVENT ON 01/17/2012											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
1/17/2012 9:46	0	0.47	203	0.42	1.68	0.010	1.28	8	5	57	28
1/17/2012 10:16	30	0.56	69	0.32	1.96	0.011	0.74	10	4	42	31
1/17/2012 10:56	40	0.42	42	0.20	1.86	0.010	0.73	7	3	44	28
1/17/2012 11:36	40	0.36	55	0.25	1.77	0.012	0.74	12	3	49	28
1/17/2012 12:36	60	0.31	27	0.26	1.62	0.010	1.11	9	3	45	29
1/17/2012 14:06	90	0.26	32	0.26	1.47	0.012	0.97	7	3	48	31
1/17/2012 15:36	90	0.23	25	0.28	1.51	0.010	1.15	22	3	48	33
1/17/2012 17:36	120	0.20	29	0.23	1.54	0.011	1.12	7	3	52	30
1/17/2012 19:36	120	0.19	29	0.31	1.68	0.010	1.20	7	3	59	32
1/17/2012 22:06	150	0.18	50	0.31	1.83	0.011	1.22	9	3	47	34
1/18/2012 0:36	150	0.18	35	0.26	0.91	0.010	1.51	8	4	62	36
1/18/2012 3:36	180	0.16	38	0.17	1.72	0.010	1.24	10	8	56	38

WATER QUALITY DATA FOR STORM EVENT ON 05/14/2012											
Sampling Time	**Duration**	**Inflow**	**TSS**	**TP**	**TKN-N**	**NO_2-N**	**NO_3-N**	**Total Pb**	**Total Cu**	**Total Zn**	**Chloride**
INFLOW	**minutes**	**$L\ s^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$mg\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$\mu g\ L^{-1}$**	**$mg\ L^{-1}$**
5/14/2012 16:42	0	1.29	243	0.48	2.32	0.022	0.40	13	34	64	76
5/14/2012 17:12	30	1.58	91	0.32	1.79	0.015	0.26	11	20	54	56
5/14/2012 17:52	40	3.75	60	0.39	1.27	0.011	0.27	7	16	62	30
5/14/2012 18:52	60	1.93	47	0.25	1.30	< 0.001	0.11	7	14	35	58
5/14/2012 20:22	90	0.67	43	0.18	1.33	< 0.001	< 0.10	5	12	29	62
5/14/2012 21:52	90	0.43	53	0.23	1.49	< 0.001	0.12	9	19	35	79
5/14/2012 23:52	120	0.43	55	0.26	1.65	0.015	0.10	9	16	36	100
5/15/2012 1:52	120	0.69	52	0.27	1.26	0.014	< 0.10	9	15	38	91
5/15/2012 4:22	150	4.48	110	0.27	0.88	< 0.001	0.14	12	13	34	33
5/15/2012 6:52	150	6.81	69	0.16	1.17	< 0.001	0.12	6	8	33	22
5/15/2012 9:52	180	0.93	42	0.17	0.96	< 0.001	< 0.10	5	10	32	42
5/15/2012 12:52	180	0.24	48	0.26	0.48	< 0.001	< 0.10	6	9	31	61

n/a: No data;
Concentrations measured below laboratory detection limit are reported as '< (detection limit)'

References

APHA, AWWA, WPCF (1995), Standard methods for the examination of water and wastewater, 19th Ed., Washington, D. C.

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. (1998). *Crop Evapotranspiration: Guidelines for computing crop water requirements*. FAO Irrigation and Drainage Paper 56, FAO Corporate Document Repository.

Barrett, M. E., Walsh, P. M., Malina, J. F., Charbeneau, R. J. (1998). "Performance of vegetative controls for treating highway runoff." *J. Environ. Eng.*, 124 (11), 1121-1128.

Barraud, S., Dechesne, M., Bardin, J.P., and Varnier, J.C. (2005). "Statistical analysis of pollution in stormwater infiltration basins. *Wat. Sci. Tech.*, 51 (2), 1-9.

Bartoldus, C. C. (1994). "EPW: A procedure for the functional assessment of planned wetlands." *Water, Air, and Soil Pollution*, 77 (3-4), 533-541.

Berman, T., and Bronk, D.A. (2003). "Dissolved organic nitrogen: A dynamic participant in aquatic ecosystems." *Aquat. Microb. Ecol.*, 31 (3), 279–305.

Birch, G. F., Matthai, C., Fazeli, M. S., and Suh, J. Y. (2004). "Efficiency of a constructed wetland in removing contaminants from stormwater." *Wetlands*, 24 (2), 459-466.

Birch, G. F., Fazeli, M. S., and Matthai, C. (2005). "Efficiency of an infiltration basin in removing contaminants from urban stormwater." *Environ. Monit. Assess.*, 101 (1), 23-38.

Blackwell, M. S. A., and Pilgrim, E. S. (2011). "Ecosystem services delivered by small-scale wetlands." *Hydrologic Sciences Journal*, 56 (8), 1467-1484.

Blaney, H. F., and Criddle, W. D. (1962). "Determining consumptive use and irrigation water requirements." *USDA ARS Tech. Bull. 1275*, Washington, DC.

Boesch, D. F., Brinsfield, R. B., and Magnien, R. E. (2001). "Chesapeake Bay eutrophication: Scientific understanding, ecosystem restoration, and challenges for agriculture." *J. Environ. Qual.*, 30 (2), 303-320.

Booth, D. B., and Jackson, C. R. (1997). “Urbanization of aquatic systems : Degradation thresholds, stormwater detection, and the limits of mitigation.” *J. Am. Water Resour. Assoc.*, 33 (5), 1077-1090.

Braga, A., Horst, M., and Traver, R. G. (2007). “Temperature effects on the infiltration rate through an infiltration basin BMP.” *J. Irrigat. Drain Eng.*, 133 (6), 593-601.

Brinson, M.M.(1993). A *hydrogeomorphic classification for wetlands*. Wetlands research program technical report WRP-DE-4, U.S. Army Corps of Engineers, Washington, D.C.

Brouwer, C., and Heibloem, M. (1986). *Irrigation water management*. FAO Training manual no.3, Part I: Principles of irrigation water needs, Part II: Determination of irrigation water needs. Food and Agriculture Organization of the United Nations, Rome, Italy. <http://www.fao.org/docrep/s2022e/s2022e07.htm> (Nov 18, 2009).

Brydon, J., Roa, M. C., Brown, S. J., and Schreier, H. (2006). “Integrating wetlands into watershed management: Effectiveness of constructed wetlands to reduce impacts from urban stormwater.” *Environmental Role of Wetlands in Headwaters, J. Krecek, and M. Haigh, ed., NATO science series: IV: Earth and environmental sciences*, Springer, Netherlands, 63, 143-154

Carleton J. N., Grizzard, T. J., Godrej, A. N., Post, H. E., Lampe, L., and Kenel, P. P. (2000). “Performance of a constructed wetland in treating urban stormwater runoff.” *Water Environ. Res*., 72 (3), 295-304.

Code of Maryland Regulations (COMAR). (2006). “Numerical criteria for toxic substances in surface waters.” 26.08.02.03–2, <http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.03-2.htm> (Aug. 11, 2010).

Collins, K. A., Lawrence, T. J., Stander, E. K., Jontos, R. J., Kaushal, S. S., Newcomer, T. A., Grimm, N. B., and Cole Ekberg, M. L. (2010). “Opportunities and challenges for managing nitrogen in urban stormwater- A review and synthesis.” *Ecol. Eng.*, 36 (11), 1507-1519.

Comings, K. J., Booth, D. B., and Horner, R. R. (2000). “Storm water pollutant removal by two wet ponds in Bellevue, Washington.” *J. Environ. Eng.*, 126 (4), 321-330.

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T. (1979). *Classification of wetlands and deepwater habitats of the United States*. FWS/OBS-79/31. Office of Biological Services, U.S. Fish and Wildlife Service, Washington, DC.

Cruff, R. W., and Thompson, T. H. (1967). *A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments*. Contributions to the hydrology of the Unites States, Geological Survey Water-Supply Paper 1839-M, Washington D.C.

Dale, P. E. R., and Knight, J. M. (2008). "Wetlands and mosquitoes: A review." *Wetl. Ecol. Manag.*, 16 (4), 255-276.

Davis, A.P., Shokouhian, M., Ni, S. (2001a). "Loading Estimates of Lead, Copper, Cadmium, and Zinc in Urban Runoff from Specific Sources." *Chemosphere*, 44 (5), 997-1009.

Davis, A. P., Shokouhian, M., Sharma, H., and Minami, C. (2001b). "Laboratory study of biological retention for urban stormwater management." *Water Environ. Res*., 73(1), 5-14.

Davis, A. P. and McCuen, R. H. (2005). *Stormwater management for smart growth*, Springer, New York.

Davis, A.P. (2008). "Field performance of bioretention: Hydrology impacts." *J. Hydrol. Eng.*, 13 (2), 90-95.

Dechesne, M., Barraud, S., and Bardin, J. P. (2005). "Experimental assessment of stormwater infiltration basin evolution." *J. Environ. Eng.*, 131 (7), 1090-1098.

DeBusk, K.M., Hunt, W. F., and Line, D. E. (2011). "Bioretention outflow: Does it mimic nonurban watershed shallow interflow?" *J. Hydrol. Eng.*, 16 (3), 274-279.

Dick, G. O., Smart, R. M., and Snow, J. R. (2004) *Aquatic vegetation restoration in Drakes Creek, Tennessee*. Aquatic plant control research program bulletin, Vol A-04-1.

Dietz, M. E., and Clausen, J. C. (2008). "Stormwater runoff and export changes with development in a traditional and low impact subdivision." *J. Environ, Manage.*, 87 (4), 560-566.

Dunne, T., and Leopold L. B. (1978). *Water in environmental planning*, WH Freeman, New York.

Emerson, C. H., and Traver, R. G. (2008). "Multiyear and seasonal variation of infiltration from storm-water best management practices." *J. Irrigat. Drain Eng.*, 134 (5), 598-605.

Emerson, C. H., Wadzuk B. M., and Traver, R. G. (2010). "Hydraulic evolution and total suspended solids capture of an infiltration." *Hydrol. Process.*, 24 (8), 1008-1014.

Fisher, J., and Acreman, M. C. (2004). "Wetland nutrient removal: A review of the evidence." *Hydrol. Earth Syst. Sci.*, 8 (4), 673-685.

Fennessy, M. S., Jacobs, A. D., and Kentula, M. E. (2004). *Review of rapid methods for assessing wetland condition*. EPA-620-R-04-009. United States Environmental Protection Agency, Washington, DC.

Fennessy, M. S., Rokosch , A., and Mack, J. J. (2008). "Patterns of plant decomposition and nutrient recycling in natural and created wetlands." *Wetlands*, 28 (2), 300-310.

Ferguson, B. K. (1990). "Role of the long-term water balance in management of stormwater infiltration." *J. Environ.* Manage., 30 (3), 221-233.

Furumai, H., Balmer, H., and Boller, M. (2002). "Dynamic behavior of suspended pollutants and particle size distribution in highway runoff." *Wat. Sci. Tech.*, 46 (11-12), 413-418.

Galloway, J. N., Aber, J. D., Erisman, J. W., Seitzinger, S. P., Howarth, R. W., Cowling, E. B. (2003). "The nitrogen cascade." *Bioscience*, 53 (4), 341–356.

German, J., Svensson, G., Gustafsson, L. G., and Vikstrom, M. (2003). "Modelling of temperature effects on removal efficiency and dissolved oxygen concentrations in stormwater ponds." *Wat. Sci. Tech.*, 48 (9), 145–154.

Glenn, D. W. III, and Sansalone, J. J. (2002). "Accretion of pollutants in snow exposed to urban traffic and winter storm maintenance activities. II." *J. Environ. Eng.*, 128 (2), 167–185.

Guo. Q. (1997). "Sediment and heavy metal accumulation in dry storm water detention basin." *J. Environ. Manage.*, 123 (5), 295-301.

Herngren, L., Goonetilleke, A., and Ayoko, G. A. (2005). "Understanding heavy metal and suspended solids relationships in urban stormwater using simulated rainfall." *J. Water Res. Plan. Manage.*, 76 (2), 149-158.

Hobbs, E. H., and Krogman, K. K. (1966). "A comparison of measured and calculated evapotranspiration for alfalfa in southern Alberta." *Canadian Agricultural Engineering*, 1-11.

Holman-Dobbs, J. K., Bradley, A. A., and Potter, K. W. (2003). "Evaluation of hydrologic benefits of infiltration based urban storm water management. *J. Am. Water Resour. Assoc.*, 39 (1), 205-215.

Juday, D. G., Brummer, J. E., and Smith, D. H. (2011). "Use of alternative temperature expressions with Blaney-Criddle." *J. Irrigat. Drain Eng.*, 137 (9), 573-584.

Juston, J. M., and DeBusk, T. A. (2011). "Evidence and implications of the background phosphorus concentration of submerged aquatic vegetation wetlands in Stormwater Treatment Areas for Everglades restoration." *Water Resour. Res.*, 47, W01511, 1-13.

Kadlec, R. H. (2003). "Effects of pollutant speciation in treatment wetlands design." *Ecol. Eng.*, 20 (1), 1-16.

Kadlec, R. H., and Knight, R. L. (1996). *Treatment wetlands*, 1st Ed., CRC Press, Boca Raton, FL, USA.

Kaushal, S. S., Groffman, P. M., Likens, G. E., Belt, K. T., Stack, W. P., Kelly, V. R., Weathers, K. C., Band, L. E., and Fisher, G. T. (2005). "Increased salinization of fresh water in the northeastern U.S." *Proc., National Academy of Sciences*, 102 (38), 13517-13520.

Kaushal, S. S., Groffman, P. M., Band, L.E., Shields, C. A., Morgan, R. P., Palmer, M.A., Belt, K. T., Swan, C.M., Findlay, S. E. G., and Fisher, G. T. (2008). "Interaction between urbanization and climate variability amplifies watershed nitrate export in Maryland." *Envrion. Sci. Technol.*, 42 (16), 5872-5878.

Kaushal, S. S.,and Lewis Jr., W. M. (2005). "Fate and transport of organic nitrogen in minimally disturbed montane streams of Colorado, USA." *Biogeochemistry*, 74 (3), 303-321.

Kim, J-Y., and Sansalone, J. J. (2008). "Event-based size distributions of particulate matter Transported during urban rainfall-runoff events." *Water Res.*, 42 (10-11), 2756-2768.

Konrad, C. P., and Booth, D. B. (2005). “Hydrologic changes in urban streams and their ecological significance.” *American Fisheries Society Symposium*, 47, 157–177.

Kreeb, L.B. (2003). *Hydrologic efficiency and design sensitivity of bioretention facilities.* Honor’s Research, University of Maryland, College Park, MD.

Lee, J.H., Yu, M.J., Bang, K.W., and Choe, J.S. (2003). “Evaluation of the methods for first flush analysis in urban watersheds.” *Wat. Sci. Tech*, 48 (10), 167-176.

Li, H. and Davis, A. P. (2009). “Water quality improvement through reductions of pollutant loads using bioretention.” *J. Environ. Eng.*, 135 (8), 567-576.

Lindsey, G., Roberts, L., and Page, W. (1992). “Inspection and maintenance of infiltration facilities.” *J. Soil Water Conserv.*, 47 (6), 481-486.

Lott, R. B., and Hunt, R. J. (2001). “Estimating evapotranspiration in natural and constructed wetlands.” *Wetlands*, 21 (4), 614-628.

Mack, J. J. (2004). *Integrated wetland assessment program. Part 4: Vegetation index of biotic integrity (VIBI) and tiered aquatic life uses (TALUs) for Ohio wetlands*. Ohio EPA Technical Report WET/2004-4. Wetland Ecology Group, Division of Surface Water, Ohio Environmental Protection Agency, Columbus, Ohio.

