DRAFT

Revised Monitoring Program

To meet the requirements of the District Department of the Environment's NPDES permit

Prepared for:
District Department of the Environment

Draft

May 8, 2015

DISTRICT
DEPARTMENT
OF THE
ENVIRONMENT

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The following organization, under contract to the District Department of the Environment (DDOE), prepared this report:

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Executive Summary

The municipal separate storm sewer system (MS4) permit (Permit Number DC0000221, U. S. EPA 2011 and U. S. EPA 2012) for the District of Columbia requires the District to develop, public notice and submit to EPA for review and approval a revised monitoring program. This Revised Monitoring Program fulfills this requirement and describes how the program will meet the objectives set forth in the permit. It is expected that the revised monitoring program will be implemented over a five-year permit cycle spanning 2016 to 2020.

The District Department of the Environment (DDOE) is the designated MS4 Permit Administrator for the District. Internally, the Stormwater Management Division has responsibility for implementing the permit requirements. The Revised Monitoring Program builds upon a variety of monitoring activities that DDOE has carried out under previous MS4 permits since 2000. It is designed to ensure compliance with the MS4 permit; to help DDOE evaluate the effectiveness of the MS4 program; and to provide information that will inform management decisions. As such, it is essential to the success of the Consolidated TMDL Implementation Plan recently prepared by DDOE (2015).

Program Goals and Objectives

The goals of the Revised Monitoring Program are to provide data and information to allow DDOE to evaluate the effectiveness of its MS4 program and to provide support for any recommended changes in MS4 program activities. Adherence to these goals represents a shift away from a monitoring program that was largely centered on the characterization of pollutants in stormwater runoff.

The objectives for the Revised Monitoring Program are:

- Make wet weather loading estimates of pollutants from the MS4 to receiving waters.
- Evaluate the health of receiving waters.
- Conduct monitoring, as needed, for source identification purposes.
- Ensure the Revised Monitoring Program is aligned with the Consolidated TMDL IP.

The linkage of the goals and objectives of the Revised Monitoring Program with the individual monitoring programs implemented by DDOE is presented in Figure ES-1.

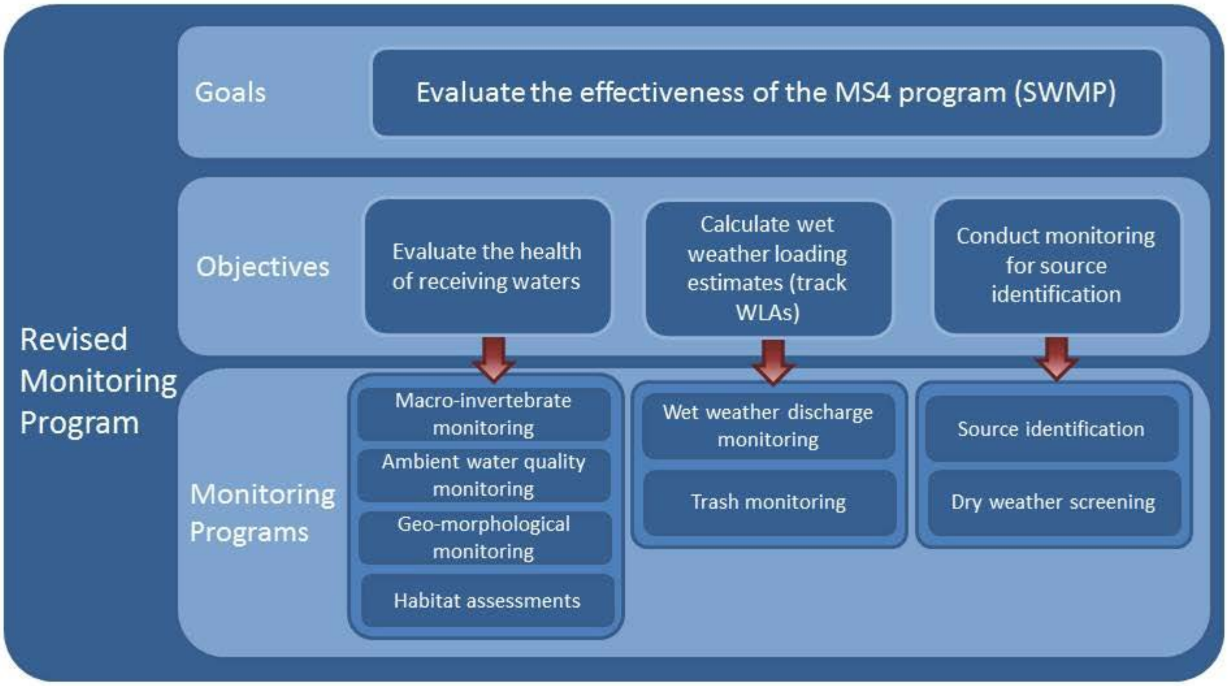

Figure ES-1. Linkage of Revised Monitoring Program goals and objectives with individual monitoring programs

As shown in Figure ES-2, the goals and objectives of the Revised Monitoring Program are closely tied to and supportive of the independent programmatic goals and objectives of DDOEs Water Quality and Watershed Protection divisions.

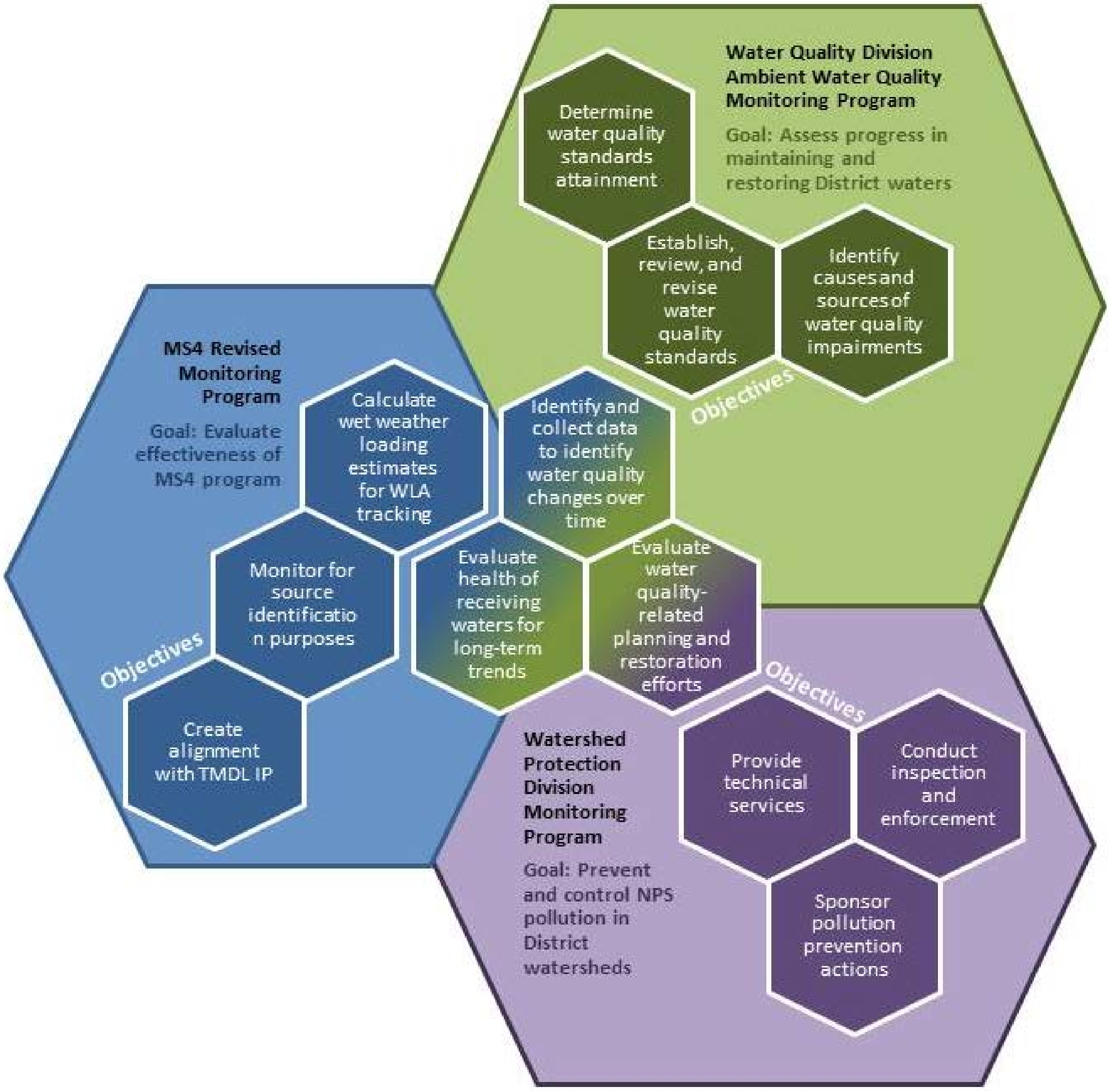

Figure ES-2. Overlap of goals and objectives of Revised Monitoring Program with other programmatic goals and objectives.

The District will take an adaptive management approach to implementation of the Revised Monitoring Program in order to integrate management with monitoring.

The Revised Monitoring Program consists of four distinct monitoring efforts.

- Wet Weather Monitoring
- Receiving Water Monitoring
- Source Identification and Dry Weather Screening
- Trash Monitoring

Each of these monitoring efforts along with brief descriptions of the quality of the stormwater program and data management are summarized in the following sub-sections.

Wet Weather Monitoring

Wet weather monitoring occurs at stormwater outfalls during rainfall events. The parameters to be monitored include those listed in Table ES-1. Trash will also be monitored during rainfall events, but at different sites. Trash will be described in a separate section.

Table ES-1. Parameters to be Monitored for Outfall Discharge (Source: MS4 Permit, Table 4)

E. coli	Lead
Total nitrogen	Zinc
Total phosphorus	Copper
Cadmium	Total Suspended Solids

The wet weather monitoring program was designed to meet the specific objectives:

- Make wet weather loading estimates of the parameters included in Table ES-1.
- Collect data to support wasteload allocation tracking.
- Ensure that collected data are statistically significant and interpretable.

The selection of wet weather monitoring sites was based on several factors including the collection of long-term wet weather data for trend analysis, collection of data from sites that are representative of the District's discharges, and collection of data to support additional needs identified over the course of this permit cycle. Site selection resulted in three monitoring sites within each of the District's major watersheds (the Anacostia, Potomac and Rock Creek watersheds). Monitoring required to support additional data needs through "special studies" would potentially add more monitoring sites to the program.

Field sampling collection practices and documentation are discussed within this Monitoring Program, however, additional detail and specificity will be included within the QAPP(s) that will be developed once this Program has been approved by EPA. Statistical analysis was undertaken to align sampling frequency with trend analysis. Parameters that have had high non-detect rates in the past (predominantly metals and organic compounds) are identified; continued monitoring of these parameters has not been recommended in this Program. If there is particular interest in any of these parameters, it is recommended that they be monitored in the context of a special study.

The use of the wet weather monitoring data to support annual reporting requirements for the Discharge Monitoring Report and the MS4 Annual Report is described.

Receiving Water Monitoring

Receiving water monitoring has been conducted on the tributaries within the District outside of the stormwater program in the past but is a new requirement under the current MS4 permit. The main objective of this effort is to evaluate the health of the receving waters within the context of the MS4. The receiving water monitoring framework of the Revised Monitoring Program consists of three tiers: 1) rapid assessment, 2) status and trends monitoring, and 3) targeted monitoring. Several indicies have been incorporated within this framework including:

- Benthic macroinvertebrates
- Geomorphological assessments
- Habitat assessments
- Receiving water quality

Site selection for receiving water monitoring that is tailored to the indices is addressed. Methods, protocols and equipment requirements are also discussed.

Dry Weather Screening and Source Identification

Dry weather screening occurs at stormwater outfalls during dry periods. It is undertaken to identify illegal, improper and unauthorized discharges to the MS4. The objective is to inspect each of the known and documented MS4 outfalls once within the five-year permit cycle.

Dry weather screening is built upon the mapping and prioritization of all MS4 outfalls. The procedures used for dry weather screening include:

- Visual monitoring
- Flow monitoring
- In-field chemical screening
- Desktop analysis and field investigation of potential sources
- Tracking and reporting

Collectively, these dry weather screening activities will identify sources of pollution that need to be addressed with changes in practices or structural solutions.

Trash Monitoring

Trash monitoring occurs at stormwater outfalls where trash traps have been installed during wet weather events. It will be implemented at three sites in the Anacostia Watershed, two in the Potomac Watershed, and one in the Rock Creek Watershed. A number of categories of trash are quantified and the total weight of trash from each site will be recorded.

Sample collection and analysis, quality control, reporting and adaptive management are described. The information collected through trash monitoring will inform the MS4 Program about trends in trash accumulation and the success of trash control efforts.

Quality of the Stormwater Program

The MS4 Permit requires the District to use the information collected through the Revised Monitoring Program to "evaluate the quality of the stormwater program." "Quality" is interpreted and defined as compliance with the MS4 permit and effectiveness of the stormwater management program. These two metrics are measured by progress made towards meeting benchmarks and milestones established in the Consolidated TMDL Implementation Plan. The approach that DDOE will use to evaluate the quality of the MS4 program is presented in Figure ES-3. As shown,

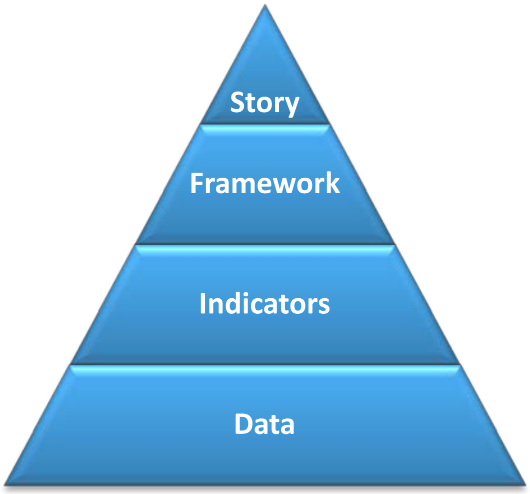

Figure ES-3. DDOE approach to evaluating the quality of the MS4 program (adapted from SCVURPPP 2001)

- The evaluation rests upon the data collected within the Revised Monitoring Program as well as information gathered through other components of the MS4 program.
- Indicators are used to show trends or responses to MS4 discharges, water quality, habitat, biology, and other programmatic objectives.
- The framework provides an integrated assessment of programmatic and watershed indicators.
- This approach allows DDOE to tell a "story" involving multiple lines of evidence to document the effectiveness of the stormwater management program.

Data Management

The data and information collected through monitoring efforts are a valuable and often irreplaceable resource. Therefore, retention and documentation of high quality data are the foundation upon which the success of monitoring programs rests.

The overarching data management goals are to:

- Ensure the highest quality and accuracy of program data.
- Fully qualify, document, and catalog all data to ensure their proper interpretation and use.
- Maintain data in an environment that ensures the long-term security and integrity of data.
- Ensure the longevity of data by keeping data formats standardized and current.
- Provide data in a variety of formats and venues to reach all potential users.

Detailed descriptions of database organization, data stewardship, data entry, metadata, data sharing, use of data from non-DDOE sources, and QA/QC are discussed and defined.

Schedule

The proposed schedule for the elements of the Revised Monitoring Program over the next permit cycle is presented in Table ES-2.

Table ES-2. Proposed Schedule for Monitoring Elements, 2016-2020.

		2016				2017				2018				2019				2020			
Monitoring Element	**Frequency**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Wet Weather Monitoring	3 wet weather events each year	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Dry Weather Screening	On a rolling basis so that each outfall is inspected once in the permit term	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Macroinvertebrates	Once during spring index period each year		🟩				🟩				🟩				🟩				🟩		
Habitat	Once during summer of the first year, then on an as-needed basis			🟩																	
Geomorphology	Once during summer of the first year, then on an as-needed basis			🟩																	
Receiving Water Quality	Once each month	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Trash	3 wet weather events each year	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Reporting																					
DMR	Due January 22 each year	🟩				🟩				🟩				🟩				🟩			
Annual Report	Due January 22 each year	🟩				🟩				🟩				🟩				🟩			
Evaluation and prioritization for next permit cycle	Once, in fourth year annual report													🟩							

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1 Introduction

The District of Columbia (the District) has been implementing monitoring efforts in response to National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) permit requirements since 2000, when its first MS4 permit was issued. The District was reissued an MS4 permit in October 2011 (Permit Number DC0000221), which was subsequently modified in November 2012. Section 5 of this permit requires the District to design a Revised Monitoring Program.

This document describes the Revised Monitoring Program. It was designed to ensure compliance with the MS4 permit; to help the District Department of the Environment (DDOE) evaluate the effectiveness of the MS4 program; and to provide information that will inform management decisions. To accomplish this, the Revised Monitoring Program incorporates four basic principles:

- Monitoring is focused on decision making – monitoring efforts are focused on data collection that is most helpful in making decisions about clearly defined regulatory, management, or technical issues.
- Monitoring intensity is oriented toward the potential for impact – monitoring efforts are focused where the potential impact is higher (i.e., higher probability of finding a pollutant source or finding a pollutant source that results in a more significant impact on District waters) and used less extensively in situations where the potential is lower or where monitoring is less likely to provide useful information.
- Monitoring is adaptive – the monitoring program incorporates the flexibility to be modified if needed. For instance, it can be modified if monitoring results identify the need to incorporate a follow-on study or if additional parameters or sites need to be monitored to gather the information required to understand sources or stressors and their impacts.
- Monitoring data are maintained in a way to be readily accessible for decision-making purposes – emphasis is placed on the collection of appropriate data. It is equally important to ensure these data are managed so that they are available when needed to assess progress and for any and all regulatory compliance purposes.

These principles are being accomplished through the incorporation of two overarching approaches within the Revised Monitoring Program:

- Core regulatory monitoring – includes long-term monitoring, intended to track compliance with specific regulatory requirements or limits, to conduct ongoing assessments, or to track trends in conditions over time. Thus, core regulatory monitoring generally occurs at fixed stations that are sampled routinely over time.
- Special studies monitoring - includes those efforts that may be shorter in duration, monitoring which may rotate location, or may collect data for a specific point in time. Examples of special

studies can include pre- and post-implementation monitoring of best management practices (BMP) at a site-specific or watershed-wide scale.

While these monitoring approaches can overlap, core regulatory monitoring will not necessarily provide enough data or information on which to base program decisions. Because of this, special studies may also be incorporated into the Revised Monitoring Program in select locations within the District or to collect specific data for a shorter duration. Determining if a special study will be developed and implemented will involve discussion within DDOE and will require answering a number of questions through a decision tree-type approach. Questions may include:

- Will data collected support MS4 programs and objectives?
- Will data collected support more than one DDOE program/project?
- Are sufficient funds available?
- What are the environmental benefits of the study?
- Do original data need to be collected or are literature values sufficient?

1.1 Drivers of the Revised Monitoring Program

As the MS4 Permit Administrator, DDOE's ultimate goal for the Revised Monitoring Program is an effective, integrated, and efficient monitoring framework that will comply with MS4 permit requirements. Although the MS4 permit is driving the development of the Revised Monitoring Program, DDOE also conducts monitoring in association with other programs not required by the MS4 permit. This includes ambient water quality monitoring and monitoring to support fisheries management. Coordination with these distinct monitoring programs will be initiated within the Revised Monitoring Program framework to achieve integration and efficiency.

While the Revised Monitoring Program has expanded its scope from the previous MS4 permit's focus of stormwater discharge characterization to evaluating the MS4 program's impact on the watersheds and its receiving waters, the focus remains on those impacts from the MS4 itself. Consequently, the Revised Monitoring Program is not focused on other pollutant sources that contribute to the impairment of water bodies in DC. Its relationship to other sources like DC Water's combined sewer system and upstream sources in Maryland and Virginia is peripheral.

In addition to a Revised Monitoring Program, the MS4 permit also requires DDOE to develop a Consolidated Total Maximum Daily Load (TMDL) Implementation Plan (IP) to define and organize a multi-year process centered on reducing pollutant loads originating within the District's MS4. The TMDL IP was developed in close coordination with the Revised Monitoring Program to ensure that the two efforts inform each other. Examples of this coordination can be found in Sections 3 (Wet Weather Monitoring), 5 (Trash Monitoring), and 6 (Quality of the Stormwater Program).

1.2 Adaptive Management

Adaptive management is an iterative, ongoing, learning process used to continually improve understanding and management policies and practices by learning from the outcomes of program activities over time (DOI 2009, City of Olympia 2003). It is a blend of scientific research, monitoring, and practical management upon which an experimental approach is applied that allows the user to test various approaches and solutions and “learn by doing” (EPA 2005). Adaptive management relies on scientific methods to evaluate how well regulatory and non-regulatory actions achieve their objectives (City of Olympia 2003). It is a necessary and useful tool because there is an inherent uncertainty about how ecosystems function and how management affects ecosystems (EPA 2005). Adaptive management recognizes and allows for this uncertainty and incomplete knowledge that typify complex ecosystem dynamics (City of Olympia 2003).

Fundamental to the adaptive management approach is the integration of “management” and “monitoring,” recognizing that any management action in the context of a complex ecological system is ultimately experimental, requiring feedback to make progress (PSSWG 2010). Monitoring is an essential part of the adaptive management process because it is a tool for decision-making or determining required adaptations to programs and practices. As a result, this concept of adaptive management is included as a key element of DDOE’s Revised Monitoring Program wherein new information about the health of the District’s watersheds influences DDOE’s subsequent data collection, planning, and decision making processes.

DDOE conducts a number of storm and surface water quality monitoring studies across the District. These studies have included characterization of urban stormwater quality, water body-specific monitoring studies, and assessments of effective BMPs. As data and information are collected over time, a more complete picture of the condition of District’s stormwater and receiving water systems is formed. This picture may also include the identification of additional data needs, such as analysis of additional parameters, sampling at additional sites, or inclusion of new monitoring techniques.

Each of the monitoring efforts described in this Revised Monitoring Program incorporate the concept of adaptive management as a way to ensure DDOE continues to collect the data and information that will actually inform managers about issues and needs, and ultimately result in improved water quality protection and reduced pollutant discharge to the storm and surface water system.

Adaptive Management

> *Adaptive management [is a decision process that] promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a ‘trial and error’ process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.*
>
> (DOI 2009)

It is not possible, however, to monitor every stormwater outfall, control structure or BMP within the District because monitoring efforts are expensive and resource intensive. DDOE’s challenge is to design monitoring activities to most efficiently identify water quality issues and inform management actions and management tools. Therefore, a balance between site-specific monitoring and the application of models to expand the understanding of the MS4 is advantageous. Monitoring is necessary as implementation of practices and programs proceed. This is important because monitoring helps DDOE evaluate the effectiveness of the requirements included in the MS4 permit as well as the effectiveness of the controls used to reduce the various pollutants addressed through the TMDL IP.

Conducting monitoring to assess the performance of specific BMPs allows for determination of whether the practices are performing as anticipated. Monitoring during the implementation process reveals what practices or designs are working. If monitoring data indicate that control measures are not performing as anticipated, adjustments to factors in the model that incorporates the performance of these practices might be needed. Evaluation of alternative practices and programs within the stormwater program may also be warranted.

Through the application of the adaptive management approach to TMDL implementation, the District will continue to evaluate the effectiveness of different controls at reducing different sources of pollution. This process of “learning by doing”, which is inherent in adaptive management, will provide the District with insight and knowledge that will help it most effectively target controls for different sources based on site-specific monitoring information.

Ultimately the information collected will be used to inform the overall adaptive management strategy, and be used to modify future activities or verify the activities are appropriate to help ensure control goals are met.

1.3 Revised Monitoring Program Contents

While an approach for the Revised Monitoring Program is laid out in this document, it is important to note that specific details, such as the final location of monitoring sites, parameters to be analyzed, or frequency of monitoring proposed, should be considered preliminary, and may be modified based on wider DDOE data needs that may be incorporated into this monitoring effort, monitoring site access issues, comments and feedback from the public and/or EPA, etc.

Additionally, while a significant amount of information is included within each section of this document, it does not include the level of detail necessary to carry out the monitoring without a quality assurance project plan (QAPP). An approved QAPP already exists for current monitoring programs (e.g., wet weather monitoring, trash monitoring). These documents will be revised as needed to mirror the approach discussed in this Revised Monitoring Program. In addition, a QAPP will be developed for new monitoring efforts, such as the receiving water monitoring that will be conducted to meet the MS4 permit requirements.

The Revised Monitoring Program is organized as follows:

Section 2 – Goals and Objectives – this section discusses the drivers behind the Revised Monitoring Program and the interrelationship with other DDOE monitoring programs.

Section 3 – Wet Weather Monitoring – this section describes data that will be collected during wet weather events from stormwater outfalls to characterize the impact of the MS4 program on stormwater discharges.

Section 4 – Receiving Water Monitoring – this section describes a program that is new to the MS4 permit and responds to the MS4 permit objective for DDOE to evaluate the health of receiving waters. It discusses how receiving water quality will be used to evaluate the impact and effectiveness of the stormwater program.

Section 5 – Source Identification and Dry Weather Screening – this section describes the identification of sources of pollution to the MS4 system as well as screening of any dry weather discharges from stormwater outfalls that may occur.

Section 6 – Trash Monitoring – this section describes monitoring of trash from stormwater outfalls during wet weather events. Trash monitoring is discussed separately from other wet weather monitoring because the methodology required to collect trash is significantly different than other water quality parameters.

Section 7 – Quality of the Stormwater Program – this section describes how information collected through the Revised Monitoring Program will be used to evaluate the effectiveness of the stormwater program. It describes how DDOE is interpreting this requirement, the approach that will be used to achieve this requirement, and how associated information will be conveyed to EPA and stakeholders.

Section 8 – Data Management – this section discusses DDOE's data management goals and objectives and the overarching process that will be used to facilitate data management within the context of the Revised Monitoring Program.

1.4 Proposed Schedule for the Revised Monitoring Program

There are many components to the Revised Monitoring Program, including:

- Wet Weather Monitoring
- Dry Weather Screening
- Receiving Water Monitoring
    - Macroinvertebrates
    - Habitat
    - Geomorphology
    - Water Quality
- Trash

The proposed schedule for all components listed above, as well as major reporting requirements within the next permit cycle (2016-2020) is provided in Table 1-1.

Table 2-1. Proposed Schedule for Monitoring Elements, 2016-2020.

		2016				2017				2018				2019				2020			
Monitoring Element	**Frequency**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Wet Weather Monitoring	3 wet weather events each year	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Dry Weather Screening	On a rolling basis so that each outfall is inspected once in the permit term	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Macroinvertebrates	Once during spring index period each year		🟩				🟩				🟩				🟩				🟩		
Habitat	Once during summer of the first year, then on an as-needed basis			🟩																	
Geomorphology	Once during summer of the first year, then on an as-needed basis			🟩																	
Receiving Water Quality	Once each month	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Trash	3 wet weather events each year	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Reporting																					
DMR	Due January 22 each year	🟩				🟩				🟩				🟩				🟩			
Annual Report	Due January 22 each year	🟩				🟩				🟩				🟩				🟩			
Evaluation and prioritization for next permit cycle	Once, in fourth year annual report													🟩							

2 Program Goals and Objectives

Development and implementation of a revised monitoring program require a comprehensive understanding of the program's overarching goals and objectives. This information helps to inform the scope, design, and execution of the monitoring program, so that the data collected can help to answer important management questions.

MS4 permit-related monitoring has been occurring within the District since 2000. DDOE's previous MS4 permits included the requirement for monitoring with a focus on characterization of dry and wet weather conditions. In the current permit's Fact Sheet, EPA explains that DDOE's new MS4 permit provides an opportunity to shift the focus of the MS4 monitoring program from characterization toward an approach that allows DDOE to "more effectively evaluate the effectiveness of the [MS4] program…"

Thus, the ultimate goal of the Revised Monitoring Program is to provide data and information to allow DDOE to evaluate the effectiveness of its MS4 program, and to provide support for any recommended changes. Section 5.1.1 of the MS4 permit outlines a series of objectives for the Revised Monitoring Program that will be used, in part, to reach this goal. Each of these objectives is described below:

- **Make wet weather loading estimates of pollutants from the MS4 to receiving waters.** These loading estimates will be used to support WLA tracking efforts and evaluate progress toward TMDL goals. DDOE needs to ensure these data are statistically significant to support the development of long term trends.
- **Evaluate the health of receiving waters.** This will include evaluating the impact of discharges from the MS4 on receiving waters as seen through water quality, biological, and geomorphological indicators. DDOE also needs to ensure these data are statistically significant to support the development of long term trends.
- **Conduct monitoring, as needed, for source identification purposes**. This will include identifying and prioritizing sources of urban runoff pollutants to the MS4 through source identification and dry weather screening efforts
- **Ensure the development of the Revised Monitoring Program is aligned with the Consolidated TMDL IP.** Various elements of the Revised Monitoring Program will feed information to the TMDL IP to directly or indirectly support the tracking of milestones, benchmarks and other programmatic performance measures. In addition, questions or issues that stem from the IP may direct modifications to the monitoring program.

Figure 2-1 depicts the goals and objectives of the Revised Monitoring Program with the monitoring programs implemented by DDOE. It should be noted that, while this may be the immediate focus of the MS4 permit-driven Revised Monitoring Program, DDOE will continue to address other goals and objectives to ensure it collects data and information needed to make program decisions that is not specifically tied to the MS4 permit.

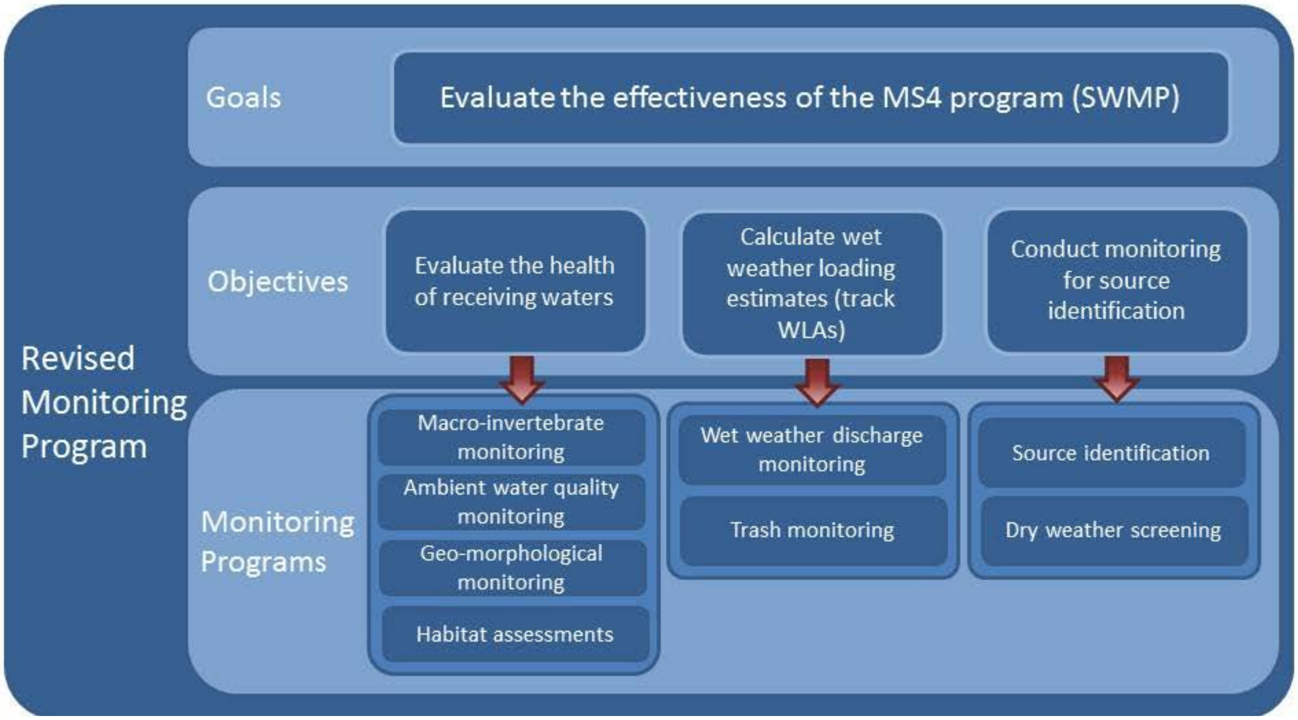

Figure 2-1. Linkage of goals and objectives of the Revised Monitoring Program with the individual monitoring programs

Other Divisions within DDOE's Natural Resources Administration conduct monitoring to meet different goals and objectives for other environmental programs. For instance, the Water Quality Division's (WQD) Monitoring and Assessment Branch has Clean Water Act (CWA) driven goals and objectives. The goal of the WQD's Water Quality Monitoring Program (WQMP) is to collect and analyze high quality data to assess progress in the District's efforts to maintain and restore the physical, chemical, and biological integrity of the District's waters.