Mallin, M. A., Ensign, S. H., Wheeler, T. R., and Mayes, D. B. (2002). “Pollutant removal efficacy of three wet detention ponds.” *J. Environ. Qual.*, 31 (2), 654-660.

Marsalek, P. (2003). “Road salts in urban stormwater: an emerging issue in stormwater management in cold climates.” *Wat. Sci. Tech.*, 48 (9), 61-70.

Marsalek, P., Watt, W. E., Marsalek, J., and Anderson, B. C. (2003). “Winter operation of an on-stream stormwater management pond.” *Wat. Sci. Tech.*, 48 (9), 133–144.

McCuen, R. H. (2005). *Hydrologic analysis and design*, 3rd *Ed.*, Prentice Hall, Upper Saddle River, NJ, USA.

MDE, State of Maryland, Department of the Environment (2000). *2000 Maryland stormwater design manual, Vols. I and II*, MDE, Baltimore.

Micacchion, M. (2004). *Integrated Wetland Assessment Program. Part 7: Amphibian index of biotic integrity (AmphIBI) for Ohio wetlands*. Ohio EPA Technical

Report WET/2004-7. Wetland Ecology Group, Division of Surface Water, Ohio Environmental Protection Agency Columbus, Ohio.

Moore, T. L. C., Hunt, W. F., Burchell, M. R., and Hathaway, J. M. (2011). “Organic nitrogen exports from urban stormwater wetlands in North Carolina.” *Ecol. Eng.*, 37 (4), 589-594.

Nepf, H.M. (1999). “Drag, turbulence, and diffusion in flow through emergent vegetation.” *Water Resour. Res.*, 35 (2), 279-289.

Neill, C., and Cornwell, J. C. (1992). “Stable carbon, nitrogen, and sulfur isotopes in a prairie marsh food web.” *Wetlands*, 12 (3), 217-224.

Oberts, G. (1994). “Performance of stormwater ponds and wetlands in winter. *Watershed Protection Techniques*, 1 (2), 64–68.

O’Neill, S. and Davis, A. P. (2012). “Water treatment residual as a bioretention amendment for phosphorus. I: Evaluation studies.” *J. Environ. Eng.*, 138 (3), 318-327.

Paul, M., and Meyer, J. L. (2001). “Streams in urban landscape.” *Annu. Rev. Ecol. Syst.*, 32, 333-365.

PA DEP (2006). *Pennsylvania stormwater best management practices manual*. Department of Environmental Protection, Bureau of Stormwater Management, and Division of Waterways, Wetlands, and Erosion Control, PA.

Pettersson, T. J. R. (1998). “Water quality improvement in a small stormwater detention pond.” *Wat. Sci. Tech.*, 38 (10), 115-122.

PLANTS, USDA (2012). National Wetland Plant List, U.S. Department of Agriculture, <http://plants.usda.gov/wetinfo.html> (September 30, 2012).

Pyke, C., Warren, M. P., Johnson, T., LaGro Jr., J., Scharfenberg, J., Groth, P., Freed, R., Schroeer, W., and Main, E. (2011). “Assessment of low impact development for managing stormwater with changing precipitation due to climate change.” *Landsc. Urban Plan.*, 103 (2), 166-173.

Reddy, K. R. and D’Angelo, E. M. (1997). “Biogeochemical indicators to evaluate pollutant removal efficiency in constructed wetlands.” *Wat. Sci. Tech.*, 35 (5), 1-10.

Reed, P. B. Jr. (1988). *National list of plant species that occur in wetlands: National summary.* U.S. Fish and Wildlife Service Biological report 88 (24), 1-244.

Sansalone, J. J., Koran, J. M., Smithson, J. A., and Buchberger, S. G. (1998). "Physical characteristics of urban roadway solids transported during rain." *J. Environ. Eng.*, 124 (5), 427-440.

Sansalone, J. J., and Glenn, D. W. III (2002). "Accretion of pollutants in snow exposed to urban traffic and winter storm maintenance activities. I." *J. Environ. Eng.*, 128 (2), 151-166.

Seitzinger, S.P., Sanders, R.W., and Styles, R. (2002). "Bioavailability of DON from natural and anthropogenic sources to estuarine plankton." *Limnol. Oceanogr.*, 47 (2), 353–366.

Semadeni-Davies, A. (2006). "Winter performance of an urban stormwater pond in southern Sweden." *Hydrol. Process*. 20 (1), 165-182.

Serra, T., Fernando, H. J. S., and Rodriguez, R. V. (2004). "Effects of emergent vegetation on lateral diffusion in wetlands." *Water Res.*, 38 (1), 139-147.

Shaw, S. B., Marjerison, R. D., Bouldin, D. R., Parlange J.-E., and Walter, M. T. (2012). "Simple model of changes in stream chloride levels attributable to road salt applications."*J. Environ. Eng.*, 138 (1), 112-118.

Shields, C. A., Band, L. E., Law, N., Groffman, P. M., Kaushal, S. S., Savvas,K., Fisher, G. T., and Belt, K. T. (2008). "Streamflow distribution of non-point source nitrogen export from urban-rural catchments in the Chesapeake Bay watershed." *Water Resour. Res.*, 44 (9), No. article W09416.

Shutes, R. B. E., Revitt, D. M., Scholes, L. N. L., Forshaw, M., and Winter, B. (2001). "An experimental constructed wetland system for the treatment of highway runoff in the UK." *Wat. Sci. Tech.*, 44 (11-12), 571-578.

Smith, R.D., Ammann, A., Bartoldus, C., and Brinson, M.M. (1995). *An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices*. Technical Report TRWRP-DE 10, U.S. Army Corps of Engineers, Washington, D.C.

Stagge, J. H. (2006). *Field evaluation of hydrologic and water quality benefits of grass swales for managing high runoff*. Master's thesis, University of Maryland, College Park, MD.

Stagge, J. H., Davis, A.P., Jamil, E., and Hunho, K. (2012). "Performance of grass swales for improving water quality from highway runoff." *Water Res.*, in press.

Stepanauskas, R., Leonardson, L., and Tranvik, L.J. (1999). "Bioavailability of wetland-derived DON to freshwater and marine bacterioplankton". *Limnol. Oceanogr.*, 44 (6),1477–1485.

Stephens, J. C., and Stewart, E. H. (1963). "A comparison of procedures for computing evaporation and evapotranspiration." Publication No. 62, *Internatl. Assn. of Scientific Hydrology*, Interned. Union of Geodesy and Geophysics, Berkeley, CA.

SMRC, Stormwater Manager's Resource Center. *Stormwater fact sheet: Infiltration basin*. Center for Watershed Protection, Inc., Ellicott City, MD. <http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Infiltration%20Practice/Infiltration%20Basin.htm> (Dec 17, 2008).

Strecker, E. W., Quigley, M. M., Urbonas, B. R., Jones, J. E., and Clary, J. K. (2001)." Determining urban storm water BMP effectiveness." *J. Water Resour. Plng. and Mgmt.*, 127 (3), 144-149.

Taylor, G. D., Fletcher, T. D., Wong, T. H. F., Breen, P. F., and Duncan, H. P. (2005)."Nitrogen composition in urban runoff- implications for stormwater management." *Water Res.*, 39 (10), 1982-1989.

Tiner, R. W. (1993a). "The primary indicators method- A practical approach to wetland recognition and delineation in the United States." *Wetlands*, 13 (1), 50-64.

Tiner, R. W. (1993b). "Using plants as indicators of wetland." *Proc. Academy of Natural Sciences of Philadelphia*, 144, 240-253.

Tiner, R. W. (2009). *Field guide to tidal wetland plants of the Northeastern United States and neighboring Canada*: *Vegetation of beaches, tidal flats, rocky shores, marshes, swamps, and coastal ponds*, 2nd *Ed.*, Univ. of Massachusetts Press, Amherst, MA, USA.

Tabari, H., Grismer, M., and Trajkovic, S. (2011). "Comparative analysis of 31 reference evapotranspiration methods under humid conditions." *Irrigation Science*, Springerlink, 1-11.

Tukimat, N. N. A., Harun, S., and Shahid, S. (2012). "Comparison of different methods in estimating potential evapotranspiration at Muda Irrigation Scheme of Malaysia." *J. Agric. Rural Dev. Trop. Subtrop.*, 113 (1), 77-85.

U.S Army Corps of Engineers Environmental Laboratory. (1987). *Corps of Engineers wetlands delineation manual*. Technical Report Y-87-1, U.S. Army Engineer Waterways Experiment Station, U.S Army Corps of Engineers, Vicksburg, MS.

USDA NRCS (2010). *Field indicators of hydric soils in the United States: A guide for identifying and delineating hydric soils, Version 7.0*. L.M. Vasilas, G.W. Hurt, and C.V. Noble (eds.). United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), in cooperation with the National Technical Committee for Hydric Soils.

U.S. EPA (1999). *Preliminary data summary of urban stormwater best management practices*. EPA-821-R-99-012. Office of Water, United States Environmental Protection Agency, Washington DC.

U.S. EPA (2001). *Functions and values of wetlands*. EPA-843-F-01-002c. Office of Water, United States Environmental Protection Agency, Washington DC.

U.S. EPA. (2002). *Methods for evaluating wetland condition: Wetlands classification.* EPA-822-R-02-017. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA (2003). *Elements of a state water monitoring and assessment program*. EPA 841-B-03-003. Office of Wetlands, Oceans and Watershed, United States Environmental Protection Agency, Washington D.C.

U.S. EPA (2005). *National management measures to control nonpoint source pollution from urban areas*. EPA-841-B-05-004. Office of Water, United States Environmental Protection Agency, Washington DC.

U.S. EPA (2009). *2009 Edition of the drinking water standards and health advisories*. EPA 822-R-09-011. Office of Water, United States Environmental Protection Agency, Washington DC.

Van Meter, R. J., Swan, C. M., Leips, J., and Snodgrass, J. W. (2011a). "Road salt stress induces novel food web structure and interactions." *Wetlands*, 31 (5), 843-851.

Van Meter, R. J., Swan, C. M., and Snodgrass, J. W. (2011b). “Salinization alters ecosystem structure in urban stormwater detention ponds.” *Urban Ecosystems*, 14 (4), 723-736.

Vollertsen, J., Astebol, S. O., Coward, J. E., Fageraas, T., Nielsen, A. H., and Hvitved-Jacobsen, T. (2009). “Performance and modelling of a highway wet detention pond for cold climate.” *Water Qual. Res. Can.*, 44 (3), 253-262.

Vymazal, J. (2007). “Removal of nutrients in various types of constructed wetlands.” *Sci. Total Environ.*, 380 (1-3), 48-65.

Wadzuk, B.M., Rea, M., Woodruff, G., Flynn, K., and Traver, R.G. (2010). “Water-quality performance of a constructed stormwater wetland for all flow conditions.” *J. Am. Water Resour. Assoc.*, 46 (2), 385-394.

Walker, T. A. (1998). “Modelling residence time in stormwater ponds.” *Ecol. Eng.*, 10 (3), 247-262.

Walker, T. A., and Hurl, A. (2002). “The reduction of heavy metals in a stormwater wetland.” *Ecol. Eng.*, 18 (4), 407-414.

Walsh, C. J., Roy, A. H, Feminella, J. W., Conttingham, P. D., Groffman, P. M., and Morgan II, R. P. (2005). “The urban stream syndrome: Current knowledge and the search for a cure.” *J. N. Am. Benthol. Soc.*, 24 (3), 706-723.

Wang, G-T., Chen, S., Barber, M.E., and Yonge, D.R. (2004). “Modeling flow and pollutant removal of wet detention pond treating stormwater runoff.” *J. Environ. Eng.*, 130 (11), 1315-1321.

Wang, L., Lyons, J., and Kanehl, P. (2003). “Impacts of urban cover on trout streams in Wisconsin and Minnesota.” *Trans. Am. Fish. Soc.*, 132 (4), 825-839.

Wiegner, T. N., Tubal, R. L., and MacKenzie, R. A. (2009). “Bioavailability and export of dissolved organic matter from a tropical river during base- and stormflow conditions.” *Limnol. Oceanogr.*, 54(4), 1233-1242

Wu, J.S., Allan, C.J., Saunders, W.L., and Evett, J.B. (1998). “Characterization and pollutant loading estimation for highway runoff.” *J. Environ. Eng.*, 124 (7), 584-592.

Wu, J. S., Holman, R. E., and Dorney, J. R. (1996). “Systematic evaluation of pollutant removal by urban wet detention ponds.” *J. Environ. Eng.*, 122 (11), 983-988.

Xu, C., Y., and Singh, V. P. (2001). "Evaluation and generalization of temperature-based methods for calculating evaporation." *Hydrol. Process.*, 15 (2), 305-319.

Yeh, T. Y. (2008). "Removal of metals in constructed wetlands: Review." *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, 12 (2), 96-101.

Phase I&II National Pollutant Discharge Elimination System
Permit No. 99-DP-3313 MD0068276
Permit Term October 2005 to October 2010

APPENDIX C
ASSESSMENT OF STREAM PROJECTS IN MARYLAND (JULY 2013)

Assessment of Stream Restoration Projects in Maryland

2013-2014 Report

<u>Prepared for:</u>

Maryland Department of Transportation
State Highway Administration
Highway Hydraulics Division
707 North Calvert Street
Baltimore, MD21202

<u>Prepared by:</u>

<u>Principal Investigator</u>

R. P. Morgan II

<u>Contributing Staff</u>

D. M. Gates

K. M. Kline

University System of Maryland
Center for Environmental Science
Appalachian Laboratory
301 Braddock Road
Frostburg, MD21532-2307

July 2013

Table of Contents

Introduction

The Maryland Department of Transportation, State Highway Administration (SHA) receivesstate and federal funding for assessment of stream restoration projects in Maryland. SHA requires scientific support (primarily biological) to assess and/or to monitor a selected set of stream restoration projects already completed, or projected to be done in the future, by the administration. Information collected from these studies, undertaken by the Appalachian Laboratory of the University of Maryland Center for Environmental Science, provides a framework and historical database of recommendations for future SHA stream restoration projects, and for assessment and potential revitalization of existing SHA restoration projects throughout Maryland.

Rationale

Stream restoration is of critical importance to the State of Maryland, as well as to the entire Chesapeake Bay watershed. The overall quality of life, now and in the future, is highly dependent on aquatic ecosystem integrity for both the quantity and quality of freshwater (Simon 1999). The integrity of surface water resources is dependent on chemical variables, flow regimes, biotic factors, energy sources, and habitat structure (Karr et al. 1986). Over the last quarter century, surveys of fish and benthic communities assessed freshwater ecosystem health (Simon 1999). Significant advances in this arena then led to the development of integrative ecological indices, such as Indices of Biotic Integrity (IBIs), which relate fish communities to both biotic and abiotic ecosystem components (Karr 1981, Karr et al. 1986). Coupled with chemical-physical water quality, habitat quality (and often quantity) is important to consider when examining fish communities, especially for any and all derived IBIs (Yoder and Smith 1999).

Stream restoration strongly focuses on revitalization of the physical habitat. However, indices of habitat quality to assess post-restoration processes have lagged behind fish and benthic IBI development. In part, this is because of the difficulty in developing accurate, precise and complete methodologies to assess quantitatively and qualitatively habitat characteristics (Platts 1976, Platts et al. 1983). The impetus for including stream habitat as an important measure came initially from western restoration activities (reviewed in Platts et al. 1983). For example, Binns (1979) developed a Habitat Quality Index for trout streams, soon to be followed by Habitat Evaluation Procedures models (HEP) and Habitat Suitability Index models (HSI) for use with the U. S. Fish and Wildlife Service in-stream flow models. Important improvements in more generalized habitat models came with the development of EPA's Rapid Bioassessment Protocols (Plafkin et al. 1989) and the Ohio EPA's Qualitative Habitat Evaluation (Rankin 1989).

Wallace (1990) points out that there are a number of factors to consider in looking at stream recovery, especially in light of recent restoration attempts. Recolonization of a disturbed or restored area is a function of many factors, often depending on stream size. Implicit in restoration is that long-term stream physical stability eventually recovers. However, benthic macroinvertebrates respond to many disturbances, and restoration processes directed towards only the physical habitat may not take into account other stressors. The importance of nearby biotic refugia, as a source for recolonization is also critical (Wallace 1990), especially upstream refugia and, to a degree, the presence of either downstream or nearby lateral watershed refugia.

Hall et al. (1999, 2002) initially developed a Physical Habitat Index for Maryland using data collected from the first round of the Maryland Biological Stream Survey (MBSS), followed by the development of a revised Physical Habitat Index for Maryland (Paul et al. 2002). Coupled with the development of fish IBIs (Roth et al. 1998) and benthic IBIs (Stribling et al. 1998) from the MBSS data set, there were now powerful tools available to assess stream integrity in Maryland, and to examine restoration efficiency. These indices were robust, and allowed inferences on stream integrity and stability, either regionally, statewide, or at site-specific levels. In addition, these indices were even more refined with additional MBSS rounds completed, and especially with the development of coldwater fish IBIs and a finer level of benthic IBIs (Southerland et al. 2005, 2007).

Functional rehabilitation of degraded streams is critical, since streams may provide multiple environmental benefits, as well as critical ecological services (Morris and Moses 1999, National Research Council 1992). Functional rehabilitation is the major key to stream restoration since a return to pre-colonization stream status is impossible, especially in Maryland, where complex patterns of land use evolved since pre-colonial days. However, analytical evaluation of stream restoration or enhancement projects is often lacking. Monitoring these projects often serves as an important "first step" in evaluating effectiveness, and is essential to adaptive resource management (Bash and Ryan 2002). Downs and Kondolf (2002) and Morgan (2005) noted that post-project appraisals, or evaluations of restoration effectiveness, are critical to assess both short-term and long-term performance attainment of stream restoration projects. Often, this critical step is lacking in most restoration projects (Downs and Kondolf 2002). SHA project analyses completed from 1998 to 2010 for SHA were discussed in Morgan et al. (2010). In this report, eight recommendations for the improvement of assessment on SHA stream restoration projects were described.

Project Objective

The overall project objective is to assess and monitor completed and proposed SHA stream restoration projects and to make recommendations for future restoration projects, as well as improvement and revitalization of current restoration projects. In addition, a monitoring schedule for examining all completed stream restoration projects in the long-term (5, 10, and 25 years) was developed based on results for each SHA stream restoration site, and is in constant refinement with new sites added.

Materials and Methods

Site Locations

Site details for each SHA restoration location are described in the results and discussion section. All sites for the FY 13 SHA work were pre-construction sites. Control sites are often very difficult to find in highly developed urban watersheds or in headwater streams. We always attempted to find control sites upstream of pre-restoration or post-restoration sites; however, many of these restoration sites were in the extreme upper part of a watershed and did not reflect the restoration area, or there were changes in control sites during the study. To compensate for this problem, we employed data from all rounds of the MBSS for comparison to the restoration site. Normally, one would try to collect samples where the condition is present and where it is absent, with all other factors being the same (Green 1979). This approach determines an effect at a site relative to a control. However, there is so much anthropogenic activity in the landscape of the coastal plain and Piedmont, as well as other physiographic provinces of Maryland, that watersheds are strongly altered through time and space. It may be necessary at some sites to move downstream into the lower part of a watershed and then determine current conditions to assess the upstream site. However, this is not the desired approach.

Benthic Macroinvertebrates

Assessment of benthic macroinvertebrates at each sampling site followed benthic macroinvertebrate protocols for MBSS sampling (Kazyak 1996, Stranko et al. 2010). At each pre-construction or post-construction project, two samples (~ 10-20 sweeps each with D-nets depending on stream size) were taken within the project boundary after site surveys (lower and middle sections, if possible). One sample was always collected near the lower (downstream boundary) of the project. The middle sample was collected approximately one-third to one-half of the distance from the upper upstream boundary of the project (benthic sampling was modified dependent on site characteristics). Two additional samples, serving as replicate controls, were collected upstream of the stream restoration project, assuming that the upstream area served as a suitable control area. If no suitable upstream control was present, one or two site samples were taken downstream. For any pre-construction sites, two benthic samples were taken within the proposed project boundaries, along with two controls from an upstream area (or downstream area) if possible. We identified a number of MBSS reference streams to provide baselines for benthic invertebrate quality for the project.

Benthic Field Sampling Protocols

A series of D-net samples (a total of ~ 1-2 m^2) were taken at each sampling location (Kazyak 1996), with an emphasis on selecting riffle/run habitat. Benthic macroinvertebrate sampling was conducted in order to qualitatively describe the community composition and relative abundance in favorable habitats. All survey methods for benthic macroinvertebrates followed MBSS protocols (Kazyak 1996), with benthic samples, as often as possible, collected from stream riffle areas because this is typically the most productive habitat in stream ecosystems. When riffle habitat was not present, other habitats sampled in the following order of preference were: gravel/broken peat and/or clay lumps in run areas; snags/logs that create partial dams or are in run habitat; undercut banks and associated root mats in moving water; submerged aquatic vegetation and associated bottom substrate in moving water; and detritus/sand areas in moving water. In the field, samples were transferred to polyethylene bottles and preserved in denatured ethanol. These benthic samples were collected during the MBSS spring index period and during the MBSS fall index period (Kazyak 1996).

Benthic Laboratory Protocols

In the laboratory, samples were washed, picked, and stored in 70% isopropyl alcohol. The first 300 organisms (to the nearest grid) were picked for identification to the lowest taxon possible (Plafkin et al. 1989), with the first 100 organisms separated for calculation of the MBSS BIBI. Only the 100 organism sample was used for calculations since the MBSS BIBI development was based on this sample number. If the sample contained less than 300 organisms, the sample was picked completely.

Benthic Macroinvertebrate Statistical Protocols

A revised Maryland benthic index of biotic integrity (BIBI) was employed for this project (Southerland et al. 2005, 2007). The new BIBI was broken into Coastal Plain, Eastern Piedmont and Combined Highlands (Table 1).

Table 1. MBSS BIBIs for Maryland by stratum and with metric scoring thresholds.

Stratum and Metric	Thresholds		
	1	3	5
Coastal Plain (7)			
Number of taxa	< 14	14-21	≥ 22
Number of EPT taxa	< 2	2-4	≥ 5
Number of Ephemeroptera taxa	< 1	1-1	≥ 2
Percent intolerant to urban	< 10	10-27	≥ 28
Percent Ephemeroptera	< 0.8	0.8-10.9	≥ 11
Number of scraper taxa	< 1	1-1	≥ 2
Percent climbers	< 0.9	0.9-7.9	≥ 8

Table 1 (Continued).			
Stratum and Metric	**Thresholds**		
	1	**3**	**5**
Eastern Piedmont (6)			
Number of taxa	< 15	15-24	≥ 25
Number of EPT taxa	< 5	5-10	≥ 11
Number of Ephemeroptera taxa	< 2	2-3	≥ 4
Percent intolerant to urban	< 12	12-50	≥ 51
Percent Chironomidae	> 63	4.7-63	≤ 4.6
Percent clingers	< 31	31-73	≥ 74
Combined Highlands (8)			
Number of taxa	< 15	15-23	≥ 24
Number of EPT taxa	< 8	8-13	≥ 14
Number of Ephemeroptera taxa	< 3	3-4	≥ 5
Percent intolerant to urban	< 38	38-79	≥ 80
Percent Tanytarsini	< 0.1	0.1-3.9	≥ 4
Percent scrapers	< 3	3-12	≥ 13
Percent swimmers	< 3	3-17	≥ 18
Percent Diptera	> 50	27-49	≤ 26

For any of the three MBSS strata, BIBI scores were determined by adding the threshold score for each metric, and then dividing by the number of metrics for each stratum. The BIBI collected at each station was compared to the control area as well as to MBSS reference stations in the vicinity of the SHA project. An IBI score range of 4.0 - 5.0 is rated good, 3.0 - 3.9 is fair, 2.0 - 2.9 is poor, and 1.0 - 1.9 is very poor (Table 2).

Table 2. Narrative descriptions of stream biological integrity associated with each of the BIBI scores.		
Good	BIBI score 4.0 - 5.0	Comparable to reference streams considered to be minimally impacted. Fall within the upper 50% of reference site conditions.
Fair	BIBI score 3.0 - 3.9	Comparable to reference conditions, but some aspects of biological integrity may not resemble the qualities of these minimally impacted streams. Fall within the lower portion of the range of reference sites.
Poor	BIBI score 2.0 - 2.9	Significant deviation from reference conditions, with many aspects of biological integrity not resembling the qualities of these minimally impacted streams, indicating some degradation.
Very Poor	BIBI score 1.0 - 1.9	Strong deviation from reference conditions, with most aspects of biological integrity not resembling the qualities of these minimally impacted streams, indicating severe degradation.

Results and Discussion

Each current SHA restoration project will be reviewed, discussed and synthesized into the context of regional Maryland values, as derived from the Maryland Biological Stream Survey (all rounds). All basic information collected at each site for FY13 is included in each site summary. In addition, photographs were taken for each site and forwarded to SHA.

SHA Site: Long Draught Branch (LDB)

Site Description: Long Draught Branch is a small first order stream located in a very highly urbanized area of Montgomery Country that includes residential development, large and small office complexes, shopping centers and very large amounts of impervious surface due to parking lots, extensive road systems and buildings (Figure 1). Throughout its stream course until it enters Clopper Lake, there are numerous storm drains discharging into the stream**.** There is also a major sewage line paralleling the stream throughout the proposed restoration areawith a few surface seeps present.

Site Coordinates:

Site coordinates for Long Draught Branch (Figure 1).			
Station	Latitude	Longitude	Comments:
Middle	39°08'34.17"N	77°13'36.61"W	Projected middle restoration site.
Lower	39°08'37.68"N	77°13'39.89"W	Projected lower restoration site.
Alpha Control	39°08'37.72"N	77°13'21.88"W	Upstream control I.
Beta Control	39°08'37.58"N	77°13'19.97"W	Upstream control II.

Benthic Community: Details on the macroinvertebrate assemblages sampled at Long Draught Branch (LDB) sites arelisted in the followingsix tables (LDB 1-6). Benthic sampling was completed at the four stations on 9 November 2012 and 29 March 2013 (Figure 1).

LDB November 2012 - For stations with a 100 + macroinvertebrate count, taxa richness, number of EPT taxa, number of Ephemeroptera taxa, percent of taxa intolerant of urban conditions, and percent of clingers were low at all four sites in November 2012 (Table LDB-1). Hydropsychidae larvae dominated the EPT collection and were the dominant macroinvertebrate clinger as well (Table LDB-3). The percent of chironomids at the Alpha Control and Middle Restoration site was low and moderate at the two remaining stations. The BIBI varied from 1.3 to 1.7 at the sites (very poor scores). The overall abundance of macroinvertebrates was low, with only the Lower Restoration site having enough macroinvertebrates to allow a 300 + macroinvertebratecount (Table LDB-2). The same trends as seen in the 100 + count were seen at this site as well. The % intolerant urban and the total EPT taxa were low for all benthic sampling stations during November – a strong indication of an urban stressed stream.

LDB March 2013 - For the two control and two restoration stations, most metrics were low (Tables LDB 5-6). Moderate values of the percent of chironomids were seen at the

Beta Control and Lower and Middle Restoration sites, with all other metrics being low. Additionally, abundance was low at the Alpha Control and the Lower and Middle Restoration sites with less than 100 macroinvertebrates collected in those samples. *Cheumatopsyche* sp. larvae were the dominant EPT collected, although in very low numbers. The BIBI varied from 1.0 to 1.3 at the sites(very poor scores).The % intolerant urban and the total EPT taxa were also low for all benthic sampling stations during March.

Physical Habitat: Physical habitat in the control area was good, although there was a limited buffer width along the stream. Shading was good for most of the control area. However, there were three problems that we observed during all benthic sampling in the upper control region. First, there was a dam upstream of the control area that formed a small pond clogged with cattails (dam coordinates:39°08'33.74"N; 77°13'10.95"W). During the summer, this shallow pond would create high temperature spikes downstream during storm events and may even create excessive stream temperatures during the summer without storm events. In addition, there were several outfalls from pavement discharging into the stream that would also generate temperature spikes during summer rain events. Second, Long Draught Branch flowed underground through large culverts for a significant distance (an estimate of ~ 0.18 km). Third, the stream originated very close to I-270 and West Diamond Avenue from spring seeps in this area. Consequently, the upstream characteristics of Long Draught Branch affected both the control and potential restoration area.

The stream area to be restored on Long Draught Branch was an urban mess. There were numerous undercut banks and large amounts of urban debris. There was some shading along the stream, but the stream buffer was broken in most areas, with a fairly large expanse of grass. We also observed some whitish-brown effluent draining from a culvert into the stream, as well as some surface drainage problems from a stream sewer system very close to Long Draught Branch. Basically, the restoration area was a classic example of the effects of urbanization on physical habitat structure.

Water Quality: At SHA's request, we collected a very limited, one-time set of water quality samples at theFY 2013 sites (4/15/13) during baseflow conditions (see Morgan et al. 2012, 2013 for water quality methodology and statistical analyses). For Long Draught Branch, total nitrogen (TN) was 1.41 mg/L, total phosphorus (TP) 0.13 mg/L, total suspended solids (TSS) 3.4 mg/L, and specific conductivity 698 µS/cm. Using the 25th percentile estimates for the Northern Piedmont ecoregion of Maryland (Morgan et al. 2013), the TN criteria (1.6 mg/L) was not exceeded but the TP criteria (0.010 mg/L) was exceeded by 13 times, potentially indicating some inputs into the stream from leaky sewage infrastructure. TSS was slightly elevated but this parameter is more useful in stream flow assessments during storm events. In addition, stream specific conductivity exceeded the 25thpercentile (145 µS/cm) for the Northern Piedmont by a factor of 4.8 times(Morgan et al. 2012). This elevated specific conductivity in Long Draught Branch reflects the urban stream syndrome (Walsh et al. 2005) where there is frequently high stream conductivity due to inputs from road salts and other sources.

Assessment Recommendation: Long Draught Branch is a contentious pre-restoration site. Prior to the construction of any proposed stream stabilization projects, it should be resampled at least one more time, and then 2-4 years after the completion of construction.

Table LDB - 1. Data summary of benthic macroinvertebrates collected in D-frame samples on 9 November 2012at stations in Long Draught Branch (100 + subsample; * = sample < 100 macroinvertebrates)

	Riffle Community (100+ subsample)			
Metric	**Alpha Control**	**Beta Control**	**Lower**	**Middle**
Taxa Richness	6*	6*	9*	13
Total EPT Taxa	1*	1*	1*	4
Ephemeroptera taxa	0*	0*	0*	1
% Intolerant Urban	0.0%*	0.0%*	0.0%*	8.8%
% Chironomidae	40.0%*	4.1%*	2.2%*	43.4%
[illegible]	20.0%*	4.1%*	3.4%*	18.6%
[illegible]	1.3	1.7	1.7	1.3

Table LDB - 2. Data summary of benthic macroinvertebrates collected in D-frame samples on 9 November 2012 at stations in Long Draught Branch. Only the Lower Restoration site contained more than 300 organisms for analysis.