The objectives of the WQMP are directly tied to water quality requirements found in the CWA including:

- Determining water quality standards attainment (CWA Section 305(b)).
- Identifying causes and sources of water quality impairments (CWA Sections 303(d), and 305(b)).
- Establishing, reviewing, and revising water quality standards (CWA Section 303(c)).

The monitoring program objectives also include:

- Identifying and collecting data that may be used in documenting water quality changes over time.
- Establishing appropriate and useful water quality monitoring protocols in support of the District's water quality standards.

One of the Watershed Protection Division (WPD)'s goals is to protect and restore the health of the District's watersheds. The objectives tied to this goal include:

- Enacting stormwater management and sediment and erosion control regulations for construction sites.
- Implementing an Environmental Education Program to educate District teachers, students, and residents on the benefits of environmental stewardship.
- Assessing the health of watersheds and habitats through monitoring activities.
- Recreating wetlands and restoring stream corridors and buffers to improve watershed health.

While a number of these objectives are distinct, overlap does exist for several MS4 Permit-required monitoring activities and those performed under the WQMP and WPD (Figure 2-2). The MS4 Revised Monitoring Program will take advantage of this overlap by coordinating data collection efforts across these Divisions. This will allow DDOE to build upon existing monitoring efforts, recognize efficiencies between programs, and collect data and information in a way that most effectively meets the goals and objectives of multiple programs in a coordinated manner.

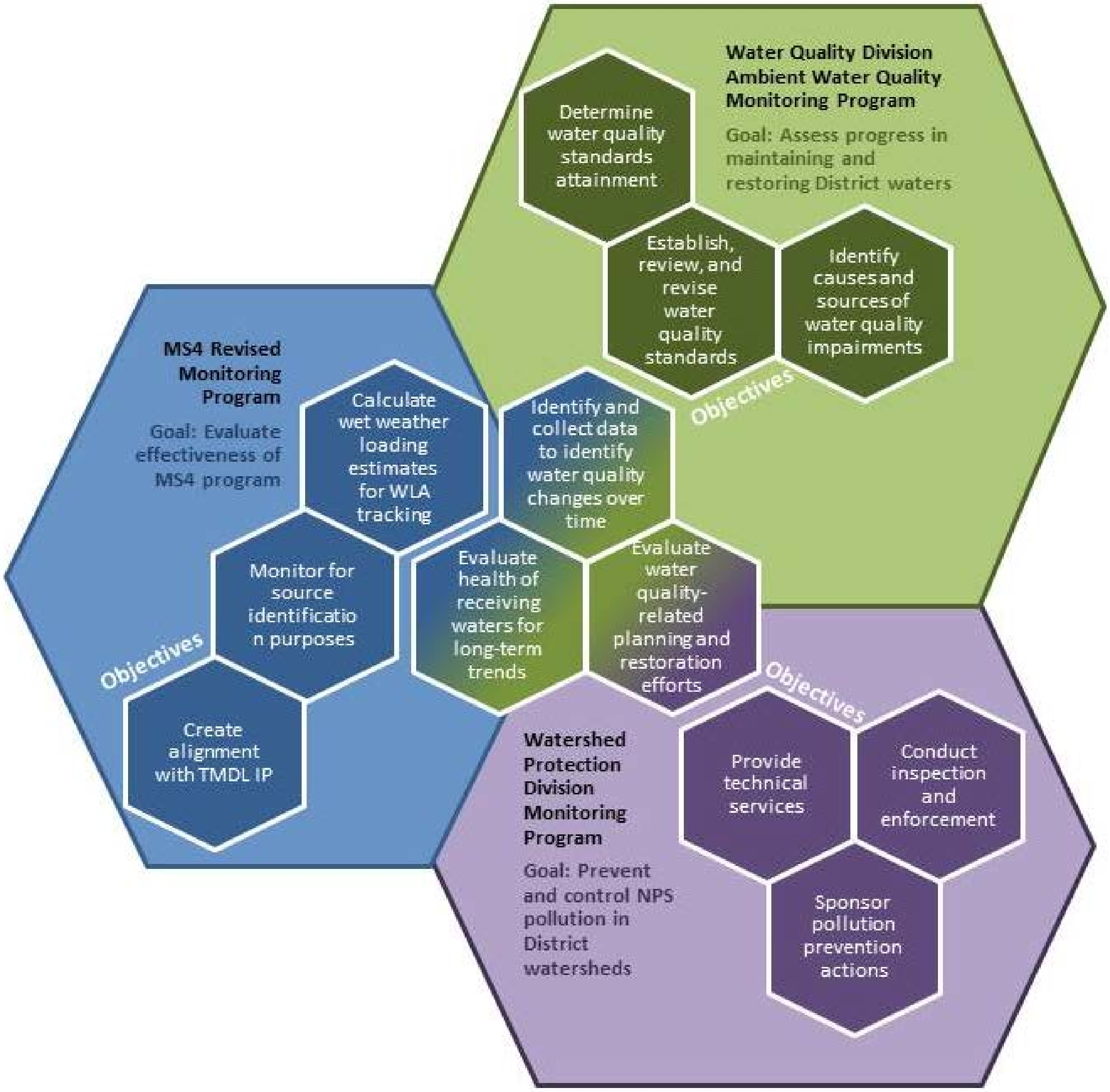

Figure 2-2. Overlap of goals and objectives of DDOE's Stormwater Management Division's Revised Monitoring Program and the Water Quality Division's Water Quality Monitoring Program

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3 Wet Weather Monitoring

3.1 Introduction

DDOE began implementing wet weather monitoring at outfalls in the District in 2000 when its first MS4 permit was issued. Wet weather monitoring continued under DDOE’s 2004 MS4 permit on a rotating watershed basis. Depending on the watershed, either eight or nine outfall stations were monitored annually. As a result, monitoring occurred in one of the watersheds each year so that each watershed was monitored once every three years. Three wet weather events were sampled at each outfall within the designated watershed each year.

Because the focus of the wet weather monitoring under previous MS4 permits was the characterization of pollutants in stormwater runoff, a large number of sites and an extensive list of parameters were analyzed for each event. The District’s current MS4 permit requires an interim version of the wet weather monitoring program that is to be implemented until the Revised Monitoring Program is approved by EPA. The interim program requires six stations (two per watershed) to be monitored each year during three wet weather events. The interim program also includes a significantly reduced list of parameters for which DDOE must monitor, removing those that routinely have shown non-detect concentrations or those for which significant water quality problems have not been identified. The revised wet weather monitoring program builds upon this interim program by continuing to focus on pollutants of concern identified by historical data.

The District’s MS4 permit includes a series of objectives for the revised wet weather monitoring program including:

- Making wet weather loading estimates of the parameters included in Table 3-1, below
- Collecting data to support wasteload allocation tracking
- Ensuring data are statistically significant and interpretable

Table 3-1. Parameters to be Monitored for Outfall Discharge (Source: MS4 Permit, Table 4)

E. coli	Lead
Total nitrogen	Zinc
Total phosphorus	Trash*
Cadmium	Copper
Total Suspended Solids	

* Trash monitoring is discussed separately in Section 6.

The revised wet weather monitoring program has been designed to meet these objectives as well as to support DDOE’s overarching MS4 permit goal of evaluating the effectiveness of the MS4 program.

3.2 Study Design

The design of the wet weather monitoring program is based on a combination of past efforts (to provide consistency) and the new requirements under the MS4 permit. The major differences in study design between previous monitoring efforts and this revised wet weather monitoring program are:

- Fewer parameters analyzed
- Randomly selected sites added
- Special studies added
- No rotation of sites from year to year based on watershed—all sites will be monitored each year across the District

The changes in this monitoring program were selected in order to address gaps identified in previous wet weather monitoring efforts, provide consistency from year to year for trend analysis, and to prioritize resources.

It should be noted that specific details discussed in this study design should be considered preliminary and will be finalized upon feedback from the public and/or EPA during this document's public comment period, desktop analysis and field visits (e.g., site accessibility issues, etc.), and incorporation of wider DDOE data needs (i.e., selecting a site that may provide data for more than one DDOE program, collecting additional water quality parameters, etc.).

3.2.1 Water Quality Parameters

The District's current MS4 permit identifies a set of parameters for which wet weather monitoring is required at outfalls. EPA established this set of parameters as those for which stormwater WLAs exist or those that occur in discharges with sufficient concentration and frequency to be considered a pollutant of concern (i.e., cadmium) (EPA 2011).

There are a number of reasons to limit wet weather monitoring to the set of parameters identified in the permit, compared to the much longer list that was analyzed for previous efforts. One is that monitoring for many other pollutants with WLAs (e.g., mercury, PCBs, pesticides) produces a high rate of non-detection, and adds little to improve DDOE's understanding of the effectiveness of the MS4 Program. A second is that monitoring for other parameters is not cost-effective. Five *in-situ* measurements will also be monitored to provide context for the other parameters (Table 3-2).

Table 3-2. Sample parameters and collection method

Composite Samples	Grab Samples	In-situ measurements
Total Suspended Solids	*E. coli*	Water Temperature
Total Nitrogen		Dissolved Oxygen
Total Phosphorus		Conductivity
Copper		pH
Lead		Hardness
Zinc		
Cadmium		

3.2.2 Storm Criteria and Sample Frequency

Wet weather monitoring at outfalls is performed only during qualifying rainfall events. A qualifying event is defined as a storm with at least 0.1 inches of predicted precipitation that occurs at least 72 hours from the end of a previous rainfall event with at least 0.1 inches of measured rainfall within the District. Three wet weather events will be sampled per year.

Rainfall data will be collected from the Reagan airport weather station, or another weather station that is determined to be closer or otherwise more appropriate for accurate storm prediction.

3.2.3 Monitoring Sites

The selection of wet weather monitoring sites is based on several factors including the collection of long-term wet weather data for trend analysis, collection of data from sites that are representative of the District’s discharges, and collection of data to support the additional needs as identified over the course of this permit cycle. While land use was initially considered in the site selection process, it was determined that it was an unnecessary factor. This is because the land use in each subwatershed in the District is, in general, homogeneous, and thus, it is difficult to correlate discharge characteristics with any specific land use. Site selection resulted in three monitoring sites within each of the District’s major watersheds (the Anacostia, Potomac and Rock Creek watersheds). Monitoring required to support additional data needs through “special studies” would potentially add more monitoring sites to the program.

3.2.3.1 Selection of Continuous Record Sites

Three monitoring sites were selected to maintain a continuous record with data collected to date and to evaluate the statistical significance of any changes observed in outfall water quality samples over time (including events from previous permit cycles). This group of continuous record monitoring sites includes one site within each of the District’s three major watersheds. Sites were selected from the existing pool of sites that have been sampled for past wet weather events. These sites will not change over the course of the permit cycle.

A desktop analysis was conducted to consider which sites are representative of conditions throughout each major watershed and appropriate for trend analyses. The 26 MS4 monitoring sites used between 2001 and 2013 were considered the “baseline” group of locations. A matrix was developed that characterized each site by land use, percent impervious cover, major watershed, drainage area, receiving body of MS4 effluent, whether the MS4 pipe may contain portions of a historic (now piped) stream, and if the MS4 pipe drains to or from Maryland (Appendix 1). All of these characteristics were considered in order to determine the past “representativeness” of the sites within the District, and to help determine if there were any locations that would not meet the needs of the new permit requirements. The precise location of sites and issues at each site (e.g., access) were obtained and included in the analysis. The proposed continuous record sites are:

1. Anacostia HS (Anacostia River watershed)[1]
2. Archbold Parkway (Potomac River watershed)
3. Walter Reed/Ft Stevens (Rock Creek watershed)

3.2.3.2 Selection of Random Sites

In addition to the continuous record sites described above, a stratified random selection method was used to randomly select two additional sites within each of the three major watersheds in the District.

Sample sites were randomly generated with the Generalized Random Tessellation Stratified (GRTS) methodology. This technique was employed to ensure that selected sampling sites are spatially balanced among the major watersheds. The GRTS process is an alternative to a purely random sampling approach, which may result in a cluster of sampling points in one area and leave another area free of sample points (EPA, 2015). The core concept of GRTS is to iteratively apply a hierarchical grid, until no two potential sample sites are within the same cell, and subsequently selecting sample sites so that adjacent cells are unlikely to be randomly chosen as sample sites (See Appendix 2 for more details on GRTS).

Sampling sites were selected from a pool of all outfalls greater than or equal to 24 inches in diameter in the MS4 area of the District. All outfalls meeting these criteria in the District were included in the randomization process, to ensure that the selected outfalls are representative of all outfalls. The median size pipe in the MS4 area is 24 inches and thus, the most representative size. It is assumed that pipes greater than 24 inches will drain a greater mix of land uses and greater land area, and therefore be more representative of the mixed land use of the District in general. Conversely, smaller pipes are assumed to drain smaller areas, possibly even a single business, and may produce outlier results. Figure 3-1 shows the sites that were selected using the GRTS approach and Table 3-3 provides additional details on these outfalls.

Three over-sample sites were also chosen in GRTS. These sites are “back up” sites to be used in case an outfall is determined to be inaccessible, unsafe, is tidally influenced, or otherwise inappropriate for sampling. Any outfall deemed inappropriate for wet weather monitoring will be replaced only with an over-sample site from the same watershed. All of the randomly-selected sites will continue to be monitored for each wet weather event within the permit cycle, unless an unforeseen issue (e.g., access, vandalism, etc.) is identified by DDOE that provides reasonable justification for proposing another site.

3.2.3.3 Selection of Special Study Sites

In addition to the annual wet weather sampling program at continuous record and random sites described above, “special studies” may be implemented in order to support the TMDL implementation plan or other DDOE monitoring goals. Some examples for special studies include:

- Monitoring for pollutants other than the nine recommended in Table 3-1 to determine if more sensitive analytical methods will produce results that show a detectable level of the pollutant where previous results have been largely non-detectable.

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[1] The current Anacostia High School wet weather site is a manhole so the nearest outfall will be selected if feasible

- Monitoring additional sites in catchments where more development and redevelopment is expected to occur (e.g., Hickey Run, Broad Branch) in order to track impact of BMP implementation.
- Monitoring of flow in a continuous manner to improve the runoff module of the IP Modeling Tool.
- Monitoring additional sites in the Watts Branch watershed because of the size of the Watts Branch Watershed and the significant investment in stream restoration and stormwater management made by both the federal and District governments.

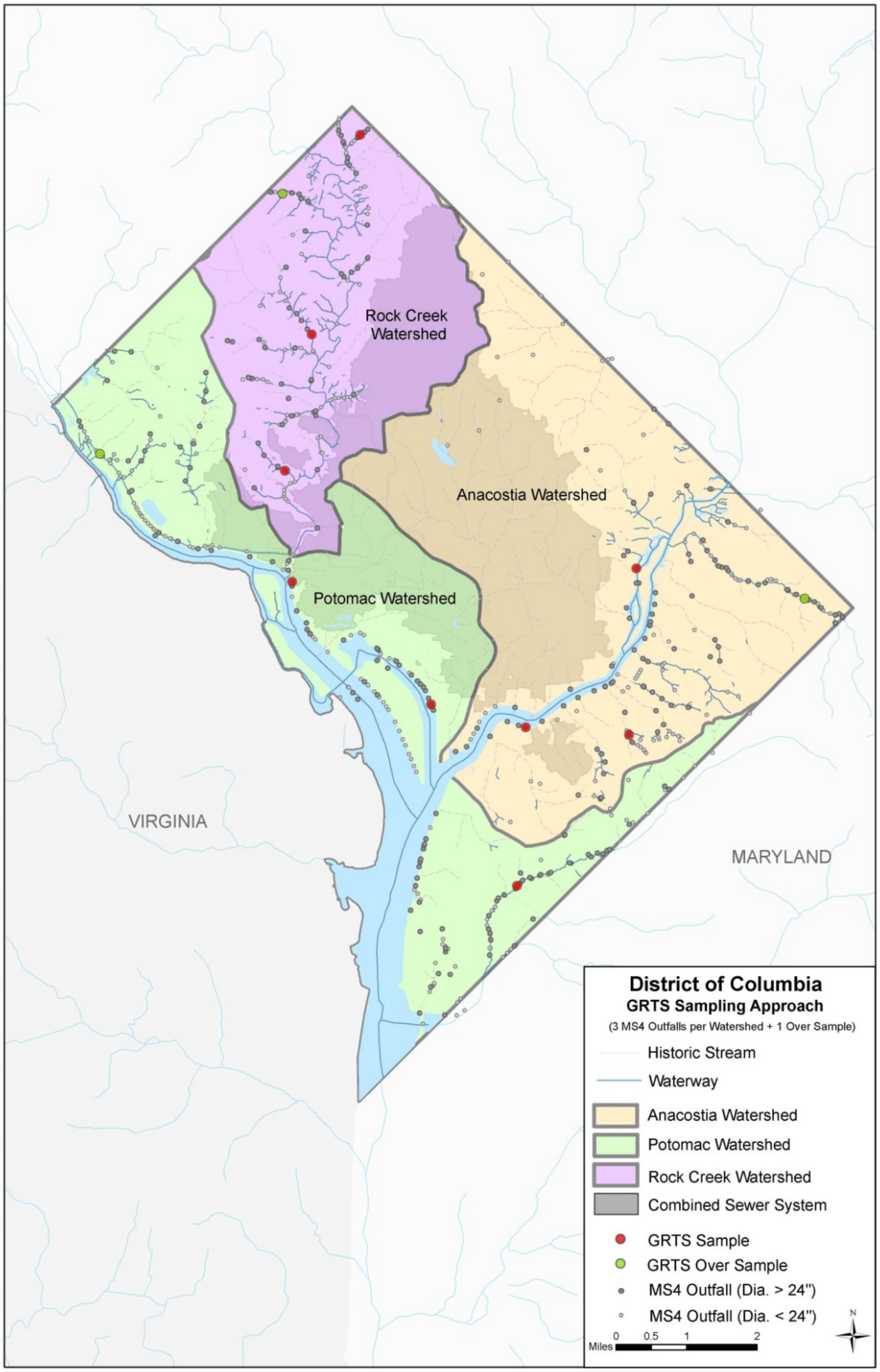

Figure 3-1. Example of sites selected using the GRTS approach for wet weather sampling

Table 3-3. Information on Randomly Selected Wet Weather Outfall Monitoring Sites*			
Wet Weather			
Watershed	Outfall Unique ID	Diameter (in)	Receiving Water
Potomac River	F-391-C-6-7-SW	24	Washington Ship Channel
Potomac River	F-240-K-3-NW	72	Potomac River
Potomac River	F-284-CD-19-20-SE	48	Oxon Run
Potomac River	F-22-TU-11-12-NW	72	C&O Canal
Anacostia River	F-538-CD-7-8-SE	42	Anacostia River
Anacostia River	F-412-IK-7-8-SE	48	Texas Avenue Tributary (unnamed tributary to)
Anacostia River	F-683-IK-3-4-NE	24	Anacostia River
Anacostia River	F-562-RS-1-2-NE	24	Watts Branch
Rock Creek	F-357-EF-33-34-NW	36	Portal Branch
Rock Creek	F-186-IK-11-12-NW	24	Normanstone Creek
Rock Creek	F-139-IK-19-20-NW	24	Broad Branch
Rock Creek	F-91-IK-29-30-NW	54	Pinehurst Branch (unnamed tributary to)

*Sites include the two randomly selected sites as well as two randomly selected “oversample” sites per watershed that will be available if primary sites are determined to be unsuitable.

3.3 Sample Collection

This section provides an overview of the field sampling collection methods and documentation that will be implemented during the monitoring program.

3.3.1 Sampling Procedure

3.3.1.1 Composite Samples

There are two methods for collecting composite samples: flow proportional composite auto-sampling and time-based composite sampling. Flow-proportional composite auto-sampling will be used where possible at all sampling sites. Flow-proportional sampling involves collecting an equal volume of stormwater at equal increments of flow volume. For example, one sample aliquot is collected for every thousand cubic feet of flow. Flow-proportional sampling enables collection of samples at a higher frequency when flow rates are higher, and at a lower frequency when flow rates are lower. This method provides a direct measure of the relationship between pollutant concentration and flow rate, and it allows for a direct calculation of event mean concentration (EMC) for the contributing drainage area. Flow-proportional sampling requires the use of an auto-sampler capable of collecting flow-proportional samples.

Flow-proportional composite sampling requires estimation of the expected volume of discharge during the wet weather event to avoid collecting too small of a sample volume or filling all of the available sample volume before the completion of the wet weather event. There should be sufficient bottle capacity to collect more volume than required by the lab in order to allow for larger or smaller than expected storm events. In addition, the auto-sampler must be paired with a flow meter to trigger the collection of samples based on a specific flow interval contingent on the expected volume of the wet weather event. If a flow meter cannot be installed, a level sensor will be used in conjunction with pipe cross-section information.

If there are restrictions that prevent installing a flow meter within the pipe, or the use of an auto-sampler, another nearby location will be selected that allows for this equipment installation. If a nearby site is not available, or it is determined that this type of installation is generally not possible due to physical, permitting, or safety constraints, then time-based sampling will be used.

Time-based composite sampling requires manual compositing of samples from time-series aliquots. Sample aliquots of the same volume are taken at a specific time interval (e.g., every 15 minutes). If possible, a flow meter or level sensor will be used to measure pipe flow. If this is not possible, visual estimation of pipe flow at the time of each sample aliquot sample is required for this method. Manual time-based compositing and visual estimation of pipe flow are not as accurate and will only be used when automatic flow-proportional composite sampling is not possible.

3.3.1.2 Grab Samples

Grab samples will be collected using manual methods and equipment to monitor for *E. Coli*. Grab samples will be collected by holding a sterile sample bottle container under the outfall of a discharge pipe, at the lip of an inlet grate, or by dipping a container downstream of a discharge with the container opening facing upstream, depending on monitoring site configuration.

3.3.2 Field Sampling Practices and Documentation

If field preservation is required, the appropriate preservative will be placed into the sample container prior to sample collection. All samples collected will be stored in the appropriate container type no longer than the time allowable for the analyte and the analysis performed. Field meters will be calibrated in accordance with the manufacturer’s recommendations.

Water quality samples will be labeled and field logs filled out with important information. Completed chain-of-custody forms will be required for all samples to be analyzed. A chain-of-custody is a legally-binding record of the date and time periods that samples were in the possession (e.g. custody) of the parties indicated.

Further details will be provided in a QAPP.

3.3.3 Storm Event Data

Storm event data will be collected in association with each wet weather monitoring event in accordance with MS4 permit Section 5.2.2. This information is collected to provide specifics of weather conditions when data is collected to help with interpreting results. Storm event data recorded in the field log must include:

- Date and duration (hours) of the event sampled
- Direct measurement or estimate of rainfall amounts (in inches) associated with the event

- Duration (in hours) between storm events sampled and the end of the previous measurable storm event (greater than 0.1 inch of rain)

3.4 Statistical Significance

The MS4 permit states that monitoring data should be statistically significant and interpretable. A statistical analysis was undertaken to address this requirement. In particular, this analysis was focused on identifying the number of samples required to significantly detect changes from existing wet weather monitoring data. This analysis was based on water quality data previously collected by DDOE at each outfall from 2001 to 2013. For the detailed report, see Appendix 3.

Prior to performing this statistical analysis, the concentrations of each pollutant were compared across each of the major watersheds using an Analysis of Variance (ANOVA) to determine if samples from outfalls could be pooled. The results from the ANOVA test indicated that TSS and zinc were the only pollutants that were significantly different across the major watersheds. For these significance estimates, it was assumed that pollutant trends will not deviate in the future, and all pollutant data, with the exception of TSS and zinc, can be taken at any sampling site to identify District wide changes with the desired significance. This approach will limit the need to extrapolate trends observed at single outfalls to make characterizations about the entire District. TSS and zinc measurements must be compared only to existing data from the same watershed.

The results of the statistical analysis are summarized in Table 3-4. The number of samples required to detect a 25% change in mean concentration and number of years to detect a change estimate future measurements based on analysis of past data. This is provided as an example of the analysis done, but does not imply that the number of samples needed to detect a 25% change will be collected during wet weather.

Table 3-4. Required samples to detect 25% change in mean concentration for power = 0.80 and p<0.05

Pollutant	No. of existing measurements	Minimum No. of samples to detect 25% change*	No. of years to collect samples
Total Nitrogen	200	67	2.5
Total Phosphorus	203	45	1.7
Total Suspended Solids (Anacostia)	78	N/A	N/A
Total Suspended Solids (Potomac)	61	N/A	N/A
Total Suspended Solids (Rock Creek)	59	N/A	N/A
Copper	212	159	5.9
Fecal Coliform Bacteria[2]	121	N/A	N/A
Lead	205	N/A	N/A
Zinc (Anacostia)	93	63	7.0
Zinc (Potomac)	61	293	32.6
Zinc (Rock Creek)	66	109	12.1

*Gains no longer considered appreciable when power can be rounded to the same hundredth of the maximum attainable power. For explanation of “N/A” entries in the table, see Appendix 3.

The time it will take to detect 25% changes (p<0.05, power=0.80) from the existing dataset differs for each pollutant due to the existing number of and variability in the existing sample measurements. With the proposed sampling frequency of three events per year, a 25% change can be identified for TN and TP within a five-year permit cycle, and the same changes can be identified in copper and zinc in the Anacostia watershed within two permit cycles. The detection of 25% changes in the remaining pollutants with the desired significance could not be reached because of the very high variability in the existing data. This does not necessarily mean that this change will go unidentified, but the likelihood that a change will be identified is less than the desired power. While differences in concentration means before and after the Consolidated TMDL IP gets underway may not be statistically significant, the changes may still help discern patterns of improvements in the MS4.

3.5 Reporting Requirements

There are two major reports that must be submitted each year to EPA that summarize the annual monitoring results: the Discharge Monitoring Report (DMR) and MS4 Permit Annual Report. Additionally, six months before the expiration of the current permit, a new MS4 permit application must be submitted, which will include the analytical data collected through this monitoring program.

The requirements for the DMRs and Annual Reports are described below.

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[2] Fecal coliform bacteria data were used as a surrogate for E. Coli since there were insufficient E. Coli data collected for statistical analysis.

3.5.1 Discharge Monitoring Reports

DMRs are due each year on the anniversary of the effective date of the Permit (January 22nd in the current Permit term). Data may be uploaded to http://www.epa.gov/netdmr or, if that page is unavailable, an original and one copy must be sent to the two addresses provided in section 5.7 of the permit (NPDES Permits Branch of EPA Region 3 and NMFS Northeast Region). The DMRs must include all analytical chemical results of all monitoring described in Section 5 of the permit (storm event data, wet weather loading, dry weather screening, and flow). Results should also include any data collected that were not required by the permit. For example, if a pollutant was monitored more frequently than required by the permit, it still must be included in any calculations of load, etc.

3.5.1 MS4 Annual Reports

MS4 Annual Reports are also due each year on the anniversary of the effective date of the Permit. These reports provide a summary of Stormwater Management Program (SWMP) implementation and monitoring results from the previous year. DDOE must also post the Annual Report to the DDOE website at the same time as it is submitted to EPA, and convene a meeting with EPA to present annual progress and plans for the following year. The meeting will establish the appropriateness of reporting materials and format

Any revision to the Annual Report must be approved by EPA. If EPA does not approve any part of the report, DDOE will have 30 days to address comments. EPA may address comments themselves if DDOE does not do so in a satisfactory manner (or within 30 days of receiving comments from EPA).

Additional items to be reported in the annual report are listed in section 6.2.1 of the MS4 Permit.

3.5.2 Record Retention

DDOE must retain records of all monitoring information (including all calibration and maintenance records, recordings from continuous monitoring equipment) for at least five years from the date of the sample, measurement, or report. These records shall include:

- The date, exact location, time and methods of sampling or measurements
- The individual(s) who performed the sampling or measurements
- The date(s) analyses were performed
- The individual(s) who performed the analyses
- The analytical techniques or methods used
- The results of such analyses

3.6 Implications of Non-Detected Parameters

A large percentage of wet weather monitoring samples for certain pollutants resulted in non-detects (NDs), meaning that the concentration in stormwater samples was below that of the detection limit (DL; the lowest level at which a concentration can be detected in the laboratory). For all available wet weather data between 2001 and 2013, 9 of the 21 measured parameters for which TMDLs exist in the District had a 90% or higher percentage of NDs. An additional three parameters had non-detect rates of approximately two-thirds of all samples collected (Table 3-5) or greater. This is an important issue to consider because assembling a dataset with a high percentage of NDs for certain parameters is not cost effective, and the data have the potential to skew analysis and interpretation of data for future management. However, before eliminating such pollutants from future analysis, it is also important to consider whether the analytical method and corresponding DL is appropriate for DDOE's needs. A comparison of analytical methods and DLs/Reporting Levels (RLs; the lowest reported level of concentration) used over the past several years with current DC water quality criteria (WQC) revealed that in some cases the DLs were higher than at least one water quality criteria. For example, the DDT isomers (DDD, DDE, and DDT) have two WQC, based on a 4-day and 1-hour average concentration. The 4-day WQC for all isomers (0.001 ug/l) are lower than both the DL and RL (0.10 ug/l), but the 1-hour WQC are not (Table 3-5). Thus there is a concern that inappropriate analytical methods have prevented accurate evaluations of pollutant concentrations against WQC (it is possible for a pollutant concentration that registers as an ND to still be above the WQC). This has implications for future management decisions and practices to protect receiving water quality, such as if WLAs for TMDLs are being met.

Table 3-5. Non-detect rates, detection levels, and analytical methods for DC wet weather outfall monitoring*

Parameter	Units	N	% NDs	WQC	DL/RL	Method
TSS	mg/l	198	3%		/1.0	SM(20) 2540D
TN	mg/l	200	9%		0.025/1.0	SM (20) 4500
TP	mg/l	203	0%		0.0017/.010	365.1
Fecal Coliform Bacteria	MPN/100ml	121	1%	200	20/20	SM(20) 9221E
E. coli	MPN/100ml	29	3%	126/410	2.0/2.0	SM(20) 9221F
BOD	mg/l	185	7%		2.0/2.0	SM(20)5120(B)
Oil and Grease	mg/l	156	66%	10	1/5	1664A
Arsenic	ug/l	162	67%	150/340	0.61/2.0	200.8
Cadmium	ug/l	229	73%	Hardness-dependent	0.22/0.50	200.8
Copper	ug/l	212	3%	Hardness-dependent	0.24/1.0	200.8
Lead	ug/l	205	5%	Hardness-dependent	0.24/1.0	200.8
Mercury	ug/l	137	95%	0.77/1.4	0.027/0.20	245.1
Zinc	ug/l	220	3%	Hardness-dependent	1.1/5.0	200.8

Table 3-5. Non-detect rates, detection levels, and analytical methods for DC wet weather outfall monitoring*

Parameter	Units	N	% NDs	WQC	DL/RL	Method
Chlordane	ug/l	134	99%	0.0043/2.4	0.10/0.10	608
DDD	ug/l	133	99%	0.001/1.1	0.10/0.10	608
DDE	ug/l	134	96%	0.001/1.1	0.10/0.10	608
DDT	ug/l	133	92%	0.001/1.1	0.10/0.10	608
Dieldrin	ug/l	135	96%	0.056/0.24	0.10/0.10	608
Heptachlor Epoxide	ug/l	133	99%	0.0038/0.52	0.10/0.10	608
PAHs	ug/l	2883	96%	50-800	0.95-3.8/5.0	625
Total PCBs**	ug/l	90	100%	0.014	0.10/0.10	608

*DLs and RLs and analytical methods are from 2011 wet weather results (Microbac Laboratories, Baltimore, MD). %NDs and n are from the entire record of wet weather data, 2001-2013. WQC reported are for Class C waters only (fishable/swimmable). If a specific water quality criterion is missing from the table it is because it either does not exist (blank) or it is hardness-dependent and thus, varies, as indicated on the table. Standards for metals are in the dissolved form. E. Coli replaced fecal coliform as the EPA-recommended bacteria indicator starting in 2008, however E. Coli was not analyzed in wet weather samples until 2013.

**Analysis was performed only on those samples with results reported for Total PCBs. Individual PCB congener and Aroclors were reported for some events and sites, and were detected in some cases, but it was inconsistent across years.

As stated above, due to a variety of issues, monitoring of parameters that have had high non-detect rates in the past is not recommended for the Revised Monitoring Program. Instead, DDOE may monitor for these parameters under special studies, but only if a more sensitive analytical method and DLs are chosen than what has been used previously in order to ensure the ability to compare against WQC.

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4 Receiving Water Monitoring

4.1 Introduction

DDOE has been conducting receiving water monitoring in the District for over a decade to meet CWA Section 305(b) and 303(d)-related requirements. The current MS4 permit requirements, however, directs DDOE to evaluate the health of the District's receiving waters in an effort to meet the permit's overarching goal of evaluating the effectiveness of the MS4 program (See Section 2 for additional discussion). Biological and physical metrics were also added as monitoring requirements in the most recent MS4 permit as they have been shown to be better indicators (compared to chemical monitoring in receiving waters) of the effectiveness of stormwater controls (EPA 2011). The receiving water monitoring component of the Revised Monitoring Program has been designed to not only satisfy the MS4 permit requirements, but also to utilize existing monitoring efforts and identify efficiencies between monitoring efforts where possible.

A discussion of the existing receiving water monitoring, the monitoring framework, the study design, and sampling and assessment protocols are discussed below.

4.2 Existing Receiving Water Monitoring

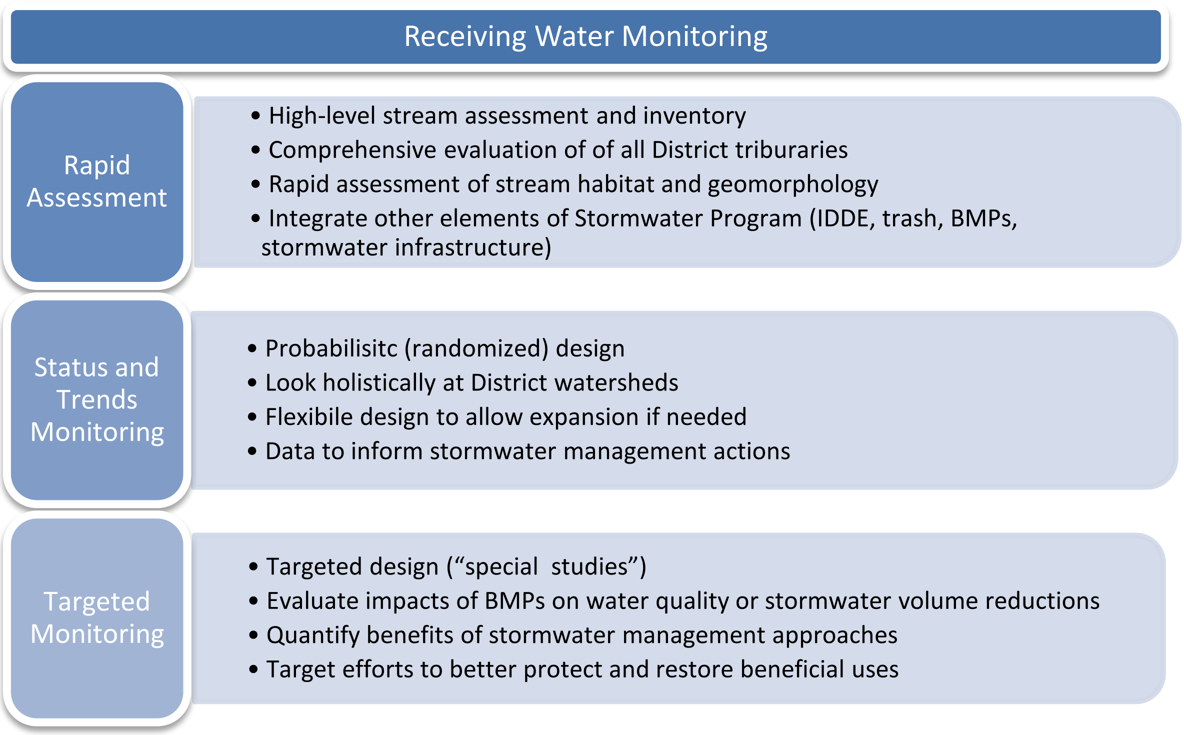
While receiving water monitoring has not previously been required under the MS4 program, DDOE currently implements monitoring in association with non-MS4 related programs that includes collecting ambient water quality, fish, and macroinvertebrate samples and conducting physical habitat assessments. Monitoring sites are located throughout the District and monitoring is conducted on a number of different schedules for addressing program objectives outside the MS4 permit. These objectives include evaluating water quality trends, tracking progress toward meeting the aquatic life designated use, and monitoring real time water quality.

Receiving water monitoring is also performed in association with various District restoration activities. For instance, DDOE implements pre- and post-implementation water quality, biological, flow, and geomorphological monitoring of select projects, such as stream restoration or intensive watershed retrofitting efforts.

4.3 Monitoring Framework

As conveyed in Figure 4-1, the receiving water monitoring framework of the Revised Monitoring Program consists of three tiers: 1) rapid assessment, 2) status and trends monitoring, and 3) targeted monitoring. Within this framework several indicies have been incorporated including:

- Benthic macroinvertebrates
- Geomorphological assessments
- Habitat assessments
- Receiving water quality



Receiving Water Monitoring

Rapid Assessment

- High-level stream assessment and inventory
- Comprehensive evaluation of of all District triburaries
- Rapid assessment of stream habitat and geomorphology
- Integrate other elements of Stormwater Program (IDDE, trash, BMPs, stormwater infrastructure)

Status and Trends Monitoring

- Probabilisitc (randomized) design
- Look holistically at District watersheds
- Flexibile design to allow expansion if needed
- Data to inform stormwater management actions

Targeted Monitoring

- Targeted design (“special studies”)
- Evaluate impacts of BMPs on water quality or stormwater volume reductions
- Quantify benefits of stormwater management approaches
- Target efforts to better protect and restore beneficial uses

Figure 4-1. Program tiers of the receiving water monitoring competent of the Revised Monitoring Program

4.3.1 Rapid Assessment

The first tier, **Rapid Assessment**, includes a high-level stream assessment and inventory that will be conducted in the first year of the permit cycle. This will include DDOE walking all wadeable (i.e., first through fourth order tributaries, not mainstem reaches) stream reaches within the District to conduct a comprehensive, baseline analysis of these streams. Habitat (using the MBSS methodology) and geomorphological (Rosgen Level 1 classification) assessments will be conducted during the stream walks. Additionally, DDOE will evaluate other environmental features along the stream reach, such as infrastructure (i.e., stormwater and wastewater pipes and outfalls) and other elements, such as dump sites and stream buffer deficiencies. Hand-held GPS equipment will be used during these stream walks to facilitate rapid and accurate data collection. The purpose of this data collection effort will be two-fold: 1) to develop a baseline by which to compare changes or trends over time and 2) to identify issues (i.e., potential restoration projects, dump sites, or other problem areas) that DDOE can work to address through the remainder of the permit cycle.

4.3.2 Status and Trends Monitoring

The second tier, **Status and Trends** monitoring, includes the routine water quality and macroinvertebrate monitoring at randomized sites by ecoregion and stream order. “Status” monitoring includes the assessment of current conditions, while “trend” monitoring is performed to evaluate changes at sites over time (i.e., a permit cycle or longer). The status of receiving waters can be analyzed annually, while trends will require an appropriate amount of time to accurately detect changes. As found in other similar studies, “trends require sufficient sampling to determine significant changes from natural variability, but also require the system has sufficient time to respond to actions or lack of action. More sampling does not necessarily mean a quicker detection of trends" (PSSW 2010).

Evaluating receiving waters in relation to the MS4 is challenging due to the number of other inputs that may confound our understanding the impacts to these waters (see discussion in Section 7, the *Quality of the Stormwater Program*). While the randomized design of this tier can help DDOE make watershed comparisons in a statistically robust way, "the intent of the status and trends monitoring is not to identify every variable or establish the loading or variability of each parameter…", but "…to produce sufficient information to inform stormwater management actions and to determine over time whether these actions are improving the beneficial uses of receiving waters" (PSSW 2010).

4.3.3 Targeted Monitoring

The third tier, **Targeted Monitoring**, includes focused monitoring efforts that are used to evaluate whether best management practices or stormwater management efforts achieve water quality improvements or stormwater volume reductions. These "special studies" will be implemented for several different purposes. For instance, DDOE may identify a drainage area where extensive retrofits are planned. Monitoring efforts could be implemented in the area to assess pre- and post- pollutant and/or stormwater volume discharges and, subsequently, to evaluate the effectiveness of these efforts. Additionally, existing DDOE monitoring of restoration activities could be extended or modified to collect additional data to help determine trends and effectiveness.

4.4 Study Design

The design of the receiving water monitoring component of the Revised Monitoring Program includes site selection, the use of reference streams, and sampling timing and frequency and reflects, where possible, the approach established by the Maryland Department of Natural Resources (MDNR) Maryland Biological Stream Survey (MBSS) (MDNR 2014). MBSS protocols have been incorporated to this study as they are robust, locally used, and frequently updated and have been used by DDOE in the past. It should be noted that specific details discussed in this study design should be considered preliminary and will be finalized upon feedback from the public and/or EPA during this document's public comment period, desktop analysis and field visits (e.g., site accessibility issues, etc.), and incorporation of wider DDOE data needs (i.e., selecting a site that may provide data for more than one DDOE program, collecting additional water quality parameters, etc.).

4.4.1 Site Selection

The site selection process was largely based on the approach described in the MBSS study design. One difference from the MBSS approach is that watershed drainage area was not used in the DDOE approach because of the relatively small size of the District. While land use was considered initially in the site selection process, it was eventually deemed unnecessary. This is because the land use in each subwatershed in the District is, in general, homogeneous, and thus, difficult to correlate receiving water quality with a specific land use. Site selection is focused on two particular variables: stream order and eco-region. A random sampling of tributary stream segments stratified by stream order (stream order one through four) was used (Mercurio, et. al. 1999). Mainstem streams were not included in the analysis.

The focus on lower order streams is consistent with the need to conduct macroinvertebrate monitoring in wadeable streams. Because there are few fourth-order stream reaches in District tributaries, only one site within this stream order was selected, compared with four sites selected within in each of the first through third order stream reaches.

The DDOE study design also used ecoregion (Coastal Plain and Eastern Piedmont) to stratify the site selection process. This is consistent with the MBSS study design because there are separate indices for each ecoregion. For instance, two separate MBSS Physical Habitat Indices were developed for two geographic strata: Coastal Plain and non-Coastal Plain (Mercurio, et. al. 1999). Benthic macroinvertebrate IBI metrics were developed by ecoregion in 2005 (Southerland, et. al. 2005)

An initial group of 52 potential sites were selected using a randomized sampling approach that ensured spatial balance within a stratum. This group of 52 sites was randomly divided into two groups or 26 sites: selected sites and “over-sample” sites. The latter group of sites will be used in cases where the original site is not suitable due to access or other issues (safety, tidal influence, etc.). All perennial streams within the District were classified into one of seven possible strata:

- First-order streams in Eastern Piedmont
- Second-order streams in Eastern Piedmont
- Third-order streams in Eastern Piedmont
- Fourth-order streams in Eastern Piedmont
- First-order streams in Coastal Plains
- Second-order streams in Coastal Plains
- Third-order streams in Coastal Plains

4.4.2 Reference Streams

Reference streams represent streams that have been minimally influenced by anthropogenic disturbance. The reference conditions in reference streams reflect the potential quality of biological communities in various stream settings. The use of reference streams is an important component to the development of meaningful criteria to assess

Use of Reference Streams

> *In reference streams “temporal trends in ecological condition should be attributable primarily to seasonal and annual variations in precipitation (and resultant droughts or floods) and temperature/dissolved oxygen regimes, as well as biotic interactions. Stress caused by these natural changes can have drastic effects on stream biota (e.g., benthic macroinvertebrates and fish), effects that should be detected by the biological indicators and ancillary chemical/physical measurements taken...*
>
> *Therefore, monitoring a set of minimally-disturbed (more ideally, pristine) streams in places not likely to experience anthropogenic impacts offers the best means of discerning changes in biological indicator scores across years at stream sites sampled along the entire gradient of disturbance that are also being influenced by natural variability.”*
>
> *MDNR 2010*

stream conditions. Degradation is evaluated as a deviation from reference conditions.

There are no appropriate reference steams in the District because it is highly urbanized. While "pristine" streams also no longer exist within Maryland, a number of the remaining streams have been designated as meeting reference site requirements in the MBSS program (Becker et. al. 2010). Because the Revised Monitoring Program's receiving water monitoring efforts will rely upon MBSS protocols, DDOE will assess its receiving waters in comparison to several MBSS reference sites in Maryland from the Eastern Piedmont Region and the Western Shore Region of the Coastal Plain.

4.4.3 Sample Timing and Frequency

The frequency by which monitoring occurs varies by indicator (e.g., macroinvertebrates, water quality, etc.). For instance, the MBSS protocol requires a seasonal 'index period' over either spring or summer months.

The spring index period (March 1 through April 30) is most suitable for identification of anthropogenic stressors to benthic macroinvertebrates due to temperature and acidification of streams (MDNR 2014). Some habitat metrics are also most appropriate for this time period (see Table 4-2). The summer index period (June 1 through September 30) was chosen for the remaining habitat and geomorphological assessments because the low flow period for area streams occurs during the summer months, meaning that habitat is most limited and assessments will evaluate "worst-case" scenarios for instream habitat for fish and other organisms. In addition, stream level and temperature are more conducive for wading at this time of year.

Sampling frequencies for the indices are as follows:

- Benthic macroinvertebrates – once a year
- Water quality sampling – once a month, though frequency may vary by parameter as needed
- Physical habitat and geomorphological monitoring – once a year in first year of permit cycle, and as needed in association with targeted monitoring

As discussed further in Appendix 4, DDOE conducted a statistical analysis of existing District receiving water data. Given the variability of these receiving water data, statistically significant *trends* are difficult to achieve in a permit cycle despite increased sampling frequency. As shown through similar studies, such as a five-year USGS study of streams in Fairfax County, Virginia (Jastram 2014), determining *patterns* in data may be more feasible.

4.5 Sampling Protocols and Equipment

Field sampling methods and equipment will vary between different elements of the receiving water monitoring program, which are detailed in the following sections. There are a number of items that are common to multiple monitoring program elements including:

- All sampling and data collection protocols have associated field data sheets, quality assurance/quality control (QA/QC) procedures, and chain of custody forms (where appropriate). Where appropriate, data collection may be recorded digitally, as long as there is redundancy in place (e.g., data is digital and printed off on hard copy). All data will be stored in a central geodatabase that can store locational information as well as data sets. See Section 8, Data Management for additional discussion.

- While sample collection chain-of-custody forms will be specific to the sample type being collected, all forms must be filled out completely and legibly.
- Sample labeling will be waterproof and legible to laboratory staff.
- Photographs will be taken at each site at the time each sample is collected or assessment is conducted. There will be at least one photo of the stream looking upstream and one looking downstream.
- Current and recent (past 24 hours) weather will be recorded for each sampling or assessment activity.
- The stream will not be disturbed upstream of sampling/assessment activities.
- Unless otherwise noted, all monitoring activities will be conducted within the same 75 meter stream reach per site.

Unless otherwise noted, assessment protocols will adhere to those established by the Maryland Biological Stream Survey (MBSS).

4.5.1 Water Quality Sampling

Water quality sampling will be performed according to the QAPP that will be developed in association with this program. Water quality parameters proposed in Table 4-1 are those that are collected in association with the MBSS program and represent parameters that will be most effective in helping DDOE to evaluate the health of the District's receiving waters within the MS4.

Table 4-1. Parameters to be Analyzed for Receiving Water Monitoring

pH	Total phosphorus
Acid neutralizing capacity	Chloride
Sulfate	Specific conductance
Nitrite (as nitrogen)	Dissolved organic carbon
Nitrate (as nitrogen)	Hardness
Ammonia	Copper
Total nitrogen	Zinc
Orthophosphate	

4.5.2 Benthic Macroinvertebrate Sampling

Benthic macroinvertebrate samples can only be collected if the site is wadeable, is not too turbid to see the associated habitat, does not feature any nearby impoundments, and is not tidally-influenced. Within the stream reach, sampling will be conducted at a combination of macroinvertebrate-supporting habitats. These habitats may include riffles, root wads, woody debris, leaf pack, and undercut banks.

Benthic macroinvertebrate sampling buckets must be labeled on the exterior and interior (e.g., waterproof paper with site information written with waterproof ink) with date, time, and a site ID. Each sample bucket will include material from a 20 square-foot area per site. Habitats will be sampled in relative proportion to each available habitat at the site. The MBSS collection method is as follows:

1. Begin at the downstream edge of the habitat and place the collection net (e.g., D-net) in the substrate. Hand-rub large sticks and stones within the net's one square-foot area to dislodge organisms. Disturb the substrate down to 5-8 cm below the surface. Repeat rubbing of disturbed sticks and stones. Repeat entire process near the upstream edge of the habitat, and again as necessary within the 20 square-foot area. For log and snag substrates, position the net downstream and rub substrate by hand or with a brush. Use the net in a sweeping or jabbing motion to dislodge organisms from root wads, submerged macrophytes, or other habitats.
2. The sampling is completed when the requisite 20 square-foot area has been sampled, or when the net becomes filled so that water doesn't easily pass through. Wash the net into a partially-submerged sieve bucket, and inspect for organisms then remove and discard large pieces of debris, stones, and leaves. Remove any vertebrates as well. Agitate and rotate the sieve bucket to remove fine sediments. Thoroughly rinse the net in stream water to prepare it for the next sample.
3. Composite samples will be transferred from the sieve bucket to the sample bucket and preserved in 95% ethanol. After applying an internal label and placing a tight-fitting lid on the bucket, gently mix the sample and the preservative.
4. Samples are kept for five years, and then discarded. Subsamples are archived in perpetuity.

In addition to the collection of new data, it will be important to ensure that any past data that has been collected by DDOE, yet not yet analyzed, is done so within the first permit year to ensure DDOE has the most complete data set possible. DDOE will also evaluate other biological data sets that have been collected by other entities (e.g., National Park Service) to determine its value in supplementing DDOE's data and information.

4.5.3 Geomorphological Assessments

A high-level geomorphological assessment will be conducted as part of the rapid-assessment stream walks that will also assess habitat and infrastructure concurrently. Geomorphological assessments will help determine whether a stream is connected to its floodplain, whether channel alteration has occurred, and whether the stream is capable of conveying flow and sediment efficiently and safely.

The geomorphological assessment will use a Rosgen Level I classification system that groups streams by class based on slope, amount of entrenchment, ration of width to depth, and sinuosity (Figure 4-2) (Rosgen 1994). This rapid assessment and classification of stream channels replaces the more labor and time-intensive comprehensive MBSS assessment method, which also requires a long list of equipment. The assessment can also use the same data collection and storage device that is used for the habitat assessment and infrastructure inventory.

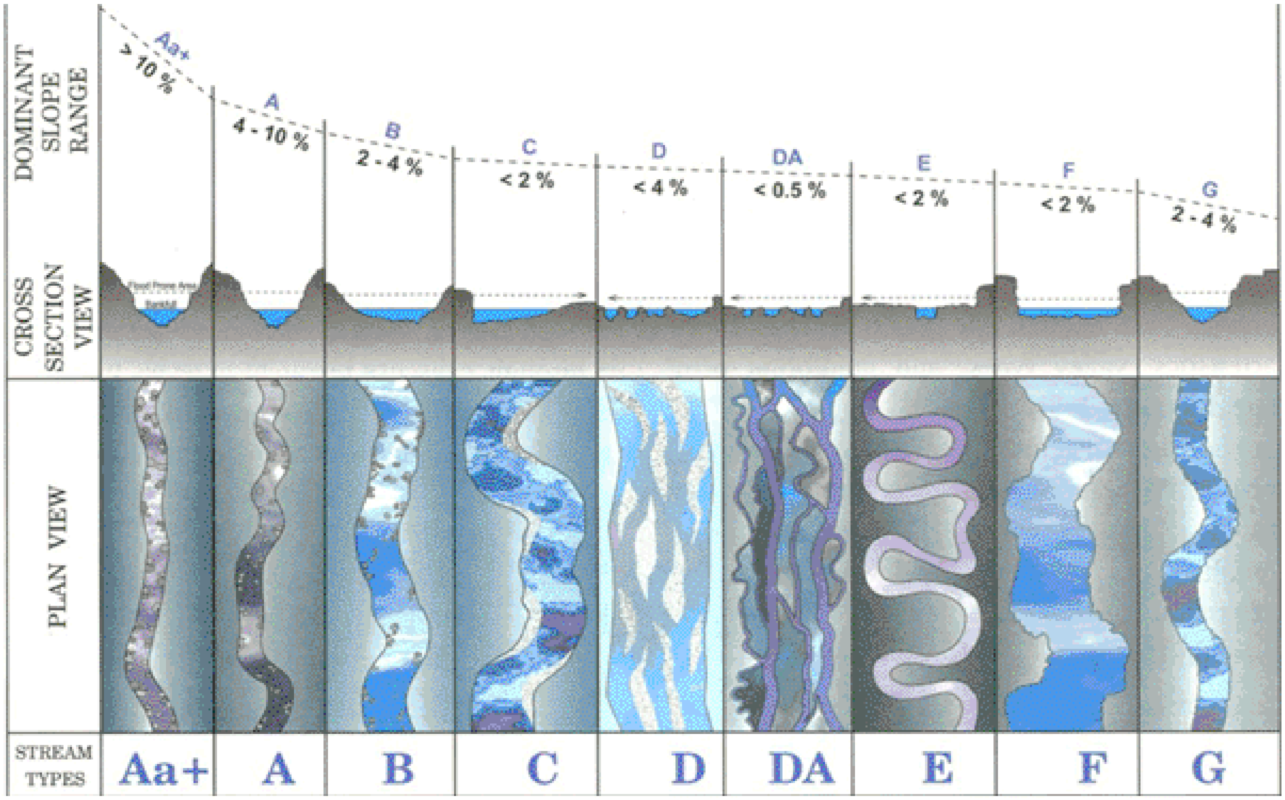


Figure 4-2. Representation of Rosgen Level 1 Classifications of Major Stream Types

4.5.4 Habitat Assessments

The MBSS physical habitat assessment protocol is adapted from a combination of EPA's Rapid Bioassessment Protocol (RBP) and Ohio EPA's Qualitative Habitat Evaluation Index (QHEI). The MBSS protocol recommends that several habitat metrics be collected during the spring index period, while the remaining are collected during the summer index period (Table 4-2). Habitat assessment parameters associated with the spring index period will be evaluated in association with the collection of macroinvertebrates. Parameters associate with both the spring and summer index periods will be collected during the rapid assessment (stream walk) that will be performed during this summer period.

Table 4-2. Habitat Assessment Parameters (MDNR 2014)

Parameter	Description
Trash rating*	Assessed on a 0-20 scale, with 20 representing a trash-free site.
Remoteness*	Distance to the nearest road, estimated to the nearest 10m.
Riparian buffer width*	Average width of the buffer on each side of the stream, to the nearest meter.
Adjacent land cover*	Land cover type adjacent to the stream buffer, from a code-based list.
Riparian vegetation*	Dominant vegetation types, from a code-based list.
Buffer breaks*	If breaks are present anywhere on the 75m reach, “Yes”.
Buffer break type*	Severity of a buffer break, if it exists, recorded as minor or severe.
Channelization*	Evidence of channel straightening or dredging, length is measured along the stream reach.
Land use*	Indication of whether each land use type is present within the stream reach.
Stream gradient*	Measurement/estimate of the stream slope over the 75m reach.
Embeddedness	The ratio of coarse to fine riffle substrate.
Shading	Estimate of percent shading due to overhanging vegetation for the wetted portion of the reach.
Woody debris	Count of in-stream large woody debris at least 10cm in diameter.
Root wads	Count of in-stream live tree root wads at least 16cm in diameter.
Stream character	Evaluation of whether any of 15 stream features are absent, present, or extensive within the reach.
Maximum depth	Maximum depth within the reach, estimated or recorded to the nearest cm.
Wetted width, thalweg depth, thalweg velocity	All three parameters are measured at four transects within the reach; 0, 25, 50, and 75m. Wetted width is measured from bank to bank, thalweg depth is the maximum depth at each transect, and thalweg velocity is the velocity at the deepest part of each transect.
Flow	Depth and meter-based velocity measurements used to determine stream flow; a minimum of ten sets of measurements and a maximum of 25 will be recorded.
Bank Erosion	Quantification of erosion (length and average height) along each bank, including erosion severity.
Bar formation and substrate	Determination of whether bar formation is absent, minor, moderate, or extensive. Dominant particle types that form the bar will also be recorded.
Bank stability	Scoring of bank stability, on a 0-20 scale.

* MBSS recommended for Spring Index Period

4.5.5 Other Environmental Features

The stream walk conducted in association with the rapid stream assessment effort provides the opportunity to collect a wide variety of data and information. In addition to habitat and the rapid geomorphological assessment, a number of other features will also be assessed including items such as:

- Utilities – the type pipe or outfall (e.g., sanitary, stormwater) and the potential impact to the stream based on current condition

- Obstructions - any material, natural or manmade, obstructing the stream channel and perceived the impact
- Erosion points – impacts within or along the stream channel, such as head cuts or bank erosion
- Dumpsites – locations where dumping of trash or disposal of liquid or solid materials are occurring
- Crossings – locations along the stream channel where flow is being impacted due to a structure (e.g., bridge) or modification of the stream channel (e.g., berm) that allows crossing
- Buffer deficiencies – areas along the stream where the stream's vegetative buffer has been removed and has been replaced with other materials, such as lawn, a parking lot, etc.

In addition to gathering these data for analysis associated with the quality of receiving waters, pertinent information associated with these features will also be collected and provided to the appropriate DDOE Division or Branch as needed for follow-up. For instance, the identification of an illicit discharge would result in reporting it to the WQD's Inspection and Enforcement Branch. Similarly, the identification of a leaking sanitary sewer pipe next to a stream would result in reporting it to DC Water. This will help ensure necessary follow-up occurs and issues identified during this stream walk are efficiently addressed.

4.5.6 Fish Sampling

Fish sampling to assess population (abundance and diversity of species) is a resource-intensive task that requires extensive training and strict adherence to safety protocols. Urban stream reaches may also have little or no fish presence due to low flows or blockages in stream reaches. Many of the District's smaller, wadeable streams have few fishes, with relatively low species diversity, and pollution tolerant species, due to low stream flows, blockages to fish passage, and "flashiness" of flows during storm events. Therefore, mobilization for fish sampling has not been deemed a prudent allocation of resources that will be informative to the MS4 program.

Stream walks, discussed below, will include evaluation of fish presence/absence, but no further details. These findings will be used to determine if fish sampling may be appropriate in a certain reach. For the purposes of evaluating the effectiveness of the MS4 program, fish monitoring is not necessary, but considered to be supplemental to the program if the determination is made it should be collected in a particular reach.

If collected, qualitative or quantitative MBSS fish sampling protocols and methods will be used (MDNR 2014), as appropriate per observations made during stream walks, and monitoring will occur in the summer index period (June 1 to September 30).

4.5.7 Data Management and Reporting

All data collected through the Revised Monitoring Program receiving water monitoring efforts will be maintained in a central geodatabase that can store locational information as well as data sets. Metadata for all data sets will be recorded.

DDOE will review monitoring data on an annual basis and report these findings within the MS4 Annual Report. The fourth year of the permit cycle will also involve a comprehensive review of monitoring data within the context of the evaluation of the Quality of the Stormwater Program, as discussed further in Section 7. Additional discussion on Data Management is included in Section 8.

4.5.8 Adaptive Management

Adaptive management within the context of monitoring natural resources acknowledges the uncertainty about how ecological systems function and how they respond to management actions. The results of the monitoring program will support decision-making, reducing uncertainty, and improving the effectiveness of the program through time (Atkinson et. al. 2004).

Adaptive management will influence each tier of this monitoring framework differently. Rapid assessment monitoring will gather data and information on a high level across the District. These data may then be used to influence DDOE's focus on issues that have been identified through this effort (i.e., trash dump sites, severely eroded stream banks, etc.) and then adapt existing management and/or monitoring efforts to address these issues.

Status and trend monitoring efforts will gather data to help DDOE determine if receiving water conditions are changing over time as the result of MS4 program implementation. This information will be used to inform DDOE's future stormwater and TMDL implementation-related activities or the need for additional data and information that may require additional or modified monitoring efforts. While the detection of statistically significant trends may not be feasible within a single permit cycle, patterns seen at receiving water monitoring sites may help inform DDOE of potential areas of focus in subsequent monitoring cycles.

Special studies may be used to investigate the performance of individual BMPs or groups of BMPs at the neighborhood or watershed scale. The data and information gathered through special studies will help inform DDOE of the effectiveness of specific programs/practices or the need to gather more extensive data to determine watershed-scale changes.

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5 Dry Weather Screening & Source Identification

5.1 Introduction

Studies have found that dry-weather flows from MS4s can contribute significant pollution to receiving waterbodies, and thus are an important component of stormwater monitoring programs (e.g., CWP & Pitt 2004; Pitt and McLean 1986; McLean 1987). DDOE's Revised Monitoring Program includes dry weather screening and source identification activities to allow DDOE to more fully understand the sources of pollutants and associated stressors on the MS4 system and its receiving waters. These activities allow DDOE to determine:

- Where and at what frequency dry weather flows exist,
- If they are allowable or illicit (per Section 1.2 of the MS4 permit),
- What their resulting environmental impact is, and
- What actions DDOE may take to address these discharges (e.g., require a permit for a newly discovered discharge, initiate enforcement action, etc.).

A targeted approach to identify where dry weather discharges are occurring and to investigate potential dry weather pollution sources through screening, mapping and inventorying, visual monitoring, outfall inspections, desktop analysis, follow-up monitoring, and tracking and reporting is described in the following sub-sections.