Long Draught Branch Sampling Sites (300 + subsample)	
Metric	**Lower Restoration**
Taxa Richness	10
Total EPT Taxa	1
Ephemeroptera taxa	0
% Intolerant Urban	0.0%
% Chironomidae	4.2%
% Clingers	2.5%

Table LDB - 3.Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Long Draught Branch on 9 November 2012. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

Long Draught Branch Sampling Sites (100 + subsample)				
Taxa	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Turbellaria				
Cura sp.	3	50		7
Gastropoda				
Lymnaeidae			6	1
Physidae			1	
Planorbidae				
Menetus sp.		6		
Pelycepoda				
Sphaeriidae		13	70	35
Insecta				
Ephemeroptera				
Heptageniidae				1
Odonata				
Coenagrionidae				
Enallagma sp.			4	
Gomphidae				
Progomphus sp.				1
Plectoptera				
Leuctridae				1
Taeniopterygidae				
Taeniopteryx sp.				9
Trichoptera				
Hydropsychidae	1	2	1	
Cheumatopsyche sp.			2	6
Lepidoptera				
Noctuidae	1			
Coleoptera				
Elmidae				
*Stenelmis*sp.				2
Diptera				
Ceroptogonidae				
Culcoides sp.			1	
Chironomidae				1
Tanypodinae				1
Orthocladinae	2	2	2	6
Chironomini				41
Tanytarsini	2	1		
Empididae				
Hemerodromia sp.			1	
Simulidae				
Simulium sp.				1
Stratiomyidae				
Odontomyia sp.	1			
Tipulidae				
Tipula sp.			1	

Table LDB - 4. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Long Draught Branch on 9 November 2012. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

Long Draught Branch Sampling Sites (300 + subsample)	
Taxa	**Lower Restoration**
Gastropoda	
Lymnaeidae	7
Physidae	3
Planorbidae	
Helisoma sp.	1
Pelycepoda	
Sphaeriidae	91
Insecta	
Odonata	
Coenagrionidae	
Enallagma sp.	4
Trichoptera	
Hydropsychidae	1
Cheumatopsyche sp.	2
Diptera	
Ceratopogonidae	
Culcoides sp.	1
Chironomidae	1
Orthocladinae	4
Empididae	
Hemerodromia sp.	1
Tipulidae	
*Tipula*sp.	2

Table LDB - 5. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations in Long Draught Branch (* = sample < 100 macroinvertebrates).

Metric	Alpha Control	Beta Control	Lower Res.	Middle Res.
Taxa Richness	5*	11	9*	5*
Total EPT Taxa	1*	1	1*	2*
Ephemeroptera taxa	0*	0	0*	1*
% Intolerant Urban	0.0%*	0.0%	0.0%*	0.0%*
% Chironomidae	75.0%*	41.9%	44.9%*	53.3%*
[illegible]	2.8%*	11.4%	14.3%*	13.3%*
[illegible]	1.0*	1.3	1.3*	1.3*

Table LDB - 6.Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (totalsampling area approximately 1 m^2) at sites in Long Draught Branch on March 2013. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

Taxa	Alpha Control	Beta Control	Lower restoration	Middle Restoration
Turbellaria				
Phygocata sp.	3	24		
Nematoda		2		
Annelida				
Oligichaeta				
Lumbriculidae	3	6	4	
Naididae	2	4	1	2
Enchytraeidae			1	
Tubificidae		11	2	
Gastropoda				
Lymnaeidae			5	
Pelycepoda				
Sphaeriidae		8	9	2
Insecta				
Collembola		1		
Ephemeroptera				
Caenidae				
*Caenis*sp.				1
Trichoptera				
Hydropsychidae			1	
Cheumatopsyche sp.	1	2	3	1
Diptera				
Chironomidae	2			
Tanypodinae				
Orthocladinae	2	6P	3(6P)	3
Orthocladius sp.	23	44	11	5
*Eukiefferiella*sp.		5		
Chironomini				
Micropsectra sp.			1	
Tanytarsini		1	1	
Empididae				
Clinocera sp.				1
Stratiomyidae				
Odontomyia sp.			1	

Figure 1. Benthic sampling stations for Long Draught Branch.

SHA Site: Minebank Run (MBR)

Site Description: Minebank Run consists of two post-restoration sites, with stream restoration work completed from 1998-99 in the upper portion of the watershed upstream of the Baltimore Beltway (I-695). More recent stream restoration activity occurred between 2004 and 2005 in a lower site near Cromwell Valley Park (Doheny et al. 2007). The total watershed area of Minebank Run is small (3.27 m^2), and the entire stream is basically a 1st-order stream, although Harts Run (a very small, spring-fed stream) enters Minebank Run just upstream of the 2004-05 restoration area, with a lower unnamed tributary entering just above Merrick Bridge. For the FY13 study year, we focused on assessment in the lower stream restoration site since SHA provided detailed information on the location of the pre-restoration site. A suitable control area was found upstream (Figure 2).

Site Coordinates:

Site coordinates for Minebank Run (Figure 2).			
Station	Latitude	Longitude	Comments:
Middle	39°24'28.30"N	76°33'44.39"W	Middle restoration site.
Lower	39°24'25.08"N	76°33'47.71"W	Lower restoration site.
Alpha Control	39°24'15.53"N	76°34'04.47"W	Upstream control one.
Beta Control	39°24'14.67"N	76°34'07.34"W	Upstream control two.

Benthic Community: Details on the macroinvertebrate assemblages sampled at MBR sites arelisted in the following six tables (MBR 1-6). Benthic sampling was completed at the four stations on 12 November 2012 and 29 March 2013 (Figure 2).

MBR November 2012– For the 100 macroinvertebrate count, taxa richness (7-12), number of EPT taxa (3-4), number of Ephemeroptera taxa, and percent of taxa intolerant of urban conditions were low at both the control and restoration sites (MBR-1). Philopotomatidae larvae dominated the EPT collection. The percent of chironomids and percent of macroinvertebrates categorized as clingers were moderate. The tipulid*Antocha*sp. dominated the clinger category in the control sites while the trichopteran*Chimerra*sp. was the dominant clinger seen in the two restoration sites. The IBI was 1.7 at all sites (very poor). The abundance of macroinvertebrates was low at all sites in the November samples and a 300 organism count was not possible.

MBR March 2013 - Forthe 100 macroinvertebrate count, all metrics had a low value. No Ephemeroptera sp. were collected and the only EPT macroinvertebrate seen was *Chimerra* sp. at the Alpha Control and the Lower Restoration site. No macroinvertebrates intolerantof urban conditions were collected at either the control or restoration sites. The IBI was 1.0 at all sites, lower than in the November sampling.For the 300 macroinvertebrate count, all metrics had a low value. No ephemeropterans were collected and the only EPT macroinvertebrate seen was *Chimerra* sp. at the Alpha Control and the Lower Restoration site. No macroinvertebrates intolerant of urban conditions were collected at either the control or restoration sites.

Physical Habitat: During the benthic sampling in March and November, we noted that both the control and restoration site displayed the 'flashy' habitat very typical of urban streams, with down cutting in many areas. Fish habitat was very poor throughout the control and restoration areas, and there was a lack of fine sediment throughout Minebank Run. The two upstream control sites were in poor shape due to their proximity to major roads. There was also some evidence of flashy flows throughout both the restoration and control sites, with large debris scattered away from the stream.

Water Quality: For Minebank Run, the total nitrogen (TN) was 1.23 mg/L, total phosphorus (TP) 0.0069 mg/L, total suspended solids (TSS) 0.4 mg/L, and specific conductivity 714 µS/cm. Using the 25th percentile estimates for the Northern Piedmont ecoregion of Maryland (Morgan et al. 2013), the TN criteria (1.6 mg/L) and the TP criteria (0.010 mg/L) were not exceeded. TSS was not elevated (0.4 mg/L). In addition, stream specific conductivity exceeded the 25thpercentile (145 µS/cm) for the Northern Piedmont by a factor of 4.9 times(Morgan et al. 2012). This elevated specific conductivity reflects the urban stream syndrome (Walsh et al. 2005) where there is frequently high stream conductivity due to inputs from road salts and other sources. In particular, Minebank Run is in close proximity to the Baltimore Beltway, as well as to other road systems that are frequently salted.

Assessment Recommendation: The MBR site should be reassessed prior to any future restoration work.

Table MBR - 1. Data summary of benthic macroinvertebrates collected in D-frame samples on 12 November 2012 at stations on Minebank Run.

Metric	Riffle Community (100+ subsample)			
	Alpha Control	Beta Control	Lower	Middle
Taxa Richness	12	7	7	8
Total EPT Taxa	4	3	4	4
Ephemeroptera taxa	1	1	0	0
% Intolerant Urban	1.4%	0..0%	3.4%	2.4%
% Chironomidae	54.3%	59.3%	34.5%	35.7%
[illegible]	41.4%	33.3%	65.5%	59.5%
[illegible]	1.7	1.7	1.7	1.7

TableMBR - 2. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations on Minebank Run.

Metric	Riffle Community (100+ subsample)			
	Alpha Control	Beta Control	Lower	Middle
Taxa Richness	6	7	10	6
Total EPT Taxa	1	0	1	0
Ephemeroptera taxa	0	0	0	0
% Intolerant Urban	0.0%	0.0%	0.0%	0.0%
% Chironomidae	95.3%	95.0%	90.7%	94.6%
[illegible]	2.8%	0.8%	2.1%	3.6%
[illegible]	1.0	1.0	1.0	1.0

Table MBR - 3. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations on Minebank Run.

Metric	Riffle Community (300+ subsample)		
	Alpha Control	Beta Control	Middle
Taxa Richness	13	12	13
Total EPT Taxa	1	1	2
Ephemeroptera taxa	0	0	0
% Intolerant Urban	0.0%	0.0%	0.0%
% Chironomidae	95.7%	93.8%	93.7%
[illegible]	2.3%	1.6%	4.3%

Table MBR - 4 . Numbers of macroinvertebrates collected in benthic samples by combining 9-10 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites on Minebank Run on 12 November 2012. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

Minebank Run Sampling Sites (100+ subsample)				
Taxa	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Annelida				
Oligochaeta				
Lumbriculidae		1		
Insecta				
Ephemeroptera				
Baetidae	1			
Baetis sp.		1		
Odonata				
Calopterygidae				
*Calopteryx*sp.	1			
Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	4	3	4	1
Hydropsyche sp.	4		2	1
*Synphytopsyche*sp.				
Philopotomatidae				1
Chimarra sp.	2	3	7	14
Dolophilodes sp.			1	1
Coleoptera				
Stenelmis sp.	1			
Diptera				
Chironomidae	2			
Orthocladinae	33	16	10	15
Tanytarsini	3			
Empididae				
Hemerodromia sp.	1			
Muscidae				
Limnophora sp.		1		
Simulidae				
*Simulium*sp.	2		1	4
Tipulidae				
Antocha sp.	15	2	4	3
Pseudolimnophila sp.	1			
Tipula sp.				2

Table MBR - 5. Numbers of macroinvertebrates collected in benthic samples by combining 9-10 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Minebank Run on 29 March 2013. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

	Minebank Run Sampling Sites (100+ subsample)			
Taxa	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Nemerta				
Annelida				
Oligochaeta				
Naididae		2		
Enchytraeidae	1	2	1	
Insecta				
Trichoptera				
Philopotomatidae				
Chimarra sp.	2		1	
Coleoptera				
Dytiscidae			1	
Agabus sp.	1			
Hoperius sp.		1		
Elmidae				
Oulimnius sp.				
Stenelmis sp.				1
Chironomidae	3		3	15
Diamesinae				
*Diamesa*sp.	2		3	
Diptera				
Orthocladinae	14P	2(21P)	1(23P)	
*Orthocladius*sp.	82	84	57	90
*Eukiefferiella*sp.		4		
Chironomini				1
Micropsectra sp.		1		
Tanytarsini		1	1	
Empididae				
*Chelifera*sp.			3	
Clinocera sp.				2
*Hemerodromia*sp.			1	2
Simulidae				
Simulium sp.		1		
Tipulidae				
Antocha sp.	1		1	1
Tipula sp.			1	

Table MBR - 6. Numbers of macroinvertebrates collected in benthic samples by combining 9-10 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Minebank Run on 29 March 2013. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

	Minebank Run Sampling Sites (300+ subsample)		
Taxa	**Alpha Control**	**Beta Control**	**Middle Restoration**
Turbellaria			
Phygocata sp.			1
Nematoda		1	1
Nemerta		1	
Annelida			
Oligochaeta			
Naididae		6	1
Enchytraeidae	2	2	
Tubificidae			1
Insecta			
Trichoptera			
Hydropsychidae			
Hydropsyche sp.			1
Philopotomatidae			
Chimarra sp.	4	1	2
Coleoptera			
Dytiscidae			
Agabus sp.	1		
Hoperius sp.	1	1	
Elmidae			
Oulimnius sp.			
Stenelmis sp.			1
Diptera			
Chironomidae	1(9P)	1	7(41P)
Diamesinae			
*Diamesa*sp.	6	2	5
Orthocladinae	48P	2(32P)	
Eukiefferiella sp.	5	9	
Orthocladius sp.	221	179	276
Chironomini			
Dicrotendipes sp.	1		
Tanytarsini		2	
Micropsectra sp.	1	1	
Empididae			
Chelifera sp.			1
Clinocera sp.	1		4
Hemerodromia sp.	2	1	3
Simulidae			
Simulium sp.		2	
Tipulidae			
Antocha sp.	1		6
Tipula sp.	1		

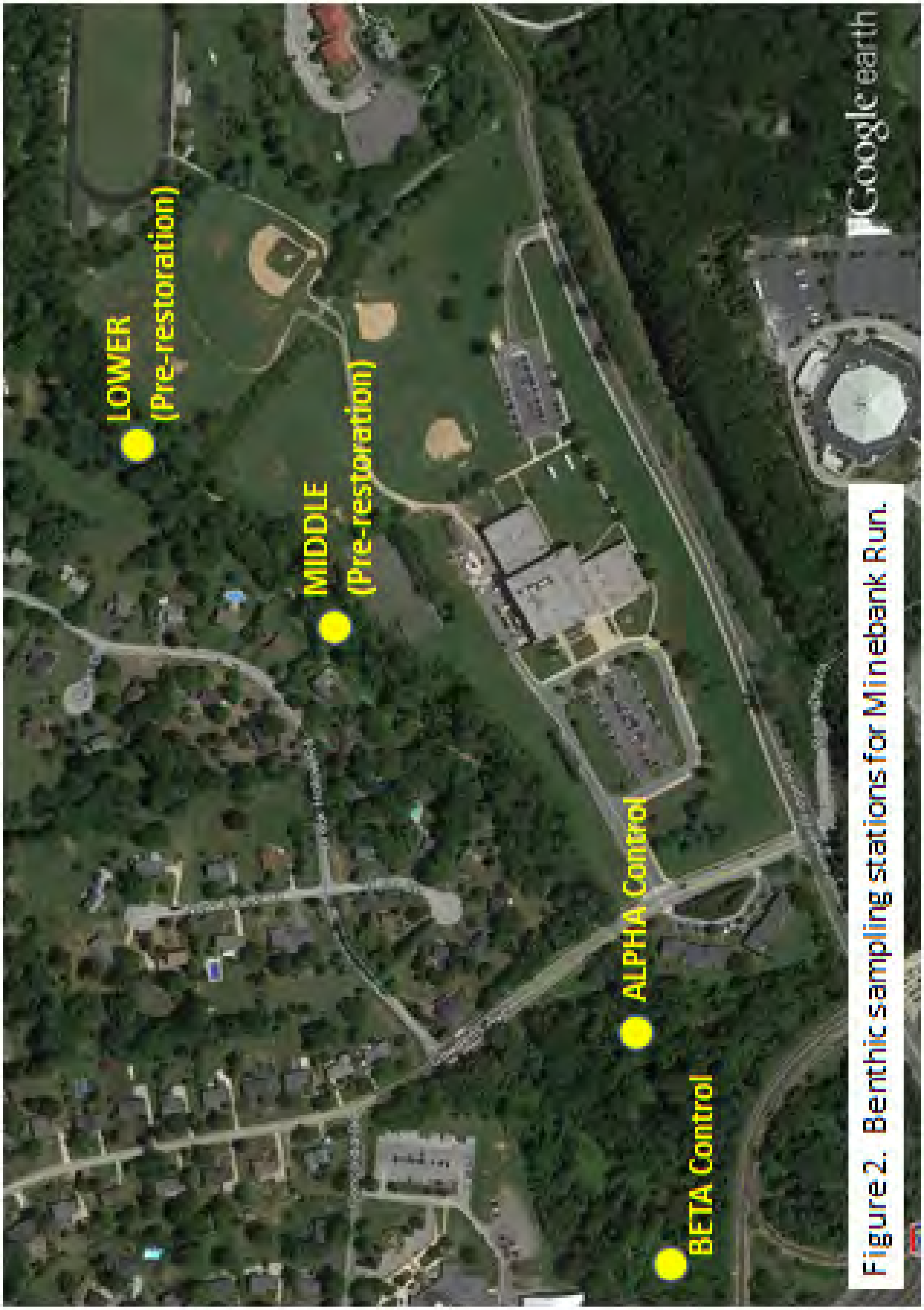


Figure 2. Benthic sampling stations for Minebank Run.