5.1.1 Dry Weather Screening

Section 5.3 of the MS4 permit describes the dry weather screening program which compels DDOE to "detect the presence of illicit connections and improper discharges to the MS4." DDOE's current dry weather screening program includes an evaluation of all known or documented outfalls within the District's MS4 area at least once by the end of the permit cycle to identify potential illicit discharges, connections, and unauthorized non-storm water flows. Targeted or "problem" areas identified through past screening efforts will be visited several times for follow up. Target areas will be prioritized over others for the first year of inspections. The sections below build on these efforts and provide additional strategies to meet MS4 permit requirements. The procedures are also summarized in Figure 5-1.

5.1.2 Mapping and Outfall Inventory

DDOE will update its current inventory of all of the outfalls in the MS4 area in order to confirm its comprehensive understanding of the storm sewer system. This database (to be developed using Microsoft Access and integrated with GIS) will include size, type, location (GPS coordinates), condition (e.g., if it is cracked), receiving water, date of last inspection, and information pertaining to the facilities that discharge to each outfall (including name, address, and description of the facility using an SIC or similar code) for each outfall. DDOE will use this information to develop updated maps of outfalls and sewersheds for use in the field conducting outfall inspections and for subsequent desktop analysis of any discharges.

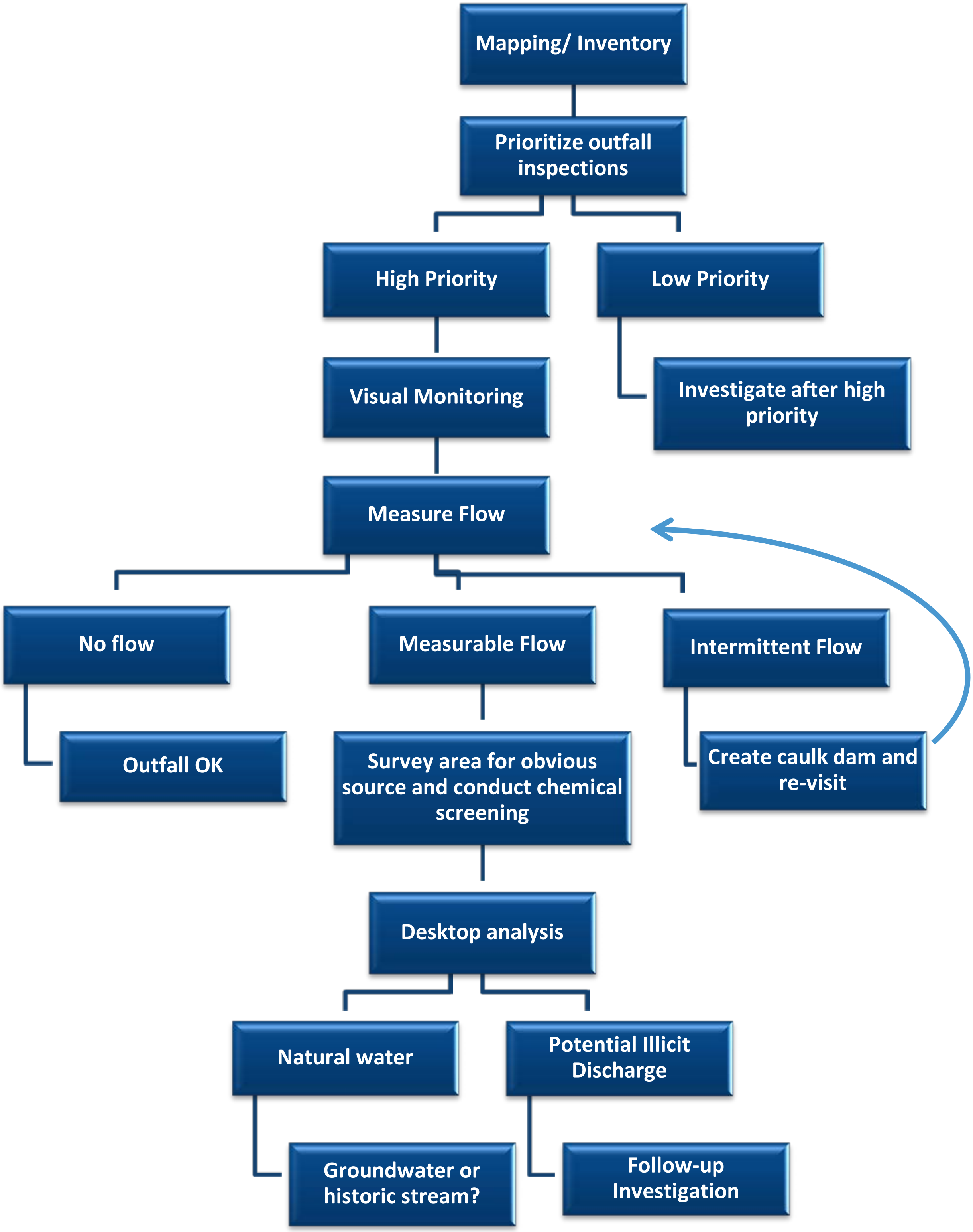

Figure 5-1. Procedures to be used for dry weather screening of outfalls in the MS4 area

5.2 Visual Monitoring

Visual monitoring is the first step in the field portion of dry weather inspections and screening. Field crews will collect and organize information for each outfall using DDOE's Dry Weather Outfall Inspection Form (Appendix 5). This includes basic information such as the outfall ID and location as well as physical characteristics, such as the presence of odor, oily sheen, turbid discharge, and floatables. Photos will be taken, and linked to the outfall database, along with the inspection forms, and any notes regarding change in condition since the last inspection. The ideal conditions for conducting visual monitoring are characterized by:

- Low groundwater, i.e., not when ground is saturated from snowmelt or recent rainfall
- No runoff-producing rainfall within 48-72 hours (CWP and Pitt 2004)

5.3 Flow Monitoring

DDOE must estimate the frequency and volume of dry weather discharges and their environmental impact to comply with MS4 permit section 5.5. Field crews conducting regular dry weather outfall inspections will make note of the presence or absence of dry weather flow, and will also estimate and record dry weather flow at any outfall where it is present and measurable.

There are two simple methods that will be used to estimate volume if measurable flow is observed during dry weather at any outfall:

1. Record the time it takes to fill a container of known volume such as a one liter sample bottle
2. Measure the velocity of flow (using a velocity meter, or any floatable material) and multiply that by the estimated cross sectional area of the flow (CWP and Pitt 2004)

Quantification of a volume such as liters per day or gallons per day can be estimated using either simple method.

After measuring the flow and estimating volume, if the source of flow is not immediately identifiable, field staff will attempt to locate the source of flow by following the storm drain line "upstream" to determine the source of the flow. This may include visually inspecting manholes along the trunk of the storm sewer until the source of the flow input is found, and subsequently investigating near-by areas draining to the storm sewer. Photos will also be taken of any relevant activity in the surrounding area that may provide information to discern the source(s) of discharge.

If there is no measurable flow, but there is evidence of intermittent discharge (e.g., staining, small trickle, algal growth), the outfall will be re-visited within three days to check for measurable flow. To assist with determining if flow exists even when not observed, a simple 1-2 inch high dam made of caulk or plumbers putty will be created in a cross section of the pipe. This temporary structure will hold any intermittent flow that can be documented and sampled during the follow up visit.

A tabulation of dry weather flow across the District will be compiled annually as outfalls have been visited to determine if there are certain areas where there is more frequent dry weather flow, and to note other observations that will help with prioritization of investigations for the next permit cycle.

5.4 In-Field Chemical Screening

The use of *in situ* chemical screening will help to identify and eliminate discharges to the MS4 occurring during dry weather that are not allowed under section 1.2 of the MS4 permit. If the source is not obvious from visual observations recorded during the outfall inventory or from previous visits to the outfall, a sample of any measureable dry weather discharge will be collected to help determine its source. Field staff will use a colorimeter (e.g., Hach DR 900 multiparameter handheld colorimeter) to analyze dry weather flow samples for five parameters: ammonia, surfactants, potassium, fluoride, and chlorine. A flow chart summarizing the parameters to be tested, and the concentrations that will help identify a range of dry weather flow sources, particularly in residential areas, is presented in Figure 5-2. In-field chemical screening is relatively inexpensive and uncomplicated. Results can be determined within the initial field visit.

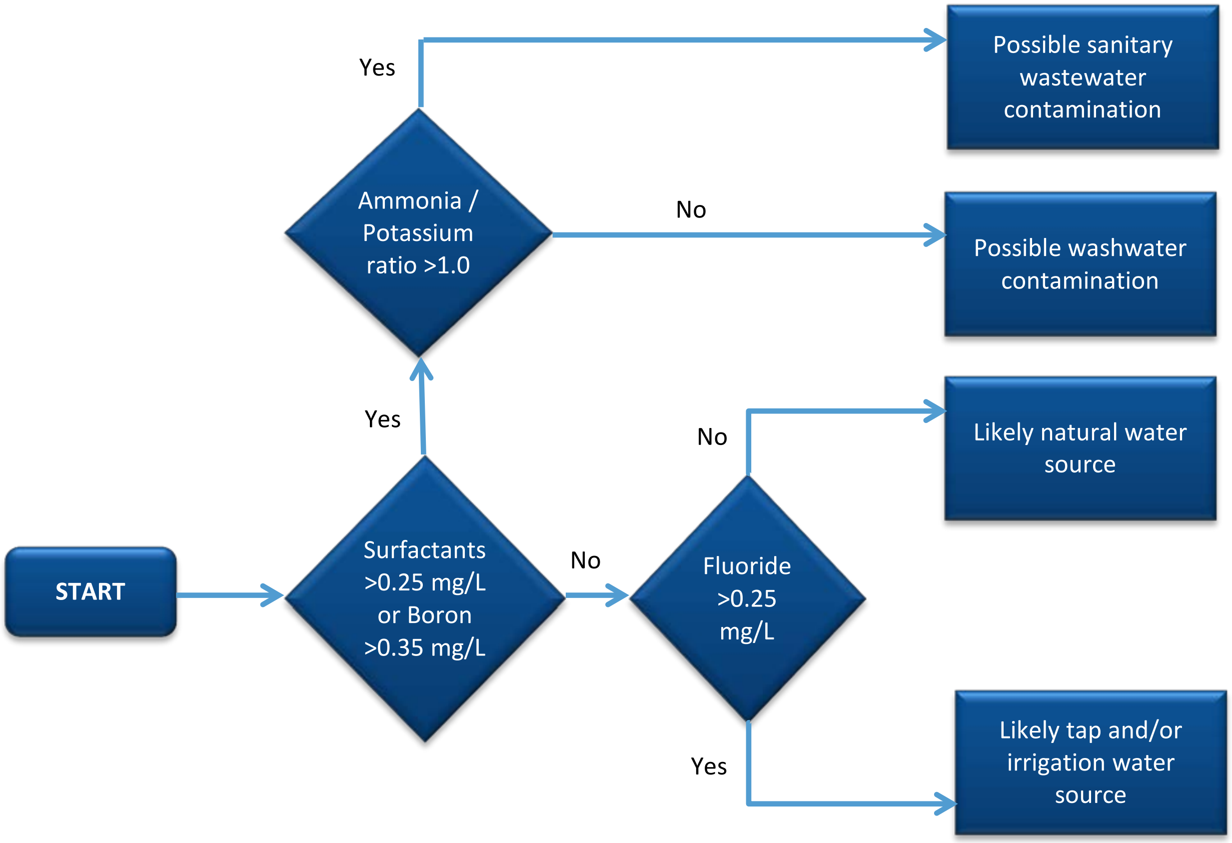

Figure 5-2. Flow Chart to Identify Sources of Dry Weather Flow in Residential Watersheds (CWP and Pitt 2004)

5.5 Desktop Analysis

The source or origin of dry weather flow must be identified if it is observed during the initial field visit. If it is not possible to identify the source of flow in the field using in-field chemical screening or other methods, a desktop analysis will be conducted to gain a general understanding of the area and identify potential sources of the discharges. The outfall inventory, along with other spatial data such as topography, aerial photos, storm and sanitary sewer infrastructure, and historic and current streams, will be used to identify the sewershed where the dry weather discharge occurred. Other outfalls in the same sewershed with dry weather flow will be identified and analyzed in batches in case they have a common source or sources. The database of “critical sources” (discussed in more detail below) will be cross-referenced to track specific facilities that may be the source(s) of the discharge.

5.5.1 Source Inventory

DDOE maintains a source inventory of all industrial, commercial, institutional, municipal, and federal, and any other NPDES-permitted facilities within the MS4 area that has been identified as a potential source of pollution to stormwater (“critical sources”). Facilities listed within the following District Department of Consumer and Regulatory Affairs (DCRA) business license categories are currently designated critical sources:

- Ambulance
- Auto rental
- Auto wash
- Bulk fuel storage
- Charitable exempt
- Consumer goods
- Dry cleaners
- Gasoline dealer
- General contractor/construction manager
- General business license
- Home improvement contractor
- Kerosene
- Motor vehicle dealer
- Moving and storage
- Parking facilities
- Pesticide operator
- Pesticide public operator
- Solid waste collection
- Solvent sales
- Tow truck
- Used car lots

Additional categories to add to this list based on section 4.4.1 of the permit include: Auto service, fueling and salvage, industrial activities, and construction sites. Efforts will be made through desktop analysis and field investigations to identify additional sources not yet included in the Critical Sources Database.

This facility information will be used in conjunction with DDOE’s spatial data, so that details about the facility, including owner/operator, facility size, and watershed, is stored and managed in the Critical Sources Database. This database will continue to be maintained and updated annually. Updates will be based on the collection of field data, information gathered from the DCRA business licensing database, and information received by the District’s Department of General Services. The DCRA business license verification website (http://pivs.dcra.dc.gov//BBLV/Default.aspx) is a real-time database providing the most accurate account of businesses operating in the District.

Facilities located outside of the District’s MS4 area will be removed from the downloaded DCRA database before being added to the Critical Sources Database. This will be accomplished by using basic database queries and GIS cross-referencing with a Master Address Repository to identify facilities located outside of the District and those located within the District’s combined sewer system. Additional validation will be conducted using aerial photography to identify facilities with outdoor operations and potential for contributing stormwater pollutants.

5.5.2 Follow Up Site Visits and Investigation

If the results of the desktop evaluation and/or information from the in-field chemical screening indicate that a dry weather discharge is not allowable, DDOE field staff will open an investigation and conduct a follow up site visit to identify the source. Follow up visits will be grouped by geographic area to conserve resources and to potentially address sources contributing to dry weather discharge in multiple outfalls. This element addresses Section 5.4 of the MS4 permit, which requires DDOE to "… identify, investigate, and address areas and/or sources within its jurisdiction that may be contributing excessive levels of pollutants to the MS4 and receiving waters…"

Several techniques may be used to identify the source of illicit discharge including dye testing, video inspection, interview of facility owners/operators, review of facility documents, visual inspection of stains, inspections of manholes leading to the storm sewer, tracking illegal dumping, and additional water quality sampling.

5.5.3 Tracking and Reporting

The results of the dry weather screening and any relevant investigations or site visits will be summarized in the inventory database and analyzed to identify any spatial or temporal patterns that may assist DDOE staff in prioritizing sewersheds for additional regulatory, educational or structural pollution controls.

DDOE will report on the progress and accomplishments of the dry weather screening program in the MS4 Annual Report. This will include the following:

- Number of outfalls visited
- Any updates to field screening protocols and parameters
- Updates to the MS4 outfall inventory including any identification and/or verification of new MS4 outfalls or removal of outfalls
- Summary on the accomplishments of the program
    - Progress towards eliminating illicit discharges and illegal dumping
    - Enforcement efforts
- New/revisions to programs and policies

6 Trash Monitoring

Trash from dumping and littering has long been an issue in the Potomac River watershed and its tributaries, such as the Anacostia River. The concern for the health of the whole Potomac River watershed sparked the development of the Trash Free Potomac Watershed Initiative in 2005. The District is a partner in the associated Potomac River Watershed Trash Treaty that commits the District to support and implement trash reduction strategies and increase education and awareness of the issues associated with trash throughout the Potomac River watershed.

DDOE identified the Upper Anacostia River and Lower Anacostia River as impaired by trash in the 2006 and 2008 Water Quality Assessment (305(b) and 303(d)) Integrated Reports (District of Columbia Department of Health 2006 and District of Columbia Department of the Environment 2008, as documented in MDE and DDOE 2010). DDOE, in conjunction with the Anacostia Watershed Society (AWS), developed the *Anacostia Watershed Trash Reduction Plan* to conduct research, to develop a comprehensive framework to guide trash reduction efforts, and to serve as the initial implementation plan for addressing litter in the District's portion of the Anacostia watershed (AWS 2008). In 2010, a TMDL for the Anacostia River Watershed in Montgomery and Prince George's Counties in Maryland and the District of Columbia was finalized. While only the Anacostia River is addressed by the trash TMDL, the monitoring efforts used to develop the TMDL guided monitoring in the Rock Creek watershed and the remainder of the Potomac River watershed within the District

DDOE's MS4 permit requires DDOE to make wet weather loading estimates and any other necessary monitoring for the purposes of wasteload allocation tracking for trash.

6.1 Previous Trash Monitoring

DDOE initiated trash monitoring in the District's portion of the Anacostia watershed, along the mainstem and all tributaries of the Anacostia River in 2008. This effort (documented in AWS 2008) involved trash counts on linear transects taken along the river and its tributaries. Monitoring was also conducted in the watershed along streets within the MS4 area using linear transects and windshield surveys. This project served to determine the quantity and composition of trash present in the Anacostia watershed. Subsequent to that study, AWS conducted MS4 outfall monitoring to develop a baseline load for the TMDL (AWS 2010). Following completion of the TMDL, the Anacostia River Watershed Trash TMDL Implementation Strategy was developed (DDOE 2013b).

As part of Implementation Strategy, six of the sewersheds within the Anacostia River watershed were identified as "hotspots". "Hotspots" are defined as sewersheds determined to have greater than average annual trash loads, shown with a load above the red line in Figure 6-1 (DDOE 2013b).

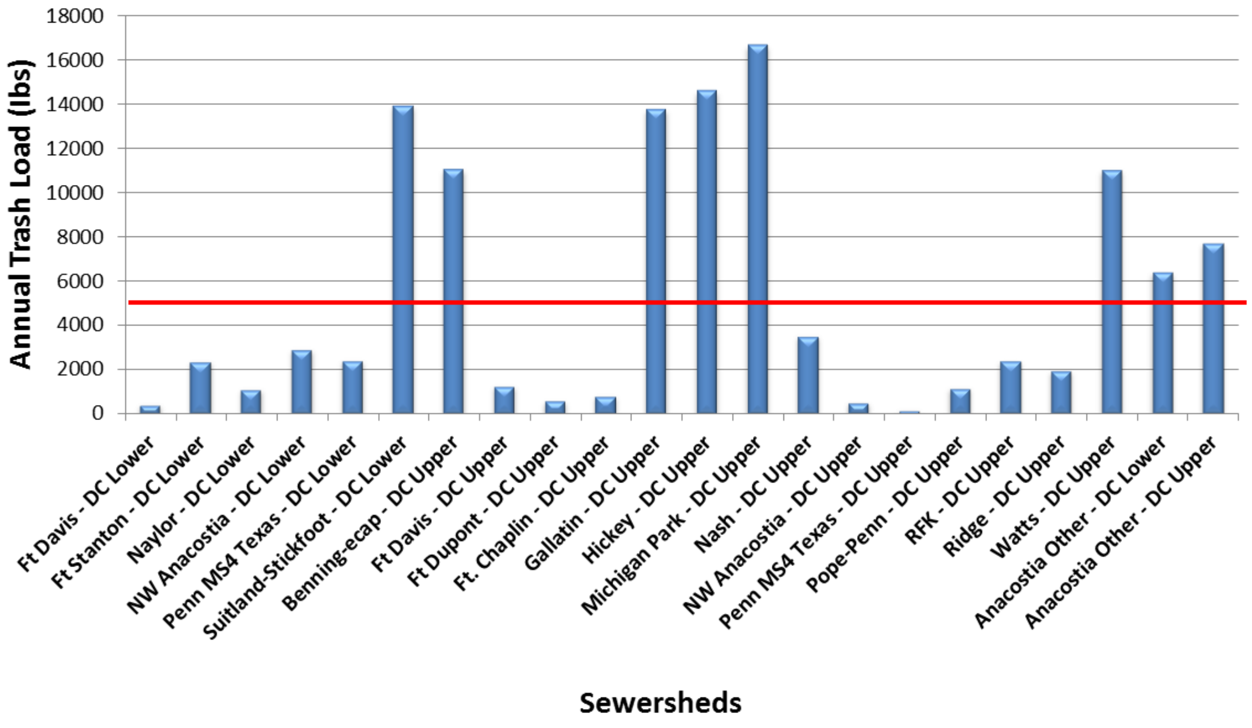

Figure 6-1. Estimated trash load for each sewershed in the District's portion of the Anacostia watershed. Six of the sewersheds have been identified as "hotspots" (DDOE 2013)

As discussed in the 2013 MS4 Annual Report, DDOE awarded a grant to the AWS in 2013 to conduct stormwater monitoring for trash at six outfalls throughout the District. Several of the stormwater monitoring stations identified in the MS4 permit were located at outfalls that were too large to allow for the trash monitoring methods that were utilized to develop the Anacostia River trash TMDL. Working with EPA Region 3, DDOE and AWS were able to identify three stormwater monitoring stations included in the original permit that were conducive to trash monitoring. These stations, along with the land use composition for their respective sewersheds, are:

- Walter Reed-Fort Stevens Drive (16th Street and Fort Stevens Road, N.W.) in the Rock Creek Watershed with a low, medium, and high density residential land use type;
- Battery Kemble Creek (49th and Hawthorne Streets, N.W.) in the Potomac Watershed with a low density residential land use type;
- Oxon Run (Mississippi Avenue and 15th Street, S.E.) in the Potomac Watershed with a medium density residential, institutional, commercial and open space land use type.

(DDOE 2013a)

An additional three locations located solely within the Anacostia River watershed were selected in collaboration with EPA Region 3 and AWS. These three locations were previously monitored during the development of the Anacostia Trash TMDL. These stations will provide data on other types of land use not addressed in the three stations above required by the MS4 permit. These stations are:

- McDonald’s outfall (Minnesota Avenue NE and Nannie Helen Burroughs Ave NE) in the Anacostia Watershed with an industrial, commercial, and residential land use type;
- Benning Road (Benning Road NE and Anacostia Avenue NE) in the Anacostia Watershed with a commercial and industrial land use type;
- New York Avenue (New York Avenue NE and South Dakota Avenue NE) in the Anacostia Watershed with a transportation right-of-way land use type.

(DDOE 2013a)

6.2 Study Design

DDOE will continue to monitor MS4 outfalls to quantify the amount of trash being discharged from outfalls in each of the major watersheds within the District. While the Quality Assurance Project Plan and Monitoring Plan (AWS 2013) was developed to provide detail associated with this trash monitoring effort, each of the elements of the monitoring program is summarized here.

Six sites will continue to be monitored through the beginning of 2015. However, DDOE evaluated the need for modification of monitoring at the Oxon Run and Benning Road and identified a number of limitations at both. For instance, the drainage area for the Oxon Run outfall is relatively large and high flows damaged several of the trash traps built and installed at the site. DDOE found that the trash traps shouldn’t be deployed when storms with greater than 1.5” of rainfall are expected. This limitation narrows the window of available storms that can be sampled at this site. Similarly, the Benning Road site lies right along the river. Once traps are installed there they are prone to damage by large floating debris and ice during the winter. DDOE lost several traps at this site and learned that it must be careful as to when it can deploy traps at this site. While DDOE will continue to collect data at these sites, it will discuss the proposal of alternative sites with EPA if deemed necessary.

DDOE will continue to place emphasis on monitoring within the Anacostia Watershed because of the Anacostia River Trash TMDL. However, sites will continue to be monitored within the Potomac River and Rock Creek watersheds as well to help DDOE evaluate trash loading rates within these portions of the District.

Data collected during the original Anacostia River TMDL study were collected solely in the Coastal Plain Physiographic Province of the District. Monitoring revealed that it takes at least 0.25 inches of rain to move trash through the MS4 in this area. However, the District is also interested in the physical dynamics of trash in the Piedmont Physiographic Province. In collaboration with EPA, the District decided to lower the qualifying storm threshold for monitoring stations located in the Piedmont area. Consequently, rainfall thresholds for sites events within the Piedmont (i.e. Walter Reed and Battery Kemble) must exceed 0.1 inches of rainfall to trigger a data collection event. Rainfall thresholds at outfalls within the Coastal Plain (i.e. all other stations) must exceed 0.25 inches of rainfall to trigger an event.

Precipitation data will be obtained from the Reagan National Airport rain gauge via the National Weather Service. Localized storm information may be obtained from other local rain gauges closer to each station via commercial weather services such as Weather Underground.

All sampling events will be separated from the last rainfall event by at least 72 hours. Data on trash from a minimum of three and a maximum of six storms per station will be obtained, with a separation of 30 days between samples (AWS 2013).

6.3 Sample Collection and Analysis

Before a storm event, trash traps (either sock or box type) are installed at one or more of the six outfalls chosen for monitoring to capture all trash larger than one inch (AWS 2013).

For each event, trash will be manually removed from each trap and placed in trash receptacles and labeled. The trash receptacles will then be taken off-site and allowed to drain excess water for up to 72 hours of collection to avoid decomposition of the organic components prior to the processing of samples (AWS 2013). Manmade trash will be separated by hand from natural material (e.g., vegetative material).

A drained weight will be recorded for trash and natural material and a total weight for each sample site will be calculated (AWS 2013). For specific types of trash, data on count, not weight, will be collected. The trash will be inventoried according to the categories used for the 2008 Anacostia Trash Reduction Plan study categories including, but not limited to:

- Food wrappers
- Cups and straws
- Tobacco products
- Takeout containers
- Paper
- Bottles and cans
- Plastic bags
- Styrofoam products
- Other

(MDE & DDOE 2010; AWS 2013).

Data collected for loading estimates and comparison to DDOE’s Trash WLA will be based on total weight of trash only.

After data collection and analysis is complete, the trash will be disposed of at an appropriate trash disposal facility. Most of the trash collected is too dirty for recycling to be a reasonable option. No laboratory analysis is involved (AWS 2013).

Both Special Use Permits and Scientific and Data Collection Permits must be obtained from the National Park Service for stations located on National Park Service property. The Special Use Permits must be renewed every five years, and the Scientific and Data Collection Permits must be renewed every two years (DDOE 2013a).

6.4 Quality Control

The sampling methodology consists of one person observing the type and quantity of trash items and a second person recording the observation. Quality control checks will be performed by reversing the roles of the personnel and comparing the data sheets. Accuracy of the total should be within five percent and accuracy of any individual item should be within 10 percent (AWS 2013).

The data will be reviewed and inspected for any unexpected trends or findings. The quality assurance manager will recommend changes in procedures that are needed to ensure that the data meet the desired end use (AWS 2013).

6.5 Reporting

The Quality Assurance Project Plan and Monitoring Plan (AWS 2013) for trash monitoring includes a detailed description of the documentation required and associated with trash collection, the records that are retained, and the reporting that is performed in association with this monitoring effort.

Data are initially recorded on paper data sheets and then transferred into an electronic database. Tables of rainfall data for the rainfall event and two days preceding the rainfall event for all sampling events are also recorded and kept on record for reporting purposes. Narrative reports will also be included in reporting (AWS 2013). Data from the trash monitoring and a brief narrative will be prepared for inclusion in the MS4 Annual Report and Discharge Monitoring Reports (DMRs) (AWS 2013).

6.6 Adaptive Management

As trash monitoring data are collected and evaluated, DDOE may decide that modifications might allow for better characterization of the accumulation and capture of trash. In addition, other monitoring elements that are not required by permit may be included within the monitoring program. This might include the use of alternative technologies such as trawls in the mainstem Anacostia, and the installation of additional, more permanent trash traps in the Anacostia River and its tributaries. Other data collection methods may also be incorporated into the monitoring framework. For example, the use of stream channel and river shoreline transects at which to collect data, and the evaluation of new methodologies such as those being used by the NOAA to monitor marine debris (as discussed further in NOAA 2013) might be considered. Other approaches such as the reliance on volunteer monitoring by submitting information via phone apps may also be incorporated into the existing program.

As this trash monitoring program continues to evolve, these and other approaches will be evaluated for feasibility, appropriateness, and cost effectiveness. Communication with EPA Region 3 will continue as needed to discuss potential changes to the monitoring program as these issues and options are evaluated.

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7 Quality of the Stormwater Program

Section 5.1.2 of DDOE’s MS4 Permit requires DDOE to use the information collected through the Revised Monitoring Program to “evaluate the quality of the stormwater program.”

It is important to note that the permit does not define the term “quality” nor does it define how it should be measured. Lacking this clarity, DDOE developed a definition and subsequent approach that clearly measures “quality”. In order to help define this term and evaluate how other stormwater programs have addressed it, numerous permits and stormwater programs were evaluated nationwide. While no other MS4 permits were found to have this identical language, some Phase II MS4s in California have similar permit requirements, but are termed “stormwater program effectiveness assessments”. A significant amount of work has been undertaken in California in the past several years to develop a process to help MS4s to implement this “effectiveness assessment.” Similarly, the use of environmental indicators to assess stormwater program effectiveness has also received significant attention. The development of DDOE’s approach to evaluating the “quality” of its stormwater program utilizes these concepts and resources.

Stormwater Program Effectiveness Assessment

> *Effectiveness assessment is a fundamental and necessary component of developing and implementing successful programs. It begins with the establishment of goals, objectives, and desired outcomes during program planning, and continues throughout subsequent implementation and review stages. A well-executed assessment element can provide managers the feedback necessary to determine whether their programs are achieving intended outcomes (complying with permit requirements, increasing public awareness, changing behaviors, etc.), and ultimately whether continued implementation will result in water quality and/or habitat improvement.*
>
> (CASQA 2005)

“Quality” is defined here as compliance with the MS4 permit and effectiveness of the SWMP. These two metrics are measured by progress made towards meeting established benchmarks and milestones. Because compliance with the MS4 permit will be used as the metric to define “quality” it is necessary to define what is included in “compliance with the permit.” Sections 1.4.1 through 1.4.3 of DDOE’s MS4 permit require development and implementation of BMPs to reduce pollutants in the MS4 discharges to the maximum extent practicable and ultimately achieve the WLAs applicable to the discharges. Section 1.4 also includes the acknowledgment that compliance with Sections 2 through 8 of the permit will be considered to be adequate progress toward achieving the WLAs.

The requirement to evaluate the quality of the stormwater program is included within the monitoring section of the MS4 permit. “Monitoring” is a very broad term and includes MS4 discharge sampling, visual monitoring, such as BMP inspections; and monitoring of progress toward other MS4 programmatic requirements like education and outreach. As a result, these “monitoring” efforts produce a wide range of data and information that must be incorporated into an approach to effectively evaluate stormwater program quality.

"Monitoring" is defined as more than just discharge sampling because it is common to face challenges when using stormwater discharge data as the only metric to assess MS4 program quality or effectiveness. For example, Santa Clara Valley Urban Runoff Pollution Prevention Program's [SCVURPPP] *Stormwater Environmental Indicators Demonstration Project – Final Report* (2001) states that "variability in stormwater pollutant concentrations, magnified by variability in runoff volume, tends to confound efforts to detect trends in pollutant loads." In addition, Cloak (2002a), who was evaluating Santa Clara's program, indicates that variability in pollutant concentrations and flows can limit the practicality of using pollutant load reductions to evaluate program quality or effectiveness.

Benchmarks

A "quantifiable goal or target to be used to assess progress toward 'milestones' and WLAs, such as a numeric goal for BMP implementation. Benchmarks are intended as an adaptive management aid and generally are not considered enforceable."