SHA Site: Plumtree Run (PTR)

Site Description: Plumtree Run (pre-construction) is a first-order stream located in Harford County near Bel Air, MD (Figure 3). It parallels Route 24 from it headwaters to West Ring Factory Road and then crosses under Route 24. The stream area to be restored is between West Ring Factory Road and Route 24. At the lower end of the restoration area, Plumtree Run crosses back under Route 24 and then eventually drains into Atkisson Reservoir (the headwaters of Winters Run draining into the Bush River). Plumtree Run presents a problem in benthic analyses since it is located on the Fall Line in Maryland, with the Piedmont to the west and the western Coastal Plain to the east of the site. For Plumtree Run, both sets of benthic metrics were calculated.

The upper headwaters of Plumtree Run are heavily affected by urbanization, with numerous, large residential developments on either side of the stream along with a large hospital complex, road infrastructure, and shopping centers. There is an overabundance of parking for the hospital, MD DMV and the shopping centers, as well as a high road density in the Atkisson Run watershed (~ 4.0 km/km^2).

Site Coordinates:

Site coordinates for Plumtree Run (Figure 3).			
Station	Latitude	Longitude	Comments:
Middle	39°30’35.02”N	76°20’23.45”W	Middle site.
Lower	39°30’30.15”N	76°20’20.15”W	Lower site.
Alpha Control	39°30’42.47”N	76°20’32.16”W	Upstream control I.
Beta Control	39°30’46.51”N	76°20’35.82”W	Upstream control II.

Benthic Community: Details on the macroinvertebrate assemblages sampled at the PTR sites arelisted in the following tables (PTR 1- 12). Benthic sampling was completed at the four PTR stations on 12 November 2012 and 29 March 2013 (Figure 3).

PTR November 2012– For PTR stations with a 100 + macroinvertebrate count, taxa richness (10-14), number of ephemeropteran taxa (0-1), and percent macroinvertebrate intolerant of urban conditions were all low to moderate, with the percent of chironomids moderate at all stations. The number of scraper taxa was moderate at the Lower Restoration site and high at the remaining sites, with % clingers high across all sites (71-90%). *Cheumatopsyche* sp. and *Chimerra* sp.larvae dominated the EPT collection and clinger category. All sites had low taxa richness, but the % Chironomidae was relatively low (6.5 – 18.2%). For the Piedmont metrics, the BIBI ranged from 1.7 at the Lower Restoration site to 2.0 at the three remaining sites. For the coastal plain metrics, the BIBI ranged from 1.9 to 2.4. All BIBI values were in the very poor to poor categories.

Abundance was low at the two control sites, so the 300 +macroinvertebrate count was available at the BetaControl site while at the AlphaControl site less than 300 macroinvertebrates were collected. The above trends were generally the same, although taxa richness and the number of EPT taxa were slightly higher, reflecting the larger sample size examined for Plumtree Run.

PTRMarch 2013– For stations with a 100 + macroinvertebrate count, taxa richness, the number of ephemeropteran taxa, and percent macroinvertebrates intolerant of urban conditions were low (9-18 taxa) at all stations, although the Lower Restoration and Middle Restoration sites had 15-18 benthic species present. The percent of chironomids was high at control sites (this may potentially reflect some nutrient loadings) and moderate at the restoration sites, with the percent of clingers low at the control sites and moderate at the restoration sites.*Cheumatopsyche* sp. and *Chimerra* sp.larvae dominated the EPT collection and clinger category.For the Piedmont metrics, the BIBI ranged from 1.0 at control sites to 2.0 at the restoration sites.For the Coastal Plain metrics, the BIBI ranged from 1.9 to 2.1.All BIBI values were in the very poor to poor categories.

Piedmont metrics for the 300 + count subsample were generally the same as for the 100 + count subsample. However, Coastal Plain metrics for the 300 + count subsample were slightly higher than the 100 + count subsample.Taxa richness was low at control sites and moderate at restoration sites, although EPT taxa were moderate at all sites. The number of scraper taxa was moderate at control sites and high at the restoration sites. The percent of ephemeropterans and percent of macroinvertebrates intolerant of urban conditions was low at all stations.

Physical Habitat: For Plumtree Run, the upstream control area (Figure 3) is bounded by heavy development for a distance of ~ 1.2 km upstream to its approximate source. For most of the stream length, the stream is shaded with relatively good stability along the banks, with a variety of plant species present (native and introduced). This stream corridor varies greatly in width as a function of housing developments and commercial properties. The eastern bank of Plumtree Run is in close proximity to Route 24 in the lower section, and is effectively forced into a channel with some gradient. There appeared to be some stream stabilization work in the past when Route 24 was constructed. In the control area, the stream bottom is a mixture of boulders, coble, gravel, and some fine sediment.

The restoration area, ~ 0.64 km in length, is downstream of the junction of Route 24 and West Ring Factory Road, and ends where Plumtree Run crosses Route 24 again. In this area, Plumtree Run has more of a flood plain than in the control area. Substrate throughout this control area was quite variable, ranging from large cobble to fine silt and clay. Also, there were a number of root wads present along the banks with deep pools present that provided fish habitat (fish were observed throughout the restoration area). Shading was good throughout the restoration reach, but bank stability was poor reflecting the flashy nature of the stream. There was an abundance of multiflora rose as well as other native and non-native plant species.

Water Quality: For Plumtree Run, the total nitrogen (TN) was 1.56 mg/L, total phosphorus (TP) 0.010 mg/L, total suspended solids (TSS) 2.2 mg/L, and specific conductivity 654 µS/cm. Using the 25th percentile estimates for the Northern Piedmont ecoregion of Maryland (Morgan et al. 2013), the TN criteria (1.6 mg/L) and the TP criteria (0.010 mg/L) were not exceeded. TSS was not elevated (2.2 mg/L). In addition, stream specific conductivity exceeded the 25th percentile (145 µS/cm) for the Northern Piedmont by a factor of 4.5 times (Morgan et al. 2012). This elevated specific conductivity reflects the urban stream syndrome (Walsh et al. 2005) where there is frequently high stream conductivity due to inputs from road salts and other sources. In particular, Plumtree Run is in close proximity to road systems that are frequently salted during ice and snow events.

Assessment Recommendation: The PTR control sites should be assessed yearly during the construction phase. In addition, a set of two samples should be taken downstream to determine if significant refugia are present for benthic organisms.

Table PTR - 1. Data summary of benthic macroinvertebrates collected in D-frame samples on 12 November 2012 at stations in Plumtree Run (Piedmont BIBI metrics).

	Riffle Community (100+ subsample)			
Piedmont Metrics	**Alpha Control**	**Beta Control**	**Lower Rest.**	**Middle Rest.**
Taxa Richness	10*	11	11	14
Total EPT Taxa	4*	4	4	4
Ephemeroptera taxa	0*	0	1	0
% Intolerant Urban	1.3%*	0.0%	0.0%	2.0%
% Chironomidae	6.5%*	16.3%	12.9%	18.2%
[illegible]	89.6%*	74.5%	71.3%	78.8%
[illegible]	2.0*	2.0	1.7	2.0

Table PTR - 2. Data summary of benthic macroinvertebrates collected in D-frame samples on 12 November 2012 at stations in Plumtree Run (Coastal Plain BIBI).

	Riffle Community (100+ subsample)			
Coastal Plain Metrics	**Alpha Control**	**Beta Control**	**Lower Rest.**	**Middle Rest.**
Taxa Richness	10*	11	11	14
Total EPT Taxa	4*	4	4	4
Ephemeroptera taxa	0*	0	1	0
% Intolerant Urban	1.3%*	0.0%	0.0%	2.0%
% Ephemeroptera	0.0%*	0.0%	1.0%	0.0%
No. Scraper Taxa	2*	2	1	2
[illegible]	1.3%*	0.0%	1.0%	0.0%
[illegible]	2.1*	1.9	2.4	2.1

Table PTR - 3. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Plumtree Run on 12 November 2012.

Plumtree Run Sampling Sites (100 + Subsample)				
Taxa	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Hoplonemerta			1	
Crustaceae				
Amphipoda				
Crangonyctidae				
*Synurella*sp.	3	9	14	2
Isopoda				
Asellidae				
Caecidotea sp.			1	
Insecta				
Ephemeroptera				
Baetidae				
*Baetis*sp.			1	
Plecoptera				
Chloroperlidae		1		
Leuctridae				
Paraleuctra sp.	1			
Trichoptera				
Hydropsychidae	9	2		1
Cheumatopsyche sp.	15	18	29	24
Hydropsyche sp.	12	8	1	7
Symphytopsyche sp.				2
Philopotomatidae		1		2
Chimera sp.	7	27	40	37
Coleoptera				
Elmidae		1		1
Stenelmis sp.	8	4	1	1
Psephenidae				
*Psephenus*sp.	2	6		1
Diptera				
Chironomidae	1	4		
Tanypodinae			1	3
Orthocladinae	4	9	8	7
Chironomini		2		1
Tanytarsini		1	4	7
Empididae				
*Hemerodromia*sp.				1
Simulidae				1
Simulium sp.	1			
Tipulidae				
Antocha sp.	14	5		1
Pseudolimnophila sp.				

Table PTR - 4. Data summary of benthic macroinvertebrates collected in D-frame samples on November 2012 at stations in Plumtree Run (Piedmont BIBI). * = <300 macroinvertebrates.

Plumtree Run Sampling Sites (300 + subsample)			
Piedmont Metrics	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Taxa Richness	13*	20	16
Total EPT Taxa	5*	5	5
Ephemeroptera taxa	0*	1	1
% Intolerant Urban	2.0%*	0.3%	2.7%
% Chironomidae	16.2%*	12.1%	13.1%
[illegible]	71.6%*	68.0%	83.2%

Table PTR - 5. Data summary of benthic macroinvertebrates collected in D-frame samples on November 2012 at stations in Plumtree Run (Coastal Plain BIBI). * = <300 macroinvertebrates.

Plumtree Run Sampling Sites (300 + subsample)			
Coastal Plain Metrics	**Beta Control**	**Lower Rest.**	**Middle Rest.**
Taxa Richness	13*	20	16
Total EPT Taxa	5*	5	5
Ephemeroptera taxa	0*	1	1
% Intolerant Urban	2.0%*	0.3%	2.7%
% Ephemeroptera	0.0%*	0.3%	0.3%
No. Scraper Taxa	2*	3	2
[illegible]	0.0%*	0.3%	0.0%

Table PTR - 6. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Plumtree Run on 12 November 2012.

	Plumtree Run Sampling Sites (300 subsample)		
Taxa	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Hoplonemerta		1	
Annelida			
Naididae		1	
Gastropoda			
Ancylidae			
Ferrissia sp.		1	
Crustaceae			
Amphipoda		5	1
Crangonyctidae	2		
Synurella sp.	15	46	5
Isopoda			
Asellidae			
*Caecidotea*sp.	1	1	
Insecta			
Ephemeroptera			
Baetidae			1
Baetis sp.		1	
Plecoptera			
Chloroperlidae	1		
Trichoptera			
Hydropsychidae	3	1	6
Cheumatopsyche sp.	25	70	66
*Hydropsyche*sp.	11	6	15
Symphytopsyche sp.	4	5	2
Philopotomatidae	2		8
Chimera sp.	37	113	130
Coleoptera			
Elmidae	1	2	2
Stenelmis sp.	5	1	3
Psephenidae			
Psephenus sp.	8	1	10
Diptera			
Chironomidae	5		
Tanypodinae		3	6
Orthocladinae	14	17	22
Chironomini	3		3
Tanytarsini	2	16	8
Empididae			1
Chelifera sp.		1	1
*Hemerodromia*sp.		1	3
Simulidae			1
Simulium sp.			
Tipulidae			
*Antocha*sp.	9	2	4
Pseudolimnophila sp.		1	
Tipula sp.		1	

Table PTR - 7. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations in Plumtree Run (Piedmont BIBI).

	Riffle Community (100+ subsample)			
Piedmont Metrics	**Alpha Control**	**Beta Control**	**Lower Rest.**	**Middle Rest.**
Taxa Richness	12	9	18	15
Total EPT Taxa	3	4	3	4
Ephemeroptera taxa	0	1	0	0
% Intolerant Urban	1.1%	2.1%	1.7%	0.0%
% Chironomidae	64.9%	75.3%	40.0%	56.5%
[illegible]	22.3%	19.6%	52.5%	38.0%
[illegible]	1.0	1.0	2.0	2.0

Table PTR - 8. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations in Plumtree Run (Coastal Plain BIBI).

	Riffle Community (100+ subsample)			
Coastal Plain Metrics	**Alpha Control**	**Beta Control**	**Lower Rest.**	**Middle Rest.**
Taxa Richness	12	9	18	15
Total EPT Taxa	3	4	3	4
Ephemeroptera taxa	0	1	0	0
% Intolerant Urban	1.1%	2.1%	1.7%	0.0%
% Ephemeroptera	0.0%	1.0%	0.0%	0.0%
No. Scraper Taxa	1	1	3	2
[illegible]	1.1%	0.0%	0.8%	0.0%
[illegible]	1.9	1.9	2.1	2.1

Table PTR - 9. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Plumtree Run on 29 March 2013. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

Taxa	Plumtree Run Sampling Sites (100+ subsample)			
	Alpha Control	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Hoplonemerta				1
Annelida				
Oligochaeta				
Naididae	5		1	1
Crustaceae				
Amphipoda		1		
Crangonyctidae				
Synurella sp.	5	5	6	3
Insecta				
Odonata				
Aeshnidae				
*Boyeria*sp.	1			
Plecoptera				
Nemouridae				
Amphinemoura sp.		1		
Trichoptera				
Hydropsychidae			1	1
Cheumatopsyche sp.	1	5	16	5
Hydropsyche sp.	1	1		2
*Symphytopsyche*sp.				1
Philopotomatidae				
Chimera sp.	4	9	14	20
Psychomyidae				
*Psychomyia*sp.			1	
Coleoptera				
Elmidae			1	1
*Oulimnius*sp.			1	
*Stenelmis*sp.	13	2	22	10
Diptera				
Ceratopogonidae				1
Chironomidae	1	3	1	10P
Diamesinae				
*Diamesa*sp.	3	3		
Tanypodinae		1		
Potthastia sp.		1		
Rheopelopia sp.			1	
Orthocladinae	8P	1(11P)	7(9P)	
*Eukiefferiela*sp.				13
*Hydrobaenus*sp.			1	9
Orthocladius sp.	35	22	10	27
Chironomini			2	
Apedilum sp.			3	
Cryptochironomus sp.			1	

Table PTR – 9 (Continued).