Milestones

"An interim step toward attainment of a WLA that upon incorporation into the permit will become an enforceable limit or requirement to be achieved by a stated date. A milestone should be expressed in numeric terms (i.e., as a volume reduction, pollutant load, specified implementation action or set of actions) when possible and appropriate."

District of Columbia MS4 Permit, Section 9

EPA also recognizes this variability. It states that the variability in frequency and duration of storm events "make it difficult to determine with precision or certainty actual and projected loadings" from municipal stormwater discharges (EPA 2002). Therefore, EPA believes that, in such situations, permit limits can be expressed as BMPs. Subsequently, measuring progress toward meeting these permit limits will rely heavily on monitoring progress of BMP implementation.

Urban runoff pollutant loads are not the only (or necessarily the most significant) factor affecting receiving waters (SCVURPPP 2001). Pollutant sources not controlled by BMPs or not under the authority of the permittee (e.g., atmospheric deposition or natural presence of trace metals in soils) may contribute substantially to the total load of many stormwater pollutants, thereby masking any reduction in controllable sources (SCVURPPP 2001). Even for those sources controlled by BMPs, BMP effectiveness varies widely with location, time, rainfall intensity, and other factors.

SCVURPPP (2001) identified a number of factors that may influence or confound perceived "effectiveness." DDOE will also take these factors into account, where appropriate, including:

- The complex nature of watersheds and the response of streams and other water bodies to land use within the watershed;
- The natural and human history of watersheds, including the legacy of industrial activities;

- The multifaceted effects of urbanization, including the changes to hydrology, flooding, drainage-ways, and water quality, as well as the damming and diversion of stream flow, that typically accompany urban development;
- An understanding of sources, fate, transport, and effects of pollutants throughout the watershed;
- The relationship between BMP implementation and watershed effects, including reductions in pollutant loads; and
- The problems of natural and random variability, as well as uncertainty in measurement, associated with environmental sampling.

(SCVURPPP 2001)

Keeping these factors in mind, the Revised Monitoring Program is designed to facilitate collection of timely and relevant data and information that both meets permit requirements, and serves as the basis for "evaluating the quality of the stormwater program." Evaluating stormwater program quality or effectiveness requires a commitment to continuous improvement of the program (Cloak 2002b). As Cloak states:

> *"Without an established process of continuous improvement, the results of indicators would carry "regulatory baggage;" that is, would suggest that an MS4 was falling short of an elusive "maximum extent practicable" standard. The continuous improvement process recognizes that "maximum extent practicable" is a moving target and that the MS4 must expect continuous change within their pollution prevention programs. Further, the continuous improvement policy insures that budget and personnel are assigned to implement recommended improvements timely"* (Cloak 2002b).

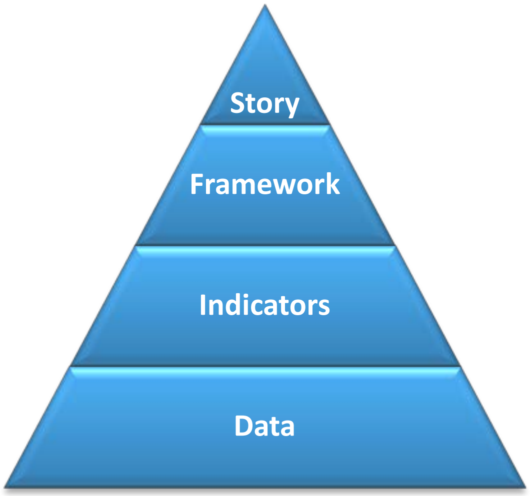

Figure 7-1. DDOE approach to evaluating the quality of the MS4 program (adapted from SCVURPPP 2001)

DDOE's approach to assessing the quality of its stormwater program is summarized in Figure 7-1. This approach includes the collection of data and information ranging from water quality sampling data (e.g., analytical water quality data) to programmatic data on progress DDOE has made to meet water quality goals and MS4 permit requirements. Programmatic, social, physical, hydrological, and environmental indicators will be used to organize these data. The indicators will then be evaluated within the context of a framework to allow DDOE to tell a "story" regarding the quality of its stormwater program. The components identified in Figure 7-1 are discussed in further detail below.

7.1 Data

A significant amount of data and information has been and will continue to be produced in association with the various elements of DDOE's MS4 program. This includes a wide range of information such as: water quality data (e.g., from both wet weather discharge and receiving waters); physical and hydrological data (e.g., flow and habitat data); biological data (e.g., macroinvertebrates, fish); and programmatic data (e.g., number of BMPs inspected, results of public surveys, and illicit discharge tracking data). These data are the building blocks of the evaluation of the quality of the stormwater program.

7.2 Indicators

While it can be important to collect a large amount of data on a given waterbody, the amount of data can be overwhelming, especially when trying to evaluate the "big picture" of a waterbody's health. This can be especially difficult when data are highly variable, or provide contradictory information about whether a waterbody is in good health or not. The Center for Watershed Protection (CWP) (1995) recognized this issue and suggested evaluating select parameters as "indicators" that help to tell the story of the whole system when it is not practical or feasible to evaluate all parameters.

Environmental indicators are direct or indirect measures that are used to show trends or responses in discharges, receiving waters, outcomes, etc. The CWP (1995) defined stormwater environmental indicators as "a measurable practice which singly or in combination with other features, provides managerially and scientifically useful evidence of the effects of stormwater runoff on ecosystem quality or trends in ecosystem quality." Indicators can be used as an essential "building block" in achieving an understanding that can lead to informed, coordinated action (Cloak 2002a).

CWP (2000) identifies a number of indicators that can be used to assess stormwater programs (Table 7-1). The CWP recommends using programmatic and social indicators in addition to measures of water quality and biological health to gauge the effectiveness (i.e., "quality") of urban stormwater programs.

A number of communities use these indicators within MS4 programs. SCVURPPP also analyzed the usefulness of these indicators within the context of the assessment of its stormwater management program. Table 7-2 provides a summary of several select CWP indicators in relation to their perceived usefulness and the framework in which they should be applied. The indicators discussed in Table 7-2 are those that SCVURPPP identified as being "very useful", "useful", or "somewhat useful."

DDOE will evaluate and adjust selected indicators as needed.

Table 7-1. Stormwater Indicators (CWP 2000)

Category	Indicator Name
Water Quality Indicators *	Water quality pollutant constituent monitoring
	Toxicity testing
	Pollutant loadings
	Exceedance frequencies of water quality standards
	Sediment contamination
	Human health criteria
Physical and Hydrological Indicators *	Stream widening/down-cutting
	Physical habitat monitoring
	Impacted dry weather flows
	Increased flooding frequency
	Stream temperature monitoring
Biological Indicators *	Fish assemblage analysis
	Macroinvertebrate assemblage
	Single species indicator
	Composite indicator (e.g., IBI)
	Other biological indicators (e.g., mussels)
Social Indicators	Public attitude surveys
	Industrial/commercial pollution prevention
	Public involvement and monitoring
	User perception
Programmatic Indicators	Number of illicit connections identified/corrected
	Number of BMPs installed, inspected, maintained
	Permitting and compliance
	Growth and development
Site Indicators	BMP performance monitoring
	Industrial site compliance monitoring

*Sometimes these are grouped as "watershed indicators."

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Table 7-2. Indicator Usefulness (adapted from SCVURPPP 2001)

Indicator Category	Sub-category	Indicators*	Usefulness for Assessment	Key conditions and requirements for enhancing usefulness	Additional or Alternative Indicators
Programmatic/ Site Indicators		Number of Illicit Connections Identified/ Corrected	Very useful	Establish programmatic indicators to complement Performance Standards and use as part of continuous improvement process	Consider appropriate programmatic indicators for public agency activities, new development, or other program elements. Consider programmatic indicators for participation in watershed management process.
		Number of BMPs Installed, Inspected, and Maintained	Somewhat useful		
		Permitting and Compliance	Useful		
		Industrial Site Compliance	Useful		
Watershed Indicators	Physical and Hydrological	Growth and Development (Imperviousness)**	May be possible to use physical condition of streams and extent of drainage modification as an indicator of success in Watershed Management	Requires long-term data sets and consistent protocols. Most effective when used to measure specific temporal effects of land use change or watershed management actions	Flow diversions, amount or proportion of altered vs. natural channel, inventory of storm drain outfalls and design flows, extent of floodplain, extent of riparian area
		Physical Habitat			
	Water Quality	Sediment Characteristics and Contamination (Sediment contamination)	May be applied at site or catchment scale to supplement programmatic measures of BMP implementation	Sediment a more robust indicator than storm flows. Best used to monitor response to clean up of specific sites or catchments.	Continuous monitoring of dissolved oxygen during summer months. Consider other indicators of urban influence on stream sediments (e.g., visual observations or oil/grease)
	Biological	Fish assemblage	Use to correlate and confirm effects of physical and hydrological changes and changes in water quality	Long-term consistent monitoring at selected sites. Select indices based on goals and practicability	Fish and macros the best biological indices because methods are established and links to stream function and beneficial uses are widely understood.
		Macroinvertebrate assemblage			
Social Indicators		Industrial/ Commercial Pollution Prevention	Can test effectiveness of specific outreach messages	Use to measure success of specific outreach campaigns	Similar approach could be applied to other groups (e.g., mobile cleaners, landscapers, restraint managers)
		Public Attitude surveys		Measure behaviors instead of attitude. Focus on everyday activities that can affect water quality	

*Indicated as “very useful”, “useful”, or “somewhat useful” by SCVURPPP (2001)

**SCVURPPP categorized this indicator as a watershed indicator rather than a programmatic indicator as the CWP did originally.

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7.3 Framework

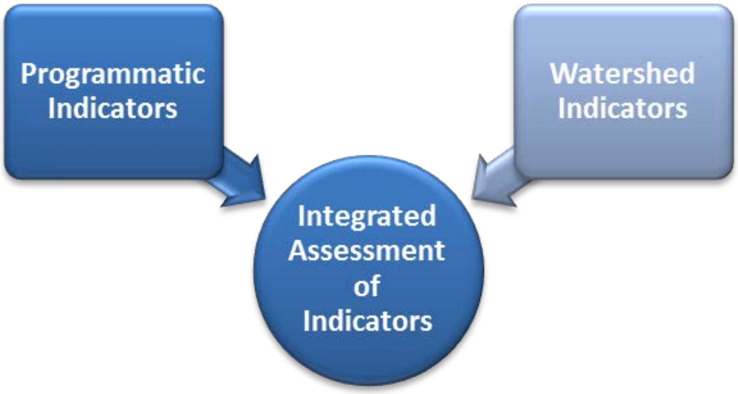

Figure 7-2. Integrated assessment framework to evaluate stormwater indicators (adapted from CASQA 2005)

Indicators will be most effective when they are assessed within an organizing framework to create a compelling, well-communicated story (Cloak 2002a). As analytical sampling data alone are not sufficient to evaluate MS4 program “quality,” the use of any one particular stormwater management indicator, program, or metric would also not be sufficient. However, integrating the pieces together to develop multiple lines of evidence can ultimately “tell the story” of how effectively the MS4 program is meeting its stormwater quality goals, benchmarks, and milestones. As recommended in the SCVURPP study (2001), DDOE’s framework will use two categories of indicators: programmatic and watershed indicators for its integrated assessment framework (Figure 7-2).

7.3.1 Assessment Methods

Both programmatic and watershed based indicators will need to be assessed to evaluate the quality of the stormwater program and the achievement of water quality-related goals (e.g., progress toward achieving WLAs) and programmatic requirements. In order to accomplish this, DDOE will establish benchmarks and milestones to serve as goals or targets by which progress can be measured.

There are a variety of ways in which progress toward meeting benchmarks and milestones can be assessed. In 2005, the California Stormwater Quality Association (CASQA) began developing an approach to assess municipal stormwater program effectiveness. As presented by CASQA (2005), “assessment methods are the specific activities, actions, or processes used to obtain and evaluate assessment data or information.” Depending on the type of indicator in question, “numerous assessment methods may be possible. Reasons for selecting a particular method include cost, ease of use, need for statistical rigor, applicability, and clarity in communicating progress to the general public” (CASQA 2005). CASQA has developed several broad categories of assessment methods that are summarized in Table 7-3.

Table 7-3. Methods available to evaluate permit efforts (EPA 2007; CASQA 2005)

Method	Definition	Example
Confirmation	Documenting whether a task has been completed.	Development of an construction operator BMP outreach brochure
Tabulation	Tracking an absolute number or value of something	Number of brochures distributed to construction operators
Surveying	Determining knowledge, awareness, etc. of a group of people	Phone survey of 100 construction operators, 50 of whom had received the BMP brochure, to gauge any differences in stormwater awareness
Quantification	Estimating pollutant loading	Modeling to determine sediment load reductions prior to initiating construction operator outreach program – assumption made about BMP use before and after program
Inspections or site visits	Observing activities or BMPs	Inspections of construction projects before and after initiating construction operator outreach program
Reporting	Utilizing reports generated by third parties	Audit of construction component of the SWMP indicated that BMPs observed and the level of understanding demonstrated by operators had improved during the last year
Monitoring	Sampling or observation in the field to determine environmental or water quality conditions	Water quality monitoring above and below three comparable active construction sites (Site 1 – trained on construction BMPs, Site 2 – no training, Site 3 – random control, unknown level of BMP understanding) to determine any differences in per/acre disturbed loading of sediment

These methods can be used to assess the "outputs" as well as the "outcomes" of an MS4 program. As discussed by Cloak (2002b), an output is the "level of investment or effort and is the most direct way to insure program accountability. An outcome measures the results of the program component, and can be affected by factors internal to the MS4 program (e.g., degree of expertise or organization) as well as external factors (e.g., economic conditions, seasons, other programs that may complement or compete with stormwater programs.)"

Table 7-4 provides several examples of the assessment methods and measures that can be used for each indicator type. While this approach provides a measureable way in which to evaluate the various elements associated with the MS4 program, also included is a significant amount of flexibility.

Measurement Example

> *The industrial inspection component of a stormwater program could be monitored for the number of inspections completed in a year (output), or the percentage of facilities in compliance (outcome), or both.*
>
> *An educational program could be monitored by expenditure on media buys (output), or by surveys that measure awareness (outcome), or both.*
>
> *Changes in outputs tell us the most about how the program is performing, and should be tied most closely to permit compliance. Changes in outcomes, on the other hand, may indicate changes in program performance – or may indicate changes in external conditions.*
>
> (Cloak 2002b)

Table 7-4. Examples of Assessment Methods and Measures by Outcome Level (Adapted from CASQA 2005)

Indicator type	Assessment method type	Assessment Measure	Examples
Programmatic Indicators	Confirmation	Task completion (yes/no)	Completed update of source inventory
	Tabulation	Implementation (# or %) Change	Number of inspections completed Increase since 2001
	Inspection	Implementation (# or %) Change	Installation of berms around trash areas Increase since beginning of program
	Reporting (discharger)	Implementation (# or %) Change	Installation of storm drain inserts % increase
	Reporting (3rd Party)	Implementation / non-compliance (# or %) Change	Number of complaints reported Decrease since beginning of program
	Survey	Implementation (# or %) Change	Number of people up pet waste Increase over last year
Social Indicators	Survey	Knowledge	Knowledge of storm drain vs. sanitary sewer
	Tabulation	Change Action Change	Increase in awareness since last survey Number of hotline calls/ website hits Increase over last year
Water Quality Indicators – pollutant loadings	Quantification	Loading Change	Copper release from brake pads Decrease since 1996
	Monitoring (sampling)	Loading Change	Diazinon loading from lawns Decrease since 2002
Water Quality Indicators – wet weather outfall discharge	Monitoring (sampling)	Benchmark	Comparison of Cu to Water Quality Objective
		Loading Change	Phosphorous loading to MS4 Increase since 1993
		Concentration Change	TSS levels in runoff Increase since 1995
Water Quality Indicators – receiving waters	Monitoring (sampling)	Benchmark Concentration	Comparison of Zn to WQS Nitrate concentration in Rock Creek
	Monitoring (observation)	Biological condition Physical habitat	Stream biodiversity Scouring of stream bank
		Biological condition Physical habitat	Loss of riparian canopy Erosion of stream bank

7.4 The "Story"

A large amount of data will be collected in association with the Revised Monitoring Program, but these data alone cannot tell the "story" of the effectiveness or quality of a stormwater program. As described by Burton and Pitt (2010), in regard to stream impairments, multiple lines of evidence are "essential in order to reach reliable conclusions of whether a problem exists". Evaluating data from a particular element of the stormwater program in isolation without considering the whole program collectively can provide a distorted picture. For instance, in-stream water quality data may indicate the receiving stream is of high quality. Upon further evaluation, however, the in-stream biological communities within the stream reach may be poor. Further evaluation may determine other factors are influencing the aquatic habitat, such as high flows through the reach during rainfall events or localized habitat impacts. Without collectively evaluating multiple lines of evidence, one may not get a clear picture of a waterbody's sources and stressors or be able to effectively determine how to mitigate impacts.

Similarly, there are many factors that impact waterbodies within the District. Some of these factors are not within the control of DDOE, such as up-stream flows from Maryland or Virginia, or pollutant contributions from federal facilities. In some situations, factors may come into play that may have unforeseen short-term impacts on the quality of the stormwater program. For instance, DDOE may implement structural BMPs as required in the MS4 permit. Water quality sampling may show little improvement in the short term. Issues such as "lag times"[3] may impact how quickly structural BMPs may result in improvement in a water body.

As such, multiple lines of evidence will be evaluated in a comprehensive manner to tell the "story" of the quality of the stormwater program. These include the various elements of the Revised Monitoring Program (e.g., wet weather outfall monitoring, dry weather discharge monitoring, receiving water monitoring, geomorphological monitoring, biological monitoring) as well as programmatic elements associated with the MS4 program (e.g., number of trees planted, BMPs inspected, etc.).

7.5 Reporting on the Quality of the Stormwater Program

DDOE has a number of existing reporting requirements under the MS4 permit, including DMRs and the MS4 Permit Annual Report, which will be used to report on the evaluation of the "quality of the stormwater program." Reporting on the quality of the stormwater program will be "more than an exercise in collecting and tabulating data; evaluation data must be analyzed, interpreted, and reported so that results can be applied to such purposes as documenting effectiveness of BMPs, reporting information to the public, and planning future management activities (EPA 2008)."

Table 7-5 includes an example of how this information can be included within the Annual Report. Table 7-6 conveys how the indicators referenced in Table 7-5 are defined with examples demonstrating how these can be used. Building upon information that is already currently conveyed within the Annual Report, Table 7-5 includes each element required of the MS4 permit in the first column. Subsequent

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[3] Defined as the time elapsed between installation of a BMP and the first measurable improvement in water quality in the target water body (Meals et al 2009).

information can also be included including items such as current baseline conditions, benchmarks and milestones, and any needed modifications to the associated program requirement.

Section 2 of 5.1.2 of the MS4 permit requires DDOE to:

- "…identify and prioritize additional efforts needed to address water quality exceedances, and receiving stream impairments and threats" and to
- "…identify water quality improvements or degradation."

These requirements will be discussed in DDOE's fourth year Annual Report. As discussed by EPA in its fact sheet on *Evaluating the Effectiveness of Municipal Stormwater Programs* (2008), fourth-year annual reports "are a good opportunity to use data gathered under the entire permit period to guide future management direction." Conveying this information in the fourth year report will also provide DDOE the opportunity better gauge water quality changes or needed program modifications as the result of true trends rather than year-to-year variability.

7.6 Integration with the Consolidated TMDL IP

The methodology described in this section can be used to help track progress towards achieving TMDL-related benchmarks and milestones as described in the Consolidated TMDL IP (DDOE 2015). As described in the IP, the primary type of data used to track the achievement of WLAs is the BMPs implemented to capture and treat stormwater runoff before it enters the MS4 system, and the area controlled by BMPs. The specific BMP monitoring data collected includes:

- Type of BMP
- Location of BMP
- Implementation date
- Area controlled by the BMP
- Design stormwater volume retained by the BMP

BMPs fall under the programmatic indicators category as described in section 7.2. The IP Modeling Tool is the assessment part of the framework used to calculate load reduction for each BMP implemented and, when lumped with other BMPs in the same watershed, it is possible to evaluate the progress towards meeting WLAs. This information will be used, along with monitoring data to tell the "story" of how stormwater pollution is increasing or decreasing in a watershed, and when WLAs are achieved.

The monitoring programs described in this report will in turn help to inform the IP. MS4 outfall monitoring data will be used to supplement BMP monitoring information and can confirm that individual WLAs have been achieved. The other monitoring data (e.g., dry weather screening, receiving water) will provide context for watershed health and will help to inform management strategies regarding MS4 discharges and loads.

More information on how data from the Revised Monitoring Program is used in the Consolidated TMDL IP can be found in Chapter 7 ("Tracking Progress in Meeting MS4 WLAs") of that document.

Table 7-5. Example of Reporting of Information Associated with Evaluation of the Quality of the Stormwater Program*

MS4 Permit Program Category	Indicator Type	Data Collection Method	Baseline (i.e., starting point)	Benchmark (short term goal)	Short-term Goal Achieved? (yes/no)	Accomplished to Date (cumulative benchmark summary if applicable)	Milestone (5-year permit cycle goal)	5-year Goal Achieved? (yes/no)	Long-term Goal (5+ years)	Program Modifications Needed (yes/no)	Notes
Permit Administration	Programmatic	Confirmation									
Legal Authority											
Stormwater Advisory Panel and Technical Workgroup											
Program Funding and Costs											
Implementation of Stormwater Control Measures											
Standard for Long-Term Stormwater Management											
Code and Policy, Site Plan Review, Verification and Tracking	Programmatic	Confirmation									
Off-site Mitigation / Fee-in-Lieu											
Green Landscaping Incentives											
Retrofit Program											
Tree Canopy											
2013	Programmatic	Tabulation	35% tree canopy	25% increase in tree planting rates	yes	36%	36% tree canopy		40% tree canopy by 2035		Casey Trees graded the District an A-
			planting 3,000/yr	plant 4,150 trees/yr	yes	4,150	plant 20,750 trees over 5 years				DDOE, federal and private entities play a role in meeting 40% goal
2014			35% tree canopy	25% increase in tree planting rates	yes	37%					
			planting 3,000/yr	plant 4,150 trees/yr	yes	8,300	plant 54,000 trees across city				
Tree Survival Rate			80% survival rate		no	80%	85% survival rate		90% survival rate		
Green Roofs											
2013	Programmatic	Tabulation	1,285,000 sq ft	install 70,000 sq ft/yr in MS4 area	no		350,000 sq ft installed on District properties				
2014					yes	120,000 sq ft					
				Perform structural assessment of District properties	yes						
O&M of Retention Practices											
District owned and operated practices	Programmatic										
Non-District Owned and operated practices											
Stormwater management guidebook and training											
Public Education and Participation											
Education and Outreach	Social										
Measurement of Impacts											
Recordkeeping											
Public Involvement and Participation											
Monitoring and Assessment Controls											
Revised Monitoring Program											
Macroinvertebrates	Monitoring (sampling)										
Geomorphology	Monitoring (observation)										
Habitat	Monitoring (observation)										
Ambient Water Quality	Monitoring (sampling)										
Trash Monitoring	Monitoring										
Area and Source Identification Program	Monitoring										

*Note that the information included with this table are examples of the types of data and information that could be included in such an analysis. Numbers included here are for demonstration purposes only.

Table 7-6. Indicator Types, Definitions, and Examples

Method	Definition	Example
Confirmation	Documenting whether a task has been completed	Development of a construction operator BMP outreach brochure
Tabulation	Tracking an absolute number of value of something	Number of brochures distributed to construction operators
Surveying	Determining knowledge, awareness, etc. of a group of people	Phone survey of 100 construction operators, 50 of whom had received the BMP brochure, to gauge any differences in sw awareness
Quantification	Estimating pollutant loading	Modeling to determine sediment load reductions prior to initiating construction operator outreach program
Inspection or site visits	Observing activities or BMPs	Inspections of construction projects before and after initiating construction operator outreach program
Reporting	Utilizing reports generated by DDOE and third parties	Audit of construction component of the SWMP indicated that BMPs observed and the level demonstrated had improved over past year
Monitoring	Sampling or observation in the field to determine environmental or wq conditions	Water quality monitoring above and below three active construction sites to determine differences in per/acre disturbed loading of sediment

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8 Data Management

Data collection is the fundamental task of the Revised Monitoring Program, and is necessary to help ensure DDOE meets the goals and objectives of the MS4 permit and other related programs. Without careful management, however, these data lose value.

Data management is essential to link monitoring efforts and information analysis. For example, data collected to characterize water quality before and after a stream restoration project must be properly managed in order to determine effectiveness of the restoration (EPA 2011). Careful data management facilitates better sharing of data to the public and promotes a wider understanding of the impacts of stormwater and efforts to combat pollutant sources in the District.

> **Data Management**
>
> *This is the process of organizing, storing, retrieving, and maintaining the data that are collected through monitoring efforts or other programs.*
>
> *This includes record-keeping procedures, data-handling procedures, and the approach used for data storage and retrieval of electronic data.*
>
> *(EPA 2011)*

The purpose of data management is to facilitate storage, use, and ultimately, analysis of the data. The data and information collected through monitoring efforts are a valuable and often irreplaceable resource. Therefore, retention and documentation of high quality data are the foundation upon which the success of monitoring programs rest. To ensure the data are compiled and stored to most effectively meet DDOE’s needs, several questions were evaluated including:

1. What type of data are needed or will be used and why (what regulatory or other purpose do the data serve)?
2. How are data collected?
3. Where and how are data stored/maintained?
4. When and how often are the data updated?
5. What are the sources of data and what inter-relationships exist between data sources?
6. What are the data quality requirements and how are they addressed (QA)?
7. Who is responsible for the data management?
8. How will these data be incorporated into resource management decisions?
9. How will institutions and networks assimilate these materials and put them to productive use as more baseline inventory, monitoring, and legacy data become available?
10. Will all data be archived on site or do alternatives exist or need to be planned?
11. How will data be managed over time?

The following sections summarize the recommended elements of a data management system necessary to support the Revised Monitoring Program based on the answers to the above list of questions.

8.1 Data Management Goals and Objectives

DDOE's overarching data management goals are to:

- Ensure the highest quality and accuracy of program data;
- Fully qualify, document, and catalog all data to ensure their proper interpretation and use;
- Maintain data in an environment that ensures the long-term security and integrity of data;
- Ensure the longevity of data by keeping data formats standardized and current; and,
- Provide data in a variety of formats and venues to reach all potential users.

The following objectives help further frame these goals (adapted from Press 2005):

- Outline the procedures and work practices that support effective data management:
- Guide current and future staff to ensure that sound data management practices are followed;
- Guide the enhancement of legacy data to match formats and standards;
- Encourage effective data management practices as an integral part of project management so all data are available and usable for DDOE decisions now and into the future;
- Establish roles and responsibilities of DDOE staff for managing data;
- Identify necessary elements for a functional data management program and describe any anticipated changes to those elements;
- Establish an organizational schema for data and information so that they are retrievable by staff, cooperators, and the public;
- Establish basic quality control standards; and,
- Establish standards for data, data distribution, and data archiving to ensure the long-term integrity of data, associated metadata, and any supporting information.

8.2 Database Organization

An essential element of effective data management is a data storage, management, and retrieval system. DDOE's monitoring data (quantitative and qualitative) will be input into separate Microsoft Access databases for each component of the Revised Monitoring Program described in the preceding chapters: wet weather monitoring, dry weather screening, receiving water monitoring, and trash monitoring. The formatting of these data will take into account several factors, including formatting previously used by DDOE and formatting that will allow for consistency with other local programs (i.e., Metropolitan Washington Council of Governments water quality database, Chesapeake Bay Program's Information Management System).

Using multiple databases allows for faster querying and provides the flexibility needed to expand each database without altering performance. The databases will be accessed through a master database using a graphical user interface (GUI). The GUI provides a method for non-technical users to easily access data in each of the databases. The GUI also has the capability to link analytical and spatial data to create maps that can communicate the results in a powerful way to a wide audience.

Each database will be composed of a number of tables to organize the data. Each table will include a different type of data with a unique key (e.g., sample ID number) to link tables. For example, the wet weather monitoring data will need separate tables for sample results (units, QA code), sample collection information (time, date, method, collector), parameters (analytical method, dissolved or total basis), storm event information (inches of precipitation, time since last storm, source of weather data), and sample station information (coordinates, any notes). The database will also include fields for method detection limits to allow for better interpretation of findings of non-detection.

It is essential to have a coordinated and integrated data management system. Each Division or Branch within DDOE does not need to develop its own data management system for monitoring data. Instead one system of databases will be created and accessible to all DDOE staff that collect or use the monitoring data. These integrated databases will make sharing and communicating data, an important element of the Revised Monitoring Program, easier to both internal and external users.

8.3 Data Stewardship

Multiple Divisions and Branches within DDOE collect monitoring data. Assigning a party responsible for the maintenance of each database will help ensure consistency and accountability for related data management issues. To ensure data management is centralized and to avoid multiple versions of databases being changed, one person will be appointed to serve as Data Manager. This person’s responsibilities are to:

- Serve as point person to receive all lab data, and data collected in the field from DDOE field staff and contractors
- Organize all data collected for the stormwater program on DDOE’s network and into the databases
- Retain all hardcopy records (detail list is below)
- Maintain and update the master database
- Generate the data queries needed for various tables and figures for MS4 annual reports, DMRs, and internal reports
- Upload relevant data to EPA’s STORET each year
- Upload data to DDOE’s website
- Communicate with outside agencies (e.g., NPS, USGS, local universities) regarding data collected and how to best coordinate data storage and analysis

8.4 Data Entry

Data quality will be rigidly controlled from the point of collection to the point of entry into the databases. Field and laboratory personnel will carefully record data so that it can be seamlessly uploaded into the databases at DDOE. Data collected in the field will be entered into the DDOE databases from field computers/handheld devices within three days from when the data are collected, and any hardcopy records will be filed appropriately with the Data Manager.

Laboratory data will be reviewed and entered into the database as soon as it is available, with the goal of having data review take place within five working days of receipt from the lab. For some parameters, it might be appropriate to set up automatic checks to flag duplicate values or values outside a pre-set range. Additional data validation will include expert review of the verified data to identify possible suspicious values. In some cases, consultation with the individuals responsible for collecting or entering original data may be necessary to resolve problems. After all data are verified and validated, they will be merged into the monitoring program’s database. To prevent loss of data from computer failure at least one set of duplicate (backup) data files will be maintained. Original laboratory data sheets (i.e., hard copy) will be maintained in a secure location where they will not be lost or tampered with. Data will be carefully checked against copies of the original final data sheets prior to data analyses.

Once the data has been entered in the appropriate monitoring program database, the Data Manager will print a paper copy of the data and proofread it against the original field data sheets. Statistical and graphical analysis may be used to reveal whether keystroke errors occurred during data entry. Once verified, errors in data entry will be corrected at that time and documented. Outliers and inconsistencies will be flagged for further review and investigation. Data flagged as being an outlier or otherwise inconsistent will be discarded if appropriate.

8.5 Metadata

The MS4 permit requires specific data to be collected and maintained for all monitoring performed as part of the permit. DDOE will retain records of all monitoring information including all original lab and field data for a period of at least five years from the date of the sample or measurement. DDOE will store electronic data reports from the laboratory as well as maintain files containing any records necessary to reconstruct the analytical details associated with a particular monitoring event. Records will include:

- COC forms
- Field equipment calibration and tuning records (as applicable)
- Analytical standards preparation logs
- Method SOPs
- Analytical QC results (including method blanks, internal standards, surrogates, replicates, and spike and spike duplicate results, as applicable)
- Raw data (e.g., instrument printouts)

- Details of the QA/QC program in place at the time that the data analyses were conducted
- Date, exact place, and time of sampling or measurements;
- Name(s) of individual(s) who performed the sampling or measurements;
- Date(s) analyses were performed;
- Name(s) of individual(s) who performed the analyses;
- Analytical techniques or methods used; and
- Results of such analyses.

If monitoring results are not available for any reason (i.e., sampling discontinued, laboratory errors, etc.) this information will be recorded as well to allow those reviewing the data to understand why information is missing and to ensure there is not an error in the dataset.

8.6 Data Sharing

As noted above, one of the main purposes of data management for the Revised Monitoring Program is to facilitate a wider understanding of the impacts of stormwater and efforts to combat pollution sources. Methods for sharing data may include:

- Producing web-accessible data and information (e.g., maps, tables, and figures) for DDOE's website
- Regular reporting for managers, political leaders, the public, and stakeholders
- Scientific interactions through professional papers, conferences, and workshops

(PSAMP 2008)

8.7 Data Quality Assurance & Quality Control

Quality assurance and quality control of all data collected is essential to the long term management and stewardship of the Revised Monitoring Program. Many of the monitoring programs described in this Revised Monitoring Program have their own QAPP, while others will require development of a new QAPP. A consolidated QAPP that addresses all monitoring programs must be developed that centralizes much more detailed information on data management and quality control to supplement the information in this chapter, including the following:

- Responsible parties and lines of communication between the parties (e.g., DDOE, EPA)
- Data Quality Objectives
- Documentation and Records Keeping
- Sampling Design
- Sampling Methods
- Sample Handling and Custody

- Analytical Methods
- Quality Control
- Instrument/Equipment Testing, Inspection and Maintenance
- Instrument/Equipment Calibration and Frequency
- Assessment and Oversight
- Reporting
- Data Review and Verification

A dedicated QA Officer will be assigned to address these tasks and ensure that any appropriate recommendations are implemented.

8.8 Data from Non-DDOE Sources

Analyzing and interpreting Revised Monitoring Program data, and placing it in a relevant context, can be strengthened by integrating the program's data with research and/or monitoring results from other sources. For example, if there is suspected groundwater infiltration in a certain area of the District's MS4, it would be useful to examine USGS groundwater monitoring data and maps to determine if groundwater is the source of dry weather discharge to the MS4. Another example would be to compare and supplement data collected under the Revised Monitoring Program with the macroinvertebrate, vegetation, and water quality monitoring performed in Rock Creek Park by the National Park Service's National Capital Region Network. Careful data management in standard formats will enable sharing and analysis of data between agencies to be done with relative ease and make for a more robust Revised Monitoring Program. DDOE will communicate with these agencies and others collecting data in the region to explore the possibility of data sharing.

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Appendices

Appendix 1. Matrix of Previously Monitored Outfall Stations

Appendix 2. Memorandum: Generalized Random Tessellation Stratified (GRTS) method

Appendix 3. Memorandum: Statistical Analysis of Wet Weather Outfall Monitoring Data

Appendix 4. Memorandum: Receiving Water Monitoring Statistical Analysis

Appendix 5. Field Data Form

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APPENDIX 1:

Matrix of Previously Monitored Outfall Stations

Matrix of previously monitored outfall stations

Outfall ID	Outfall or Manhole?	Station Name	Receiving Body	Border Station	Notes	Suspected historic stream?	Drainage area (acres)	Impervious area (acres)	% Impervious (sewershed)	% Impervious (Major Watershed)
156	Manhole	Anacostia HS	Anacostia River	no			252	102	40	35
208	Manhole	East Capitol St.	Kingman Lake	no			15	9	58	35
0	Manhole	Ft Lincoln BMP	unknown trib to Anacostia	no			6	0	0	35
999	Outfall	Gallatin and 14th St.	Chillum Rd NE Trib, then into MD	yes	pipe drains to trib that drains to MD	maybe	672	252	37	35
222	Manhole	Hickey Run	Hickey Run	no			12	10	80	35
1038	Manhole	Nash Run	Nash Run	no			13	5	37	35
187	Manhole	O St Pumping Station	Anacostia River			yes	19	16	80	35
147	Manhole	Stickfoot Sewer	Kingman Lake	no		yes	665	238	36	35
998	Manhole	Varnum and 19th St.	unknown trib to NW Branch in MD	yes	pipe drains into MD and eventually effluent discharges into daylighted stream in MD	maybe	1086	454	42	35
952	Outfall	Archbold Parkway	Foundry Branch	no			36	22	62	44
986	Outfall	Battery Kemble	Battery Kemble Creek/Fletchers Run	no			10	3	28	44

Matrix of previously monitored outfall stations										
Outfall ID	**Outfall or Manhole?**	**Station Name**	**Receiving Body**	**Border Station**	**Notes**	**Suspected historic stream?**	**Drainage area (acres)**	**Impervious area (acres)**	**% Impervious (sewershed)**	**% Impervious (Major Watershed)**
953	Manhole	C&O Canal	C&O Canal	no		maybe	1030	353	34	44
1017	Manhole	Dalecarlia Tributary	Dalecarlia Tributary	no			26	9	33	44
966	Manhole	Foundry Branch	Foundry Branch	no			46	26	55	44
124	Outfall	Oxon Run	Oxon Run	no			41	17	41	44
283	Manhole	Tidal Basin	Tidal Basin	no			14	6	41	44
330	Manhole	Washington Ship Channel	Washington Ship Channel	no			31	27	89	44
879	Outfall	Broad Branch	Broad Branch	no	DDOE daylighting project scheduled for this stream	yes	628	263	42	42
784	Manhole	Klingle Valley Creek	Klingle Valley Creek	no			60	30	50	42
513	Manhole	Melvin Hazen Valley Branch	Rock Creek	no		maybe	156	74	47	42
591	Outfall	Military Road and Beach Dr.	Rock Creek	no		yes	25	1	4	42
750	Outfall	Normanstone Creek	Norman-stone Creek	no			20	8	39	42
913	Outfall	Oregon and Pinehurst	Pinehurst Branch	no			4	1	26	42
945	Outfall	Portal and 16th	Portal Branch	yes	pipe comes in from MD and discharges to Portal Branch		7	3	42	42
851	Outfall	Soapstone Creek	Soapstone Creek	no			314	146	47	42
896	Outfall	Walter Reed/Ft Stevens	Luzon Branch	no			24	13	54	42

APPENDIX 2:

Generalized Random Tessellation Stratified (GRTS) Method

Memorandum

From: B. Crary, H. Bourne, B. Udvardy, K. Ridolfi
Date: 3/26/2015
Project: DDOEIP
To: J. champion
CC: Click here to enter text.

SUBJECT: **GRTS Sampling**

Summary

The Generalized Random Tessellation Stratified (GRTS) method was employed to propose a spatially balanced set of wet weather and receiving water sampling locations based on a predetermined number of sampling locations. The use of ANOVA identified that TSS and Zinc concentrations in monitoring locations have historically been significantly different across watersheds, and thus wet weather monitoring locations were stratified so that samples will be collected equally across the three watersheds. Statistical differences were more difficult to identify across the receiving water sampling locations due to the large variety of factors influencing a water body. Thus, broad stratifications such as ecoregion and strahler order were applied to ensure balanced sampling among streams of different geographic characteristics and flow.

Generalized Random Tessellation Stratified (GRTS) Sampling

Generalized Random Tessellation Stratified (GRTS) sampling is a common approach to ensure that sampling locations are spatially balanced (EPAa. 2015). The GRTS process is an alternative to a purely random sampling approach, which may result in a cluster of sampling points in one area and leave another area free of sample points.

The core concept of GRTS is to iteratively apply a hierarchical grid, until no two potential sample locations are within the same cell (EPAa. 2015). Each cell is assigned a random number at each hierarchical grid level, and each random number is combined to create a unique hierarchical address. Each cell is then sorted based on the reverse order of its address. For example, if the original address of the cell is ‘12’, the reverse address becomes ‘21’. Each cell is sorted after this reverse transformation, and *n* samples locations are chosen at equal *n*+1 intervals along the ordered list. More detail on this approach and how it maintains spatial balance can be found on the EPA website.

Stratifications can be incorporated into the GRTS procedure such that locations with certain characteristics are sampled at predefined frequencies. Within the district, several stratifications were considered and each are discussed in the sections below.

The GRTS sampling selection was performed in R statistical package with the ‘spsurvey’ library (R Core Team 2014; Kincaid 2013).

Stratifications

Watershed

The watersheds contributing to the Potomac, Rock Creek, and Anacostia waterbodies were manually delineated as part of the DDOE’s IP Model Tool. An Analysis of Variance (ANOVA) demonstrated that TSS and Zn measurements were different across watersheds ($p<0.05$). Because at least one pollutant was spatially biased, watersheds were incorporated as a sampling strata for wet weather locations.

Ecoregion

Ecoregions define a geographic area which share natural conditions and ecological characteristics The District, itself, is comprised of two EPA Level IV Ecoregions, Northern Piedmont (referred to later as ‘Eastern Piedmont’ and Coastal Plains (EPAb. 2015). It was assumed that aquatic characteristics of each perennial waterway may be influenced differentially based on which ecoregion in which it is located, thus each potential sampling stream was classified by its ecoregion.

EPA’s delineation for the Northern Piedmont and Coastal Plains crossed directly through Rock Creek, and this led to the conclusion that these delineations lacked an adequate resolution for classification purposes. EPA’s delineations were examined and manually adjusted so that Rock Creek and all of its tributaries were classified as Northern Piedmont, while any waterway lying to the east of the Rock Creek and Potomac merger was classified as Coastal Plains.

Strahler Order

Strahler stream order is a classification system used to define stream size based on a hierarchy of tributaries. Stream order can be related to drainage area and stream size and can be related to the expected ecological function of a stream system (Ward, et. al 2008)

Strahler hierarchy was manually applied to all hydrolines included in the DC OCTO Hydroline.ply, assuming that any polyline was perennial, and this stratification was applied to avoid measurement biases due to stream size. Stream orders for the Potomac River, Anacostia River, and Rock Creek as they enter the District’s boundary were assigned based on the NHD Plus Strahler Order database (McKay 2012). If a stream was conveyed through a pipe, strahler order was considered unchanged at the exit of the piped section.

Wet Weather Monitoring Locations

Wet weather outfall monitoring locations were randomly selected with the GRTS procedure using watershed delineation for stratification purposes.

DDOE provided locations of all existing outfalls, and all of these sites were considered as potential sample locations provided that the outfall diameter was greater than the District median of 24 inches. A total of 264 outfalls were subsequently considered. Analysis determined that three sites and one oversample site per stratum be selected per watershed. The selected sampling locations are shown in Figure A2-1 and listed in Table A2-1.

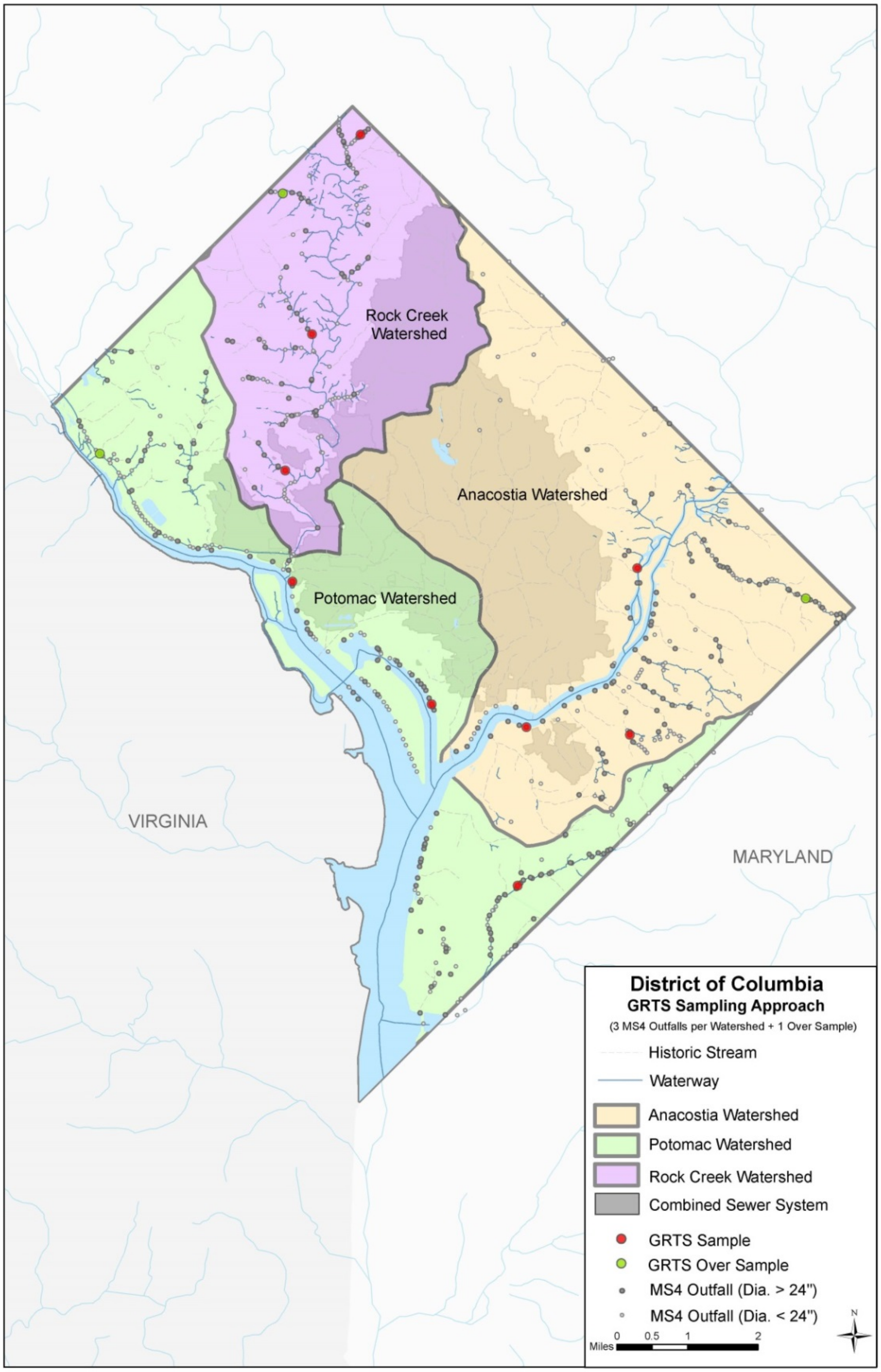

Figure A2-1. GRTS Generated Wet Weather Monitoring Locations

Table A2-1. GRTS Generated Wet Weather Monitoring Location Details.

Watershed	Outfall Unique ID	Diameter (in)	Receiving Water
Potomac River	F-391-C-6-7-SW	24	Washington Ship Channel
Potomac River	F-240-K-3-NW	72	Potomac River
Potomac River	F-284-CD-19-20-SE	48	Oxon Run
Potomac River	F-22-TU-11-12-NW	72	C&O Canal
Anacostia River	F-538-CD-7-8-SE	42	Anacostia River
Anacostia River	F-412-IK-7-8-SE	48	Texas Avenue Tributary (Tributary to)
Anacostia River	F-683-IK-3-4-NE	24	Anacostia River
Anacostia River	F-562-RS-1-2-NE	24	Watts Branch
Rock Creek	F-357-EF-33-34-NW	36	Portal Branch
Rock Creek	F-186-IK-11-12-NW	24	Normanstone Creek
Rock Creek	F-139-IK-19-20-NW	24	Broad Branch
Rock Creek	F-91-IK-29-30-NW	54	Pinehurst Branch (Tributary to)

Receiving Water Monitoring Locations

Receiving water monitoring locations were randomly selected with the GRTS procedure using Strahler order and ecoregion for stratification purposes.

A total of 52 (26 primary targets and 26 oversample locations) sample sites were selected. The number of sites per stratum was scaled by the total length of qualified stream. The strata and the stream length corresponding to each stratum are listed in Table A2-2. The oversamples sites are “back up” sites selected because of the potential for the primary targeted sites to be inaccessible or unfeasible.

Table A2-2. Receiving Water Strata Information

Stratum	Stream Order	Ecoregion	Sites + Oversamples	Total Length (miles)
A	1	Eastern Piedmont	8+8	19.8
B	2	Eastern Piedmont	4+4	10.1
C	3	Eastern Piedmont	2+2	4.1
D	4	Eastern Piedmont	1+1	0.1
E	1	Coastal Plains	5+5	11.8
F	2	Coastal Plains	5+5	12.7
G	3	Coastal Plains	1+1	2.3

GRTS was applied on a continuous scale along all hydrolines in the Hydroline.ply (accessed through DC OCTO), with the following exceptions:

- Stream segments which have a stream order greater than four.
- The C&O Canal was excluded because it does not share typical characteristics with other receiving waters.

All other hydrolines were potential sampling locations. The results of the GRTS sampling process for receiving water monitoring are shown in Figure A2-2 and locations are identified in Table A2-3.

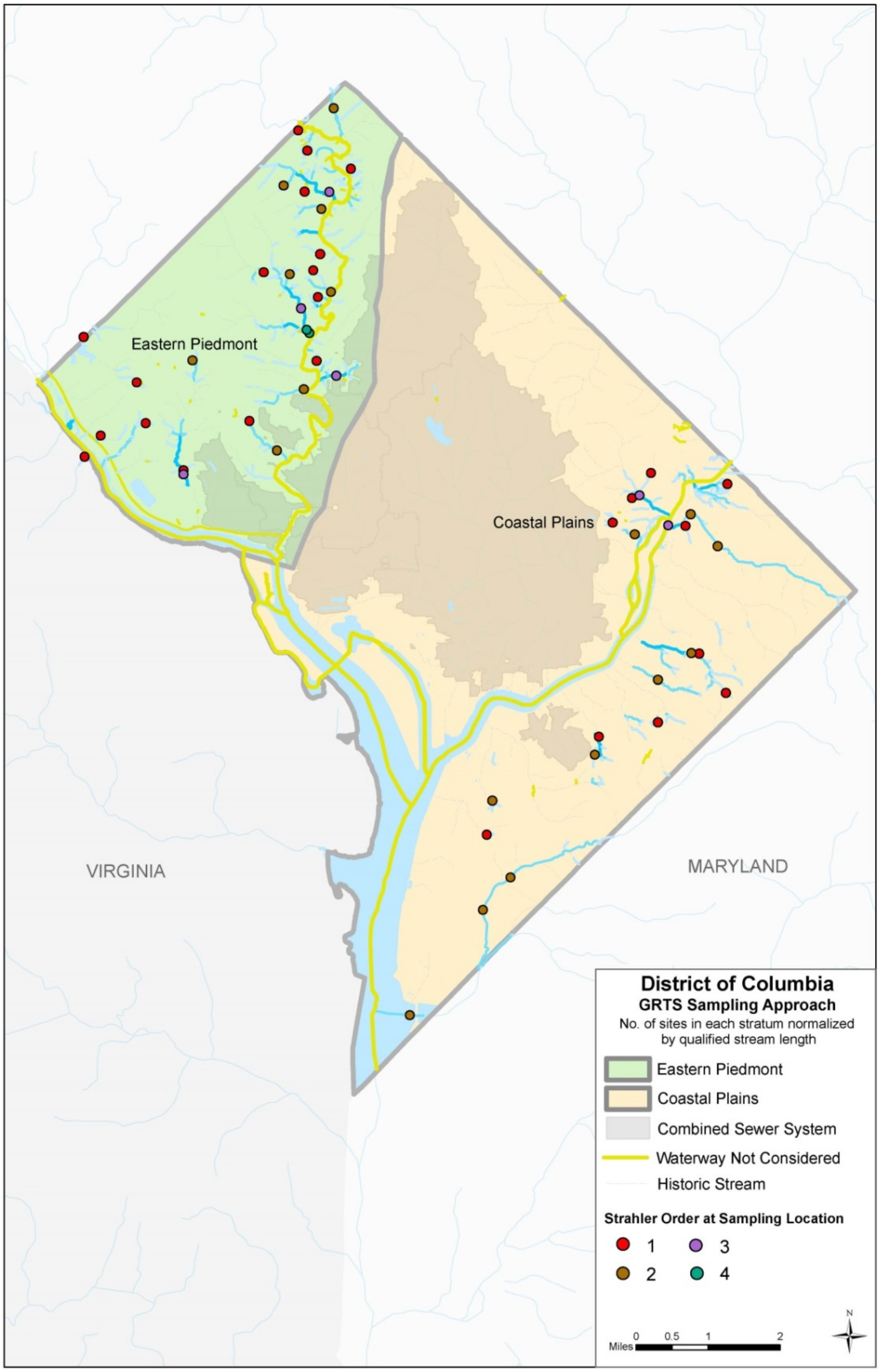

Figure A2-2. GRTS generated Receiving Water Monitoring Locations

Table A2-3. GRTS Generated Receiving Water Monitoring Location Details.

Strahler Stream Order	Ecoregion	Receiving Water	Longitude	Latitude
1	Eastern	Rock Creek (Unnamed Tributary to)	1298702.	468092.
1	Eastern	Potomac (Unnamed Tributary to)	1288848.	455391.
1	Eastern	Battery Kemble Creek (Unnamed Tributary	1286082.	458838.
1	Eastern	Rock Creek (Unnamed Tributary to)	1297922.	478832.
1	Eastern	Rock Creek (Unnamed Tributary to)	1298870.	471249.
1	Eastern	Potomac (Unnamed Tributary to)	1281602.	456383.
1	Eastern	Potomac (Unnamed Tributary to)	1285430.	461835.
1	Eastern	Pinehurst Branch (Unnamed Tributary to)	1297720.	475832.
1	Eastern	Rock Creek (Unnamed Tributary to)	1298360.	470041.
1	Eastern	Normanstone Creek	1293698.	459007.
1	Eastern	Broad Branch (Unnamed Tributary to)	1294727.	469905.
1	Eastern	Rock Creek (Unnamed Tributary to)	1301138.	477506.
1	Eastern	Rock Creek (Unnamed Tributary to)	1298610.	463404.
1	Eastern	C&O Canal (Unnamed Tributary to)	1282795.	457933.
1	Eastern	Unnamed Dalecarlia Tributary	1281535.	465173.
1	Eastern	Rock Creek (Unnamed Tributary to)	1297269.	480318.
2	Eastern	Pinehurst Branch (Unnamed Tributary to)	1296193.	476262.
2	Eastern	Bingham Run	1298979.	474554.
2	Eastern	Broad Branch (Unnamed Tributary to)	1296658.	469776.
2	Eastern	Normanstone Creek	1295704.	456850.
2	Eastern	Fenwick Branch	1299861.	481945.
2	Eastern	Rock Creek (Unnamed Tributary to)	1299679.	468467.
2	Eastern	Klingle Valley Run	1297664.	461333.
2	Eastern	Foundry Branch	1289516.	463454.
3	Eastern	Broad Branch	1297478.	467273.
3	Eastern	Pinehurst Branch	1299544.	475810.
3	Eastern	Piney Branch	1300042.	462324.
3	Eastern	Potomac (Unnamed Tributary to)	1288856.	455095.
4	Eastern	Broad Branch	1298096.	465441.
4	Eastern	Broad Branch	1297889.	465693.
1	Coastal Plains	Hickey Run (Unnamed Tributary to)	1321737.	453350.
1	Coastal Plains	Watts Branch (Unnamed Tributary to)	1325658.	451307.
1	Coastal Plains	Anacostia (Unnamed Tributary to)	1311086.	428680.

Table A2-3. GRTS Generated Receiving Water Monitoring Location Details.

Strahler Stream Order	Ecoregion	Receiving Water	Longitude	Latitude
1	Coastal Plains	Fort Stanton (Unnamed Tributary to)	1319312.	435861.
1	Coastal Plains	Hickey Run (Unnamed Tributary to)	1323135.	455184.
1	Coastal Plains	Fort Dupont	1328614.	439074.
1	Coastal Plains	Anacostia (Unnamed Tributary to)	1320315.	451543.
1	Coastal Plains	Unnamed Texas Avenue Tributary to)	1323635.	436928.
1	Coastal Plains	Fort Dupont (Unnamed Tributary to)	1326681.	441951.
1	Coastal Plains	Nash Run (Unnamed Tributary to)	1328737.	454377.
2	Coastal Plains	Watts Branch	1328010.	449828.
2	Coastal Plains	Anacostia (Unnamed Tributary to)	1321929.	450676.
2	Coastal Plains	Fort Stanton	1319023.	434533.
2	Coastal Plains	Oxon Run	1305449.	415444.
2	Coastal Plains	Popes Branch	1323634.	440019.
2	Coastal Plains	Oxon Run	1310811.	423170.
2	Coastal Plains	Watts Branch	1326043.	452162.
2	Coastal Plains	Anacostia (Unnamed Tributary to)	1311498.	431174.
2	Coastal Plains	Fort Dupont	1326090.	441978.
2	Coastal Plains	Oxon Run	1312835.	425538.
3	Coastal Plains	Watts Branch	1324392.	451340.
3	Coastal Plains	Hickey Run	1322286.	453544.

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APPENDIX 3:

Statistical Analysis of Wet Weather Outfall Monitoring

Memorandum

From: B. Crary, H. Bourne, K. Ridolfi
R. O'Banion

Date: 03/26/2015

Project: DDOEIP

To: J. Champion

CC: Click here to enter text.

SUBJECT: Wet Weather Monitoring Statistical Analysis

Abstract

District Department of Environment's (DDOE's) municipal separate storm sewer system (MS4) permit requires that wet weather monitoring data be sufficient to ensure that the data are "statistically significant and interpretable". Sampling power estimates were performed to demonstrate the number of samples required to significantly detect changes from baseline wet weather monitoring sample data. Twenty-five percent changes in the means of Total Nitrogen, Total Phosphorus, Copper, and Zinc in the Anacostia watershed, Potomac watershed, and Rock Creek watershed can be detected significantly with power of 0.8 with 67, 45, 159, 63, 292, and 109 samples, respectively. The maximum power achievable for 25% change detection is 0.74 for Lead and 0.41 for Fecal Coliform Bacteria. The maximum powers achievable for TSS in the Anacostia watershed, Potomac watershed, and Rock Creek watershed are 0.77, 0.60, and 0.56, respectively. High variability in wet weather monitoring contributes to the high level of effort required to detect fine changes, particularly in the cases of Lead and Fecal Coliform Bacteria.

Power and Sample Size Calculations for Post-Implementation Outfall Monitoring

DDOE's MS4 permit requires that a revised monitoring program be developed that allows the District to make wet weather loading estimates and conduct wasteload allocation tracking. A key component of this requirement is that the "number of samples, sampling frequency and number and locations of sampling stations must be adequate to ensure data are statistically significant and interpretable" (EPA 2011). To ensure that the revised monitoring sampling plan for wet weather events is statistically significant, a power analysis was completed. The analysis uses all available water quality data collected by DDOE at outfalls from 2001 to 2013. With these data, a statistical approach was used to determine the number of samples required to detect statistically significant differences between baseline (first year of permit cycle, 2016) and at the end of the permit cycle (2019, hereafter referred to as "post-implementation") samples for differences of 5%, 10%, and 25% of the baseline mean.

Baseline Outfall Monitoring Data

Applicable baseline data has been collected by DDOE at monitoring locations across the District's MS4 dating back to 2001. Samples have been collected and measured from the drainage sites at various waterways which feed into the Anacostia River, the Potomac River, and Rock Creek. Prior to performing a power analysis, an Analysis of Variance (ANOVA) was used to determine that significant differences ($p<0.05$) across the watersheds existed only for Total Suspended Solids (TSS) and Zinc. Concentrations of TSS and Zinc were grouped accordingly prior to performing the power analysis. For each remaining pollutant of interest (those that are required in the permit to be monitored for wet weather, Table 3-2), samples taken from different watersheds were grouped and treated as a single sample set, since no underlying differences could be detected.

Two – Sample Independent t-test

It was assumed that post-implementation monitoring samples will be compared to the baseline sample set using a two-sample independent t-test. This approach assumes no temporal variability between samples taken from either population. Underlying differences in the sample populations can be identified by comparing the sample set means and testing the null hypothesis:

$$H_o = \mu_{pre,i} - \mu_{post,i} = 0$$

Where:

$H_o = null\ hypothesis$

$\mu_{pre,i} = Pre - implentation\ event\ mean\ concentration\ of\ pollutant\ i$

$\mu_{post,i} = Post - implentation\ event\ mean\ concentration\ of\ pollutant\ i$

One of the assumptions of a t-test is that the underlying population distributions are normal, thus several pollutant were transformed to satisfy this assumption. See Table A3-1 for summary of transformations for each pollutant.

Table A3-1. Normalization transformations

Pollutant	Transformation
Total Suspended Solids (Anacostia)	Natural Log
Total Suspended Solids (Potomac)	Natural Log
Total Suspended Solids (Rock Creek)	Natural Log
Total Nitrogen	Power, λ = 0.5454
Total Phosphorus	Power, λ = 0.3434
Copper	Natural Log
Fecal Coliform Bacteria	Natural Log
Lead	None
Zinc (Anacostia)	Power, λ = 0.4646
Zinc (Potomac)	Power, λ = 0.4646
Zinc (Rock Creek)	Power, λ = 0.4646

Using a predefined Type I error rate of 0.05 (5% probability of erroneously rejecting the null hypothesis), the null hypothesis will either be rejected or accepted using by calculating the test statistic, t, and comparing it to $t_{\alpha,0.05}$ (Zar 1999). The t-test should be a “one-sided” test because the test should be performed with an alternative hypothesis that $\mu_{pre,i} > \mu_{post,i}$. It is anticipated that the post-implementation event mean concentration will be less than the baseline event mean concentration.

Power and Type II Error

Common convention is to predefine an acceptable level of risk for a Type I error, usually 5%, but this convention does not address situations in which there is an erroneous failure to reject the null hypothesis (Type II error). In terms of MS4 monitoring, a Type II error would be a failure to detect a true underlying difference in the pre- and post-implementation sample means. In the case of a t-test, statistical power refers to the probability of detecting a difference in means when it truly exists:

$$Power = 1 - \beta$$

Where: $\beta = probability\ of\ committing\ a\ Type\ II\ error$

Conventionally, an “acceptable” Beta is considered 20%. This translates to a statistical power of 0.80. As a general rule, power will increase with increasing sample sizes.

Monitoring Variables

As the requirement to develop a Revised Monitoring Program does not include specific expectations for program design, the time frame in which statistically significant differences must be identified is also undefined. Additionally, the number of samples that must be taken and the number of sites at which samples must be taken are also variables included in this assessment.

Although the sample size requirement equation depends only on *n, n* is dependent upon the number of sites chosen, the number of sampled events per year, and the number of years the sampling will take place. This relationship can be expressed as:

$$n = n_{ss} n_{sy} n_{se}$$

Where: $n = number\ of\ monitoring\ samples$

$n_{ss} = number\ of\ sample\ sites$

$n_{sy} = number\ of\ sampling\ years$

$n_{se} = number\ of\ sampling\ events\ per\ year$

The number of sample sites was evaluated at 5, 10, and 15 years, and *n* was calculated for $n_{sy} = 1$ through $n_{sy} = 30\ years$.