Taxa	Alpha Control	Beta Control	Lower Restoration	Middle Restoration
Tanytarsini		4	12	2
*Neozavrelia*sp.	14	27		
Tanytarsus sp.			1	
Empididae				
*Chelifera*sp.			2	
Clinocera sp.			2	
*Hemerodromia*sp.	1		2	2
Simulidae				
Simulium sp.				
Tipulidae				
*Antocha*sp.	2		1	1
Pseudolimnophila sp.				
*Tipula*sp.			2	

Table PTR – 10. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations in Plumtree Run (* = <300 macroinvertebrates).

Riffle Community (300+ subsample)				
Piedmont Metrics	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Taxa Richness	21	12	24	19
Total EPT Taxa	3	5	3	4
Ephemeroptera taxa	0	0	0	0
% Intolerant Urban	0.3%	1.4%	1.0%	0.3%
% Chironomidae	64.8%	76.8%	41.0%	52.4%
[illegible]	54.3%	57.2%	70.0%	56.1%

Table PTR - 11. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations in Plumtree Run (* = <300 macroinvertebrates).

Riffle Community (300+ subsample)				
Coastal Plain Metrics	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Taxa Richness	21	12	24	19
Total EPT Taxa	3	5	3	4
Ephemeroptera taxa	0	0	0	0
% Intolerant Urban	0.3%	1.4%	1.0%	0.3%
% Ephemeroptera	0.0%	0.0%	0.0%	0.0%
[illegible]	2	1	4	3
% Climbers	1.0%	0.0%	2.6%	2.5%

Table PTR - 12. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Plumtree Run on 29 March 2013. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

	Plumtree Run Sampling Sites (300+ subsample)			
Taxa	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Hoplonemerta				1
Turbellaria				
Phygocata sp.			1	2
Annelida				
Oligochaeta				
Naididae	5		1	3
Crustaceae				
Amphipoda	4	2	1	
Crangonyctidae				
Synurella sp.	7	5	13	3
Insecta				
Odonata				
Aeshnidae				
Boyeria sp.	1			
Gomphidae			1	
Plecoptera				
Nemouridae				
Amphinemoura sp.		1		
Trichoptera				
Hydropsychidae	2		1	1
Cheumatopsyche sp.	7	7	40	28
Hydropsyche sp.	1	1		4
Symphytopsyche sp.		1		2
Philopotomatidae			1	1
Chimera sp.	20	11	27	63
Psychomyidae				
*Psychomyia*sp.			1	
Coleoptera				
Elmidae			1	2
Oulimnius sp.			1	
Stenelmis sp.	43	2	68	24
Psephenidae				
*Psephenus*sp.	4		2	1
Diptera				
Ceratopogonidae				1
*Monohelea*sp.				3
Chironomidae	7	4	4(1P)	2(25P)
Diamesinae				
Diamesa sp.	9	3	1	1

Table PTR – 12 (Continued).

Taxa	Alpha Control	Beta Control	Lower Restoration	Middle Restoration
Tanypodinae		1		
*Potthastia*sp.		1		
Rheopelopia sp.			3	
Orthocladinae	5(31P)	5(15P)	8(17P)	
Eukiefferiela sp.	5			46
Hydrobaenus sp.			1	13
Orthocladius sp.	106	39	55	60
Chironomini			1	
Apedilum sp.			4	
Cryptochironomus sp.			1	
Polypedilum sp.			1	
Tanytarsini	10	4	23	12
*Micropsectra*sp.	1		3	8
*Neozavrelia*sp.	15	32		
Tanytarsus sp.	1		4	
Empididae				
Chelifera sp.	1		6	2
*Clinocera*sp.	2		2	
Hemerodromia sp.	1		7	4
Simulidae				
Simulium sp.				
Tipulidae				
Antocha sp.	3	2	7	7
*Limonia*sp.	1			
Pseudolimnophila sp.				
Tipula sp.	1			

Figure 3. Benthic sampling stations for Plumtree Run.

SHA Site: Tuscarora Creek - Monocacy River Project

Project Description: SHA is planning to improve the interchange of Monocacy Boulevard and Route 15 in the near future. As part of the project, SHA will install a level spreader system to mitigate any potential roadway runoff effects. The current work will assess the effectiveness of level spreaders in controlling nutrient inputs to Big Tuscarora Creek.

Site Description: Station descriptions are listed within the site coordinate table, with all stations currently pre-construction. Basic water quality parameters include total nitrogen, total phosphorus, conductivity and total suspended solids (this suite of water quality parameters may be expanded in the future if needed). In addition, stable isotope analyses of carbon, nitrogen and oxygen are concurrently being completed on these six stations. Following level spreader installation, an increased level of nutrient sampling will be done at the spreader system site and on Tuscarora Creek.

Site Coordinates:

Site coordinates for six Tuscarora Creek (TCM) stations in Frederick County (Figure 4). Big Tuscarora enters the Monocacy River above Route 26. Little Tuscarora joins the Big Tuscarora just northwest of Willowbrook Road.			
TCM Station	Latitude	Longitude	Comments:
TUSKY 001	39°27’47.74”N	77°23’37.43”W	Big TCM at railroad bridge crossing.
TUSKY 002	39°27’51.02”N	77°24’37.43”W	Big TCM below bridge on US Route 15 near Monocacy Boulevard.
TUSKY 003	39°28’36.05”N	77°25’15.48”W	Big TCM at bridge on Bloomfield Road.
TUSKY 004	39°28’10.56”N	77°25’00.98”W	Little TCM below bridge on Opossumtown Pike.
TUSKY 005	39°29’27.15”N	77°25’39.48”W	Big TCM below bridge on Sundays Lane.
TUSKY 006	39°27’55.33”N	77°26’56.76”W	Little TCM below bridge on Yellow Springs Road.

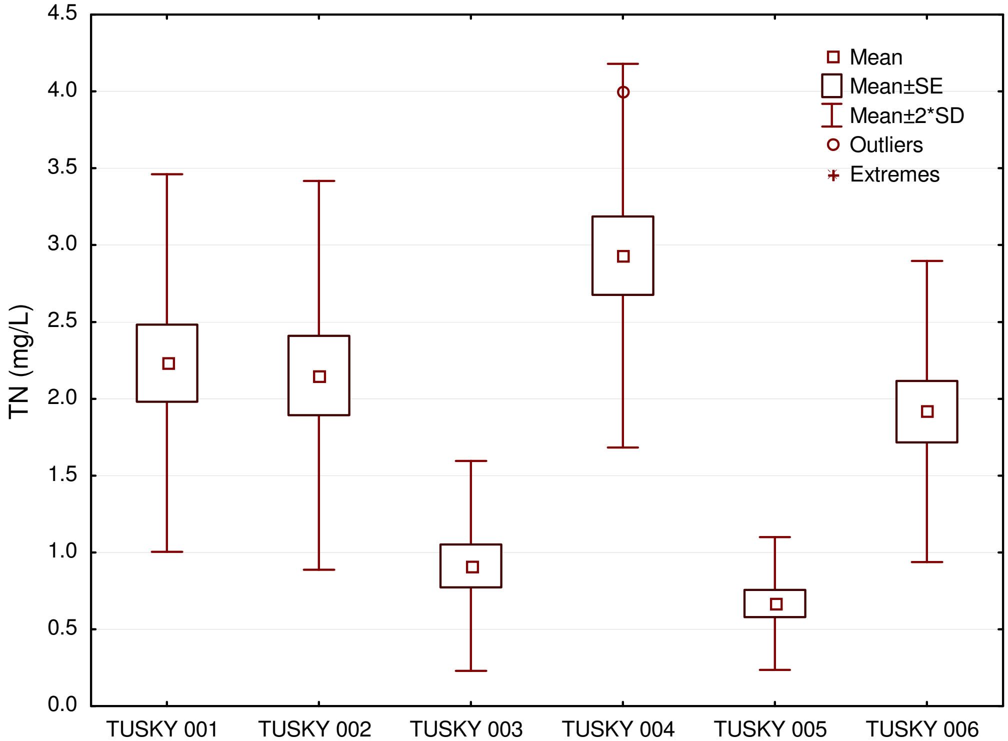


Figure Tusky1. Box plots of TN (mg/L) for the six Tuscarora Creek stations.

TN – For the six Tuscarora Creek stations (Figure Tusky 1), four exceeded both the 25^{th} (1.6 mg/L) and the 75^{th} (1.8 mg/L) TN percentile estimates for the Northern Piedmont ecoregion of Maryland (Morgan et al. 2013). The driver for TN at both TUSKY 001 and 002 is the Little Tuscarora Creek (TUSKY 004 and 006) where mean TN was 2.9 and 1.9 mg/L respectively (Table TUSKY-1). The two upstream Big Tuscarora stations (TUSKY 003 – 0.91 mg/L and 005 – 0.67 mg/L) did not exceed the 25^{th} (1.6 mg/L) TN percentile, although the values were slightly higher than the Y-intercept TN value of 0.51 mg/L (Morgan et al. 2013). The highest TN value observed was 4.0 mg/L at TUSKY 004 and the lowest 0.47 mg/L at TUSKY 005.

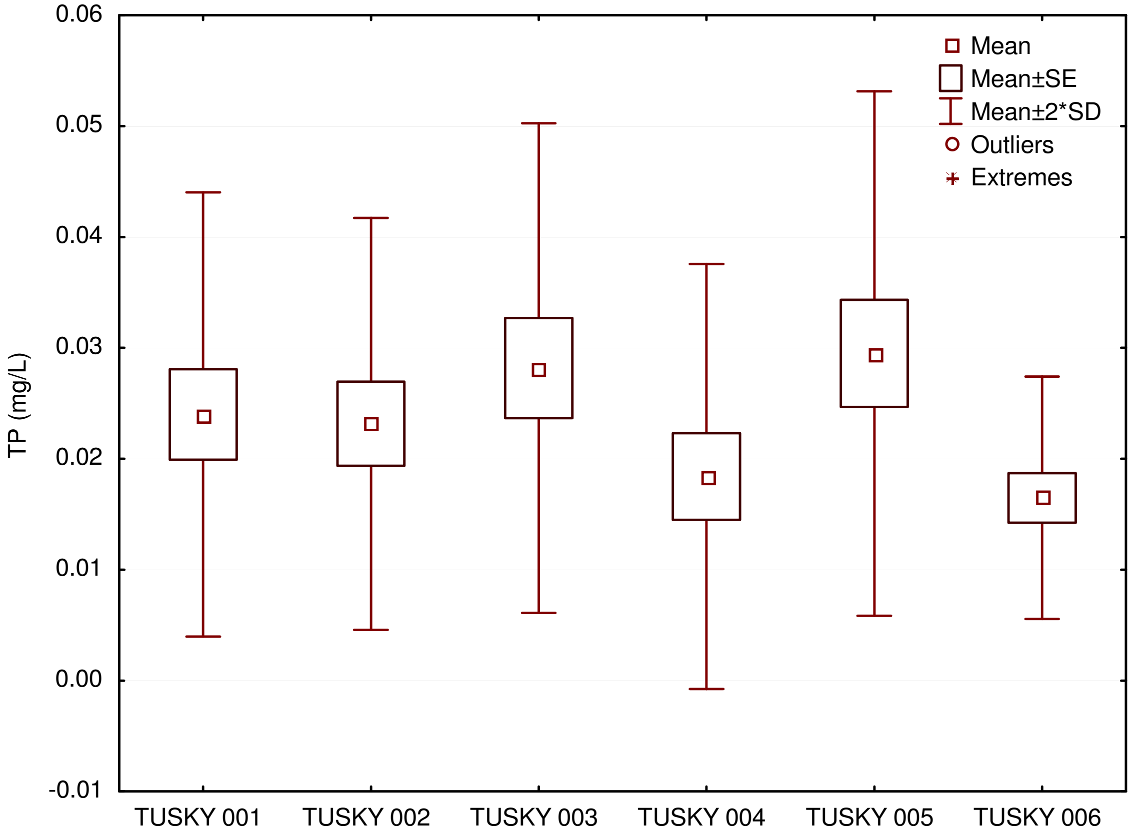


Figure Tusky 2. Box plots of TP (mg/L) for the six Tuscarora Creek stations.

TP – For the six Tuscarora Creek stations (Figure Tusky 2), all exceeded both the 25th (0.010 mg/L) and the 75th (0.015 mg/L) TP percentile estimates for the Northern Piedmont ecoregion of Maryland (Morgan et al. 2013). The two stations on Little Tuscarora were the lowest with mean values of 0.018 mg/L (004) and 0.016 mg/L (006), with the other four stations ranging from 0.023 – 0.030 mg/L mean TP (Table TUSKY-1). The highest TP value observed was 0.048 mg/L at TUSKY 005 and the lowest 0.0080 mg/L at TUSKY 004.

Table TUSKY – 1. Summary statistics for TN, TP, TSS and conductivity for the six Tuscarora Creek stations (Figure 4) sampled from 2012 through 2013 during baseflow conditions for six sampling dates.

Parameter/Station	Mean	SD	Minimum	Maximum
TN (mg/L)				
TUSKY 001	2.2	0.61	1.5	3.0
TUSKY 002	2.2	0.63	1.3	3.0
TUSKY 003	0.91	0.34	0.60	1.4
TUSKY 004	2.9	0.62	2.4	4.0
TUSKY 005	0.67	0.22	0.47	0.92
TUSKY 006	1.9	0.49	1.3	2.7
TP (mg/L)				
TUSKY 001	0.024	0.010	0.012	0.036
TUSKY 002	0.023	0.0093	0.012	0.034
TUSKY 003	0.028	0.011	0.016	0.046
TUSKY 004	0.018	0.0096	0.0080	0.028
TUSKY 005	0.030	0.012	0.015	0.048
TUSKY 006	0.016	0.0055	0.011	0.023
TSS (mg/L)				
TUSKY 001	5.5	4.2	2.0	13.8
TUSKY 002	4.4	3.2	1.2	10.6
TUSKY 003	3.3	3.1	0.40	9.2
TUSKY 004	2.8	1.6	1.4	5.6
TUSKY 005	2.8	2.0	1.0	6.7
TUSKY 006	7.1	6.0	0.80	14.6
CONDUCTIVITY (µS/cm)				
TUSKY 001	270	68.3	154	350
TUSKY 002	255	66.5	147	332
TUSKY 003	150	43.9	86.3	204
TUSKY 004	282	45.7	215	332
TUSKY 005	142	42.4	80.3	195
TUSKY 006	180	34.3	138	230

TSS – The six Tuscarora sites ranged from 2.8 to 7.1 mg/L average TSS, with a low TSS of 0.40 at TUSKY 003 and a high of 14.6 mg/L at TUSKY 006 during baseflow measurements (Table TUSKY 1). There appears to be variation in the measurement of TSS at each site as evidenced by the large SD values observed.

The criteria for total suspended solids (TSS) and turbidity criteria are unclear, with only a few states having set criteria for a number of reasons. Three states - Utah, North Dakota, and South Dakota - have similar criteria fortheir cold water streams; 35 mg/L, 30 mg/L, and 30 mg/L as a 30 day average or 58 mg/L dailymaximum, respectively. Both Utah and South Dakota have higher thresholds for warm waterstreams; 90 mg/L and 150 mg/L as a 30 day average or 263 mg/L daily maximum, respectively.TSS isan extremely important cause of water quality deterioration leading to aesthetic issues, higher water treatment costs, biotic decline and an overall degrading of aquatic environments.