Power Estimates for Variable Sample Size

Power estimates were calculated for a range of post-implementation sample sizes using the ‘pwr’ package in R (Champely 2012). The calculation was performed using the ‘pwr.t2n.test’ command, which is derived from the method described by Cohen (1988). This calculation was performed on a fixed baseline sample size, variable post-implementation sampling size, and variable effect size, where effect size is defined as:

$$d = \frac{|\mu_{pre,i} - DL * \mu_{pre,i}|}{\sigma}$$

Where: $\sigma = standard\ deviation$

$$DL = Detection\ level\ (0.95, 0.90, or\ 0.75\ based\ on\ desired\ detectable\ difference)$$

If concentrations were transformed to meet the normal assumption for the t-test, then *d* was defined as (using natural log transformation as example):

$$d = \frac{|\ln(\mu_{pre,i}) - \ln(DL * \mu_{pre,i})|}{\sigma_{tranformed}}$$

Where: $\sigma_{tranformed} = standard\ deviation\ of\ the\ transformed\ dataset$

It was also assumed that the baseline and post-implementation standard deviations were equal. Cohen's effect size is a better indicator of whether a specified detection difference (e.g. 5%, 10% or 20%) because the variability of the data is considered. Cohen suggests that, for general cases, effect sizes of 0.2, 0.4, and 0.6 be considered for detection of small, medium, and large changes, respectively (Cohen 1988).

Results and Discussion

Using the power equations and variables described above, a series of plots were developed to show the relationship between statistical power and number of sample years. Curves for Total Nitrogen, Total Phosphorus, Total Suspended Solids, Copper, Fecal Coliform Bacteria, Lead, and Zinc are seen in Figures A3-1 through 11[4]. Baseline population characteristics and effect sizes are provided for each pollutant in Table A3-2

Table A3-2. Pollutant sample population characteristics

Pollutant	Mean (mg/l)	Standard Dev.	Effect size, d (5%)	Effect size, d (10%)	Effect size, d (25%)
Total Nitrogen	3.71	3.12	0.07	0.14	0.35
Total Phosphorus	0.41	0.32	0.08	0.16	0.41
Total Suspended Solids	107.72	161.37	0.05	0.10	0.27

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[4] Note that Cadmium is not yet included in this analysis. The database upon which this analysis was based was that which was used to develop EMCs for the TMDL IP Modeling effort. Because there are no TMDLs for Cadmium in the District, this parameter has not yet been included in the database. Once the database is revised with these data, this statistical analysis will also be calculated for this parameter.

Table A3-2. Pollutant sample population characteristics

Pollutant	Mean (mg/l)	Standard Dev.	Effect size, d (5%)	Effect size, d (10%)	Effect size, d (25%)
(Anacostia)					
Total Suspended Solids (Potomac)	52.01	76.78	0.04	0.09	0.24
Total Suspended Solids (Rock Creek)	76.50	119.80	0.04	0.09	0.23
Copper	0.38	0.18	0.04	0.10	0.26
Fecal Coliform Bacteria	22963 (MPN/100 ml)	55143 (MPN/100 ml)	0.02	0.05	0.13
Lead	0.03	0.04	0.03	0.06	0.16
Zinc (Anacostia)	0.12	0.14	0.08	0.16	0.41
Zinc (Potomac)	0.07	0.10	0.07	0.13	0.35
Zinc (Rock Creek)	0.07	0.10	0.07	0.15	0.38

The small effect sizes calculated for 5%, 10%, and 25% changes in the population means reflect the very large standard deviation for each pollutant. Comparing these effect sizes to 0.2, Cohen's threshold for detecting small changes, it is not surprising that such large sample sizes are required to detect changes in the mean. With the current monitoring data, detecting 5% and 10% changes with power of 0.8 is not possible. However, statistically significant changes of 25% in the means of Total Nitrogen, Total Phosphorus, Total Suspended Solids, Copper, and Zinc can each be detected with 293 or fewer samples (Table A3-3).The standard deviations of Fecal Coliform Bacteria and Lead are large enough that the highest powers achievable for 25% change detection are approximately 0.41 and 0.74, respectively.

Table A3-3. Required samples to detect 25% change in mean concentration for power = 0.80

Pollutant	No. of existing measurements	Minimum No. of samples to detect 25% change*	No. of years to collect samples
Total Nitrogen	200	67	7.4
Total Phosphorus	203	45	5.0
Total Suspended Solids (Anacostia)	78	N/A[1]	N/A
Total Suspended Solids (Potomac)	61	N/A[2]	N/A
Total Suspended Solids (Rock Creek)	59	N/A[3]	N/A
Copper	212	159	5.9
Fecal Coliform Bacteria	121	N/A[4]	N/A
Lead	205	N/A[5]	N/A
Zinc (Anacostia)	93	63	7.0
Zinc (Potomac)	61	293	32.6
Zinc (Rock Creek)	66	109	12.1

[1] No appreciable gains in power beyond 4,500 samples (power approximately 0.77)
[2] No appreciable gains in power beyond 7,900 samples (power approximately 0.60)
[3] No appreciable gains in power beyond 2,700 samples (power approximately 0.56)
[4] No appreciable gains in power beyond 5,000 samples (power approximately 0.41)
[5] No appreciable gains in power beyond 6,000 samples (power approximately 0.74)
*Gains no longer considered appreciable when power can be rounded to the same hundredth of the maximum attainable power.

This level of effort to detect changes in concentration was not unexpected. Other similar studies have come to the same conclusion. For example, the San Diego County MS4 co-permittees (SDCC) evaluated long-term effectiveness of the impacts of the MS4 program on water quality. As part of this effort the SDCC developed a power analysis, similar to that described above, which estimated that between 33 and 3,339 samples would be required to detect 10% changes in means for certain parameters (SDCC 2011). It was also determined that such detection was unlikely within one permit cycle. Ultimately, the large variability of wet weather monitoring data contributes to the difficulty in detecting subtle changes in pollutant concentrations.

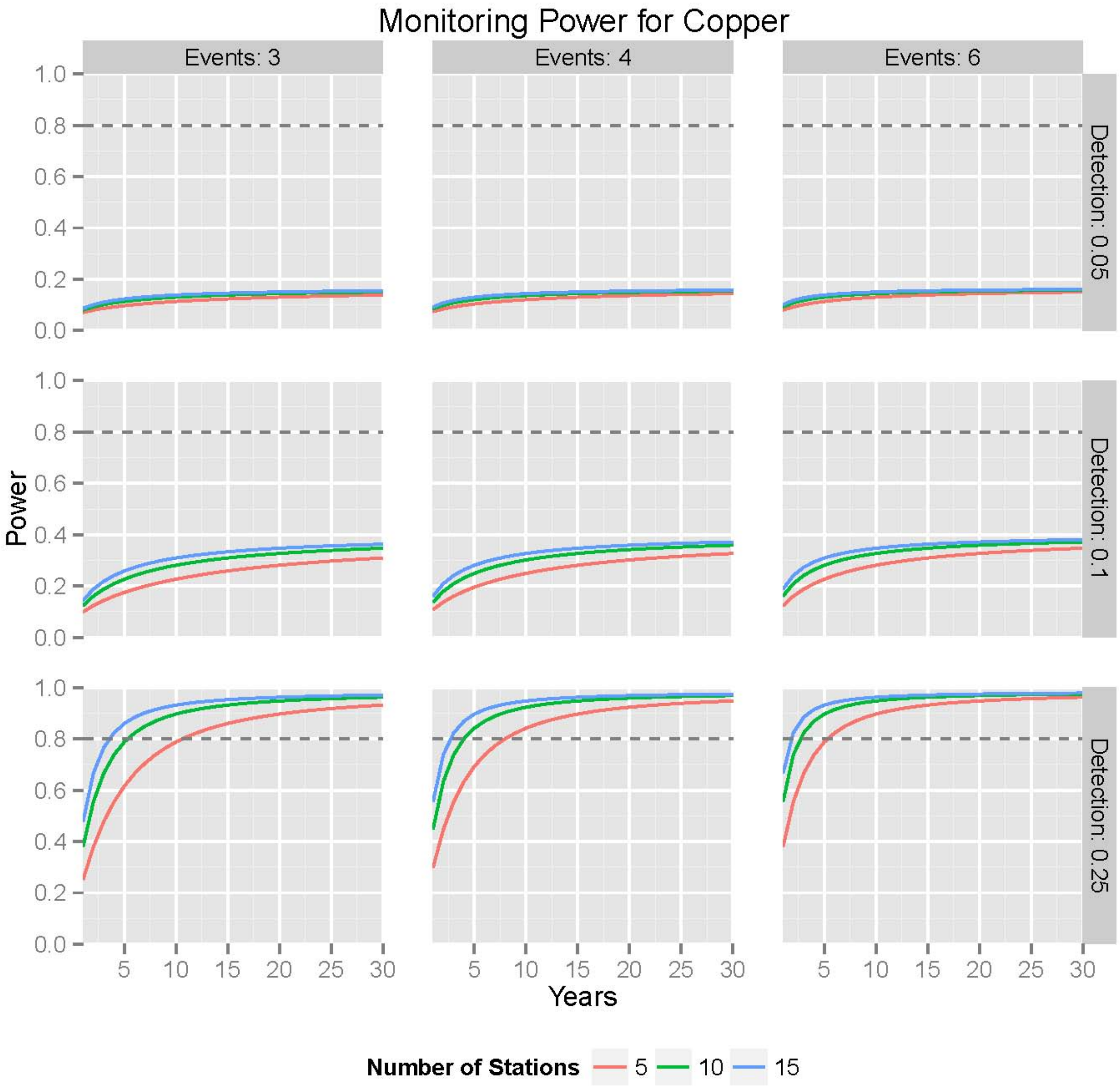

Figure A3-1. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Copper concentrations

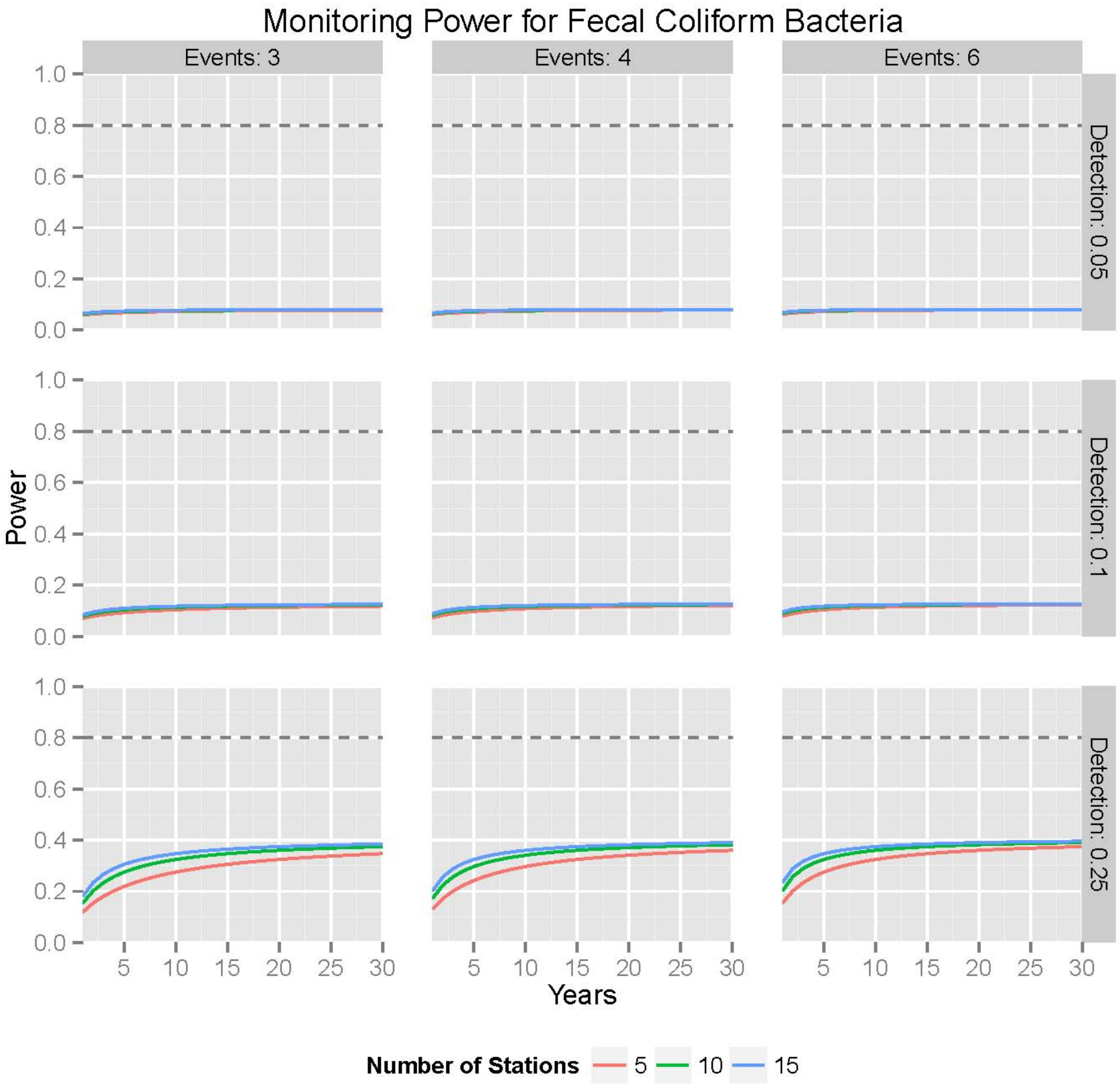

Figure A3-2. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Fecal Coliform Bacteria concentrations

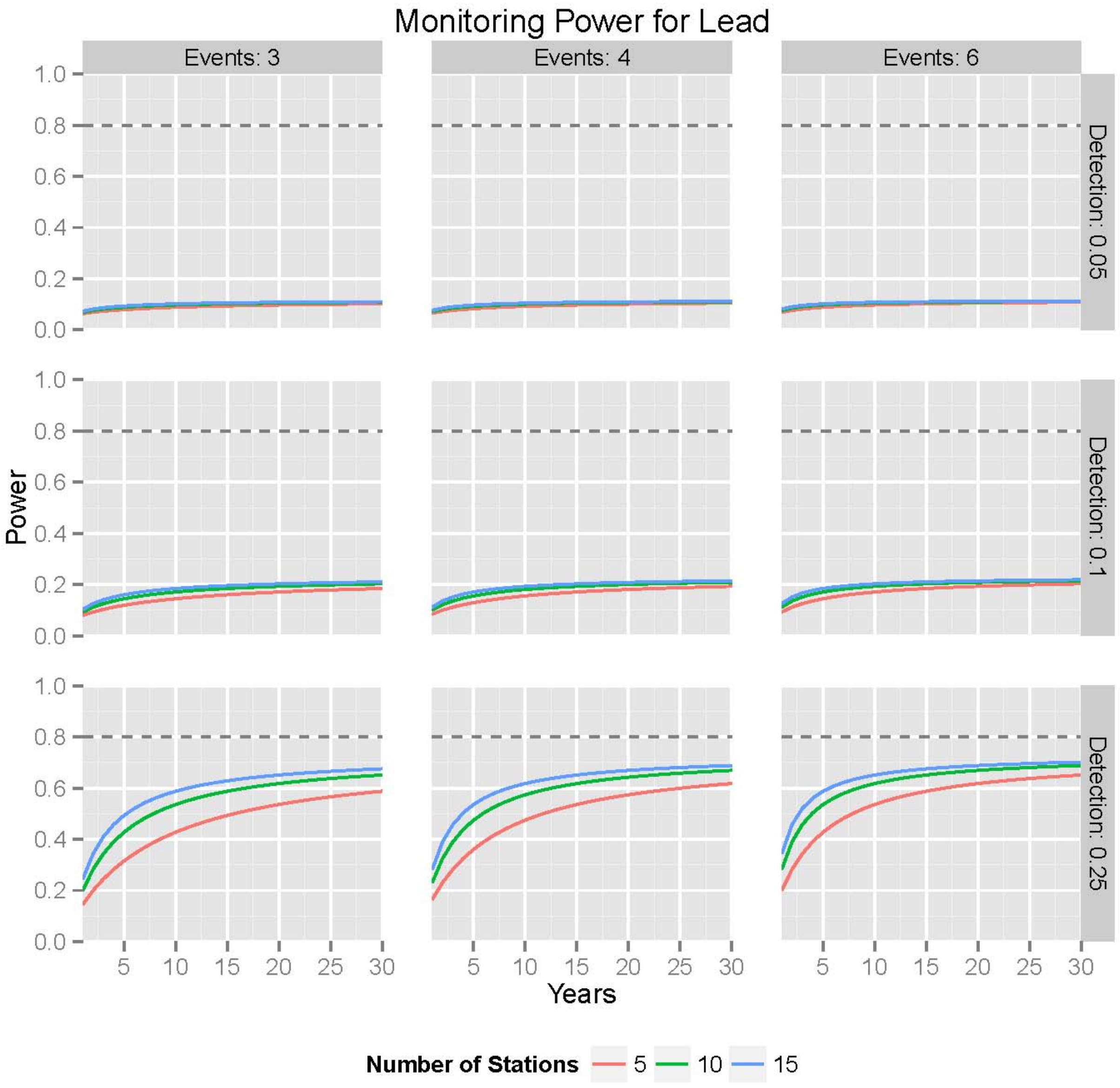

Figure A3-3. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Lead concentrations

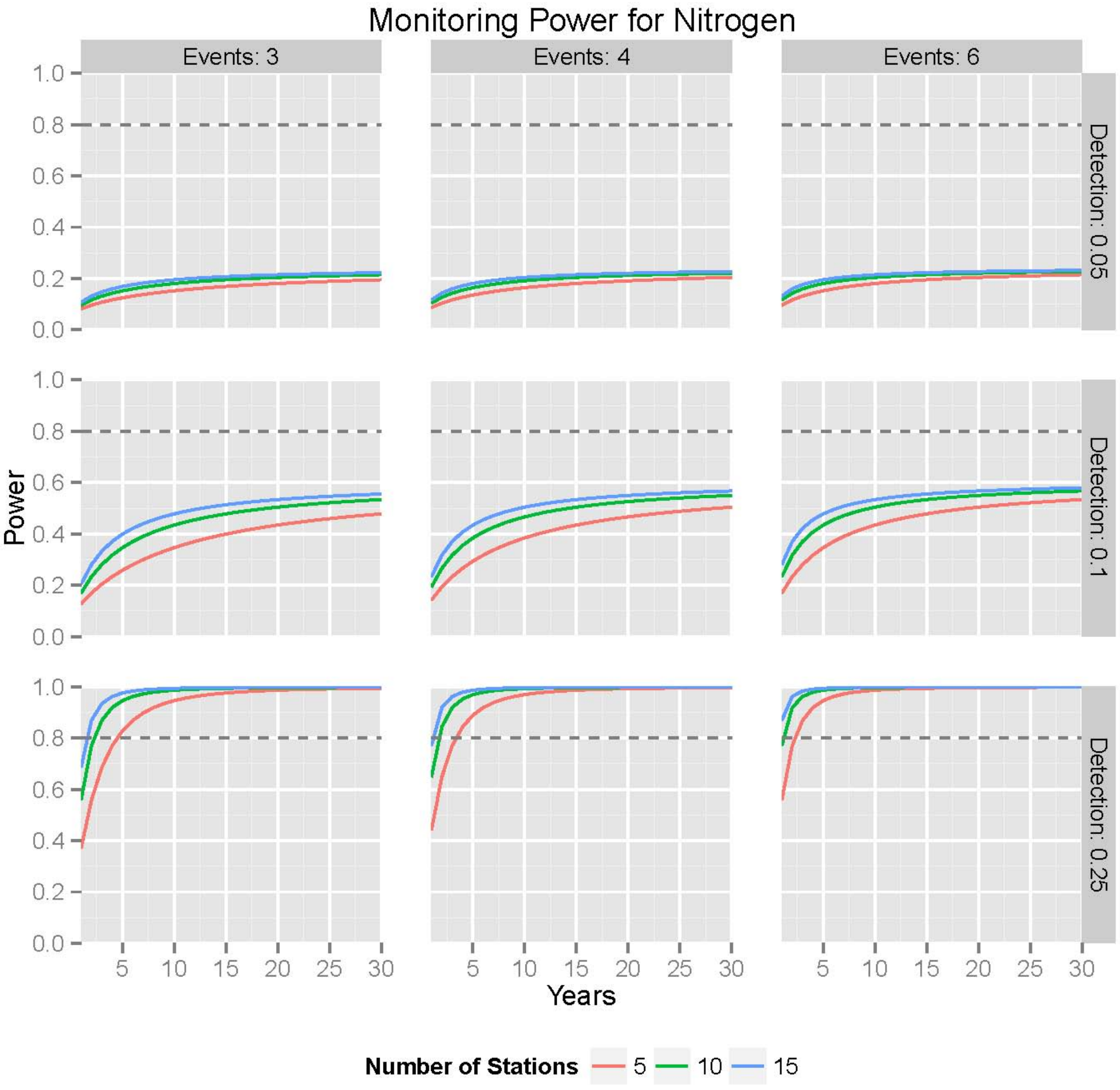

Figure A3-4. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Total Nitrogen concentrations

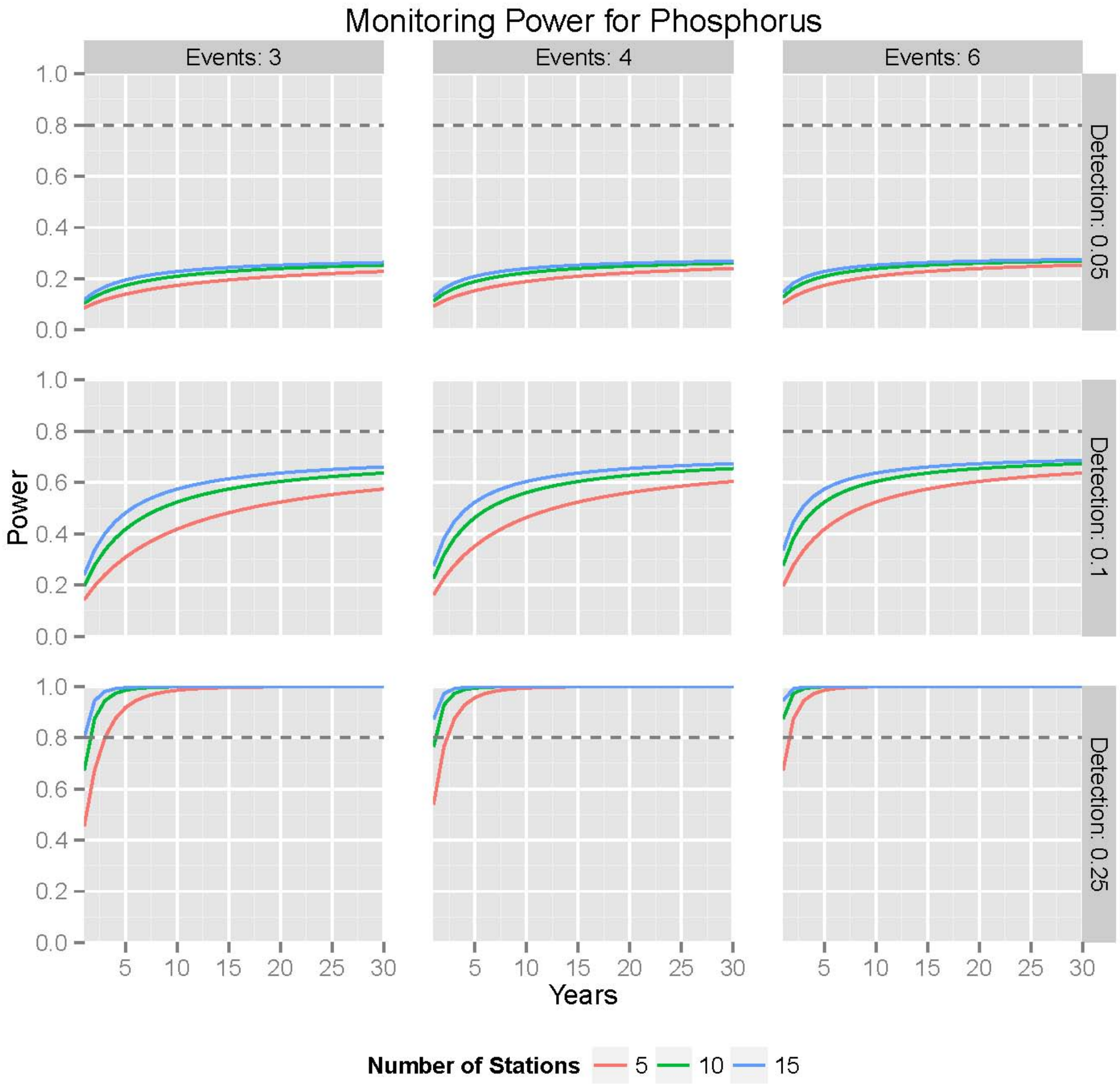

Figure A3-5. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Total Phosphorus concentrations

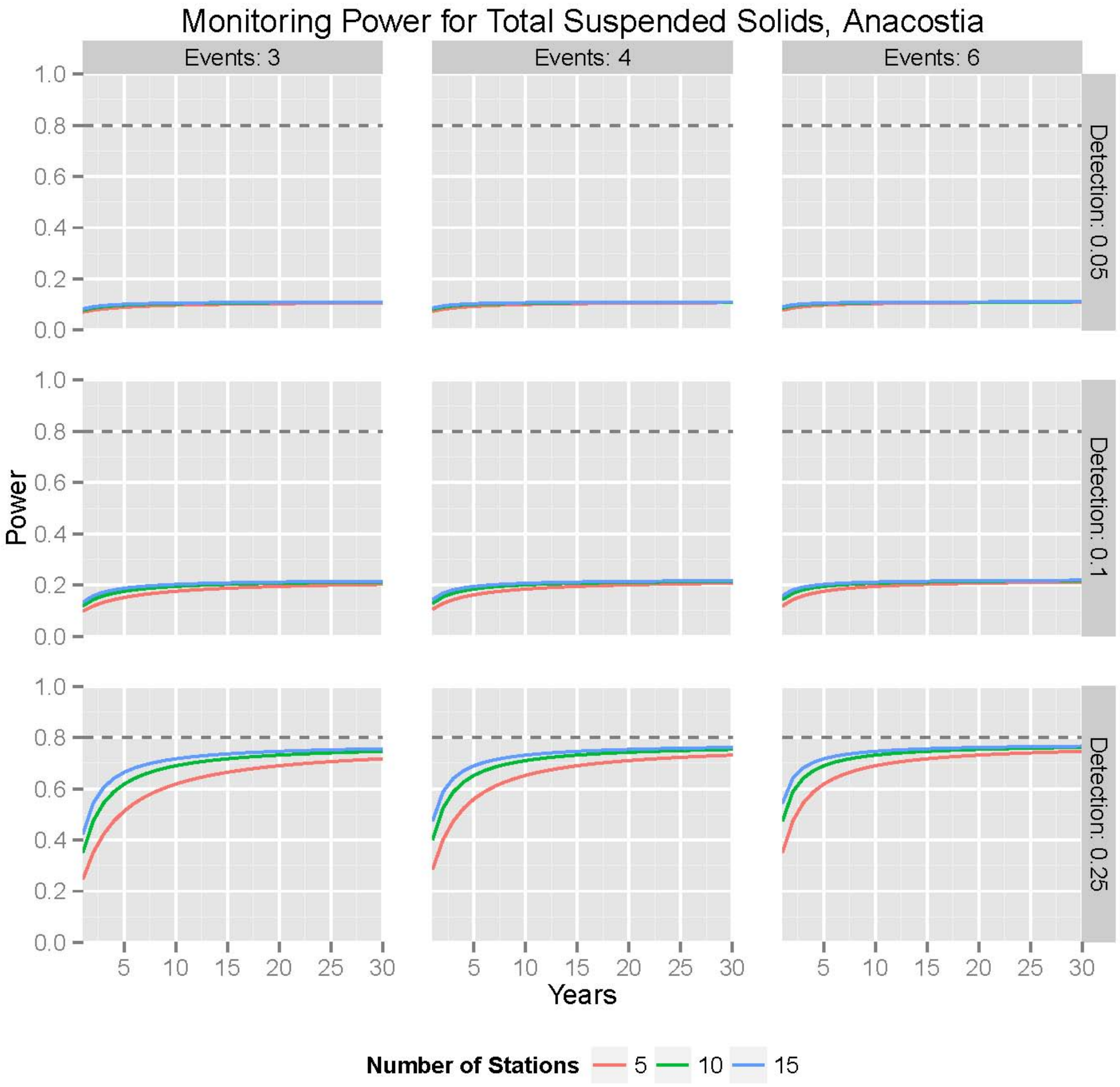

Figure A3-6. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Total Suspended Sediment concentrations in the Anacostia watershed

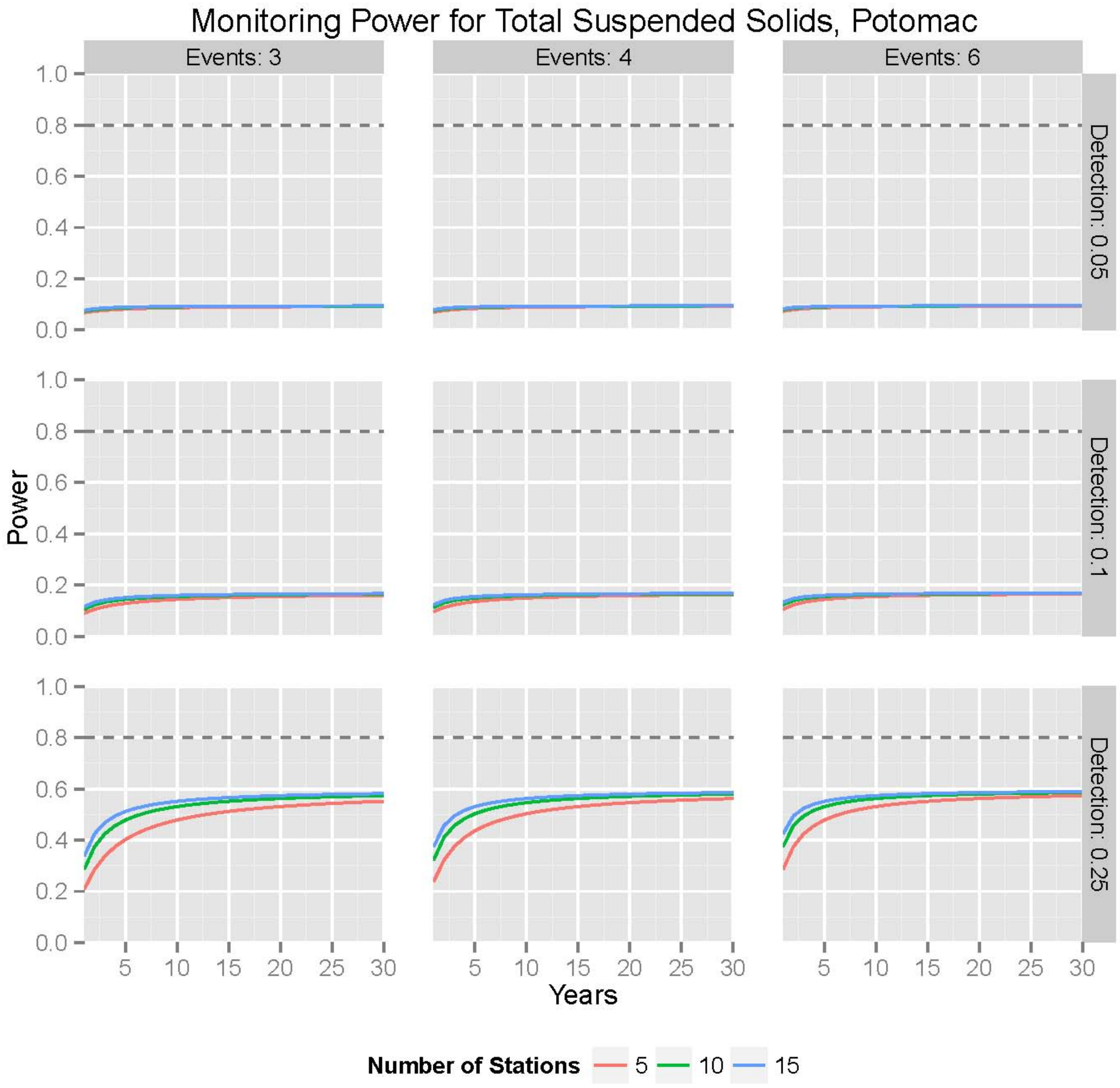

Figure A3-7. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Total Suspended Sediment concentrations in the Potomac watershed