Conductivity – Forthe six Tuscarora stations mean conductivity ranged from 142 at TUSKY 005 to 282 µS/cm at TUSKY 004 (Table TUSKY-1). The lowest value was 80 µS/cm at TUSKY 005, with the highest (350 µS/cm) at TUSKY 004. Average stream specific conductivity at the six sites exceeded the 25th percentile (145 µS/cm) at all but one station (TUSKY 005) for the Northern Piedmont (Morgan et al. 2012). The elevated specific conductivity reflects the urban stream syndrome (Walsh et al. 2005) where there is frequently high stream conductivity due to inputs from road salts and other sources.

Stable Isotopes – One of the key questions in global nitrate dynamics is the origin of nitrate in the water column (Chang et al. 2002, Kendall et al. 2007), an important factor to consider in the TMDL nutrient process. To determine nitrate origin in the Tuscarora Creek watershed, we collected stable isotope samples concurrently with general water quality sampling at the six stations, followed by determination of $\delta^{15}N$(‰) and $\delta^{18}O$(‰) in nitrate (NO_3) by CASIF (http://casif.al.umces.edu/).

For $\delta^{15}N$, values ranged from ~ -5.3 to +8.9 (Figure Tusky-3), with $\delta^{18}O$ ranging from -8 to +10. For oxygen, the typical $\delta^{18}O$ range was observed that correlates with the soil nitrification of ammonia and organic matter (Chang et al. 2002, Kendall et al. 2007), presumably from the ammonia in both fertilizer and precipitation. The $\delta^{15}N$ range also agrees with the presence of ammonia in fertilizer and precipitation although the higher $\delta^{15}N$ values suggest denitrification processes in soil ammonia. Because of high TN in the watershed, we suspect that the major nitrogen driver is agricultural practices.

There was a significant linear relationship ($\rho = 0.0011$) of $\delta^{15}N$(‰) to $\delta^{18}O$(‰), although explanatory power was weak with a $r^2 = 0.23$ (Figure Tusky-3), but the overall pattern was similar to the $\delta^{15}N$(‰) to $\delta^{18}O$(‰) relationship observed in agricultural Mississippi River sites by Chang et al. (2002). Using a bag plot (Sun and Genton 2011), we determined that there were 13 distinct outliers (31%) for $\delta^{15}N$(‰) and $\delta^{18}O$(‰) values (Figure Tusky-4). These outliers are the marked points outside of the light and dark blue areas of the graph (the dark blue area represents an envelope of the 50% central region around the median for $\delta^{15}N$ and $\delta^{18}O$, and the light blue area the maximum non-outlier envelope, or 1.5 times the central region empirical rule), with the shape of the bag approximating the linear regression model (Figure Tusky-3). Nine of the 13 data points were either June or July samples, while four points were October or December samples. This may indicate some variation in soil nitrogen processes during the summer and perhaps into the fall. The $\delta^{15}N$ and $\delta^{18}O$ data suggests that atmospheric, nitrate fertilizer, and manure and septic waste inputs are minimal and the stream nitrogen patterns relate more to ammonia in fertilizer and precipitation (Kendall et al. 2007).

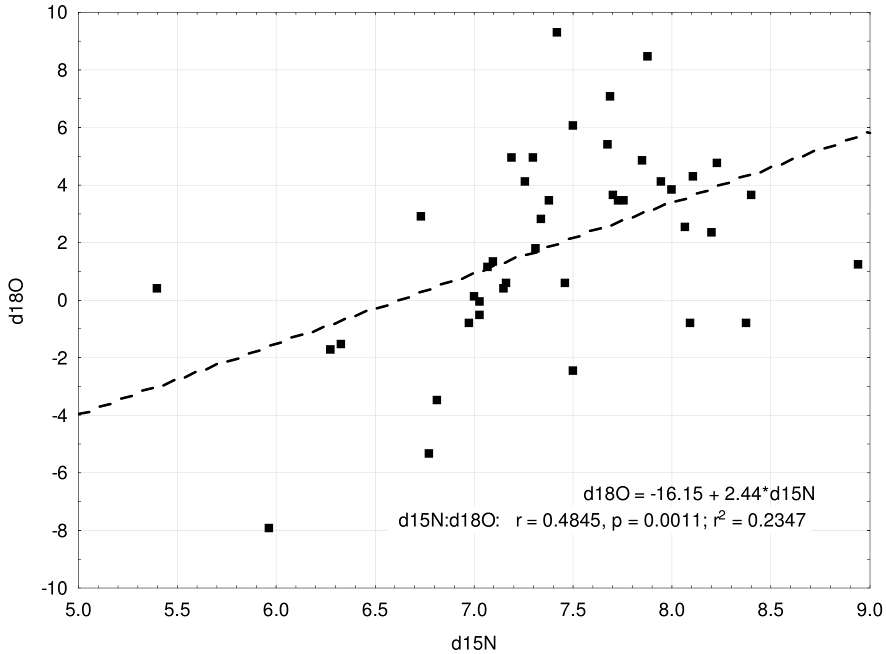


Figure Tusky-3. Linear relationship of $\delta^{15}N$(‰) to $\delta^{18}O$(‰) in nitrate for the six Tuscarora stations sampled from 2012 to 2013.

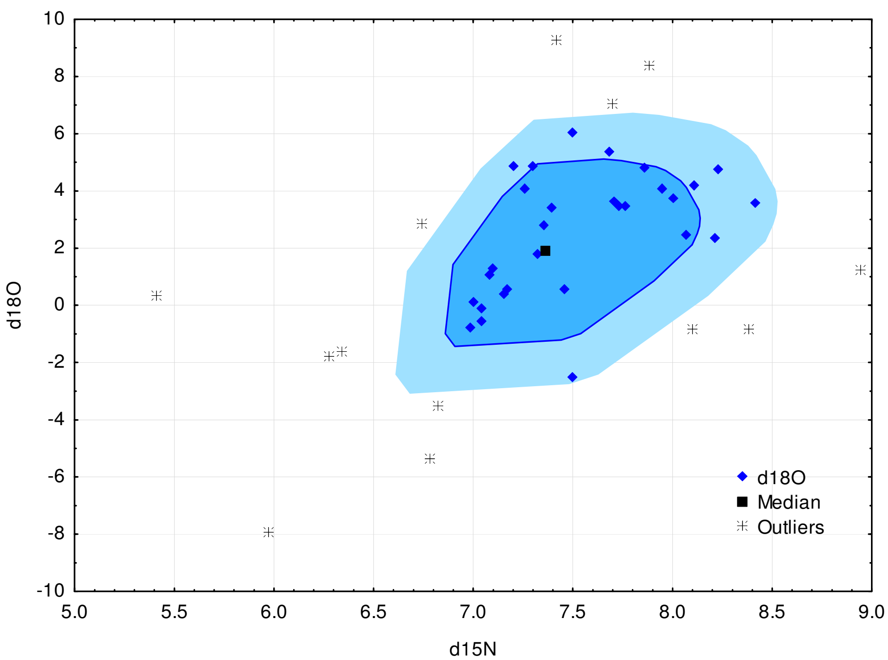


Figure Tusky-4.Bag plot of the relationship of $\delta^{15}N$(‰) to $\delta^{18}O$(‰) in nitrate for the six Tuscarora stations sampled from 2012 to 2013.

Assessment Recommendation: This is an ongoing SHA pre-construction project with water quality sampling approximately every one-two months during baseflow in order to develop a nutrient baseline for post-project work after installation of a level spreader system at the junction of Monocacy Boulevard and Route 15.

Figure 4. Water quality sampling sites in the Tuscarora Creek watershed near Frederick, MD.

SHA Site: Upper Little Patuxent (ULP)

Site Description: The UpperLittle Patuxent River is a pre-restoration site located to the south of Route 144 (Old Frederick Road) in Ellicott City, with one control site near Route 144 and one near Route 40. The restoration area is located in a broad floodplain, with residential housing on both sides of the stream. There is some limited commercial development along Route 40 at the junctions of Bethany Lane, Centennial Lane, Route 144 and Route 40 that may potentially affect the Upper Little Patuxent River.

Site Coordinates:

Site coordinates for Upper Little Patuxent (Figure 5).			
Station	Latitude	Longitude	Comments:
Middle	39°16'25.57"N	76°51'09.97"W	Projected middle site.
Lower	39°16'20.76"N	76°51'10.21"W	Projected lower site.
Alpha Control	39°16'32.22"N	76°51'09.01"W	Upstream control I.
Beta Control	39°16'43.29"N	76°51'09.54"W	Upstream control II.

Benthic Community: Details on the macroinvertebrate assemblages sampled at the ULP sites arelisted in the following tables (ULP 1- 8). Benthic sampling was completed at the four ULP stations on 9 November 2012 and 29 March 2013 (Figure 5).

ULP November 2012– For stations with a 100 + macroinvertebrate count, taxa richness,% intolerant urban and percent clingers were moderate at control sites and low at the restoration sites. For example, taxa richness was 18 for the Alpha Control and 24 for the Beta Control versus 14 and 13 for the Lower and Middle Restoration sites respectively (Table ULP-1). The number of EPT taxa (5-9) was moderate at all sites. However, the percent of taxa intolerant of urban conditions at the control sites (28-31%) were higher than the two restoration sites (14%), with the percent chironomidsshowing a reverse pattern of being lower at the control sites (17-26%) and higher at the two restoration sites (46-54%). The percent of ephemeropteran taxa was low (0-1) at all stations. Hydropsychidae larvae dominated the EPT collection while *Taeniopteryx* sp. nymphs were the dominant macroinvertebrate clinger. The BIBI was 2.0 (poor) at the restoration sites and 2.7 (poor) at control sites. The overall abundance of macroinvertebrates was low. Only the lower restoration site had enough macroinvertebrates to allow a 300 + count (Table ULP-2), with % intolerant urban, % Chironomidae and % clingers in close agreement with the 100 + count.

ULPMarch 2013– For stations with a 100 + macroinvertebrate count, taxa richness was moderate at the control sites and low at the restoration sites. The number of EPT taxa at the Beta Control site was moderate. However, the number of EPT taxa, number of ephemeropteran taxa, percent of taxa intolerant of urban conditions, and percent of chironomids and percent clingers at all sites were low.Hydropsychidae and philopotomatid larvae dominated the EPT collection while simulid larvae were the dominant macroinvertebrate clinger. Chironomids constituted more than 50% of the macroinvertebrates collected at each site; consequently, abundance of the other macroinvertebrates was low. The BIBI was low (very poor) at all control and restoration sites, ranging from 1.0 to 1.7 at these sites.

For stations with a 300 + macroinvertebrate count, taxa richness was high at the control sites and moderate at the restoration sites. Hydropsychidae and philopotomatid larvae dominated the EPT collection while simulid larvae were the dominant macroinvertebrate clinger. All other benthic metrics were generally low. Dipteran larvae accounted for the majority of the macroinvertebrates in the clinger category.

Physical Habitat: For the Upper Little Patuxent River project, the proposed restoration area below MD Route 144 is a broad flood plain (historically, was there a small dam and reservoir in this area sometime in the past?). The stream bottom was primarily fine sands and clay with very little solid substrate present, and there were areas with deep entrenchment of the stream into the softer materials present. There was great difficulty in finding riffle areas suitable for benthic sampling, not only in the restoration site but also in the control area. There was poor shading since most of the vegetation was not deciduous.

For both the control and restoration area, there was a pipeline located along the eastern side of the stream. In addition, there was also a sewage line running through both the control and restoration areas. It appears that the area between Route 40 and Route 144 is mowed frequently, and there is evidence of human disturbance throughout both areas.

Water Quality: For the Upper Little Patuxent River, the total nitrogen (TN) was 1.5 mg/L, total phosphorus (TP) 0.010 mg/L, total suspended solids (TSS) 2.2 mg/L, and specific conductivity 458 µS/cm. Using the 25th percentile estimates for the Northern Piedmont ecoregion of Maryland (Morgan et al. 2013), the TN criteria (1.6 mg/L) and the TP criteria (0.010 mg/L) were not exceeded. TSS was not elevated (2.2 mg/L). However, stream specific conductivity exceeded the 25th percentile (145 µS/cm) for the Northern Piedmont by a factor of 3.2 times (Morgan et al. 2012). This elevated specific conductivity reflects the urban stream syndrome (Walsh et al. 2005) where there is frequently high stream conductivity due to inputs from road salts and other sources. In particular, this site is in close proximity to many major road systems (I-70, Route 40 and Route 144) that are frequently salted during ice and snow events.

Assessment Recommendation: The ULP sites should be assessed after the stream restoration is completed.

Table ULP - 1. Data summary of benthic macroinvertebrates collected in D-frame samples on 9 November 2012 at stations in Upper Little Patuxent.

Metric	Riffle Community (100+ subsample)			
	Alpha Control	Beta Control	Lower	Middle
Taxa Richness	18	24	14	13
Total EPT Taxa	6	9	5	6
Ephemeroptera taxa	1	1	0	1
% Intolerant Urban	27.9%	30.9%	13.9%	14.4%
% Chironomidae	26.0%	17.1%	53.5%	46.2%
[illegible]	46.2%	72.4%	23.8%	20.2%
[illegible]	2.7	2.7	2.0	2.0

Table ULP - 2. Data summary of benthic macroinvertebrates collected in D-frame samples on 9 November 2012 at stations in Upper Little Patuxent– 300 + subsample.

Metric	Lower Restoration
Taxa Richness	23
Total EPT Taxa	7
Ephemeroptera taxa	1
% Intolerant Urban	15.8%
% Chironomidae	52.5%
[illegible]	23.9%

Table ULP - 3. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Upper Little Patuxent on 9 November 2012. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

Taxa	Site	Upper Little Patuxent Sampling Sites (100+ subsample)			
		Alpha Control	Beta Control	Lower Restoration	Middle Restoration
Pelycepoda					
Sphaeridae		22	7	1	35
Sphaerium sp.				20	
Crustaceae					
Amphipoda					
Crangonyctidae					
Synurella sp.		2	2		
Decopoda					
Cambaridae					
Orconectes sp.			1		
Procambarus sp.		1			
Insecta					
Heptageniidae		3	6		1
Stenonema sp.		2	9		
Odonata					
Coenagrionidae			1		
Gomphidae					
Lanthus sp.			1		
Progomphus sp.		1			
Plecoptera					
Leuctridae		1	4	1	4
Leuctra sp.			1		
Paraleuctra sp.		4			
Perlodidae			1		
Taeniopterygidae					
*Taeniopteryx*sp.		23	30	13	10
Megaloptera					
Corydalidae					
*Nigronia*sp.			1		
Trichoptera					
Glossossomatidae					
*Glossossma*sp.			1		
Hydropsychidae			1		
Cheumatopsyche sp.		2	10	3	1
Hydropsyche sp.			1	1	1
*Symphytopsyche*sp.		4	4		
Hydroptilidae				1	
Philopotomatidae					
*Chimerra*sp.			5		1
Dolophilodes sp.		1			

Table ULP – 3 (continued).

	Alpha Control	Beta Control	Lower Restoration	Middle Restoration
Coleoptera				
Elmidae	1			
Dubiraphia sp.		1	1	
Optioservus sp.	3	1	1	1
*Oulimnius*sp.				1
*Stenelmis*sp.	1	1		
Diptera				
Ceratopogonidae				
Culicoides sp.	1			
Chironomidae	2	3	1	4
Orthocladinae	13	6	3	3
Chironomini	8	9	47	40
Tanytarsini	4	3	3	1
Empididae				
Chelifera sp.	1			
Hemerodromia sp.		1	2	
Simulidae				1
*Simulium*sp.	4	7	2	
Tipulidae				
*Antocha*sp.		5	1	

Table ULP - 4. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Upper Little Patuxent on 9 November 2012 – 300 + subsample. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

Upper Little Patuxent Sampling Sites (300 + subsample)	
Taxa	**Lower Restoration**
Pelycepoda	
Sphaeridae	1
Sphaerium sp.	55
Crustaceae	
Amphipoda	
Crangonyctidae	
Synurella sp.	1
Insecta	
Ephemeroptera	
Heptageniidae	1
Dromogomphus sp.	1
Ophiogomphus sp.	1
Progomphus sp.	3
Macromidae	
*Macromia*sp.	1
Plecoptera	
Leuctridae	2
Paraleuctra sp.	1
Taeniopterygidae	
Taeniopteryx sp.	40
Trichoptera	
Hydropsychidae	
Cheumatopsyche sp.	4
Hydropsyche sp.	1
Symphytopsyche sp.	1
Hydroptilidae	1
Coleoptera	
Elmidae	
Dubiraphia sp.	1
Optioservus sp.	6
Oulimnius sp.	1
Diptera	
Chironomidae	4
Tanypodinae	
Orthocladinae	11
Chironomini	121
Tanytarsini	13
Empididae	
*Chelifera*sp.	2
Hemerodromia sp.	2
Simulidae	1
Simulium sp.	5
Tipulidae	
Antocha sp.	3

Table ULP - 5. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations in Upper Little Patuxent.

Metric	Riffle Community (100+ subsample)			
	Alpha Control	**Beta Control**	**Lower**	**Middle**
Taxa Richness	18	19	13	10
Total EPT Taxa	2	5	1	0
Ephemeroptera taxa	1	1	0	0
% Intolerant Urban	0.0%	0.0%	2.2%	0.0%
% Chironomidae	75.7%	75.9%	65.9%	87.3%
[illegible]	16.8%	16.1%	15.4%	11.8%
[illegible]	1.3	1.7	1.0	1.0

Table ULP - 6. Data summary of benthic macroinvertebrates collected in D-frame samples on 29 March 2013 at stations in Upper Little Patuxent.

Metric	Riffle Community (300+ subsample)			
	Alpha Control	**Beta Control**	**Lower**	**Middle**
Taxa Richness	27	28	24	17
Total EPT Taxa	3	7	4	3
Ephemeroptera taxa	1	1	0	1
% Intolerant Urban	0.7%	1.0%	2.0%	0.7%
% Chironomidae	74.1%	75.2%	68.4%	94.8%
[illegible]	16.5%	20.5%	18.4%	11.1%

Table ULP - 7. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Upper Little Patuxent on 29 March 2013. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

	Upper Little Patuxent Sampling Sites (100+ subsample)			
Taxa	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Turbellaria				
*Phygocata*sp.			2	
Annelida				
Oligochaeta				
Naididae		3		
Tubificidae				1
Gastropoda				
Lymnaeidae	1			
Pelycepoda				
Sphaeridae	3	2	10	1
Crustaceae				
Amphipoda				
Crangonyctidae				
Synurella sp.		1		
Insecta				
Ephemeroptera				
Ephemerellidae				
Heptageniidae	1			
*Stenonema*sp.	2	2		
Odonata				
Gomphidae				
Gomphus sp.		1		
*Progomphus*sp.	1			
Trichoptera				
Hydropsychidae		1		
Cheumatopsyche sp.		1		
Symphytopsyche sp.		3		
Philopotomatidae			1	
Chimerra sp.	1	2	2	
Coleoptera				
Elmidae	3		1	
Dubiraphia sp.				1
Macronymus sp.		1		
*Optioservus*sp.	1			
Oulimnius sp.			2	
*Stenelmis*sp.	4		3	
Diptera				
Chironomidae	7(6P)	3(6P)		1
Tanypodinae				
Diamesinae				
Diamesa sp.	1	1	2	4

Table ULP – 7 (continued).

Taxa	Alpha Control	Beta Control	Lower Restoration	Middle Restoration
Orthocladinae	1		3P	5P
Eukiefferiella sp.		1		
Orthocladius sp.	59	70	50	80
*Theinemanneila*sp.				4
Chironomini			2	2
Polypedilum sp.	5			
Tanytarsini	2	4	2	
Micropsectra sp.			1	
Empididae				
Chelifera sp.	3	1	4	
Clinocera sp.	1	2	3	
Hemerodromia sp.	1	1		
Simulidae				1
Prosimulium sp.				1
Simulium sp.	1	2	2	6
Stegopterna sp.	1	3		3
Tipulidae				
Antocha sp.		1		
*Hexatoma*sp.			1	
Tipula sp.	1			

Table ULP - 8. Numbers of macroinvertebrates collected in benthic samples by combining 9 D-frame aquatic net samplings (total sampling area approximately 1 m^2) at sites in Upper Little Patuxent on 29 March 2013. Insect quantities represent numbers of larvae or nymphs unless designated otherwise by a P for pupa or A for adult.

	Upper Little Patuxent Sampling Sites (300 + subsample)			
Taxa	**Alpha Control**	**Beta Control**	**Lower Restoration**	**Middle Restoration**
Turbellaria				
*Phygocata*sp.			4	
Annelida				
Oligochaeta				
Naididae		3		
Tubificidae				1
Gastropoda				
Lymnaeidae	1			
Pelycepoda				
Sphaeridae	10	4	14	2
Crustaceae				
Amphipoda				
Crangonyctidae				
*Synurella*sp.	1	1		
Insecta				
Ephemeroptera				
Ephemerellidae				
Heptageniidae	1	1		1
Stenonema sp.	7	7		
Odonata				
Gomphidae				
Gomphus sp.	1	2		
Progomphus sp.	2		2	
Plecoptera				
Nemouridae				
Ostrocerca sp.			1	
Perlodidae		1		
Trichoptera				
Hydropsychidae	1			
Cheumatopsyche sp.	2	5		
Hydropsyche sp.		2	1	
Symphytopsyche sp.		6	1	1
Philopotomatidae				
*Chimerra*sp.	1	4	3	1
Uenoidae				
Neophylax sp.		1		
Coleoptera				
Elmidae	4	2	3	
Ancyronyx sp.			1	1
Dubiraphia sp.	1			1
Macronymus sp.		1		
Optioservus sp.	3		6	
*Oulimnius*sp.	1		3	1
Stenelmis sp.	7	3	9	

Table ULP – 8 (continued).

	Alpha Control	Beta Control	Lower Restoration	Middle Restoration
Diptera				
Chironomidae	8(19P)	13(29P)	7	6
Tanypodinae				
Potthastia sp.	1			
Diamesinae				
Diamesa sp.	2	4	2	9
Orthocladinae	3	1	8P	11P
Eukiefferiella sp.		1		17
Orthocladius sp.	154	168	141	216
Pseudorthocladius sp.		5		
Theinemanneila sp.				8
Chironomini	16		5	4
*Chironomus*sp.	1			
Apedilum sp.		1	1	
Cryptochironomus sp.	1			
Polypedilum sp.	6	3		
Tanytarsini	8	1	6	3
Micropsectra sp.	1	1	1	
Tanytarsus sp.		1		
Empididae		1		
Chelifera sp.	3	2	5	
*Clinocera*sp.	7	3	7	
Hemerodromia sp.	11	2	2	
Simulidae	1	3		1
Prosimulium sp.	2	5	7	2
Simulium sp.	3	4	3	16
*Stegopterna*sp.	2	8	3	6
Tipulidae				
Antocha sp.	4	3		
*Dicranota*sp.			1	
Hexatoma sp.			1	
Tipula sp.	1		1	

Figure 5. Benthic sampling stations for the Upper Little Patuxent.

Landscape Attributes

During the current work on stream restoration sites, we noted that several sites had large amounts of impervious surface. Consequently, we performed a GIS analysis on the amount of forest, urban and agricultural areas within each watershed, using the lowest point in the watershed as the watershed boundary (Table LA-1).

Table LA-1. Summary of % forest (deciduous forest, evergreen forest, mixed forest), % agriculture (pasture/hay, cultivated crops) and % urban (developed open space, developed light intensity, developed medium intensity, developed high intensity) for four SHA stream restoration sites studied from 2012 to 2013.

Site	Year	% Forest	% Agriculture	% Urban
Long Draught Run	2001	2.3	6.5	91.1
	2006	2.3	6.5	91.1
Minebank Run	2001	17.8	2.5	79.4
	2006	17.9	2.2	79.6
Plumtree Run	2001	14.1	1.8	83.5
	2006	12.2	0.70	86.4
Upper Little Patuxent	2001	28.3	19.1	45.4
	2006	27.8	19.5	47.0

All four sites contain significant urbanization within their watersheds, varying from 45.4 to 91.1 % urban (Table LA-1). Long Draught Run appears to be stable since there is no land left to be converted to urban unless smaller structures are removed and higher density structures are built. The other three sites all show a slight increase in % urban over time. For stream restoration activities, these high levels of urbanization need to be taken into account.

Literature Cited

Bash, JS and CM Ryan. 2002. Stream restoration and enhancement projects: Is anyone monitoring? Environmental Management 29:877-885.

Binns, NA. 1979. A habitat quality index for Wyoming trout streams. Fish. Res. Rep. Monogr. Ser. No. 2, Wyoming Game and Fish Department, Cheyenne, WY.

Chang, CYC, C Kendall, SR Silva, WA Battaglin and DH Campbell. 2002. Nitrate stable isotopes: tools for determining nitrate sources among different land uses in the Mississippi River Basin. Canadian Journal of Fisheries and Aquatic Sciences 59:1874-1885.

Doheny, EJ, RJ Starsoneck, PM Mayer, and EA Striz. 2007. Pre-restoration geomorphic characteristics of Minebank Run, Baltimore County, Maryland 2002-2004. U.S. Geological Survey Scientific Investigations Report 2007-5127, 49 pp.

Downs, PW and GM Kondolf. 2002. Post-project appraisals in adaptive management of river channel restoration. Environmental Management 29:477-496.

Green, RH. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York, NY.

Hall, LW, R P Morgan II, E Perry, and A Walz. 1999. Development of a provisional physical habitat index for Maryland freshwater streams. Final Report CBWP-MANTA-EA-99-12. Prepared for: State of Maryland, Department of Natural Resources, Tidewater Administration, Chesapeake Bay Research and Monitoring Division, Annapolis, MD.

Hall, LW, RP Morgan II, E Perry, and A Walz. 2002. Development of a provisional physical habitat index for Maryland freshwater streams. Environmental Monitoring and Assessment 77:265-291.

Karr, JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21-27.

Karr, JR, KD Fausch, PL Angermeier, PR Yant, and IJ Schlosser. 1986. Assessing biological integrity in running waters: A method and its rationale. Illinois Natural History Survey Special Publication Number Five, Champaign, IL.

Kazyak, PF. 1996. Maryland biological stream survey sampling manual. Prepared for: State of Maryland, Department of Natural Resources, Tidewater Administration, Chesapeake Bay Research and Monitoring Division, Annapolis, MD.

Kendall, C, EM Elliott and SD Wankel. 2007. Tracing anthropogenic inputs of nitrogen to ecosystems. Pages 375-449 in R Michener and K Lajtha (eds.) Stable Isotopes in Ecology and Environmental Science, Blackwell Publishing, Malden, Maine.

Morgan II, RP. 2005. Are we failing at stream restoration? First International Conference on Environmental Science and Technology, American Academy of Sciences, New Orleans, LA.

Morgan II, RP, DM Gates, MJ Kline, MR Lutmerding and MR Sell. 2010. Assessment of stream restoration projects in Maryland: 1998-2010. Prepared for: Maryland Department of Transportation, State Highway Administration, Highway Hydraulics Division, Baltimore, MD.

Morgan II, RP, KM Kline, MJ Kline, SF Cushman, MT Sell, RE Weitzell and JB Churchill. 2012. Stream conductivity: relationships to land use, chloride, and fishes in Maryland streams. North American Journal of Fisheries Management 32:941-952.

Morgan II, RP, KM Kline and JB Churchill. 2013. Estimating reference nutrient criteria for Maryland ecoregions. Environmental Monitoring and Assessment 185:2123-2137.

Morris, S and T Moses. 1999. Urban stream rehabilitation: A design and construction case study. Environmental Management 23:165-177.

National Research Council. 1992. Restoration of aquatic ecosystems: Science, technology, and public policy. National Academy Press, Washington, DC.

Paul, MJ, JB Stribling, RJ Klauda, PF Kazyak, MT Southerland and NE Roth. 2002. A physical habitat index for wadeable streams in Maryland. Prepared by Tetra Tech, Inc., Owings Mills, MD, Versar and Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Program. CBWP-MANTA-EA-03-4.

Plafkin, JL, MT Barbour, KD Porter, SK Gross, RM Hughes. 1989. Rapid Bioassessment Protocols for Use in Streams and Rivers. Benthic Macroinvertebrates and Fish. EPA/444/4-89-001. Office of Water, U. S. Environmental Protection Agency, Washington, D.C.

Platts, WS. 1976. Validity of methodologies to document stream environments for evaluating fishery conditions. Pages 267-284 in Instream flow needs procedures, Volume Two, American Fisheries Society, Bethesda, MD.

Platts, WS, WF Megahan, and GW Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. General Technical Report INT-138. Intermountain Forest and Range Experiment Station. U.S. Forest Service, USDA, Ogden, UT.

Rankin ET. 1989. The qualitative habitat evaluation index (QHEI): Rationale, methods and application. Ohio Environmental Protection Agency, Division of Water Quality Planning and Assessment, Ecological Assessment Section, Columbus, OH.

Roth, NE, MT Southerland, SB Weisberg, JC Chaillou, PF Kazyak, SA Stranko, RJ Klauda, LW Hall, and RP Morgan II. 1998. Development and evaluation of a fish index of biotic integrity for Maryland streams. Environmental Management and Assessment. 51:89-106.

Simon, TP. 1999. Introduction: Biological integrity and use of ecological health concepts for application to water resource characterization. Pages 3-16 in TP Simon (ed.), Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, FL.

Southerland MT, GM Rogers, MJ Kline, RP Morgan, DM Boward, PF Kazyak, RJ Klauda and SA Stranko. 2007. Improving biological indicators to better assess the condition of streams. Ecological Indicators 7:751-767.

Southerland MT, GM Rogers, MJ Kline, RP Morgan, DM Boward, PF Kazyak, RJ Klauda and SA Stranko. 2005. New biological indicators to better assess the condition of Maryland streams. Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Program, Annapolis, MD.

Stranko, S, D Boward, J Kilian, A Becker, M Ashton, A Schenk, R Gauza, A Roseberry-Lincoln and P Kazyak. 2010. Maryland Biological Stream Survey, Round Three Sampling Manual, Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Program, Annapolis, MD.

Stribling, JB, BK Jessup, JS White, D Boward, and M Hurd. 1998. Development of a benthic index of biotic integrity for Maryland streams. Prepared by Tetra Tech, Inc., Owings Mills, MD and Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Program. CBWP-MANTA-EA-98-3.

Sun, Y and MG Genton. 2011. Functional boxplots. Journal of Computational and Graphical Statistics 20:316-334.

Wallace, JB. 1990. Recovery of lotic macroinvertebrate communities from disturbance. Environmental Management 14:605-629.

Walsh, CJ, AH Roy, JW Feminella, PD Cottingham, PM Groffman and RP Morgan II. 2005. The urban stream syndrome: current knowledge and search for a cure. J. North American Benthological Society 24:706-723.

Yoder, CO and MA Smith. 1999. Using fish assemblages in a state biological assessment and critical program: Essential concepts and considerations. Pages 17-56 in TP Simon (ed.), Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, FL.