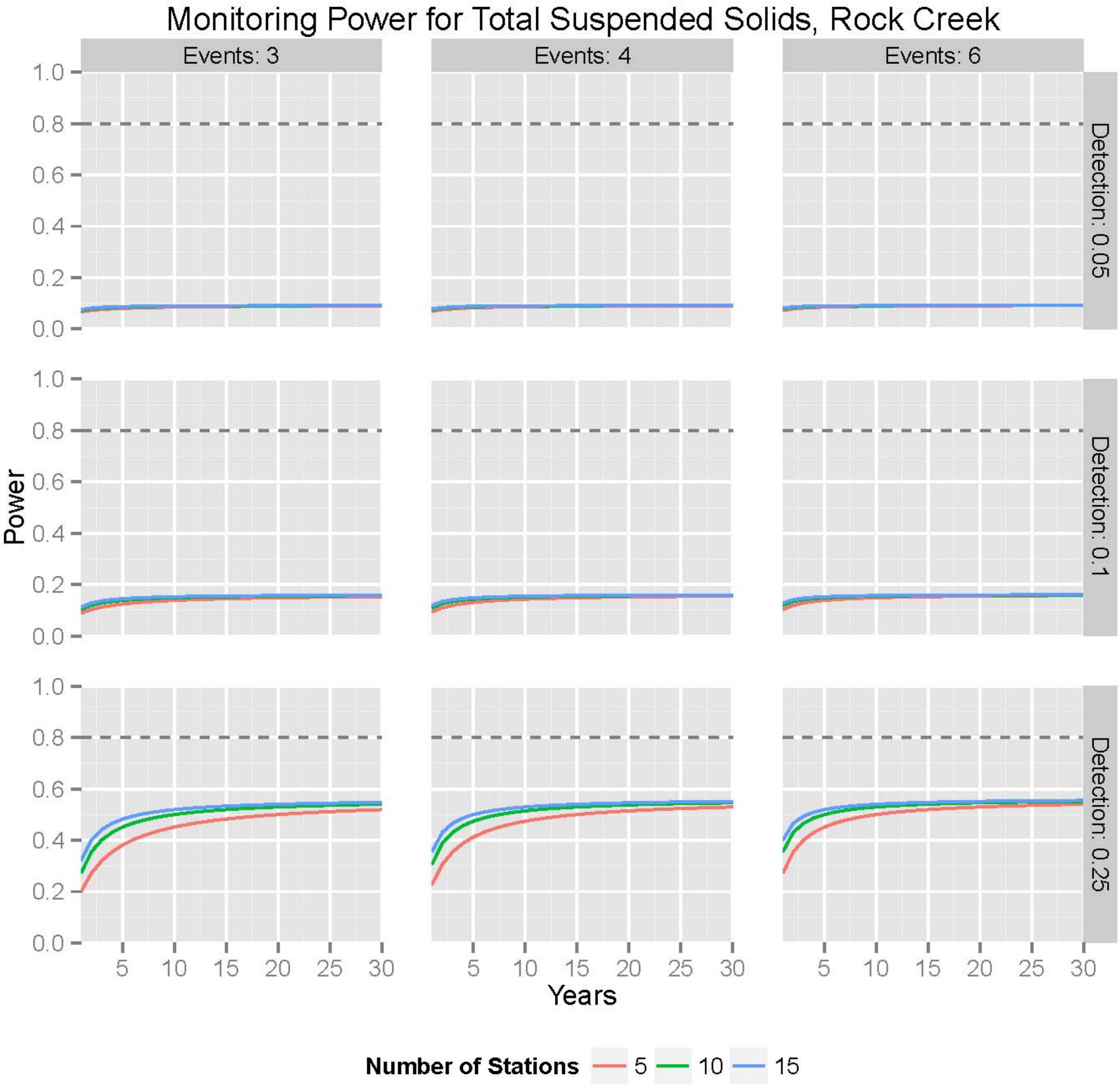

Figure A3-8. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Total Suspended Sediment concentrations in the Rock Creek watershed

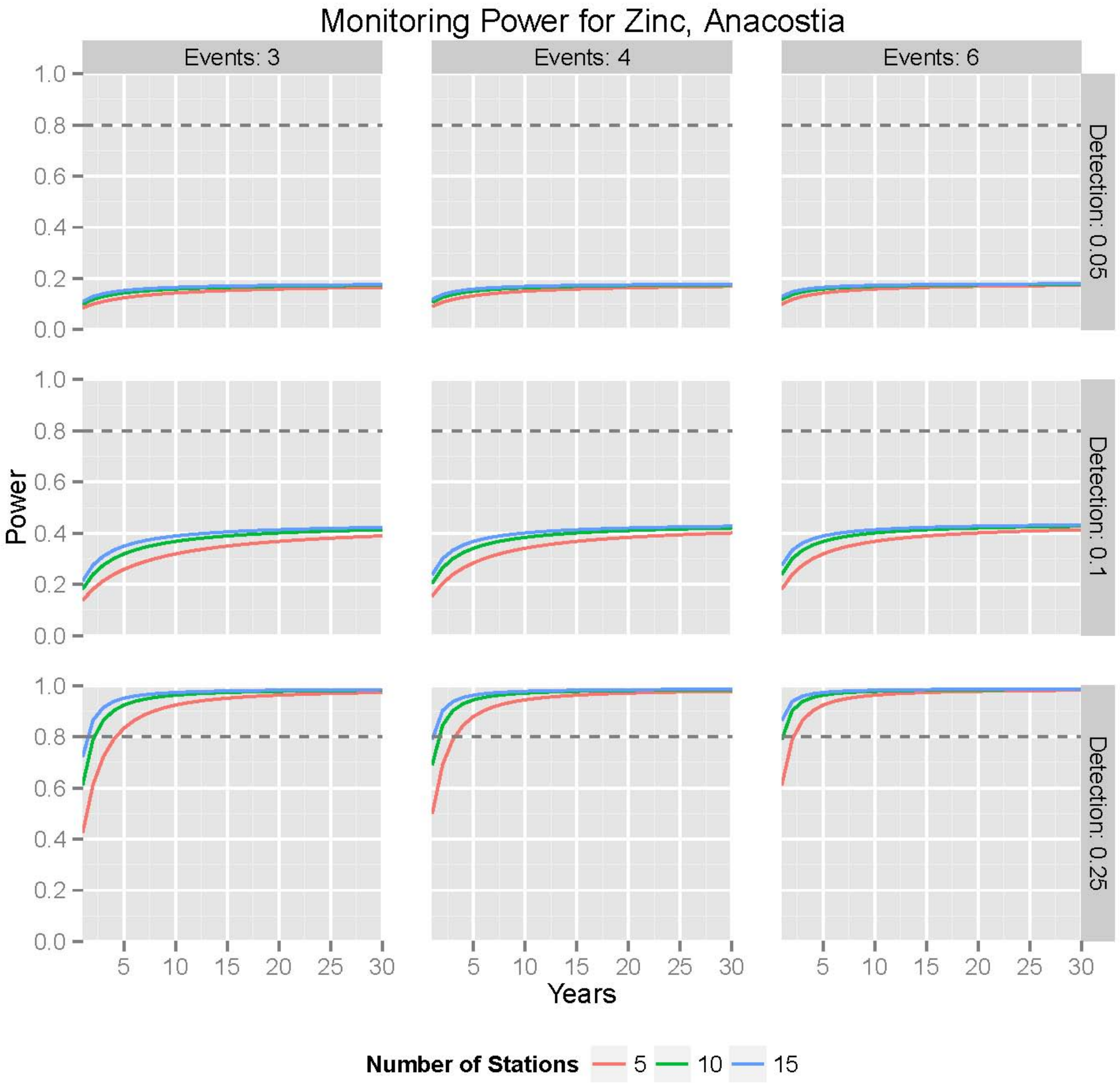

Figure A3-9. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Zinc concentrations in the Anacostia watershed

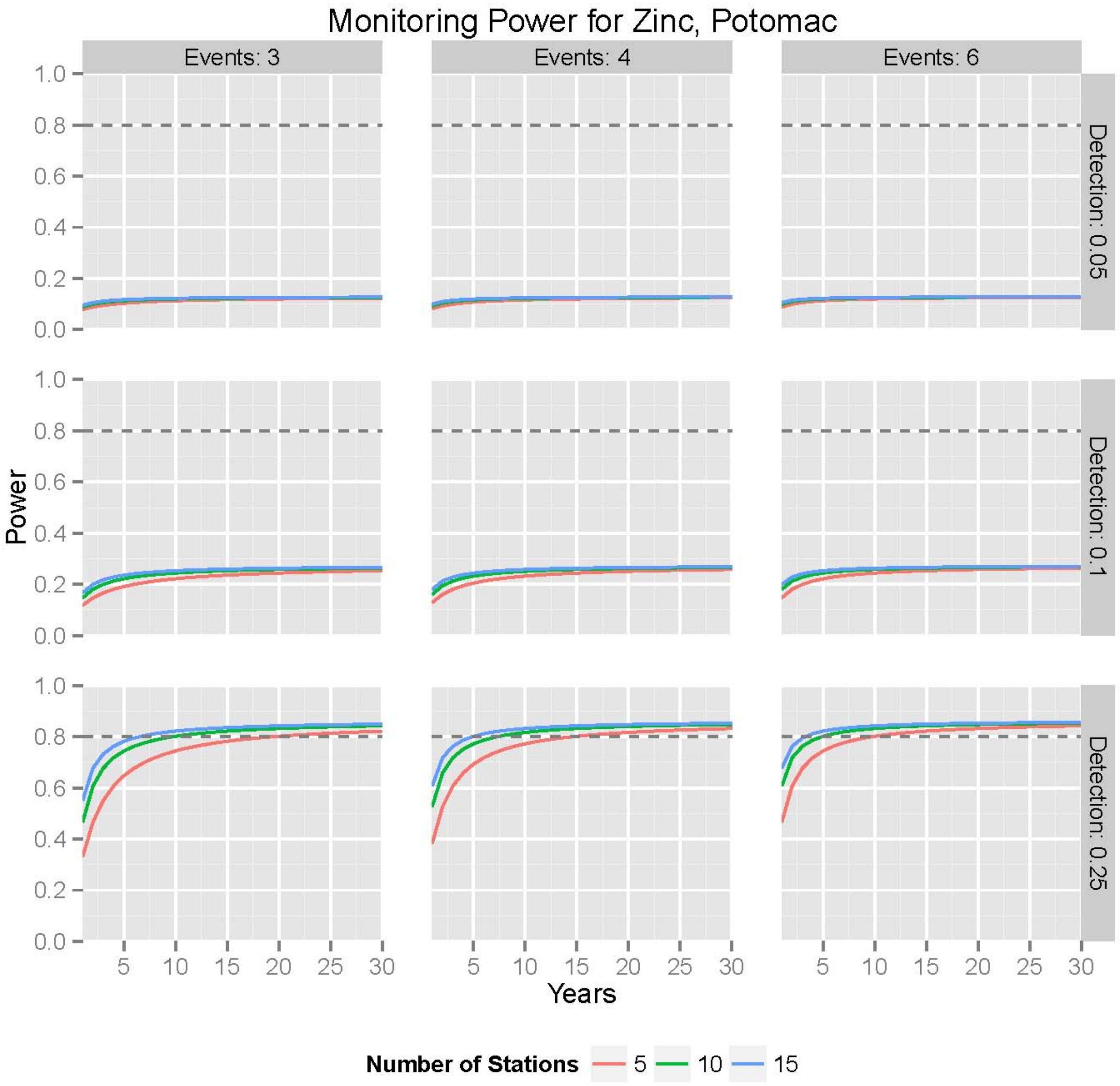

Figure A3-10.: Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Zinc concentrations in the Potomac watershed

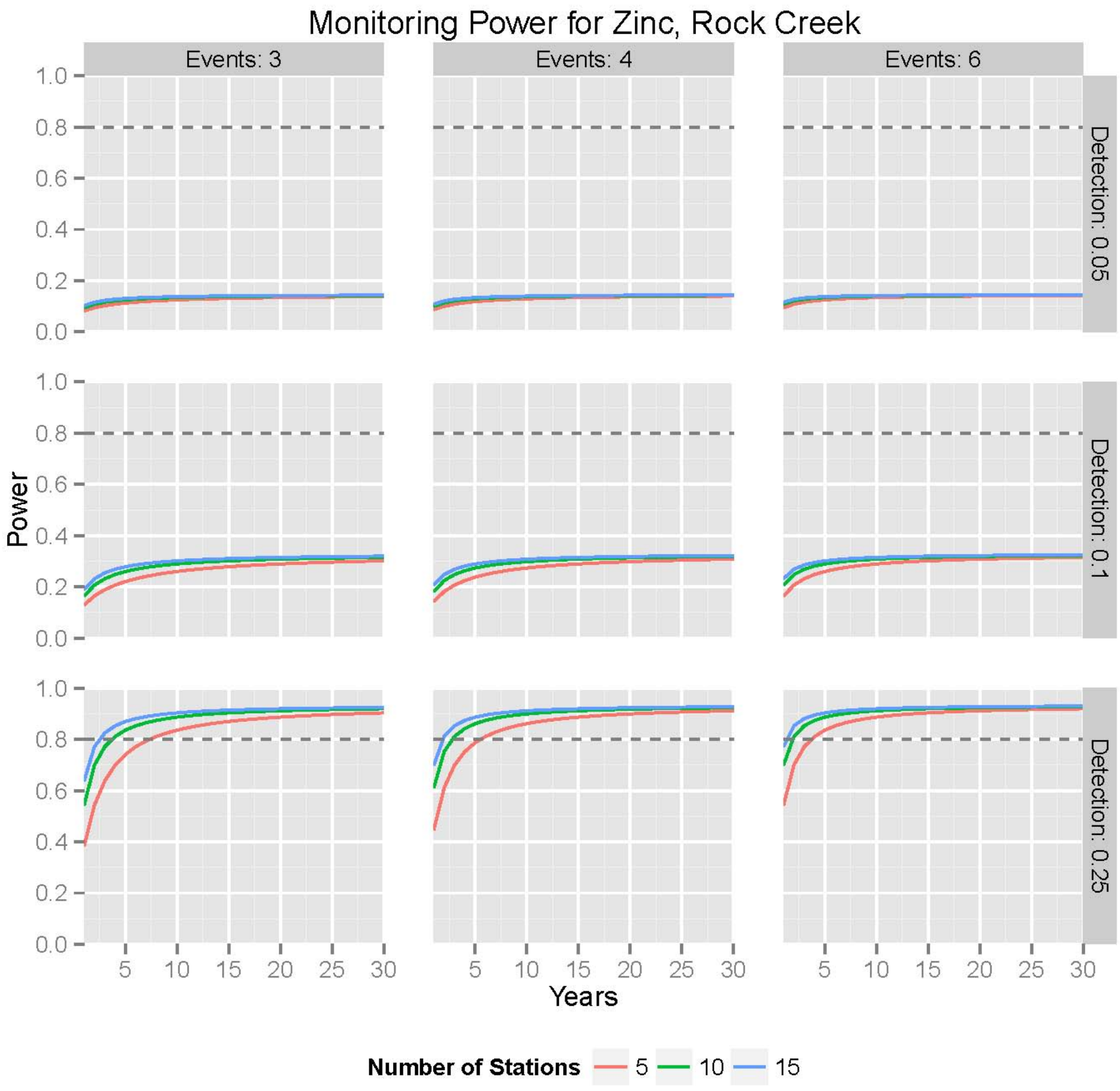

Figure A3-11. Power estimates for event and station combinations, shown for detectable differences of 5%, 10%, and 25% between the baseline and post implementation means of Zinc concentrations in the Rock Creek watershed

References

Jacob Cohen (1988). Statistical Power Analysis for the Behavioral Sciences. 2nd Edition. Routledge, London, UK.

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

APPENDIX 4:

Receiving Water Monitoring Statistical Analysis

Memorandum

From:	B. Crary, H. Bourne, B. Udvardy	**Date:**	3/26/2015
		Project:	Click here to enter text.
To:	J. Champion Click here to enter text.	**CC:**	Click here to enter text.

SUBJECT: **Receiving Water Monitoring Statistical Analysis**

Summary

District Department of Environment's (DDOE's) municipal separate storm sewer system (MS4) permit requires that the health of the receiving waters be evaluated using biological and physical indicators, and that the number of samples, sample frequency, and sampling locations be adequate to ensure that the data are "statistically significant and interpretable" for the detection of long-term trends.

Sampling power estimates were performed with a Mann Kendall test to demonstrate the number of samples required to significantly detect linear trends in concentration. If monthly sampling occurs, true changes of 10% of the original mean per year or greater would be identified within two permit cycles (10 years) at 23 of DDOE's existing 30 monitoring stations with 80% power. This change is not identifiable within 10 years at seven stations because these stations have relatively high variability of concentrations, which makes it difficult to discern trends quickly. More frequent sampling will reduce the overall time required to detect trends of this magnitude. The detection of finer changes (<10%/year) would require an increasingly large number of samples to be statistically significant.

Power and Sample Size Calculations for Long-term Trend Detections of Receiving Waters

DDOE's MS4 permit requires that a monitoring program be developed to allow the District to evaluate the biological and physical health of receiving waters. This permit requires that the number monitoring samples, frequencies, and locations be sufficient to ensure the statistical significance and interpretability of long-term trends (EPA 2011). A power analysis was completed to estimate the number of samples needed to meet this requirement. The analysis uses receiving water quality data previously collected by DDOE at 30 monitoring sites from 2001 to 2013. With these data, a statistical approach was used to determine the number of samples required to detect statistically significant trends of various magnitudes after the implementation of the MS4 program (herein referred to as "post-implementation").

Magnitude of Change

Receiving water monitoring data variability is high within this particular dataset (mean coefficient of variation = 0.97; Table A4-1). Early detection of small trends is made difficult by the high standard deviations compared to the station means, and thus, 10%/year changes from the original mean is defined here as a “small trend”. Changes of this magnitude may be unlikely to be truly occurring, particularly in the early stages of implementation of MS4 programs and practices, but changes of this size may be observed within a reasonable return period (~10 years for each station if monthly sampling occurs). Thus, changes of 10%/year were chosen as a statistical model for this analysis, although an exploration of this variable is presented in Table A4-3 later in this document.

Table A4-1. Station Receiving Water Monitoring Summary Data

Station	n	Mean TSS (mg/L)	Standard Dev.	Current Trend Slope*	Is Current Trend Significant?**
ANA01	141	17.67	11.07	-0.67	Yes
ANA05	81	19.73	9.63	-0.77	Yes
ANA08	96	23.12	11.41	-0.23	No
ANA11	80	23.71	10.73	-0.70	Yes
ANA14	170	23.36	19.36	-0.60	Yes
ANA19	88	17.44	11.56	0.00	No
ANA21	171	15.70	11.60	-0.17	No
ANA24	86	13.64	12.06	0.23	No
ANA28	102	21.65	13.11	-0.24	No
ANA29	102	14.02	19.11	0.00	No
ANA30	92	12.29	8.78	0.00	No
PCW04	100	8.65	6.69	0.00	No
PTB01	69	9.48	5.58	-0.24	No
RCR01	66	18.97	43.96	0.00	No
RCR09	66	17.79	37.06	0.00	No
RCR12	69	10.33	7.78	-0.43	No
TCO01	53	8.68	7.00	0.39	No
TCO06	55	12.31	10.54	0.00	No
TMI01	32	7.78	14.08	0.00	No
DC-C1	28	29.14	61.22	-0.16	No
DC-C2	28	25.46	54.49	0.07	No
DC-C3	27	28.26	65.75	0.00	No
PMS01	48	6.92	5.46	0.00	No
PMS10	87	5.75	3.66	0.00	No
PMS21	86	6.58	5.04	0.00	No

Table A4-1. Station Receiving Water Monitoring Summary Data

Station	n	Mean TSS (mg/L)	Standard Dev.	Current Trend Slope*	Is Current Trend Significant?**
PMS29	82	7.60	4.05	0.00	No
PMS37	49	8.45	4.06	0.00	No
PMS44	40	8.98	4.24	-0.21	No
PMS51	36	10.03	5.68	-0.49	Yes
PMS52	51	7.88	4.10	0.00	No

***Slope is based on Sen's Nonparametric estimate**

****Based on Mann-Kendall Test with existing data**

Statistical Test

As previously stated, a power analysis was performed to estimate the sample size required to detect trends of 10%/year of the station mean with a Mann-Kendall test. A significant trend is defined as have a Type-I error rate of less than 5%. Monte Carlo simulation was used to approximate the sample size required to detect changes of this magnitude with a Type-II error rate of 20% (Power = 80%), assuming that the sample frequency is once a month.

Pollutants of Interest

While the permit requires sample frequencies and locations sufficient to ensure statistical significance, no pollutants are specified for this permit requirement. Upon inspection of the existing monitoring data, it was concluded that TSS would be used for statistical analysis. TSS was chosen for the following reasons:

- TSS has a long and continuous record of concentrations at many sampling stations in each of the Districts three major watersheds.
- TSS commonly serves as a surrogate for the concentrations of other contaminants.
- There are TMDLs in place for TSS within the District.

Statistical Test

Mann – Kendall Trend

Sample size requirements to detect trends of 10% of the pre-implementation mean/year or greater were performed using Monte-Carlo simulation with the Mann-Kendall trend test (MK). The MK test is non-parametric test used to identify whether a monotonic trend exists. Because the test is non-parametric, no normal transformations need to be performed.

The null hypothesis of the MK test is that no monotonic trend exists, and this hypothesis is tested against the alternative that a monotonic trend does exist using the test statistic, Z_{mk}, where:

$$Z_{mk} = \frac{(S-1)}{\sqrt{VAR(S)}}\ if\ S > 0$$

$$Z_{mk} = 0\ if\ S = 0$$

$$Z_{mk} = \frac{(S+1)}{\sqrt{VAR(S)}}\ if\ S < 0$$

The test statistic is computed using a sign indicator value, S, which compares how often later time points less than or greater than earlier time points. S is computed with the following equation:

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} sign(x_j - x_k)$$

Where: $S = sign\ indicator$

$n = number\ of\ samples$

$x = sample\ observation$

$j, k = sample\ time\ pairings\ in\ which\ j > k$

More simply, S is computed by determining the sign of the resulting difference between applicable sample pairings in which the earlier sample is subtracted from the later sample. There are n(n-1)/2 applicable pairings. The test statistic is the number of positive differences – the number of negative differences. A positive S value indicates that later observations are larger than the earlier observations (upward trend) and negative S value indicates that earlier observations are larger than later observations (downward trend).

The variance of S is given by:

$$VAR(S) = 1/18\left[n(n-1)(2n+5) - \sum_{p-1}^{g} t_p(t_p - 1)(2t_p + 5)\right]$$

Where: $g = number\ of\ measurement\ values\ observed\ more\ than\ once, or\ 'tiedgroups'$

$t_p = the\ number\ of\ observations\ in\ p^{th} group$

Once computed, the test statistic, Z_{mk}, is compared to the critical value, Z1-α, of the standard normal distribution. The critical value for a two-sided test with a Type I error rate of α=0.05 is +/- 1.964.

Mann Kendall Power and Sample Size Estimates

Statistical power is defined as the probability of correctly accepting the alternative hypothesis for a given test. As a general rule, power can be increased by increasing the sample size or decreasing the variability of the data. Conventionally, 80% is considered an “acceptable” power.

A Monte-Carlo simulation was implemented in Visual Sample Plan to estimate the number of samples required to detect a trend using the MK test (Pulsipher 2005). One thousand sets of *n* random measurements were generated based on each station’s variability, and power was defined as the number of trend detections that was achieved in the set. The sample size *n* was increased until the desired power of 80% was achieved.

Sen’s Nonparametric Estimate of Slope

Sen’s estimate of nonparametric slope is the median of all individual slope estimates, where individual estimates are made between a measurement at each time point and all measurements at subsequent time points. The slope between two individual points is defined as:

$$Q = \frac{y_j - y_k}{t_j - t_k}$$

Where: $Q = Slope$

$y_{j,k} = measurements\ at\ times\ t_j, t_k$

$t_j, t_k = times\ at\ which\ y_j, y_k were\ measured$

For a sample set of n, there are N = n(n-1)/2 individual slope estimates, and Sen’s nonparametric estimate of slope is the median of all N calculations.

Analysis and Discussion

The analysis found that a ten percent change from the original mean could be identified in 23 of the 30 monitoring stations within two permit cycles (10 years) (Table A4-2). Significant trends could theoretically be monitored within another seven years at the remaining stations with the same sampling frequency. The reason this trend would go undetected at seven stations is the relatively high variability in each station’s data compared to its mean (Table A4-1).

The Mann-Kendall Test considers both upward and downward trends, but it should be noted that downward trends of 10% of the original mean/year would result in concentrations of 0 by year ten. While this does not violate any statistical assumptions, this means that if a significant downward trend of 10% of the original mean/year cannot be detected in 10 years, the trend will go undetected by statistical means by the time there is no pollutant left in the waterbody to detect. The only way to statistically identify such a trend would be to increase sampling frequency.

Table A4-2. Number of Samples Required to Detect an Upward or Downward Trend of 10% of the Pre-implementation Mean per Year

Watershed	Station	Existing Sample Size (n)	Does significant trend currently exist? (alpha = 0.05)*	Number of monthly samples required to detect 10% change of original mean/year**
Anacostia	ANA01	141	Yes	82
Anacostia	ANA05	81	Yes	68
Anacostia	ANA08	96	No	72
Anacostia	ANA11	80	Yes	67
Anacostia	ANA14	170	Yes	101
Anacostia	ANA19	88	No	89
Anacostia	ANA21	171	No	94
Anacostia	ANA24	86	No	106
Anacostia	ANA28	102	No	82
Anacostia	ANA29	102	No	139
Anacostia	ANA30	92	No	90
Anacostia	PCW04	100	No	97
NW Trib	PTB01	69	No	81
NW Trib	RCR01	66	No	199
NW Trib	RCR09	66	No	182
NW Trib	RCR12	69	No	95
NW Trib	TCO01	53	No	98
NW Trib	TCO06	55	No	104
NW Trib	TMI01	32	No	162
Potomac	DC-C1	28	No	186
Potomac	DC-C2	28	No	186
Potomac	DC-C3	27	No	198
Potomac	PMS01	48	No	98
Potomac	PMS10	87	No	84
Potomac	PMS21	86	No	95
Potomac	PMS29	82	No	76
Potomac	PMS37	49	No	70
Potomac	PMS44	40	No	70

Table A4-2. Number of Samples Required to Detect an Upward or Downward Trend of 10% of the Pre-implementation Mean per Year

Watershed	Station	Existing Sample Size (n)	Does significant trend currently exist? (alpha = 0.05)*	Number of monthly samples required to detect 10% change of original mean/year**
Potomac	PMS51	36	Yes	77
Potomac	PMS52	51	No	74

***Mann Kendall non-parametric test with alpha=0.05**

****10% of pre-implantation mean at each station**

It is important to consider whether this magnitude of concentration change is likely to occur. As evident in the results, it takes a large of amount of data to significantly identify a trend of 10% change per/year. This is a very fine level of statistical detection, but it is, perhaps, unrealistic to expect this magnitude of annual reduction or increase in TSS concentration.

The ability to identify trends over time also depends on the sampling frequency. More frequent sampling will allow trends to be revealed more quickly or with more certainty. The effect of variable sampling frequencies and detection levels were explored at station TCO01. Table A4-3 shows that these two parameters can have a large effect on the ability to discern trends. As expected, more frequent sampling reduces the overall time to identify trends and fewer samples are required to detect larger magnitudes of change. Given the enormous efforts required to identify change, the sampling frequencies in this analysis were chosen to accommodate realistic field efforts rather than unrealistic statistical requirements.

Table A4-3. Relationship between Sampling Frequency and Ability to Detect Trends of Various Magnitudes at Station TC001

Sampling Frequency	Number of samples needed to detect an annual change of:			
	5% of original mean	**10% of original mean**	**25% of original mean**	**50% of original mean**
Weekly	411	259	142	89
Two per month	258	163	88	56
Monthly	152	96	54	35
Three per year	61	40	22	15
Annually	31	20	12	9
Sampling Frequency	**Time (in years) needed to detect an annual change of:**			
	5% of original mean	**10% of original mean**	**25% of original mean**	**50% of original mean**
Weekly	7.9	5.0	2.7	1.7
Two per month	9.9	6.3	3.4	2.2
Monthly	12.7	8.0	4.5	2.9
Three per year	15.3	10.0	5.5	3.8
Annually	31.0	20.0	12.0	9.0

Practicality and Limitations

Under the current receiving water monitoring program implemented by DDOE's WQD, samples have been collected semi-monthly for approximately 13 years at the Anacostia stations and approximately eight years at the Northwest Tributary and Potomac stations. A separate Mann-Kendall test was performed on the existing data showed that significant trends only current exist at five of the 30 stations. The inability to detect many existing trends in the receiving water data was due to the large variability of the data and the relatively small sample size for each station (Table A3-1). These results illustrate the extreme difficulty in achieving significant results for trend detection of environmental data, and suggest that future trends may be equally difficult to discern.

While a great effort would be required to detect trends with 'statistical significance', the existing data do provide practical significance. One major practical use of the historical data is the potential to compare this data with future datasets. Such statistical tests such as the t-test or Wilcox rank test may be used to compare the effect of watershed protection efforts by comparing pre- and post-implementation concentrations. Other uses of these data include the ability to inform future sampling plans, provide insight into water quality and health, and allow visual inspection of patterns that may not be measurable with statistics.

References

Matzke, B. D., J. E. Wilson, L. L. Newburn, S. T. Dowson, J. E. Hathaway, L. H. Sego, L. M. Bramer, and B. A. Pulsipher. 2014. PNNL-23211, Pacific Northwest National Laboratory, Richland, Washington.

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

APPENDIX 5:

Field Data Form

GOVERNMENT OF THE DISTRICT OF COLUMBIA
DEPARTMENT OF THE ENVIRONMENT

Natural Resources Administration
Water Quality Division, Planning and Enforcement Branch
Washington, D.C. 20002
Phone: (202) 535-2600; Fax (202) 535-1363

DDOE
DISTRICT DEPARTMENT OF THE ENVIRONMENT

Dry Weather Outfall Inspection Form

Location Information:

Date:		**Time:**		**Outfall ID:**		**Inspectors:**			
Weather and Temperature:									
Outfall Location:									
Proximity to Road:		**Reference Point:**							
Receiving Water Body:		**Material:**		**Shape:**					
Size:		**Structural Condition:**							
Flow:	☐	**No flow**	☐	**Trickle**	☐	**Steady**	☐	**Intermittent**	
If Intermittent, describe:	**Flow rate:**								

Physical Characteristics:

Turbidity:	☐	Clear	☐	Cloudy	☐	Opaque		**Other**
Odor:	☐	None/Natural	☐	Sewage/Septic				**Other**
Floatables:	☐	None	☐	Present				
Oil Sheen:	☐	None	☐	Present				
Vegetation:	☐	None	☐	Present, if yes describe:				
Sediment:	☐	None	☐	Present, if yes describe:				

General Observations:

Any Tests Conducted?	☐	Yes	☐	No			
Temp	°C	pH		D.O	mg/L	Conductivity	mS/cm
Follow-Up required	☐	Yes	☐	No			
Photo Taken	☐		☐		Photo no.		

Results:

Comments:

Actions Taken: