D.C. Water Resources Research Institute
Annual Technical Report
FY 2013

Introduction

This report is a summary of the activities of the District of Columbia (DC) Water Resources Research Institute (WRRI) for the period - March 1, 2013 through February 28, 2014. Hosted under the College of Agriculture, Urban Sustainability and Environmental Sciences (CAUSES) of the University of the District of Columbia, the Institute continued to coordinate water related research, training and outreach activities in the District of Columbia. According to the Sustainable DC plan, 100% of waterways should be fishable and swimmable by 2032. The mission of the Institute is to help the District meet this ambitious goal by providing interdisciplinary research and training support.

For the last 10 years, the Institute has provided seed grants for 74 research projects and trained more than 200 graduate and undergraduate students. The seed grant created the opportunity to train students and new faculty in water science and technology research projects, and leverage extramural funding. Through the Institute, the University of the District of Columbia received $2 million in financial support to build state-of-the-art research and training laboratories for environmental and water quality testing, as well as modeling and simulation.

In FY13, the Institute funded and implemented research activities and training that addressed all water issues, to include identifying city water resources and environmental problems, and contributing to their solutions. Nearly 50 graduate and undergraduate students were trained on the high-end analytical technologies from various majors such as water resources, environmental science, civil engineering, computer science and food science. The Institute's new Environmental Quality Testing Lab is equipped with the latest model of Inductive Couple Plasma Mass Spectrophotometer, Gas Chromatograph Mass Spectrophotometer, and Time of Flight Mass Spectrophotometer with Direct Sample Analyzer. The modeling and simulation lab has key Environmental Protection Agency (EPA) approved models that applies for the Total Maximum Daily Load assessment as well as Geographical Information System. The Institute continues developing and maintaining new environmental quality testing and modeling tools to advance water research and training at UDC.

In addition, the Institute has been working closely with other organization in the region and landgrant centers in CAUSES to conduct outreach and information transfer activities. In collaboration with the American Water Resources Association in the National Capitol Region (AWRA-NCR), the Institute organized the 2nd Annual Water Symposium on April 4, 2014, at the University of DC. This symposium, designed based upon the previous year's success, sought to bring together experts from government agencies, academia, the private sector and non-profits to discuss challenges and opportunities for sustainable management of water resources and infrastructure in the region. In addition, in close collaboration with other landgrant centers in CAUSES, such as the Center for Sustainable Development, the Center for Urban Agriculture, and the Center for 4-H and Youth Development, the Institute conducts outreach activities by distributing newsletters, media releases and factsheets, and training and attracting youth to prepare them to the water sciences and technologies.

Research Program Introduction

In FY 2013, the Instituted funded four research projects that address the three components of integrated urban water system: storm water runoff and sewer system, the wastewater treatment plant and receiving waters. The Institute is also working towards establishing certified environmental that can support all water projects in DC area and beyond. Dr. Arash Massoudieh's project introduces the Bayesian parameter estimation technique that can be applied to the optimization of activated sludge operations at the Blue Plains Wastewater Treatment Plant, one of the largest wastewater treatment plants in the world. Optimization of this large plant is crucial for energy efficiency and treatment to reduce the impact of effluent quality on the Chesapeake Bay watershed.

Dr. Charles Glass's work focuses on the evaluation of the effectiveness of different green infrastructure devices in removing stormwater runoff contaminants. The three devices in this study are identified as: bioswale, swale-bioretention and bioretention. The effectiveness of the green devices was analyzed based on the laboratory analysis of both the influent and the effluent quality for 10 storm events. The findings of this work are crucial for selecting green devices that can significantly improve stormwater runoff quality and thereby improve DC waterways.

Dr. Caroline Solomon's project focuses on studying the effect of organic nitrogen (urea) from combined sewer overflow on the productivity and physiology of harmful algae in the Anacostia River. In this project, water samples were collected at 10 sites and analyzed for nutrient concentrations, bacteria and phytoplankton composition, nitrogen uptake and assimilation enzyme rates. The finding of this project provides better understanding of the impact of combine sewer overflows and organic N in the Anacostia River.

Finally, the primary goal of Dr. Kobina Atobra's research project was to assess the existing data of the ground water quality in DC and plan for regular monitoring. The objective of this research is to establish the protocol and guidance for a continuing long term, consistent monitoring of in organic chemicals, nutrients and other constituents found in the groundwater of the District of Columbia, as well as improving the tracking and modeling of chemical and physical changes that will be essential during the next decade to distinguish trends in groundwater quality and quantity.

Monitoring Groundwater for Developing Alternative Source of Water Supply for Homeland Security in the District of Columbia

Basic Information

Title:	Monitoring Groundwater for Developing Alternative Source of Water Supply for Homeland Security in the District of Columbia
Project Number:	2013DC148B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	DC
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Water Quantity
Descriptors:	None
Principal Investigators:	Kobina Atobrah, Tolessa Deksissa

Publications

There are no publications.

Monitoring Groundwater for Developing Alternative Source of Water Supply in the District of Columbia: Progress Report

By

Tolessa Deksissa and Kobina Atobrah
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May, 2014

Abstract

The purpose of this project is to assess the available data pertaining to groundwater quantity and quality in the District of Columbia as planning phase to establish a long term monitoring stations. Groundwater in urban settings is not only the last reserve for water supply, but it is also the ultimate sink for persistent urban pollutants. During dry season, surface water supply depends mainly on ground water discharge through baseflow to streams. Furthermore, when surface water is contaminated either by natural or manmade processes, ground water can be an alternative source for water supply. District of Columbia, like most urban areas, is on the fast track of industrial development with increased activities of construction, remodeling or tunneling that are likely to significantly impact the quality and quantity of its groundwater. To explore if ground water can augment the water supply in DC, regular monitoring of ground water is critical. The objective of this project was to establish the protocol and guidance for a continuing long term monitoring of ground water quantity and quality in the District of Columbia, and to improve the tracking of changes in ground water quantity and quality that will be essential for sustainable water resources management of the district. This preliminary study showed that exploring or gathering of more ground water quantity and quality data is crucial to determine the current status as well as predict the future trend of DC ground water quality.

1. Introduction

Ground water was the first as well as is the last reserve to meet the future demand for water supply in the global urban expansion. When surface water supply is limited, cities must import or purchase water from other cities or exploit their ground water reserves (Chowdhury et al. 2013; Ku et al, 1992). During dry season, surface water supply mainly depends on ground water. Approximately 75% of community water systems in U.S. rely on ground water (U.S. Environmental Protection Agency, 2002).

Nevertheless, the potential of ground water as an alternative source for water supply in an urban setting is not explored in the Nation’s capital. Ground water provides a critical source of water for agricultural irrigation and industries (Garduno and Foster, 2010). When natural disasters such as hurricanes or manmade processes impair the existing surface water supply, uncontaminated ground water can be an alternative source. Furthermore, the growth of urban farming to address global warming and food insecurity may potentially increase water demand in urban areas. In that case surface water supply can be augmented by groundwater (Ortega-Reig et al., 2014).

The District of Columbia, like any other growing cities, is on the fast track of industrial development with increased activities of construction, remodeling or tunneling that are likely to significantly impact the quality and quantity of the underlying groundwater in various ways. Increased surface imperviousness can potentially lower ground water levels as a result of reduced infiltration of precipitation. Contaminated urban runoff and combined sewer overflows in pervious area can contaminate the ground water. Contaminated soil or land can potentially impact the ground water quality (Ayotte et al., 2014).

The scope of this study was three folds. First to explore how thirteen monitoring wells installed 20 years a go by UDC can be applied for continuous monitoring and trend analysis of ground water quality and quantity in DC. Second, to compile available data related to ground water contamination in DC. Third, to explore the potential use of urban ground water as an alternative source for water supply in DC.

2. Available Monitoring Wells

Based on previous studies, there is a significant number of monitoring wells in DC that can potentially be used for ground water quantity and quality studies. In 1989, D.C. Department of Consumer and Regulatory Affairs tasked the University of the District of Columbia's Water Resources Research Center with assessing the ground water resources of the District of Columbia (DC WRRC, 1993). Based upon their request, and to complement the already available ground water information, thirteen wells (Table 1) were installed as part of the Ground Water Resource Assessment Study. These wells were installed to assess the ambient ground water quality and quantity within the city's main geological formations and to provide information on impacts of non-point source pollution on the groundwater.

As presented in DC WRRC (1993), the locations of the thirteen wells are presented in Table 1 and Figure 1. Five wells (MW-1, 2, 3, 4, 5) were installed for monitoring the hydrologic characteristics, whereas eight other wells were installed to assess the impact of nonpoint source pollution in shallow ground water in community gardens (MW-A1,2,3 and MW-B1,2,3) and a golf course (MW-C1,2). The physical and hydraulic characteristics of these thirteen wells vary widely among the four aquifer types and within each aquifer. Highest transmissivities were found for the Potomac Group Aquifer and localized areas within the surficial aquifer. Both local and regional flow patterns exist in the District of Columbia. The local flow systems correspond to the surface water drainage basins of the Potomac River, the Anacostia River, Rock Creek and Oxon Run.

In 2002, the U.S. Geological Survey installed three monitoring wells in the tidal part of Anacostia River watershed (Miller and Klohe, 2003). Two wells were installed at the New York Avenue overpass, two wells at the Kenilworth Aquatic Gardens, and one well at Anacostia Park.

In 2005 and 2008, the USGS in collaboration with the DC Department of the Environment investigated the ground water quality of 31 wells in the district (Figure 2). Most monitoring wells are located in the Anacostia River watershed, whereas three wells are in Rock Creek watershed and only one well on the Potomac River watershed.

Table 1: The Table below show the depth, Aquifer Media, Location and methods used to installs the (13) Wells.

Well	Depth (ft.)	Aquifer Media	Location	Method
MW-1	250	Unconsolidated clay, sand	Ft. Dupont Park, SE	Hydraulic (Mud) Rotary
MW-2	50	Unconsolidated fill, sand, gravel, clay	New York Ave and 1st Street, NW	Hollow – Stem Auger
MW-3	100	Massive/ fracture rock	Dalecarlia Parkway, NW	Air – Percussion Rotary
MW-4	30	Unconsolidated fill, sand, gravel, clay	Massachusetts Ave and Constitution Ave, NE	Hollow – Stem Auger
MW-5	22	Unconsolidated fill, sand, gravel, clay	1st and N St, SW	Hollow – Stem Auger
MW-A 1, 2, 3	22	Unconsolidated fill, sand, gravel, clay	Peabody St. & 8th St, NW	Hollow – Stem Auger
MW-B 1, 2, 3	19	Unconsolidated fill, sand, gravel, clay	Nannie Helen Burroughs Ave & 48th Street, NE	Hollow – Stem Auger
MW-C 1, 2	18	Unconsolidated Saprolite	Rock Creek Golf Course Hole 17	Hollow – Stem Auger

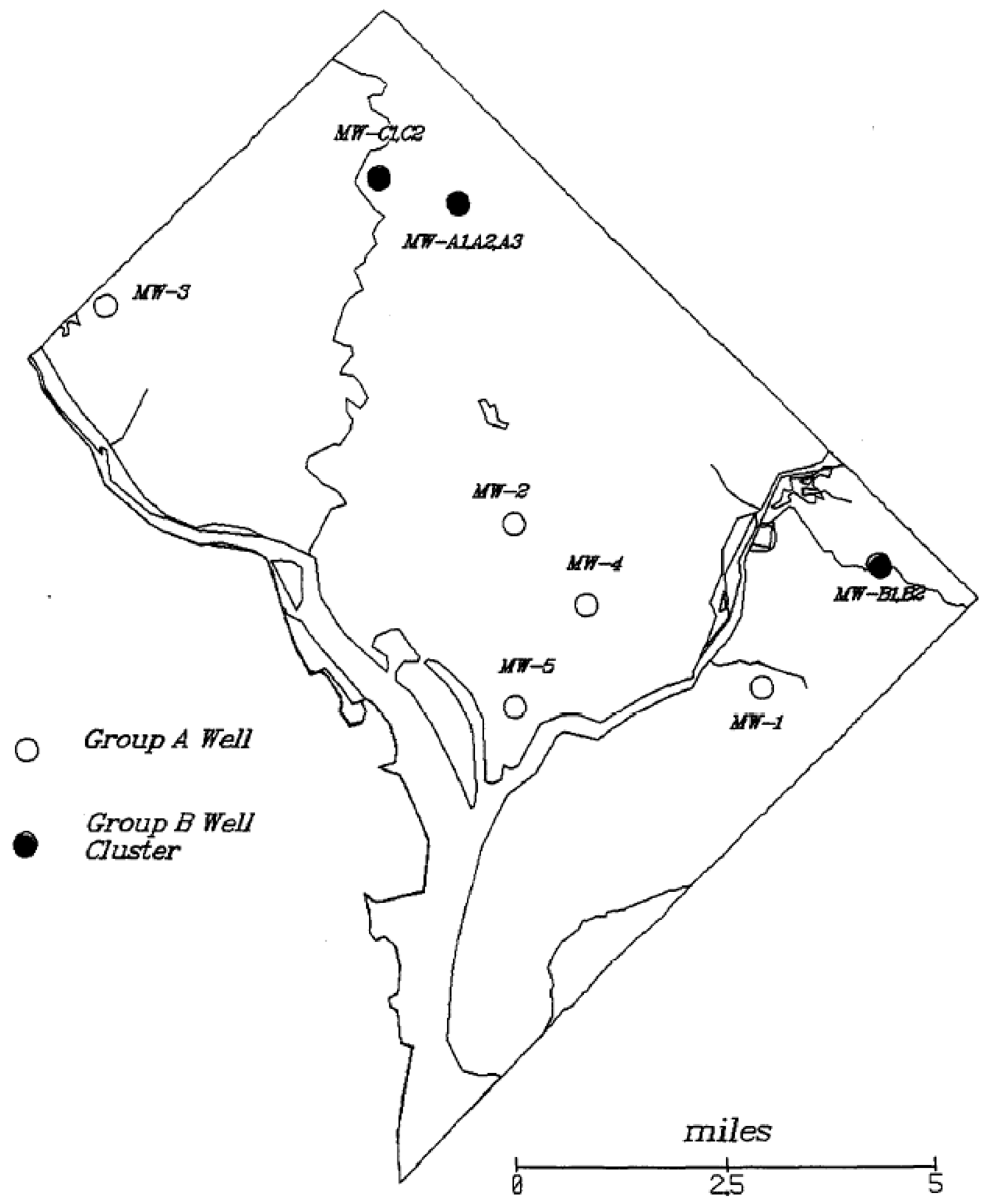

Figure 1: General location map of ground water monitoring wells installed during the ground water resource assessment study (after DC WRRC, 1993)

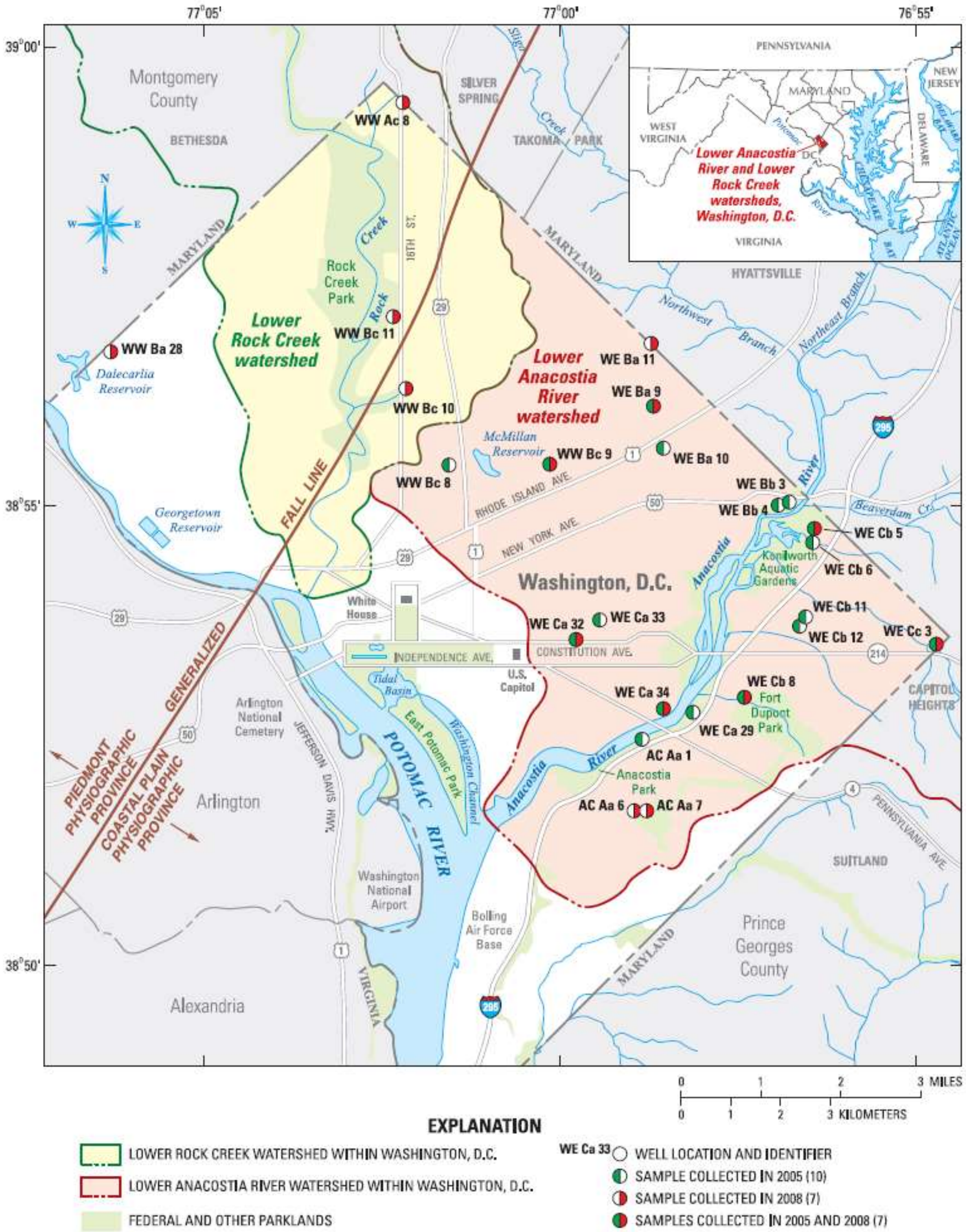

Figure 2: Location of USGS monitoring site for pesticide analysis in 2005 and 2008 (after USGS, 2010), including lower parts of the Anacostia River and Rock Creek watersheds, and Federal and other parklands in Washington, D.C.

3. Groundwater Level

In an urban setting, both ground water rise and depletion are important issues which must be addressed in sustainable water resources management. Groundwater depletion can be due to less pervious layer of the system, whereas groundwater level rise is mainly due to leakage from sewer system or main water break or leakage from distribution system (Sharp et al., 2003). Monitoring data showed that groundwater level can rise up to 20 feet after nearby water main break in DC (DCWRRC, 1993). Regardless of groundwater use for water supply, such potential rise of ground water levels must be an integral part of urban water resources management.

4. Ground water Quality

4.1. Basic water quality

Urbanization can affect ground water quality in various ways. Shallow aquifers can be contaminated by runoff from paved surfaces, leaky storage tanks, surface spills, illegal dumping of hazardous waste, and leaky sewage lines (Sharp et al., 2003). In this study, ground water quality can be discussed in two categories. The 1^{st} category is basic water quality, including specific conductivity, pH, nitrate, total dissolved solids and metals. The 2^{nd} category is based on organic contaminants.

In the District of Columbia, 13 wells (Figure 1) were installed in 1992 through 1993 for monitoring both basic and organic contaminants in ground water (DC WRRC, 1993). The average pH values for nine (9) wells ranged from 4.9 – 7.8 with five (5) out of nine (9) below the minimum of the EPA water quality standards range of 6.5-8.5. The average Specific Conductance measured values for the year 1992-1993 ranged from 114.86 – 964.75 micromhos/cm . The average dissolved solids ranged from 85.25 – 583.30 ppm with three (3) out of nine (9) wells exceeded the EPA standard of 500 ppm. In general, the chemistry of well water during this year is within the normal range of typical ground water quality except dissolved solids.

In 2005 and 2008, the average specific conductance ranged from 74 - 1550 micromhos/cm. In 2005 and 2008 the pH measured values for fourteen (14) monitoring wells ranged from 4 – 7.4 with eleven (11) out of fourteen(14) below the minimum of the EPA water quality standards range of 6.5-8.5.

4.2. Pesticide contamination

Based on the 13 monitoring wells installed by UDC in 1989, the presence of pesticides was investigated as a base line study. It was concluded that the pesticide chlordane was the only substance detected during the Ground Water Resources Assessment Study from MW-5 in October of 1992 and 1993, but the detected concentration of 2 ppb does not exceed the Maximum Contaminant Level specified by U.S EPA (0.002 mg/l, 40 CFR Part 141.61). In 1989, there was no pesticide detected above the EPA standards in all wells. For a more detailed picture of pesticide occurrence in ground water and its potential contribution to the water quality of the District's rivers, it is advisable to test the ground water quality in or near residential areas as pesticide application near houses for indoor pest control. Such a project would require the installation of some more monitoring wells, which would not only provide data on the question of pesticides in the ground water, but would also enable the District of Columbia to enhance its picture of the ground water resource in general.

During July-August 2002 (Miller and Klohe, 2003), the U.S. Geological Survey assessed ground water and sediment quality in the tidal part of Anacostia River watershed. The chemical analyses included volatile organic compounds, semi-volatile organic compounds or polyaromatic hydrocarbons, organochlorine pesticides, aroclors and total polychlorinated biphenyls, metals, nutrients, biochemical and chemical oxygen demands, total phenols, total cyanide, oil and grease, and total suspended and dissolved solids in aqueous phases. The results showed that all contaminants were below the EPA reporting level except at the Benning Road monitoring well.

In 2005 and 2008, USGS investigated the presence of pesticides in 31 wells (Koterba et al., , 2010), including groundwater samples from 17 wells in the lower Anacostia River watershed from September through December 2005, and from 14 wells in the lower Anacostia River and lower Rock Creek watersheds from August through September 2008. The results showed that twenty-seven pesticide compounds were detected in the groundwater samples. No fungicides were detected. In relation to the pesticides detected, the concentration of the 27 compounds is below the Federal drinking-water standards.

Summary

Urbanization modifies the hydrology and chemistry of ground water. These modifications include systematic variation with hydrogeological setting, for example unconfined oxygenated aquifer allow free vertical movement of water and pollutants from the built infrastructure, whereas confined anoxic aquifers obstruct vertical water movement and are less prone to pollution but more readily over exploited. It is therefore crucial to determine the type of existing monitoring wells before planning for continuous groundwater quality monitoring. This preliminary study showed that collection of more groundwater quantity and quality data is crucial to determine the current status as well as predict the future trend of DC ground water. To develop comprehensive plan and guidelines, a close collaboration with DC Department of Environment and US Geological survey is needed to generate a more consistent and long term groundwater monitoring system in DC.

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Stormwater Quality Management with Green Infrastructure: Nannie Helen Burroughs Avenue

Basic Information

Title:	Stormwater Quality Management with Green Infrastructure: Nannie Helen Burroughs Avenue
Project Number:	2013DC152B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	DC
Research Category:	Engineering
Focus Category:	Water Quality, Water Quantity, Treatment
Descriptors:	
Principal Investigators:	Charles Glass

Publications

There are no publications.

Stormwater Quality Management with Green Infrastructure: Nannie Helen Burroughs Avenue

Watershed Name: Middle Potomac-Anacostia-Occoquan
HUC: 02070010

STATES: DC, MD, VA

Submitted by:

Charles Glass, Ph.D.

Department of Civil and Environmental Engineering

Howard University

Submitted to:

DC Water Resources Research Institute,

University of the District of Columbia

May 5, 2014

EXECUTIVE SUMMARY

The purpose of this research was to evaluate the effectiveness of three variations of green infrastructure devices in the removal of stormwater contaminants for ten storm events along Nannie Helen Burroughs Avenue in Washington, D.C. This was done by collecting representative samples of stormwater from both the influent and the effluent of the bioretention cells for laboratory analysis. The three devices in this study are identified as: bioswale, swale-bioretention and bioretention. The general order of performance in descending order was: the bioretention, the bioswale and the swale-bioretention. For all three devices the effluent quality was significantly improved, in aggregate for all pollutants, than the influent stormwater.

The Swale-bioretention produced negative results for total dissolved solids, copper, cadmium, nitrite, nitrate and ammonia. The percentage removals for these pollutants were -564%, -24%, -10%, -50%, -9% and -8.33% respectively. The Bioswale produced negative results for total dissolved solids, lead and total phosphorus with percentage removals of -91%, -25% and -44% respectively. The Bioretention produced negative results for total dissolved solids, cadmium and zinc with -98%, -7% and -18% removals respectively. These poor results could be as a result of poor or lack of routine and periodic maintenance which includes; replacement of sub-soil mix, annual replacement of much layer and proper maintenance of plant material (Maryland Department of Environmental Resources (DER), 2007, Yu, S. L et al., 2001).

Contents

TABLE OF ACRONYMS

- DDOT - District Department of Transportation.
- QA - Quality Assurance
- QAPP - Quality Assurance Project Plan
- BMPs - Best Management Practices
- GHI - Green Highway Initiative
- DDOE -District Department of the Environment
- (DC)WASA – District of Columbia Water and Sewer Authority
- LID - Low Impact Development
- NPDES - National Pollutant Discharge Elimination System
- MS4 - Municipal Separate Storm Sewer System
- BMPs - Best Management Practices
- TSS - Total Suspended Solids
- BOD_5 - 5-day Biochemical Oxygen Demand
- COD - Chemical Oxygen Demand
- TDS - Total Dissolved Solids
- TN - Total Nitrogen
- AAS - Atomic Absorption Spectroscopy®
- PAHs - Polycyclic Aromatic Hydrocarbons
- HPLC - High-Performance Liquid Chromatographic
- IC – Ion Chromatograph
- AEMC - Average Event Mean Concentration
- SOL - Summation of Loads

1. INTRODUCTION

Urbanization has important hydrologic and environmental implications (O'Driscoll et al., 2010; Gunn et al., 2012). Hydrologic impacts of urban expansion can be seen in increasing runoff rate and volume, decreasing soil-water, decreasing groundwater recharge and baseflow, decreasing interception and evapotranspiration (Harbor, 1994; Tang et al., 2005), and degradation of water quality in both streams and shallow groundwater due to urban waste discharge, industrial discharge, leakage from waste disposal grounds, and nonpoint source pollutant losses (USEPA, 2000). Urban runoff is rapidly becoming a major source of non-point source pollution (US EPA, 1996) and has been found to be a leading impairment source for surface waters and ground water. In 1997, Bang et al. indicated that the street solids and sewer-deposited material are major pollutants in urban runoff.

The District of Columbia is served by the Municipal Separate Storm Sewer System (MS4) and Combined Sewer System (CSS). During a storm event, some of the stormwater collected by these systems are discharged directly into the rivers causing human health effects as well as problems for the aquatic species present. Again, during runoff, suspended material and other debris transported to the sewer systems often block the systems. In order to prevent sewer blockages and improve the quality of the stormwater before reaching the sewer systems, catch basins are installed in urban locations. Catch basins are, however, completely ineffective at removing dilute pollutants from stormwater runoff. Other best management practices (BMP's) have been evaluated for the past couple of decades that are much more effective at reducing pollutants of interest before they enter natural water bodies.

The District of Columbia Department of Transportation (DDOT) commissioned the evaluation of the efficiency of three BMP's utilized by DDOT roadway infrastructure. The specific BMP's of interest in this project were a Bioswale, swale-bioretention, and bioretention.

Bioretention is a best management practice (BMP) developed in the early 1990's by the Prince George's County, Maryland, Department of Environmental Resources (PGDER). Bioretention is a terrestrial-based, water quality and water quantity control practice using the chemical, biological, and physical properties of plants, microbes, and soils for removal of pollutants from stormwater runoff. Some of the processes that may take place in a bioretention facility include sedimentation, adsorption, filtration, volatilization, ion exchange, decomposition, phytoremediation, bioremediation, and storage capacity. This same principle of using biological systems has been widely used in agricultural and wastewater treatment practices for retention and the transformation of pollutants and nutrients.

The objective of this research was to evaluate the effectiveness of three green infrastructure devices in the removal of stormwater contaminants for fifteen storm events in the District of Columbia with the hope to restore urban watersheds through the use of Green Highway Initiative principles and Low Impact Development while revitalizing an urban arterial. Representative samples of the "first-flush" of stormwater runoff were collected at the inlet and outlet points of the devices and transported to the laboratory for analysis. Data was collected based on the amount of rainfall and pollutant concentrations present in the influent and effluent runoff were accessed.

2. BACKGROUND

This project to evaluate three green infrastructure devices was a part of a total green street development program. The larger project was funded through the D.C. Government Capital Improvements Program. The total $5.7 million dollar budget was slated for design and construction of roadway Streetscape, Streetlights, Traffic Signals and best management practices for water quality along the entire 1.5 mile long corridor. Both the community and DDOT wished for the Nannie Helen Burroughs project to become the District of Columbia's first model "green street" and replicable throughout the District. DDOT utilized innovative Green Highway Initiative (GHI) and low impact development (LID) approaches to provide improved water quality of stormwater within the available budget. The technical GHI and LID approaches were implemented at the overall road plan level and the design level. The overall planning included evaluating a "road diet" that may reduce the roadway width and travel lanes while maintaining transportation and mobility throughout. "Surplus" space was available to expand non-motorized transportation facilities such as sidewalks and bicycle lanes, and provide space for additional street trees and bioretention facilities. Portions of the existing concrete and/or asphalt roadway were removed to create these facilities. The design concepts were developed and presented to the community for input.

The basic concepts behind these LID techniques are part of the Anacostia Waterfront Initiative and Great Streets Transportation Plans. The acceptance and buy in of these concepts by the community is well documented. Therefore, they have a high probability of feasibility and long-term acceptance by the community. The techniques will be selected through the collaborative effort of the partners, led by DDOT. The criteria will include environmental effectiveness, community acceptance, and the feasibility of the technique to achieve the listed multiple objectives. Howard University will participate in public meetings with DDOT throughout the project to provide input on the amount of maintenance that is required to maintain the performance of selected LID.

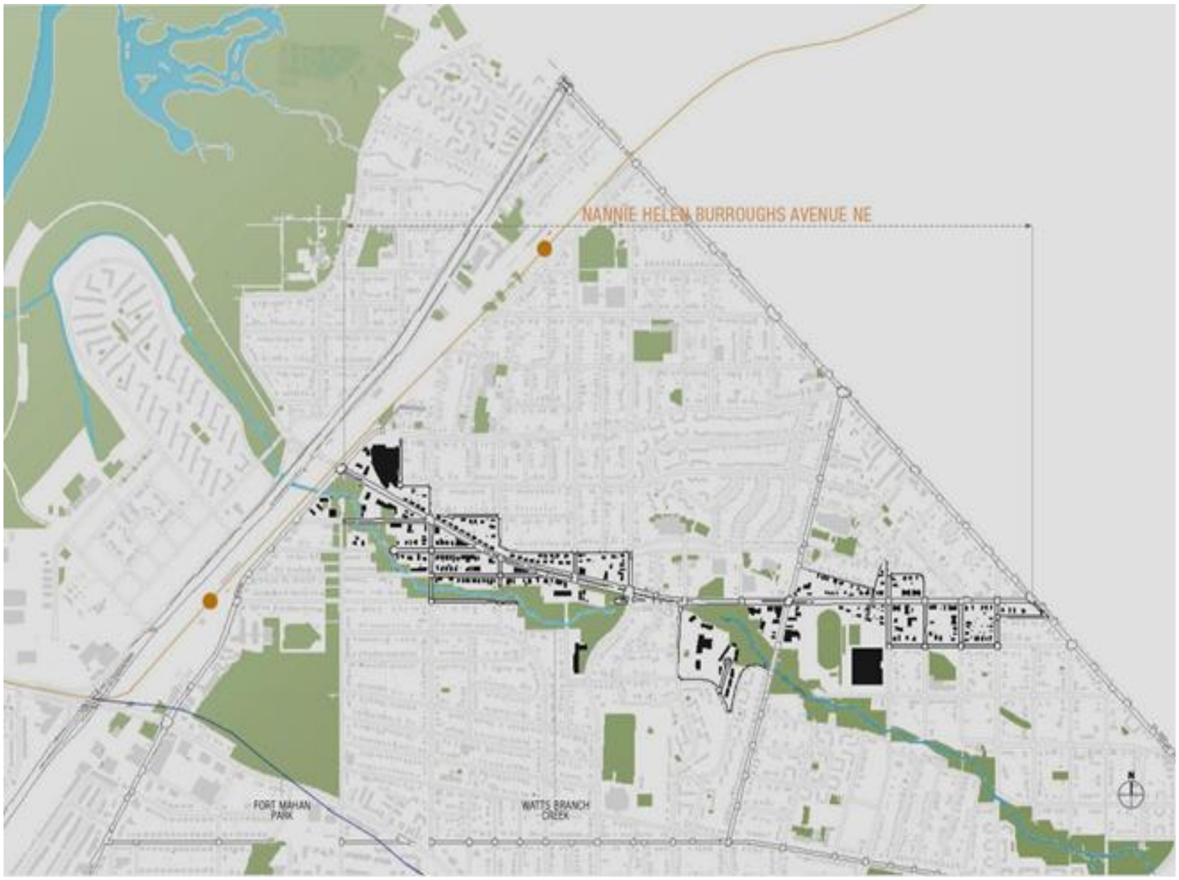

Figure 1. Project Area Map

The infrastructure along this road prior to reconstruction was dilapidated and was selected for this project because significant improvements and enhancements were required. The Nannie Helen Burroughs Avenue corridor, (see Figure 1), is adjacent to the Watts Branch and riparian buffer to Watts Branch, but lacks street trees along long segments that could provide vital canopy, shade, habitat, and stormwater management. The roadway had more travel lanes than are required for the current volume of traffic and thus had more impervious surface area than necessary. There are a number of storm sewers running under Nannie Helen Burroughs that discharge directly into Watts Branch. Additionally, the previous neglected condition of the roadway contributed to a general appearance of neglect and disinvestments along the length of the corridor, which impedes economic development in the area.

The driving force behind the physical, chemical, and biological degradation of Watts Branch is enhanced stormwater flow and rate of flow. Vast areas of impervious surface cause these flows by prohibiting infiltration, leading to flashy, intense flow conditions in the stream channel, even during moderate storm events. It is envisioned that Watts Branch will become a quality community stream and park system comparable to the National Park Service's Rock Creek Park in Northwest DC. Improving the infrastructure along the Nannie Helen Burroughs Avenue corridor will assist in achieving this vision of restored habitat, water quality, and aesthetics. Extensive stream restoration have been completed in Watts Branch by DDOE, however all of the work on this project will be performed adjacent to the Nannie Helen Burroughs Avenue and will not include improvements to water quality that are a result of those restoration efforts.

2.1 PROJECT DESCRIPTION

This project was designed to address the needs of DDOT to evaluate the impact of stormwater pollution from runoff from pervious surfaces and the effectiveness of LID devices to mitigate those impacts. Under the National Pollutant Discharge Elimination System (NPDES), Municipal Separate Storm Sewer System (MS4), the government is tasked to utilize best management practices (BMPs) to substantially minimize pollution transport from stormwater runoff.

The purpose of this grant is to assist DDOT in developing an institutional framework and action plan to restore urban watersheds through the use of GHI principals and LID while revitalizing an urban arterial.

The Howard University, Department of Civil and Environmental Engineering, monitored three three water quality BMP structures constructed by DDOT as a part of the overall Project. The locations for these structures was identified by DDOT before the rainy season begins in the spring of 2012. The sampling and monitoring of the approved BMP's were performed in accordance to the 40 CFR 122.26 (d)(2)(iii). The parameters tested were as follows:

1. TSS - Total Suspended Solids
2. COD - Chemical Oxygen Demand
3. TDS - Total Dissolved Solids
4. TN - Total Nitrogen (TKN + NO_2 + NO_3)

   Measured as Total Kjeldahl Nitrogen + Nitrite-Nitrogen(NO_2) + Nitrate-Nitrogen(NO_3)
5. Oil and Grease (Polycyclic Aromatic Hydrocarbons, also known as semi-volatile organic compouds)

   Naphthalene, Acenaphthene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(ghi)perylene, Indeno(1, 2, 3-cd)pyrene.
6. TP - Total Phosphorus
7. Ortho- Dissolved Phosphorus

8. Cd - Cadmium

9. Cu - Copper

10. Pb - Lead

11. Zn - Zinc

12. Cr - Chromium

13. As - Arsenic

14. pH and Temperature

15. Measure of Sediment Accumulation

The Howard University, Department of Civil and Environmental Engineering was expected to assist DDOT in identifying catch basins to monitor before construction was completed, and if possible before construction had begun in the catchment area. This was not possible due to delays in the awarding of the grant to Howard University. After installation of the new GHI and LID devices monitoring began in April of 2012 through September 2012. Because of contractual issues monitoring ceased from November 2012 – May 2013, then began again in May 2013 and finished at the end of September 2013. The same parameters were analyzed using the same protocols as performed during the two monitoring phases.

3. LITERATURE REVIEW

Today in the United States, stormwater pollution has become a primary non-point pollution source of concern. And according to the United States EPA stormwater pollution still remains a leading cause of water body impairment (US EPA, 2011). Stormwater treatment has therefore become very necessary in urban and suburban areas to manage stormwater runoff. However, this has proven difficult because of the number and varieties of point and non point sources. To deal with these setbacks, various stormwater best management practices (BMPs have been developed and implemented which include rain gardens (bioretention), bioswales, stormwater wetlands, and others (USEPA, 2000; Davis, 2005).

3.1 Urban Stormwater Best Management Practices:

Best Management Practices (BMPs) also known as low impact development practices (LIDs) are micro-scale control practices used to bring the natural hydrology of a site close to that of its predevelopment conditions (Coffman, 2002; HUD, 2003). They are used to manage and improve the quality of stormwater runoff (Strecker et al,. 1992). Structural BMPs are engineered and constructed systems that are used to treat stormwater runoff. Non-structural BMP's are pollution prevention practices designed to reduce the amount of pollutants present in stormwater runoff. Urban stormwater BMP's are implemented to control flow, removal pollutants and reduce pollutant source.

It is very important to control stormwater runoff flow rates because increased flow rates increase erosion. Urban stormwater BMPs reduce flow rates by storage, infiltration, and natural forms of hydrologic control. A wide range of pollutants can be removed from stormwater runoff with the use of properly designed and maintained structural BMPs (Strecker et al,. 1992). Stormwater

BMP’s utilize various chemical and physical operations to remove pollutants from stormwater. Some of these processes include filtration, absorption, nitrification, settlement, and oxidation. The implementation of Stormwater BMPs is driven by four fundamental hydrologic considerations: control of runoff volume, control of peak runoff rate, control of flow frequency, and control of water quality (PG County, 1999).

Bioswales:

Bioswale is the general term given to any vegetated swale, ditch, or depression that conveys stormwater. The fully vegetated bioswale and the open channel bioswale are the two basic types of vegetated swales based upon the degree of vegetation. Research revealed that the trapezoidal fully vegetated bioswale is the most effective bioswale at removing pollutants. Open channels do not add much more than infiltration to the process of removing pollutants. Bioswales provide good treatment of stormwater runoff without the extensive maintenance required for some other stormwater BMPs. When bioswales are well maintained and the residence time of water in a swale increases, pollutant removal rates increase. The effectiveness of bioswales is also dependent upon the retention time of the stormwater in the bioswale. The longer the retention time, generally, the higher the removal efficiency.

Stormwater runoff contributes pollutants to streams, rivers and lakes. Pesticides, herbicides, and fertilizers come from residential lawns, commercial landscaping, and recreational facilities like golf courses. Residuals also leach from lands that were previously farmland. Heavy metals in stormwater come from vehicles, buildings, roofs, and industries. Oil and grease drip regularly from cars onto streets and parking lots. Pathogens and bacteria in runoff can come from pet waste, broken or leaking sanitary sewers, wildlife, or sanitary sewer overflows. Bioswales can remove a large amount of pollutants found in stormwater runoff. Bioswales have achieved high levels of removal of suspended solids (TSS), turbidity, and oil and grease (DEQ NWR, 2003). They can also remove a moderate percentage of metals and nutrients in runoff. This lower level of removal compared to sediment or oil and grease is partly due to the large percentage of metals and nutrients that are dissolved in runoff.

Bioswale Monitoring and Performance

The effectiveness of bioswales at removing pollutants can be measured in two ways. The first is by measuring the particular pollutants of interest by their concentrations in water entering and exiting the bioswale and calculating the difference. This method does not account for the infiltration of the pollutants along the length of the bioswale which may be released at some future time or have to be remediated in the future. The second method involves performing a mass balance of pollutants in the bioswale throughout the length of the bioswale. This method will result in information on the amount of pollutants retained in the soil and vegetation of the bioswale.

Table 1 Bioswale removable efficiencies

Pollutant	Removal
Total Suspended Solids (TSS)	83 - 92%
Turbidity (with 9 minutes of residence)	65%
Lead (Pb)	67%
Copper (Cu)	46%

Total Phosphorus (TP)	29 - 80%
Aluminum (Al)	63%
Total Zinc	63%
Dissolved Zinc	30%
Oil/Grease	75%
Nitrate-N (NO_3-N)	39 - 89%

Source: DEQ NWR, 2003

Swale Bioretention:

Bioretention swales provide both stormwater treatment and conveyance functions. These systems consist of both elements of a vegetated swale and a bioretention system. These components are subtly different and the main function of the swale is that of conveyance while the primary function of the bioretention component is the promotion of soil filtration of stormwater. The swale may have a discharge capacity to convey stormwater flow for frequent events (Barling et al, 1993).

The swale component provides pretreatment of stormwater to remove coarse to medium sediments while the bioretention system removes finer particulates and associated contaminants. Bioretention swales provide flow retardation for frequent storm events and are particularly efficient at removing nutrients.

Bioretention swale performance:

Test results showed that bioretention swales removed 85%, 70% and 45% of Total Suspended Solids, Total Phosphorus and Total Nitrogen respectively (Woodfull J et al. 1993).

Bioretention

Bioretention is a terrestrial-based water quality and water quantity control practice that uses the chemical, biological, and physical properties of plants, microbes, and soils for removal of pollutants from stormwater runoff.

The system was initially developed by the Prince George's County Department of Environmental Resources (PGDER) in Maryland (US EPA, 1999). Even though the system is a non-structural BMP, it is usually engineered and placed strategically to provide treatment. Processes such as filtration, sedimentation, absorption, ion exchange, nitrification and denitrification, and decomposition allow the Bioretention to treat a wide range of pollutants present in influent stormwater.

The use of bioretention does not only provide for water quality and quantity control, but also adds value to a development. It brings landscape diversity into the built environment, establishes a unique sense of place, encourages environmental stewardship and community pride, provides a host of additional environmental benefits, increases real estate values up to 20 percent by using aesthetically pleasing landscaping.

Bioretention Performance

Bioretention uses chemical, physical, and biological processes to remove pollutants from stormwater. The ability of the bioretention to perform several different types of pollutant removal makes it an effective low impact device. The bioretention is designed to treat first-flush stormwater runoff since that is when stormwater has its highest pollutant load (US EPA, 1999).

Several studies have been conducted on the performance of bioretention and their effectiveness in removing pollutants in stormwater.

Table 2 Laboratory bioretention removal efficiency

Pollutants	**Removal Rates**
Total Phosphorus	70-83%[1]
Metals (Cu, Zn, Pb)	93-98%[1]
TKN	68-80%[1]
Total suspended solids	90%[2]
Organics	90%[2]
Bacteria	90%[2]

Source: Davis et al., 1998; PGDER, 1993

Highway Runoff Characteristics:

Highway runoff characteristics has been summarized based on: aggregate water quality parameters, metals constituents, nutrient constituents, and other less frequently measured water quality parameters such as fecal indicator bacteria, toxicity, polycyclic aromatic hydrocarbons (PAHs), and herbicides and pesticides.

Conventional and aggregate water quality parameters:

These include: total suspended solids (TSS), total dissolved solids (TDS), dissolved organic carbon (DOC), total organic carbon (TOC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), oil and grease, hardness as $CaCO_3$, temperature and pH. The three most frequently measured aggregate parameters are TDS, COD and oil and grease.

Metals constituents:

Metal constituents in the literature generally include aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), and zinc (Zn). Metal pollutant concentrations vary within each continent and between continents.

Nutrients:

Selective nutrients monitored from different studies include nitrates, nitrites, ammonium, total Kjehldal nitrogen (TKN), total nitrogen, phosphate and total phosphorus (TP). Nitrogen and phosphorus constituents can be transformed in the environment from dissolved to particulate forms or from one dissolved form to another, with an overall impact that can be substantial. The sources of nitrogen and phosphorus species measured in highway runoff may be related to both traffic and non-traffic sources.

4. MATERIALS AND METHODS

4.1 Stormwater Sampling

This project was contracted to collect influent and effluent for 15 storm events. In actuality 10 storms were sampled conducted from May, 2012 to September, 2013 due to inconsistencies in rainfall and arrival at the sites after storms had ended resulting in missing effluent. Table 4.1 lists the sample dates and the rainfall measurements at the National Airport weather station. Influent and effluent samples were evaluated with a 3 day minimum dry period between collection samples in order to ensure an adequate antecedent dry period for pollutants to accumulate after the previous storm.

Table 4.1 Sampling Dates

Sampling Date	Event Number	Samples Collected	Rainfall (Inches)
6/12/2012	1	Site 1inlet, 2inlet and 3inlet	0.26
6/26/2012	2	Site 1inlet	0.28
7/9/2012	3	1inlet, 2inlet, 2outlet and 3inlet	0.69
7/19/2012	4	Site 1inlet, 1outlet and 2inlet	0.42
8/26/2012	5	All except 3inlet	0.28
9/1/2012	6	All sites	1.64
9/19/2012	7	All sites except 1outlet	0.93
9/31/2012	8	All sites except 1outlet	0.49
6/29/2013	9	All sites	0.64
9/21/2013	10	All sites except 1outlet	0.72

4.2 Sample Storage and Preservation

Samples were labeled and carefully handled to prevent misidentification and cross contamination. After collecting the samples, they were prepared for storage or analyzed by the team at the Howard University laboratory in accordance with the protocol of Table 4.2 on the same day.

The following parameters were measured on the influent and effluent water of the three catch basins; pH, temperature, total suspended solids, total dissolved solids, chemical oxygen demand, nutrients (ammonia, nitrite, nitrate, phosphate), heavy metals such as mercury (Hg), Cadmium (Cd), Copper (Cu), Lead, (Pb), Chromium, Arsenic (As) and 16 Polycyclic Aromatic Hydrocarbons (PAH), associated with oil and grease. The 16 PAHs were; Naphthalene, Acenaphthene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(ghi)perylene, Indeno(1, 2, 3-cd)pyrene.

The accuracy of both the equipment and the sampling methodology were determined by performing these tests in triplicate. In addition, the instruments were also calibrated by creating a standard curve with at least five known values, in triplicate.

Table 4.2. Parameters Measured and the Technique Required

Constituent Name	**Analytical Method**	**Collection method**	**Containers**	**Preservative**	**Maximum holding time**
Cadmium	AAS- Furnace	Composite	Plastic, Glass	Filter on site HNO_3 to PH<2	6 mths
Chromium	AAS- Furnace	Composite	Plastic,	Filter on site	6 mths

			Glass	HNO_3 to PH<2	
Copper	AAS- Furnace	Composite	Plastic, Glass	Filter on site HNO_3 to PH<2	6 mths
Lead	AAS- Furnace	Composite	Plastic, Glass	Filter on site HNO_3 to PH<2	6 mths
Arsenic	AAS- Furnace	Composite	Plastic, Glass	Filter on site HNO_3 to PH<2	6 mths
Zinc	AAS- Furnace	Composite	Plastic, Glass	Filter on site HNO_3 to PH<2	6 mths
TS-Total Solids	Total Solids Dried at 103-105°C	Composite	Plastic, Glass	Cool, 4°C	24 hrs
TDS- Total Dissolved Solids	Total Dissolved Solids Dried at 180°C	Composite	Plastic, Glass	Cool, 4°C	24 hrs
TSS-Total Suspended Solids	Total Suspended Solids Dried at 103-105°C	Composite	Plastic, Glass	Cool, 4°C	24 hrs
COD	Closed reflux, Colorimetric Method	Composite	Glass	Filter on site H_2SO_4 to PH<2	No holding (better)
Nitrogen Ammonia	Ammonia selective Electrode	Composite	Plastic, Glass	Cool, 4°C H_2SO_4 to PH<2	24 hrs
Nitrogen-Nitrite	Ion Chromatography	Composite	Plastic, Glass	Cool, 4°C	No holding (better)
Nitrogen-Nitrate	Ion Chromatography	Composite	Plastic, Glass	Cool, 4°C H_2SO_4 to PH<2	24 hrs
Soluble (dissolved) Phosphorus	Ion Chromatography	Composite	Plastic, Glass	Filter on site Cool, 4°C	48 hrs
PAH-Poly Aromatic Hydrocarbon	HPLC	Composite	Glass	___	___
Temperature	Thermocouple	Measurement on site	Plastic, Glass	Determine on site	No holding
pH	pH-probe	Measurement	Plastic,	Cool, 4°C	6 hrs

		on site	Glass	Determine on site	

Table 4.3 Summary of the 16 Polynuclear Aromatic Hydrocarbons (PAH) Monitored

Analyte	CAS No.	Screening Criteria	Project Quantitation Limit	Standard Methods (21st Edition) MDLs (µg/L)
Acenaphthene	83-32-9	50 µg/L	5 µg/L	1.8
Acenaphthylene	208-96-8	50 µg/L	5 µg/L	2.3
Fluorene	86-73-7	50 µg/L	5 µg/L	0.21
Phenanthrene	85-01-8	50 µg/L	5 µg/L	0.64
Anthracene	120-12-7	50 µg/L	5 µg/L	0.66
Fluoranthene	206-44-0	50 µg/L	5 µg/L	0.21
Pyrene	129-00-0	50 µg/L	5 µg/L	0.27
Benzo(a)anthracene	56-55-3	50 µg/L	5 µg/L	0.013
Chrysene	218-01-9	50 µg/L	5 µg/L	0.15
Benzo(b)fluoranthene	205-99-2	20 µg/L	2 µg/L	0.018
Benzo(k)fluoranthene	207-08-9	30 µg/L	3 µg/L	0.017

Analyte	CAS No.	Screening Criteria	Project Quantitation Limit	Standard Methods (21st Edition) MDLs (µg/L)
Benzo(a)pyrene	50-32-8	30 µg/L	3 µg/L	0.023
Dibenzo(a,h)anthracene	53-70-3	20 µg/L	2 µg/L	0.030
Benzo(ghi)perylene	191-24-2	30 µg/L	3 µg/L	0.076
Indeno(1,2,3-cd)pyrene	193-39-5	30 µg/L	3 µg/L	0.043
Naphthalene	91-20-3	50 µg/L	5 µg/L	1.8

4.3 Analytical Methods

Upon arrival in the laboratory with the samples, the influent and effluent readings were taken for the temperature and pH on the 1 Liter jars from the different catch basins. The pH, Temperature and total dissolved solids were measured using the multiparameter probe. All measurements were performed in triplicate.

Total Suspended Solids: The method used to perform the TSS measurements is the Total Suspended Solids at 103-105 °C (Standard Methods, 21st Ed.). In this method, the weight of the glass-fiber filters and the aluminum dish were taken and recorded as B, mg. The sample was stirred and 60 ml of sample poured onto a glass-filter with applied vacuum. After the vacuum was turned off, the filter was removed from the filtration apparatus and transferred to the weighed aluminum dish. The sample was dried in an oven at 103-105 °C for 1 hour. The sample and dish were then taken out and allowed to cool to room temperature. After cooling, they were weighed again and recorded as A, mg. The difference between A and B gives the total suspend solids in mg.

Chemical Oxygen Demand: The Chemical Oxygen Demand test was used to determine the organic content of samples. The samples were analyzed using the HACH COD Reactor and UV Spectrophotometer. All samples were refrigerated at 4 °C. The method for low range sample concentration (HACH Water Analysis Handbook, 1989) was used throughout the analysis.

Nutrients: The nutrients that were analyzed in the laboratory included nitrite (NO_2^-N), nitrate (NO_3^-N), phosphate (PO_4^{-3}-P), and ammonia (NH_3-N).

Nitrite (NO_2-N), nitrate (NO_3-N), phosphate (PO_4^{-3}-P), (NH_3-N) were analyzed using the Dionex ICDX-120 instrument and an attached AS 40 Automated sampler unit. The procedure involved preparing 100 ppm stock solution as standards. In this case, AS14A and CS12 were the guard and analytical columns used to analyze the anions and cations, respectively.

The presence of heavy metals in the samples was analyzed using Atomic Absorption Spectroscopy (AAS) through a furnace module (800 Aanalyst, Perkin-Elmer Corporation, Norfolk, CT). The AAS is composed of AAanalyst 800 and AS 800 Auto sampler including a WinLab 32 software. During the analysis, Matrix modifiers for each of the specific heavy metals were included in the analysis to determine their accuracy. In order to preserve the heavy metal samples, 1.5 mL of HNO_3 per liter of sample was used to lower the pH to approximately 2. The samples were filtered with 0.45 µm non-sterile syringe filters before the analysis and to maintain the accuracy of the results, all lab analysis was performed within required storage time (APHA, 2005).

Polycyclic Aromatic Hydrocarbons: The method for determining the polycyclic aromatic hydrocarbons (PAHs) was accomplished using the high-performance liquid chromatographic (HPLC) method. The HPLC is an analytical system complete with column supplies, high-pressure syringes, detectors, and compatible strip-chart recorder (APHA, 2005). Extraction was done by pouring 100ml of the sample into a 500mL separatory funnel and adding 15 mL of methylene chloride. The sample was shaken and allowed to settle down for about 10 minutes. After the extraction, the sample was separated in a RotoVapor R-210 machine and Acetonitrile added to it. The samples were then filtered with a 0.2 µm non-sterile syringe filters. After placing the filtered samples in vials, analysis of the samples were performed in a Dionex SumMit HPLC machine.

Rainfall Data taken from the National Weather Service Data from the Rain Station at Reagan National, which given the variability of rain is only an estimate of the rain the fell at the four sites. Rain gauges used at previous sites were repeatedly destroyed or stolen.

3.4 Data Analysis

The USEPA (1983) has two basic methods for computing pollutant removal efficiency of stormwater devices (FHWA, 2002). The average event mean concentration efficiency ratio (E_{emc}) and summation of loads efficiency ratio (E_{sol}), both expressed as percentages:

$$E_{emc} = \left(1 - \frac{AEMC_{out}}{AEMC_{in}}\right) \times 100$$

$$E_{sol} = \left(1 - \frac{AEMC_{out}}{AEMC_{in}}\right) \times 100$$

AEMC is the average event mean concentration and SOL is the summation of loads. In and Out represent inflow and outflow. In order to calculate loads the product of event mean concentration and the volume of storms have to be calculated. AEMC and SOL can be calculated for all of the storms monitored or computed on a per storm basis, which can be more accurate, but is also more expensive and due to budgetary constraints was not considered for this project. In this project, because it was deemed too costly to calculate the flow rates into and out of each device, we are limited to calculating the AEMC only. Using the AEMC can be biased: it does not show the possible values or information on the changes in concentration associated with storm magnitude. However, given the constraints of this project, calculating the AEMC was the only avenue for analyzing the data given the fiscal constraints already mentioned.

5. RESULTS AND DISCUSSION

5.1 Performance criteria

All three devices that were evaluated have very different design characteristics and therefore attained varied performance. In order to evaluate the relative performances of each BMP the USEPA's freshwater priority (Table 5.1) and non-priority (Table 5.2) pollutant guidelines were used. This was chosen as stormwater treatment systems effluent ultimately feed fresh water bodies and therefore should adhere to these standards. Raw data for all sites are presented in the appendix.

Table 5.1 Chronic Priority Pollutants for Fresh Water

Pollutant	**Chronic Concentration (ppb)**
Copper	9
Cadmium	0.25
Zinc	120
Chromium	11
Lead	2.5
Arsenic	150

EPA

Table 5.2 Non-priority Pollutants (US EPA)

Pollutant	**Concentration (mg/L)**
pH	6.5-9.0
Dissolved Oxygen	Dependent
Temperature	Dependent
TSS	80
TDS	250

PAH	0
Total Nitrogen	10
Total Phosphorus	0.1

US EPA

5.2 Bioswale Results

The results for the NHB Bioswale were average as some of the parameters regularly met required standards. Satisfactory removal rates were achieved for TSS, $NH_{3,}$ NO3, PO_4 and COD contaminants with the system achieving 55%, 93%, 90%, 100% and 56% removal respectively as shown in Table 5.3. Chromium and arsenic also showed satisfactory results with 80% and 21% removal respectively. Of note were the concentrations of Copper, Cadmium, Zinc, and Lead. All of these priority contaminants were above acceptable levels in both influent and effluent concentrations for all storm events evaluated. Non-priority pollutants did not achieve removal rates as high as other bioretentions in other studies however the concentrations were within a reasonable range. The average pH of all 10 events influent and effluent were 7.03 ± 0.12 and 7.44 ± 0.15 respectively.

Table 5.3 Summary of Bioswale Data

Contaminant	**Influent Avg. and Std. Dev.**	**Effluent Avg. and Std. Dev**	***Removal Efficiency***
pH	**7.03** ±0.12	**7.44**±0.14	
Temp. (°C)	**25**	**26**	

TSS	**275 ± 82**	**125 ± 48**	***55%***
TDS	**81.36 ± 35**	**156 ± 24**	***-91%***
Cu	**70**	**25**	***64%***
Cd	**40**	**38**	***5%***
Zn	**162**	**150**	***7.4%***
Cr	**2.0**	**0.40**	***80%***
Pb	**7**	**9**	***-28%***
As	**1.92**	**1.51**	***21%***
TP	**0.75 ± 0.4**	**1.08 ± 0.2**	***-44%***
PO_4^{-3}	**0.23 ± 0.02**	**0.0 ± 0.1**	***100%***
NO_2^-	**0.58 ± 0.12**	**0.3 ± 0.5**	***48%***
NO_3^-	**0.2 ± 0.3**	**0.02 ± 0.15**	***0%***
NH_3	**.15 ± 0.0**	**.01 ± 00**	***93%***
COD	***87 ± 3.3***	***38 ±3.63***	***56%***

5.3 Swale-bioretention Results

The results for the NHB Bioswale were good with most of the parameters regularly meeting required standards. Satisfactory removal rates were achieved for TSS, TP, $PO_4$and COD contaminants with the system achieving 71%, 48%, 78% and 47% removal respectively as shown in Table 5.4. Zinc, chromium, lead and arsenic also showed satisfactory results with 22%, 55%, 86% and 90% removal respectively. Of note were the concentrations of Copper and

Cadmium. These priority contaminants were above acceptable levels in both influent and effluent concentrations for all storm events evaluated. Non-priority pollutants like ammonia, nitrates and nitrites did not achieve removal rates as high as other bioretentions in other studies however the concentrations were within a reasonable range. The average pH of all 10 events influent and effluent were 6.7 and 6.8 respectively.

Table 5.4 Summary Swale-bioretention Data

Contaminant	**Influent Avg. & Std. Dev.**	**Effluent Avg. & Std. Dev**	***Removal Eff.***
pH	**6.7**	**6.8**	
Temp. (°C)	**22.6**	**21.8**	
TSS	**62 ± 34**	**18 ±13**	***71%***
TDS	**28**	**186**	
Cu	**8.33**	**10.33**	***-24%***
Cd	**37.3**	**41**	***-10%***
Zn	**122.3**	**95**	***22%***
Cr	**4.27**	**1.89**	***56%***
Pb	**3.75**	**0.5**	***86%***
As	**8.83**	**0.93**	***90%***
TP	**1.98**	**1.03**	***48%***
PO_4^{-3}	**1.1**	**0.24**	***78%***

NO_2^-	**0.16**	**0.24**	***-50%***
NO_3^-	**0.33**	**0.36**	***-9%***
NH_3	**0.24**	**0.26**	***-8.33%***
COD	***113*±37.49**	***60*±1.02**	***47%***

5.4 Bioretention results

The results for the NHB bioretention were good as most of the parameters regularly met required standards. TSS and TDS results were both below chronic concentrations. Chromium, lead and arsenic also showed good results with system achieving 71%, 33% and 27% respectively as shown in table 5.5. Of note were the concentrations of copper, cadmium and zinc. All of these priority contaminants were above acceptable levels in both influent and effluent concentrations for all storm events evaluated. Non-priority pollutants did not achieve removal rates as high as other bioretentions in other studies however the concentrations were within a reasonable range. The average pH of all 10 events influent and effluent were both 6.68 $\pm$ 0.25 and 6.66 $\pm$ 0.45 respectively. COD concentrations were consistently below 160 mg/L with the exception of event 10 which rose above 400mg/l. NO_3^- concentrations for all events were below the recommended EPA standard of 10 mg/L as all events measured concentrations below 1.5 mg/L. The total phosphorous concentrations for all 10 events were above the suggested standard of 0.1 mg/L although the bioretention showed a removal efficiency of 49%.

Table 5.5 NHB Bioretention results

Contaminant	**Influent Avg. and Std. Dev.**	**Effluent Avg. and Std. Dev**	***Removal Efficiency***
pH	**6.68±0.25**	**6.7±0.45**	
Temp. (ºC)	**22**	**21**	
TSS	**111**	**72**	***35%***
TDS	**109**	**216**	
Cu	**22**	**16**	***27%***
Cd	**41**	**44**	***-7%***
Zn	**108**	**127**	***-18%***
Cr	**7**	**2**	***71%***
Pb	**3**	**2**	***33%***
As	**3.3**	**2.4**	***27%***
TP	**1.12**	**0.67**	***49%***
PO_4^{-3}	**1.31**	**0.4**	***68%***
NO_2^-	**0.15**	**0.14**	***6%***
NO_3^-	**1.3**	**1.0**	***23%***
NH_3	**0.34**	**0.04**	***88%***
COD	**77±7.01**	**49±4.37**	***36%***

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Recommendations

The data from this study are quite unique. In the graphs that are presented on all of the devices there are often holes in the graphs. For instance, there were 10 storms sampled, however for 6 of those storms, site 1, a long swale with seven inlets, did not produce any effluent. Although we have classified site one as a swale, it has at least four feet of depth between the top of the soil and the perforated PVC pipe that serves as an underdrain. From the standpoint of performance in withholding stormwater this is excellent. From the perspective of stormwater sampling this produces few results. Also, the lack of homogeneity in field sampling gave rise to high standard deviations in the results.

The three best management practices were compared using the removal efficiencies of selected significant pollutants present in stormwater. Results from the field study reveal that the best performing system is the Bioretention as it achieved the highest number of pollutants below the required standard. The bioretention system however showed poor performance in the removal of Cadmium and Zinc, achieving -7% and -18% removal respectively. The field results also show that bioswale can be effective for the removal of heavy metals in the following order: chromium 80%, copper 64%, Arsenic 21%, zinc 7.4% and cadmium 5%

Based on results from this study, the following research areas are recommended:

- To evaluate the performance of the BMPs during different seasons and under different conditions.
- To evaluate the fate and transfer of the different contaminants held within the different systems.

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Bayesian Parameter Estimation of Activated Sludge Processes In Blue Plains Waste Water Treatment Plant

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Bayesian Parameter Estimation of Activated Sludge Processes in Blue Plains Waste Water Treatment Plant: Final Report

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1. Executive Summary

In this project a Bayesian hierarchical modeling framework have been developed and used for probabilistic parameter estimation of bio-kinetic and stoichiometric parameters using real data collected at full-scale nitrification-denitrification (Nit-DeNit) reactors at the Blue Plains Wastewater Treatment Plant. Bayesian parameter estimation approach is capable of explicitly considering different sources of uncertainty and providing the Joint Probability Density Functions (JPDFs) of stoichiometric and kinetic parameters. Parameter JPDFs can then be used for chance-constrained design and optimization of the reactor. In the Bayesian approach, the prior information regarding the parameters obtained from the literature or independent laboratory studies can be incorporated into the analysis. The method also provides the posterior correlations between the parameters as well as measures of the overall sensitivity of different constituents with respect to each of the parameters that can be used to design pilot studies effective in determining the parameters. The method is demonstrated by applying the simplified version of a one-step nitrification whole plant model in Sumo (Dynamita, France) to observed concentration of a number of constituents at different stages of a Nit-DeNit reactor at the Blue Plains wastewater treatment plant (WWTP) in Washington, DC. The results indicate that data from full-scale systems can narrow down the ranges of some parameters substantially while the level of information they provide regarding other parameters can be small due to either large correlations between parameters or lack of sensitivity with respect to them under the operational condition of the reactor. The study also shows strong correlations among some biokietic and stoichiometric parameters under the operational condition of the reactor.

2. Introduction

Activated Sludge Models (ASMs) are widely used for the design and optimization of various unit processes in wastewater treatment plants (WWTP). As mechanistic models, their main goal is to predict the WWTP behavior under different conditions, and they are employed as tools for design and operation optimization of activated sludge systems. Optimization of Activated Sludge processes can substantially reduce the energy use and the amount of BOD and nutrients being discharge into receiving waters. This issue becomes even more important for plants that treat combined sewage and therefore experience a high level of fluctuations in both the volume and composition of wastewater (as in the District of Columbia). Optimizing the Activated Sludge operations at DC's Blue Plains WWTP is even more important in face of the efforts to restore the Chesapeake Bay.

The outcomes of ASM models are directly influenced by various sources of uncertainty including, which if not identified and accounted for correctly, will result in un-trustable predictions. The major sources of uncertainty include:

1. Uncertainty in model parameter values that is caused by measurement or calibration error.
2. Model input data uncertainty, i.e. uncertainties associated with influent and effluent characterization due to both measurement error and spatial and temporal heterogeneities in the system.
3. Model structural uncertainty, i.e. no ASM model perfectly represents the compartments, processes, and interactions of the real system.
4. Uncertainty associated with the numerical methods used within the model (truncation errors) [1].

The most important challenge for making ASM models applicable is identifying the values of its many stoichiometric and kinetic parameters. Despite the vast research efforts in the past, to this date, there exists no globally accepted calibration procedure for Activated Sludge reaction parameters. Also, in all approaches used so far, the uncertainty associated with the estimation of model parameters due to errors in influent and effluent data, model structural and numerical errors have been ignored.

The main goal of this project has been to develop a flexible Bayesian calibration framework that is capable of including the different sources of uncertainty in Activated Sludge Systems. The method has been applied to data collected at Blue Plains and this in hand will result in optimizing the processes of the plant. Consequently, this will improve the efficiency of the plant, minimize the energy consumption and cost of operation and reduce the amount of nutrients discharged into Potomac River.

3. Methods

a. Field Data – Full scale operation

This study has used field data gathered between February and June of 2010 from the nitrification-denitrification (Nit-DeNit) phase of the Blue Plains WWTP, in Washington, DC. A schematic of this stage is given in Figure 1. These field data can be divided into three groups: 1) daily flow rates and influent/effluent characteristics, 2) daily methanol loading rates, and 3) weekly sampling of characteristics within individual bio-reactors of the Nit-DeNit phase. These measurements include concentrations of total/volatile suspended solids (TSS/VSS), biodegradeable substrate (Ss), and nitrogen (NH3, NOx). The flowrate and influent data are shown below in Figure 2.

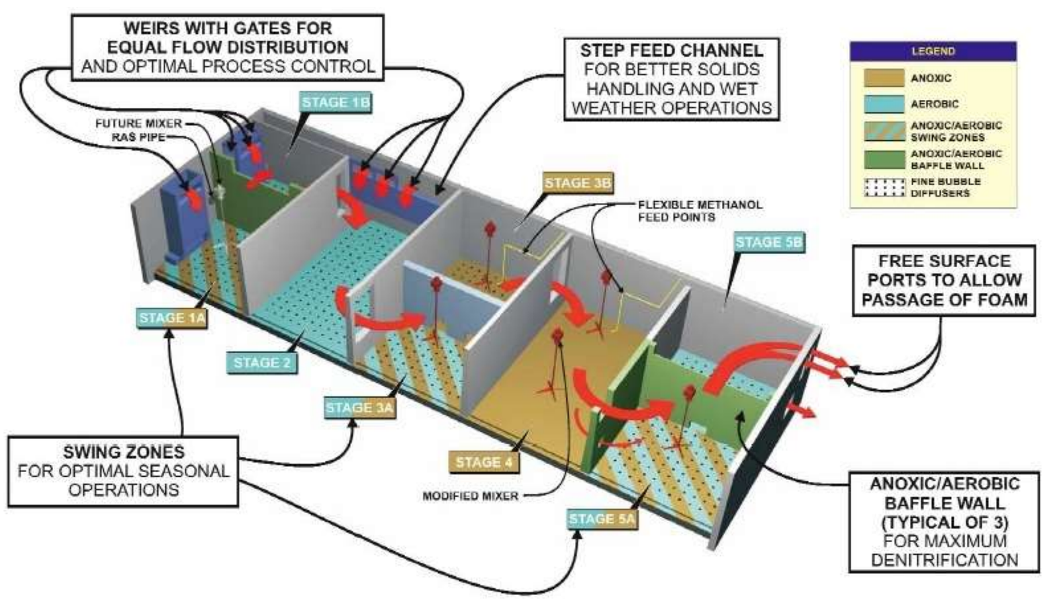

Fig. 2. Nitrification-Denitrification stage configuration at Blue Plains WWTP

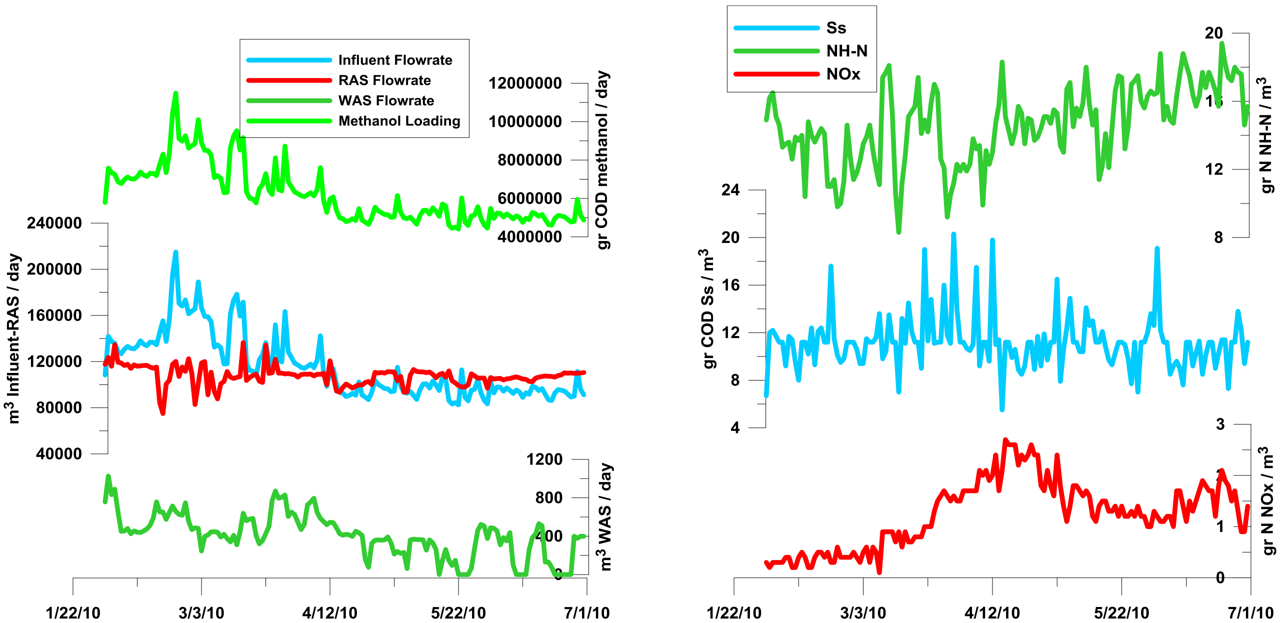

Fig. 1. Left: Daily flowrate of influent, RAS, WAS and Methanol loading rate. Right: Daily influent biodegradable substrate (Ss), ammonia (NH-N) and Nitrate (NOx).

b. Bayesian model framework

The Blue Plains Nit-DeNit configuration contains eight continuous stages, two large and six in smaller compartments. The eight reactor system for modeling in the Bayesian program framework is shown in Figure 3. Nitrification occurs in stages 1A, 1B, and 2 which are under aerobic conditions. Stage 3A is not aerated and known as a denox zone. Methanol is added in stage 3B to aid in denitrification which occurs in stages 3B, 4 and 5A under anoxic conditions. The last stage is aerated to improve biomass settling in the clarifier.

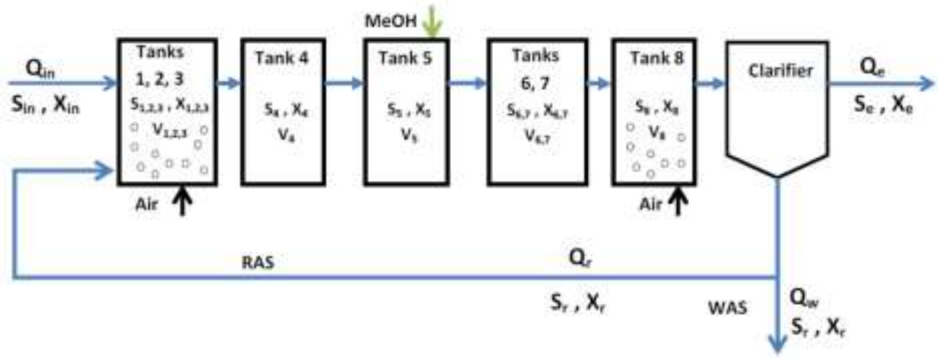

Fig. 3. Eight tank configuration in the Ni-DeNit model. The volumes are not to scale and each tank is considered a completely mixed reactor (CMR).

Transient mass balance equation for each tank can be expressed as ordinary differential equations (ODEs). Eqs. 1 and 2 show the Activated Sludge model reactions for a given constituent C (such as BOD concentration) for tank 1 and a general tank k.

$$\frac{d(V_k C_{i,k})}{dt} = \left(Q_{in} C_{i,in} + Q_r C_{i,r}\right) - Q_k C_{i,k} + k_{L,O_2} V_k \left(C_{O_2}^{sat} - C_{O_2,k}\right) + V_k \sum_{j=1}^{nr} \varphi_{i,j} R_{j,k} \quad \text{for } k = 1 \tag{1}$$

$$\frac{d(V_k C_{i,k})}{dt} = Q_{k-1} C_{i,k-1} - Q_k C_{i,k} + k_{L,O_2} V_k \left(C_{O_2}^{sat} - C_{O_2,k}\right) + \dot{m}_{MeOH,k} + V_k \sum_{j=1}^{nr} \varphi_{i,j} R_{j,k} \quad \text{for } k = 2 \text{ to } 8 \tag{2}$$

Where V_k is the volume of tank *k*, Q_k and $C_{i,k}$ are respectively the outflow rate and concentration of constituent *i* in the outflow from tank *k*, Q_{in} and $C_{i,in}$ are the inflow rate and concentration in the inflow to the first tank and Q_r and $C_{i,r}$ are the return activated sludge (RAS) flow rate and concentration in RAS to the first tank. $R_{j,k}$ is the reaction rate of reaction number *j* at tank *k* such that *nr* is the total number of reactions. $\varphi_{i,j}$ is the stoichiometric coefficient of constituent *i* in reaction *j*. k_{L,O_2} is the oxygen mass transfer rate in tank *k* through bubble aeration with a saturation concentration $C_{O_2}^{sat}$ (for those un-aerated tanks k_{L,O_2} considered as zero). $\dot{m}_{MeOH,k}$ is the methanol loading rate into tank *k*. The model proposed by [2, 3] has been used to model the clarifier.

Eleven processes including the growth and decay of several bacterial groups have been incorporated into the reaction network for this study. This network is a modification of ASM1 by the addition of the methylotroph bacteria group and is summarized in Table 1. [4]. For each process, the reaction rate based on Monod kinetic and inhibition is presented in the last column. There are 14 different constituents in the model (described in bottom row of Table 1). Stoichiometries of each constituent belonging to each reaction rate ($\varphi_{i,j}$) are shown in the inner elements of reaction matrix.

Table. 1. Reaction rates and constituents stoichiometry.

J	Reaction \ Constituent	S_I	S_S	S_M	X_I	X_S	$X_{B,H}$	$X_{B,M}$	$X_{B,A}$	X_P	S_O
1	Aerobic growth of heterotrophs		$-1/Y_H$				1				$-(1-Y_H)/Y_H$
2	Aerobic growth of heterotrophs on Methanol			$-1/Y_{HM}$			1				$-(1-Y_{HM})/Y_{HM}$
3	Anoxic growth of heterotrophs		$-1/Y_H$				1				
4	Anoxic growth of Methylotrophs			$-1/Y_M$				1			
5	Aerobic growth of autotrophs								1		$-(4.57-Y_A)/Y_A$
6	Decay of heterotrophs					$1-f_p$	-1			f_P	
7	Decay of Methylotrophs					$1-f_p$		-1		f_P	
8	Decay of autotrophs					$1-f_p$			-1	f_P	
9	Ammonification of soluble organic Nitrogen										
10	Hydrolysis of entrapped organics		1			-1					
11	Hydrolysis of entrapped organic nitrogen										
		Non-biodegradable soluble	Biodegradable substrate	Methanol	Non-biodegradable Particulate	Biodegradable Particulate	Heterotrophic biomass	Methylotrophic biomass	Autotrophic biomass	Inert particulate	Dissolved oxygen

J	S_{NO}	S_{NH}	S_{ND}	X_{ND}	Pocess rate
1		$-i_{XB}$			$\mu_H*[S_S/(K_S+S_S)]*[S_O/(K_{O,H}+S_O)]*[S_{NH}/(K_{NH,H}+S_{NH})]*X_{B,H}$
2		$-i_{XB}$			$\mu_H*[S_M/(K_M+S_M)]*[S_O/(K_{O,H}+S_O)]*[S_{NH}/(K_{NH,H}+S_{NH})]*X_{B,H}$
3	$-(1-Y_H)/(2.86*Y_H)$	$-i_{XB}$			$\mu_H*[S_S/(K_S+S_S)]*[K_{O,H}/(K_{O,H}+S_O)]*[S_{NO}/(K_{NO,H}+S_{NO})]*[S_{NH}/(K_{NH,H}+S_{NH})]*\eta_g*X_{B,H}$
4	$-(1-Y_M)/(2.86*Y_M)$	$-i_{XB}$			$\mu_M*[S_M/(K_M+S_M)]*[K_{O,M}/(K_{O,M}+S_O)]*[S_{NO}/(K_{NO,M}+S_{NO})]*[S_{NH}/(K_{NH,M}+S_{NH})]*X_{B,M}$
5	$1/Y_A$	$-i_{XB}-1/Y_A$			$\mu_A*[S_{NH}/(K_{NH}+S_{NH})]*[S_O/(K_{O,A}+S_O)]*X_{B,A}$
6				$i_{XB}-f_P*i_{XP}$	$b_H*X_{B,H}*([S_O/(K_{O,H}+S_O)]+\eta_h*[S_{NO}/(K_{NO,H}+S_{NO})]*[K_{O,H}/(K_{O,H}+S_O)])$
7				$i_{XB}-f_P*i_{XP}$	$b_M*X_{B,M}*([S_O/(K_{O,M}+S_O)]+\eta_h*[S_{NO}/(K_{NO,M}+S_{NO})]*[K_{O,M}/(K_{O,M}+S_O)])$
8				$i_{XB}-f_P*i_{XP}$	$b_A*X_{B,A}*([S_O/(K_{O,A}+S_O)]+\eta_h*[S_{NO}/(K_{NO,A}+S_{NO})]*[K_{O,A}/(K_{O,A}+S_O)])$
9		1	-1		$k_a*S_{ND}*X_{B,H}$
10					$k_H*[(X_S/X_{Bio}/(K_X+X_S/X_{Bio})]*([S_O/(K_{O,H}+S_O)]+\eta_h*[K_{O,H}/(K_{O,H}+S_O)]*[S_{NO}/(K_{NO}+S_{NO})])*X_{Bio}$
11			1	-1	$k_H*(X_{ND}/X_S)*[(X_S/X_{Bio})/(K_X+X_S/X_{Bio})]*([S_O/(K_{O,H}+S_O)]+\eta_h*[K_{O,H}/(K_{O,H}+S_O)]*[S_{NO}/(K_{NO}+S_{NO})])*X_{Bio}$
	Nitrate	Ammonia nitrogen	Soluble organic nitrogen	Particulate organic nitrogen	

c. Parameter estimation

In abbreviated form, Eqs. 1 and 2 can be expressed as:

$$\frac{d\mathbf{C}}{dt} = f(\boldsymbol{C}(t), \boldsymbol{U}(t), \boldsymbol{\Theta}) \tag{4}$$

where, $\boldsymbol{C}(t)$ is the constituents' concentration vector. The length of the vector is equal to the number of constituents times the number of tanks. $\boldsymbol{U}(t)$ is the external forcing input from influent, RAS, methanol loading rate ($\dot{m}_{MeOH,k}$), and temperature. $\boldsymbol{\Theta}$ is the stoichiometry/reaction parameter vector that is shown in Table 1. Function f in Eq. 4 is the bio-reactor model structure.

Estimation of the parameters can be performed by comparing between modeled and observed concentrations. If $\widetilde{\boldsymbol{C}}(t)$ represents the observed data vector, then the considered error function between observed and modeled concentration is $E(\widetilde{\boldsymbol{C}}, \boldsymbol{C})$. If the external forcing vector is known, then the model output becomes a function of just the parameters. So, the error function can be re-written as $E(\widetilde{\boldsymbol{C}}, \boldsymbol{\Theta})$, where $\boldsymbol{\Theta}$ is the vector of unknown parameters. If the error function has a probability distribution and independent behavior, then the likelihood function of the observed vector can be shown as function of only unknown parameters:

$$L(\boldsymbol{\Theta}) = \prod_{i=1}^{m} \prod_{j=1}^{n_i} E(\tilde{c}_{ij}, \boldsymbol{\Theta}) \tag{5}$$

where $\tilde{c}_{ij}$ is the observed concentration of constituent by type i at time or tank j, m is the total number of observed constituent and n_i is the number of total samples (in time or location) of observed type i. If the error structure is assumed to be a log-normal distribution, then the error function becomes:

$$E(\tilde{c}_{ij}, \boldsymbol{\Theta}) = \frac{1}{\tilde{c}_{ij}\sigma_i\sqrt{2\pi}} \exp\left(-\frac{\left(\ln \tilde{c}_{ij} - \ln c_{ij}(\boldsymbol{\Theta})\right)^2}{2{\sigma_i}^2}\right) \tag{6}$$

where $c_{ij}(\boldsymbol{\Theta})$ is the output modeled concentration of constituent i at time/tank j. σ_i is the unknown standard deviation of observed type i, which can be considered as a new parameter in the parameters vector, such that $\boldsymbol{\Theta} = \{\theta_1, \theta_2, \dots, \theta_k, \sigma_1, \sigma_2, \dots, \sigma_m\}$, where k is the total number of un-known parameters in Eq. 4. Maximizing the likelihood function by a deterministic optimization approach is a way to find the set of optimum parameter values $\widehat{\boldsymbol{\Theta}}$ which is called the maximum likelihood estimator (MLE) of $\boldsymbol{\Theta}$ [4].

The likelihood function of the sample $L(\boldsymbol{\Theta})$ can interpreted as a probability function of the observed data:

$$P\left(\widetilde{\boldsymbol{C}}|\boldsymbol{\Theta}\right) = L(\boldsymbol{\Theta}) \tag{7}$$

If we have some additional, prior information about the unknown parameters, we incorporate that knowledge in the form of a probability distribution for each parameter, $P(\boldsymbol{\Theta})$. This Bayesian approach can be expressed as:

$$P\left(\boldsymbol{\Theta}|\widetilde{\boldsymbol{C}}\right) = \frac{P\left(\widetilde{\boldsymbol{C}}|\boldsymbol{\Theta}\right) P(\boldsymbol{\Theta})}{P\left(\widetilde{\boldsymbol{C}}\right)} \tag{8}$$

where $P\left(\widetilde{\boldsymbol{C}}|\boldsymbol{\Theta}\right)$ is the joint probability distribution of the error function (which is equal to the likelihood function in Eq. 7), $P(\boldsymbol{\Theta})$ is the prior distribution, and $P\left(\boldsymbol{\Theta}|\widetilde{\boldsymbol{C}}\right)$ is the posterior distribution for parameters $\boldsymbol{\Theta}$. The denominator, $P\left(\widetilde{\boldsymbol{C}}\right)$, is a normalizing factor.

d. Adaptive time step

The Blue Plains Nit-DeNit daily fluctuations in wastewater influent along with the complex external forcing make the system of non-linear ODEs in Eq. 4 a stiff system of equations which needs a very small time interval to solve by an explicit method. An adaptive backward differentiation method has been implemented where the time interval varies with stiffness.

For deterministic parameter estimation, the genetic algorithm has been used to find the MLE. If $\widehat{\boldsymbol{\Theta}}$ maximizes $L(\boldsymbol{\Theta})$, it can also maximize the natural log of $L(\boldsymbol{\Theta})$. The fitness function created for the genetic algorithm is:

$$Fitness\ function = min\left(\sum_{i=1}^{\mathrm{m}} n_i \ln \sigma_i + \sum_{i=1}^{\mathrm{m}} \sum_{j=1}^{n_i} \frac{\left(\ln \tilde{c}_{ij} - \ln c_{ij}(\boldsymbol{\Theta})\right)^2}{2{\sigma_i}^2}\right) \tag{9}$$

For stochastic parameter estimation, a Metropolis-Hasting (M-H) algorithm which is a powerful Markov chain method to generate multivariable distributions has been applied. The algorithm generates a large number of random variables for unknown parameters and standard deviations based on the posterior distribution:

$$\mathbf{\Theta}^{k+1} = \begin{cases} \mathbf{\Theta}' \quad if \qquad U(0,1) < min\left[\frac{P(\mathbf{\Theta}'|\tilde{C})Q(\mathbf{\Theta}',\mathbf{\Theta}^k)}{P(\mathbf{\Theta}^k|\tilde{C})Q(\mathbf{\Theta}^k,\mathbf{\Theta}')}\right] \\ \qquad\qquad \mathbf{\Theta}^k \quad otherwise \end{cases} \tag{10}$$

In Eq. 10, $\mathbf{\Theta}^k, \mathbf{\Theta}'$ are the previous and generated/proposed parameters. $Q(\mathbf{\Theta}^k, \mathbf{\Theta}')$ and $Q(\mathbf{\Theta}', \mathbf{\Theta}^k)$ are the log-normal proposal densities, and $U(0,1)$ is the uniform random number between 0 and 1.

4. Results

In total, the Bayesian approach was successfully used to estimate twenty-five key parameters in the Nit-DeNit stage of wastewater treatment. The simulated effluent using these parameter estimates is in good agreement with the observed effluent characteristics, thus supporting their credibility. The list of examined parameters is detailed in Table 2. For all but a few, the resultant joint probability distributions for these parameters have significantly narrower credible intervals than the value ranges found in the literature.

For temperature-sensitive parameters, the Arrhenius relationship was applied. The relationship and relevant factors are given in Table 2. For parameter estimation, first the Genetic algorithm was applied using a large population and number of generations to obtain optimum deterministic values. In all, 31 parameters existed in the proposed modeled, and 25 of them were considered to be estimated. The parameter symbols, original given range of value and the results for Genetic optimum values are shown in Table 3. Plots of important constituents (methanol, ammonium, nitrite/nitrate, soluble COD, and volatile suspended solids) in Nit-Denit derived from deterministic optimum values are illustrated in Fig. 4.

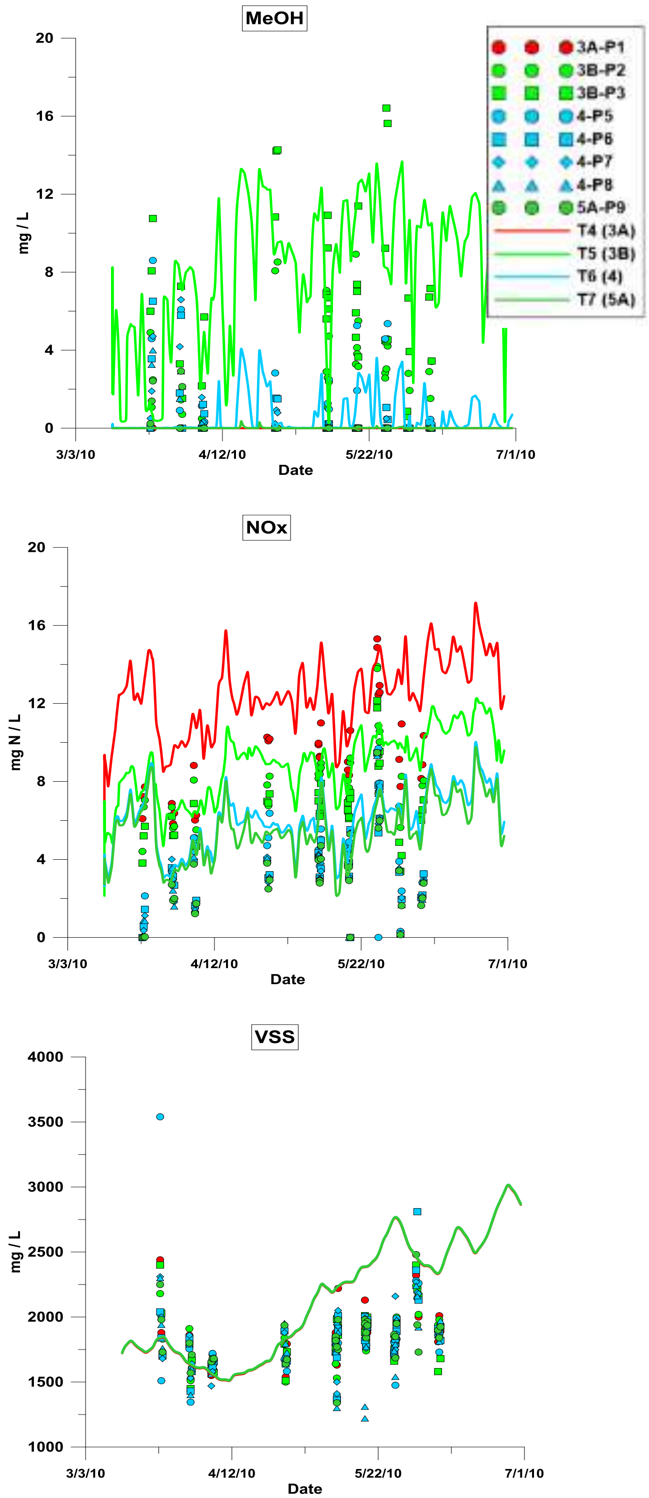

Fig. 4. Comparison between modeled results in denitrification stages based on Genetic optimum parameters (solid lines) and observed data (shapes). Red shapes and lines belong to stage 3A, yellow to stage 3B, blue to stage 4 and green to stage 5A. Different shapes with the same color belong to the same stage, but were measured from different locations within the tank.

As is expected, methanol has a high concentration in stage 3B (the reactor of methanol loading) and decreases in stages 4 and 5 (Fig. 4, a). Ammonia concentration is low in the denitrification stages illustrated as it was consumed in the earlier stages (Fig. 4, b). Nitrate (NOx) has a high concentration directly before methanol loading at stage 3A and promptly decreases (stages 3B to 5A) due to methylotrophic denitrification (Fig. 4, c). Soluble COD encompasses both methanol and soluble biodegradable substrate (Ss); due to a lack of Ss in the Nit-DeNit phase, sCOD has a same pattern as methanol (Fig. 4, d). VSS consists of all the particulate constituents. As anticipated, it has no significant change stage by stage because of slow growth and decay in comparison with changes in soluble constituents (Fig. 4, e).

For probabilistic parameter estimation, the M-H algorithm was used to generate 100,000 sample parameter sets; the probability of each parameter has been evaluated by Bayesian inference (Eq. 8). The distribution of parameters is shown in the histograms of Fig. 5. The summary (95% credible interval, median, and mean) of each histogram is reported in the last columns of Table 2. This 95% interval range of each parameter distribution can be used as a new parameter range for the Nit-DeNit system at Blue Plains. In most cases the ranges resulting from Bayesian parameter estimation are narrower than the given parameter ranges in the literature for general cases. Finally, the median and mean values of parameters from their histograms show good agreement with values genetic parameter estimation, which indicates a good prior distribution for each parameter. This study has so far shown promising success. One of the next steps will be to incorporate newly acquired hourly influent data from Blue Plains.

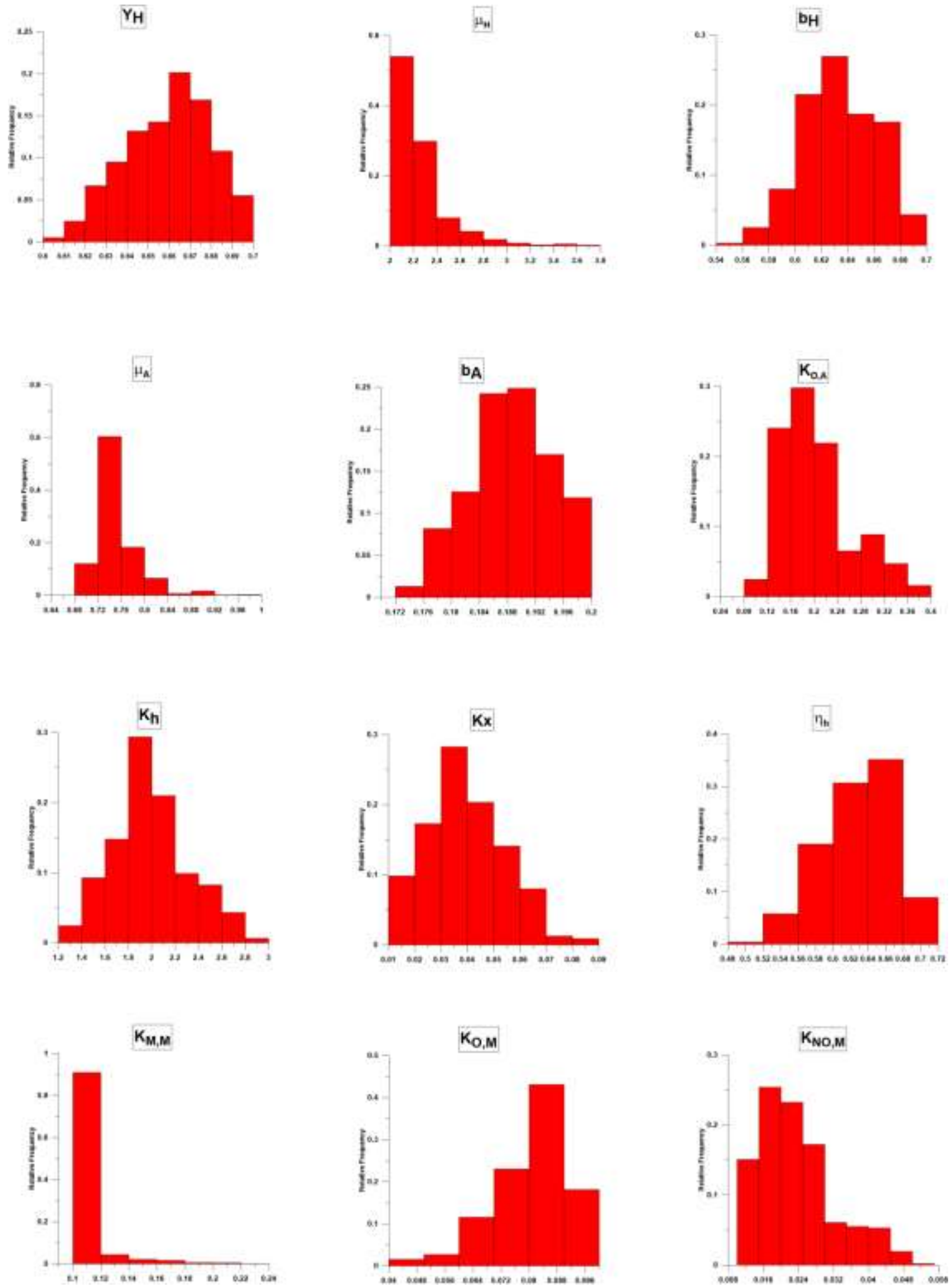

Fig. 5. Posterior distributions of parameters for 100,000 samples generated by Metropolis-Hasting algorithm.

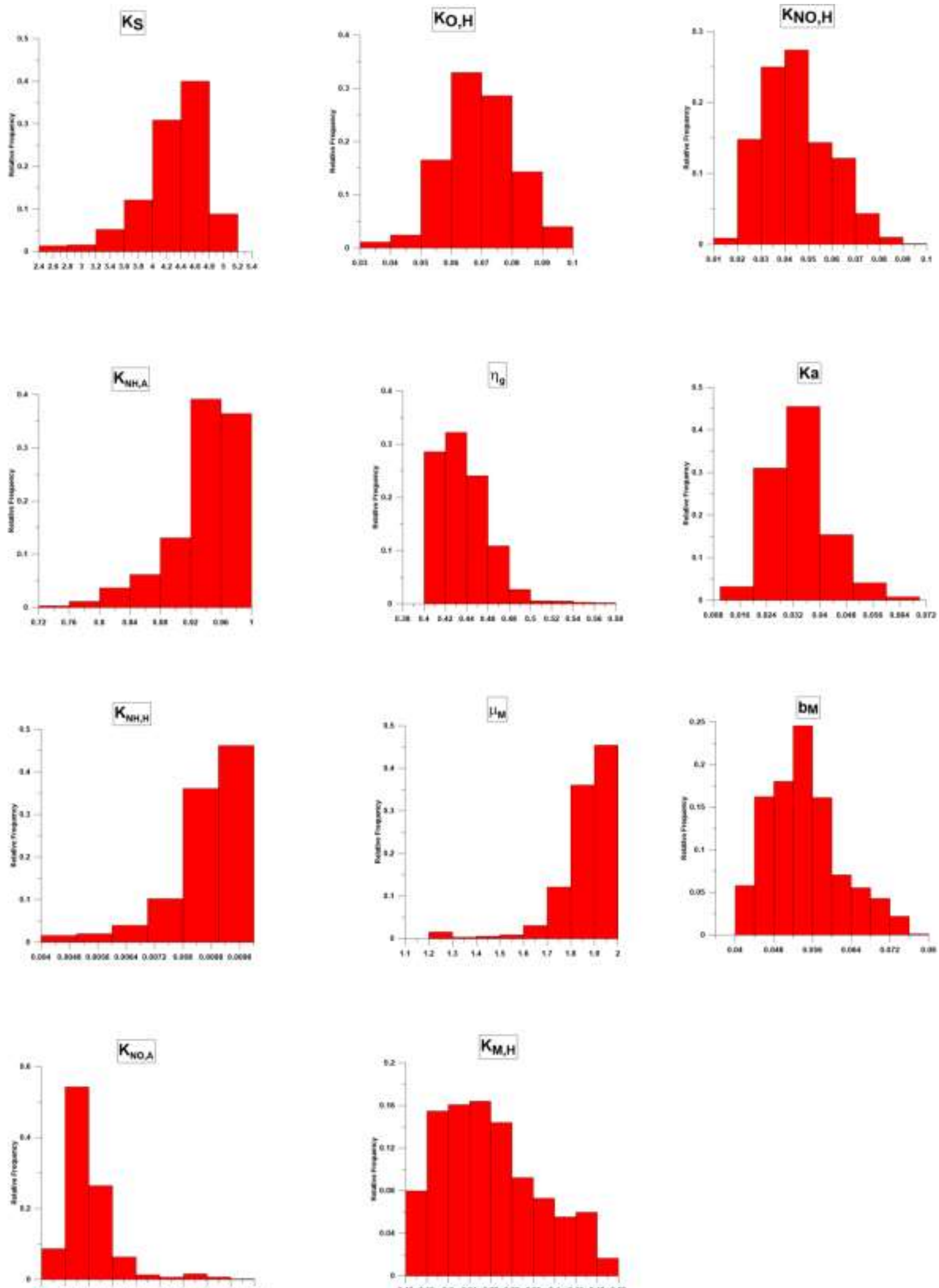

Fig. 5. (Continued)

Table. 2. Nitrification-Denitrification parameter's symbol, unit and Arrhenius factor

Type	Symbol	Parameter	Unit	Arrhenius factor θ *
Heterotrophic kinetics	μ_H	Maximum specific growth rate of Heterotrophs	d^{-1}	1.072
	K_S	Substrate half saturation for Heterotrophs	$g\ COD.m^{-3}$	1.03
	$K_{M,H}$	Methanol half saturation for Heterotrophs (aerobic)	$g\ COD.m^{-3}$	1
	$K_{O,H}$	O_2 half saturation for Heterotrophs	$g\ O_2.m^{-3}$	1
	$K_{NO,H}$	NOx half saturation for Heterotrophs	$g\ N.m^{-3}$	1
	η_g	Anoxic growth reduction for Heterotrophs	-	1
	b_H	Aerobic decay rate coefficient for Heterotrophs	d^{-1}	1
	K_{NH}	NHx half saturation for Heterotroh/Methylotroph	$g\ N.m^{-3}$	1
Methylotrophic	μ_M	Maximum specific growth rate of Methylotroph	d^{-1}	1.09
	$K_{M,M}$	Methanol half saturation coefficient	$g\ COD.m^{-3}$	1
	$K_{O,M}$	O_2 half saturation for Methylotrophs	$g\ O_2.m^{-3}$	1
	$K_{NO,M}$	NOx half saturation for Methylotrophs	$g\ N.m^{-3}$	1
	b_M	Aerobic decay rate coefficient for Methylotrophs	d^{-1}	1.03
Autotrophic kin	μ_A	Maximum specific growth rate of Autotrophs	d^{-1}	1.072
	$K_{NH,A}$	Ammonia half saturation for Autotrophs	$g\ N.m^{-3}$	1
	$K_{NO,A}$	NOx half saturation for Autotrophs	$g\ N.m^{-3}$	1
	$K_{O,A}$	Oxygen half saturation for Autotrophs	$g\ O_2.m^{-3}$	1
	b_A	Aerobic decay rate coefficient for Autotrophs	d^{-1}	1.03
Conversion k	η_h	Anoxic growth reduction for decay	-	1
	K_h	Hydrolysis rate coefficient	d^{-1}	1.03
	K_X	Hydrolysis half saturation coefficient	-	1
	K_a	Ammonification rate coefficient	d^{-1}	1.03
Stoichiometric parame	Y_H	Aerobic yield of Heterotrophs on substrate	-	1
	Y_{HM}	Aerobic yield of Heterotrophs on methanol	-	1
	Y_A	Autotroph yield	-	1
	Y_M	Methylotroph yield	-	1
	f_P	Endogenous fraction (death-regeneration)	-	1
	i_{XB}	Nitrogen fraction in biomass	$g\ N.g\ COD^{-1}$	1
	i_{XP}	Nitrogen fraction in products from biomass	$g\ N.g\ COD^{-1}$	1
* Temperature dependant parameters: $P(T) = P_{20}\theta^{(T-20)}$				

Table. 3. Summary of parameter estimation results

Symbol	Given Range		Genetic Estimated	MCMC histograms Summary			
	Low	High		2.50%	50%	97.50%	Mean
μ_H	2	10	2.05	2.024	2.15	2.50	2.18
K_S	1	20	5.00	3.563	4.42	4.90	4.38
$K_{M,H}$	0.1	0.5	0.50	0.143	0.23	0.33	0.23
$K_{O,H}$	0.02	0.1	0.06	0.054	0.07	0.09	0.07
$K_{NO,H}$	0.01	0.1	0.04	0.021	0.04	0.07	0.04
η_g	0.4	0.8	0.42	0.406	0.44	0.49	0.44
b_H	0.4	0.7	0.68	0.594	0.64	0.68	0.64
K_{NH}	0.001	0.01	0.01	0.007	0.01	0.01	0.01
μ_M	0.8	2	1.85	1.746	1.91	1.99	1.90
$K_{M,M}$	0.1	1	0.10	0.101	0.10	0.11	0.11
$K_{O,M}$	0.03	0.1	0.09	0.064	0.08	0.10	0.08
$K_{NO,M}$	0.01	0.1	0.01	0.015	0.03	0.05	0.03
b_M	0.04	0.1	0.05	0.042	0.05	0.07	0.05
μ_A	0.7	1.2	0.73	0.713	0.75	0.80	0.75
$K_{NH,A}$	0.5	1	0.86	0.899	0.96	0.99	0.96
$K_{NO,A}$	0.01	0.2	0.03	0.020	0.03	0.08	0.04
$K_{O,A}$	0.1	0.4	0.21	0.124	0.19	0.28	0.19
b_A	0.15	0.2	0.20	0.178	0.19	0.20	0.19
η_h	0.3	0.7	0.67	0.554	0.64	0.69	0.63
K_h	1	3	1.98	1.534	1.97	2.65	2.02
K_X	0.01	0.1	0.03	0.015	0.05	0.08	0.05
K_a	0.01	0.1	0.03	0.025	0.04	0.06	0.04
Y_H	0.6	0.7	0.65	0.632	0.67	0.70	0.67
Y_{HM}	0.4	0.4	fixed	-	-	-	-
Y_A	0.24	0.24	fixed	-	-	-	-
Y_M	0.4	0.4	fixed	-	-	-	-
f_P	0.08	0.08	fixed	-	-	-	-
i_{XB}	0.086	0.086	fixed	-	-	-	-
i_{XP}	0.06	0.06	fixed	-	-	-	-

5. Conclusions

In this project a Bayesian hierarchical modeling framework have been developed and used for probabilistic parameter estimation of bio-kinetic and stoichiometric parameters using real data collected at full-scale nitrification-denitrification (Nit-DeNit) reactors at the Blue Plains Wastewater Treatment Plant. The data was found to be able to narrow down the spread of the distribution with respect to the prior distributions for some of the parameters while for some other parameters the spread of the distributions was not reduced significantly. The level at which the data is able to reduce the uncertainty about a parameter depends on the sensitivity of the model outputs with respect that parameter and the internal correlation between the parameters. The results obtained from this study can be further used to perform chance-constrained optimization to minimize the risk of exceeding effluent nitrogen water quality standards and also minimize the emission of methanol in the effluent.

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Continuous Monitoring of Urea Concentrations and Harmful Algal Productivity and Physiology

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Continuous Monitoring of Urea Concentrations and Harmful Algal Productivity and Physiology in the Anacostia River: Final Report

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May, 2014

1. Executive Summary

Water quality monitoring in the Anacostia River is plagued by inconsistent and uncoordinated efforts by different municipalities throughout its watershed, but efforts have increased due to mandates from the EPA's Chesapeake Bay TMDL program. Over the years, there have been studies that collect basic and important water quality parameters (e.g. temperature, salinity, dissolved oxygen, bacteria and phytoplankton composition) that help determine the health of the Anacostia River. However, one large component that is lacking from these monitoring studies or programs is assessing the concentration and impact of organic nitrogen, especially urea, that could compose more than 50% of the total nitrogen that comes from the 17 combined sewage outfalls along the DC portion of the Anacostia River. This project involved collected samples at 10 sites for nutrient concentrations, bacteria and phytoplankton composition, nitrogen uptake and assimilation enzyme rates to better understand the impact of organic N in the Anacostia River. Urea concentrations were lower than predicted but the high ammonium (NH_4^+) concentrations suggest that urea may be breaking down rapidly to NH_4^+ via urease activity or new sources of NH_4^+ are entering the Anacostia River. The measurement of natural abundance of ^{15}N-NH_4^+ revealed that there might be multiple sources of NH_4^+ that needs to be further investigated. Precipitation was high during June 2013 that led to higher concentrations of NH_4^+ and total dissolved phosphorus (TDP) that resulted in two observed non-harmful phytoplankton blooms on the Anacostia River. The six-fold concentrations of NH_4^+ observed than historical levels is troubling because of potential toxicity to fish and other invertebrates.

2. Introduction

Of the two rivers that flow through the District of Columbia, the Anacostia River is often called the "forgotten river" as it was neglected for many decades while the neighboring Potomac River has received more attention and is monitored more closely (Wennersten, 2008). The Anacostia River recently received an overall score of C- on its report card based on several water quality parameters (Anacostia Watershed Society, 2011). However, it was difficult to create this report card because there is not an uniform and coordinated effort that monitors all of the biological, chemical and physical parameters throughout the Anacostia watershed.

The Anacostia River watershed includes three major jurisdictions: Montgomery County (MD), Prince George's County (MD) and the District of Columbia. Water quality monitoring of the Anacostia River is very fragmented with various jurisdictions having different type of consistent monitoring programs despite past efforts to coordinate all the efforts (e.g. Metropolitan Council of Governments). For instance, Montgomery County has monitored the northwest branch for fish and macro- invertebrates since 1990 (Anacostia Watershed Restoration Partnership, 2012). Their water quality monitoring program has been discontinued, so there is no current data on nutrient loading for this region. The DC Department of the Environment (DC DOE) has an Anacostia and Potomac River monitoring program where they measure temperature, dissolved oxygen, pH, depth, chlorophyll and turbidity (DC Department of the Environment, 2012) but data is only available beginning in May 2008 and is often not calibrated. Additionally, DC DOE only samples once a month, and recent data available through the Chesapeake Bay Program is only for one site (ANA0082), which is near Anacostia River Bridge on Bladensburg Road. Prince George's County does not have any consistent or coherent monitoring programs with the most recent data from May 2010-June 2011 (U.S Environmental Protection Agency, 2011). However, there have been some recent efforts to increase water quality monitoring and to combine it with some modeling and simulations by DCWRRI (e.g. Deksissa and Behera, 2008)

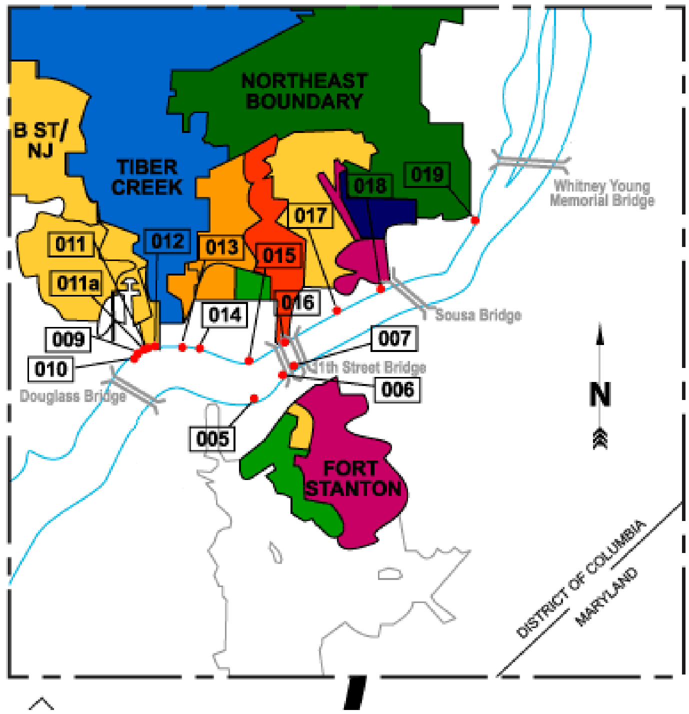

Figure 1: The 17 combined sewage outfall sites along the DC portion of the Anacostia River (DC Water and Sewage Authority, 2012)

Location	Urea concentration (μM-N)	Reference
Chesapeake Bay, mainstem	<0.01-8.16	Lomas et al. 2002; Solomon 2006
Kings Creek, Chesapeake Bay Maryland	0.3-24.2	Glibert et al. 2005
Florida Bay, Florida	0.36-1.7	Glibert et al 2004
Great South Bay, New York	<0.12-1.24	Clark et al. 2006
Neuse River Estuary, North Carolina	<0.14-43	Twomey et al. 2005

Table 1: Urea concentrations in select coastal waters in the United States

Water quality monitoring typically measures only dissolved inorganic nutrients – both nitrogen (DIN; NO_3^-, NH_4^+ and NO_2^-) and phosphorus (DIP) – based on the premise that bacteria and phytoplankton primarily uses these sources (Mulholland and Lomas, 2008) and largely ignores the organic forms of both nutrients. Dissolved organic nitrogen (DON) can make up from 14-90% of total N in rivers (Seitzinger and Sanders 1997; Wiegner et al. 2006) and some is liable and bioavailable to bacteria and phytoplankton contrary to previous beliefs that DON is completely refractory (Berman and Bronk, 2003). Recent work has shown that uptake rates of DON are similar to DIN and is a significant source of N to phytoplankton and bacteria (Bronk 2002, Berman and Bronk, 2003, Bronk et al. 2007).

A large possible source of DON to the Anacostia River is sewage overflows and treated effluent. The Anacostia has many combined sewage outfalls (CSO) that occur at 17 sites in DC (**Fig. 1**; Natural Resources Defense Council, 2012; DC Water and Sewer Authority, 2012). The combined sewage system consists of one pipe for both sanitary waste and storm water run off. During dry weather, most of the water is treated, but during wet weather the excess flow goes straight into the Anacostia River. Nutrient concentrations in the river can increase after such wet events. For instance, the three weeks after Tropical Storm Sandy hit the Eastern seaboard, NH_4^+ concentrations increased from 4.72 to 17.2 μM-N, which suggests that what were originally high levels of DON may have decomposed into NH_4^+ (Solomon et al., unpublished). Even when the sewage is treated, it is mostly dissolved inorganic nitrogen (DIN) such as NO_3^-, NH_4^+ and NO_2^- that is removed, leaving mostly DON in concentrations of > 1 mM-N (Urgun-Demirtas et al. 2008; Sattayatewa et al. 2010, Bronk et al. 2010).

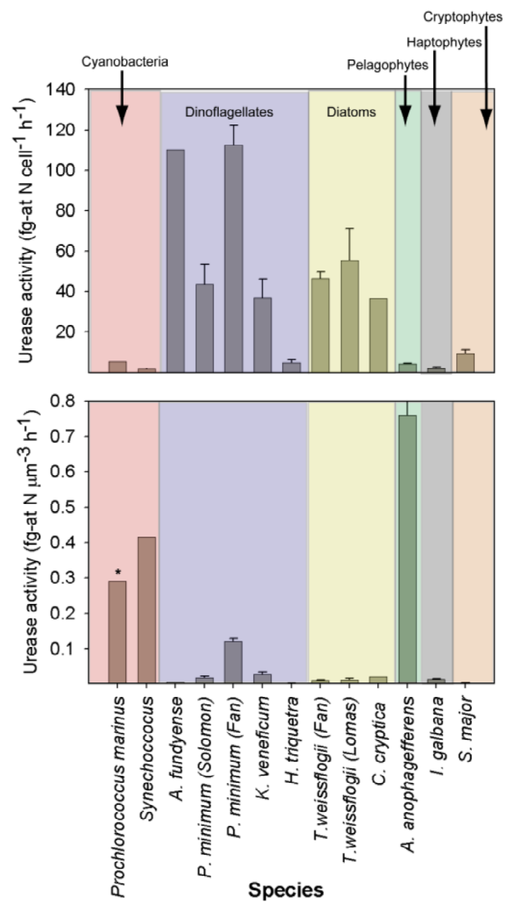

Figure 2: Comparison of urease activity rates between different phytoplankton species on per cell or per cell volume basis. *Prochlorococcus marinus* on a per cell volume basis (*) was divided by 10 to allow for visualization of other species (Solomon 2006)

One component of the dynamic and liable DON pool that may be present in high concentrations due to CSO is urea. Urea is a part of the DON pool in many aquatic systems (Antia et al. 1991, Berman and Bronk 2003, Glibert et al. 2006, Bronk et al. 2007) and concentrations in coastal waters can vary from undetectable to >40 μM-N (Lomas et al. 2002, Glibert et al. 2005, Twomey et al. 2005, Clark et al. 2006, Glibert et al. 2006; **Table 1**). Urea typically represents only ~5% on average of the DON pool, but can be more than 40% of DON in rivers draining agricultural watersheds (Glibert et al. 2005, Glibert et al. 2006), and could potentially be high near CSOs after storm events.

High levels of urea can be troubling because there are several harmful algal species (HABs) that can either use urea to support a large fraction of their N demand, have higher urease activity or grow better on urea compared to DIN sources (Solomon 2006, Solomon et al. 2010). Both dinoflagellates and cyanobacteria are emerging as taxonomic groups of phytoplankton that thrive on urea when it is present in the ecosystem. Urea may have been a culprit in a recent bloom of the dinoflagellate, *Gymnodinium,* that occurred in the Anacostia River during summer 2011 (Metropolitan Washington Council of Governments, 2011).

The rates of urea uptake and urease activity tend to be higher in dinoflagellates and cyanobacteria than other phytoplankton taxonomic groups. The maximum urea uptake rates (V_{max}) for the red algal lineage including harmful pelagophytes such as *Aureococcus anophagefferens* that often blooms in Great South Bay and Peconic Bay, New York (Lomas et al. 1996, Mulholland et al. 2002), and harmful dinoflagellates such as *Alexandrium catenalla* in Thau Lagoon in Southern France (Collos et al. 2004) is often higher than for the green lineage (Solomon et al. 2010). Higher rates of urea uptake and urease activity have also been measured where cyanobacteria dominate the phytoplankton community, such as in Florida Bay, the southwestern Florida Shelf and Chesapeake Bay (Glibert et al. 2004, Heil et al. 2007, Solomon et al. 2010). It was found that among several species of phytoplankton surveyed, including a diatom, three dinoflagellates, a cryptophyte, and a haptophyte, dinoflagellates and cyanobacteria were found to have the highest rates of activity of urease either on per cell or cell volume basis (**Fig. 2**; Solomon 2006, Glibert et al. 2008).

Higher urea availability and utilization may lead to higher toxin production by various harmful algal species. For instance, the toxin, microcystin, from the freshwater cyanobacteria *Microcystis aeruginosa* (which has appeared in the Potomac River in the past; Krogmann et al. 1986), are N-containing molecules and are synthesized by biochemical pathways that involve polyketide and nonribosomal peptide synthases (Dittman and Borner 2005) thus would be expected to increase with N enrichment. There are many other algal toxins that include saxitoxin and domoic acid that are also N-containing molecules that come from an array of dinoflagellates and diatoms (van Dolah, 2000). The bloom of the dinoflagellate, *Gymnodinium,* that occurred in the Anacostia River during summer 2011 (Metropolitan Washington Council of Governments, 2011) could have released substantial amounts of saxitoxins.

The aim of this study was to monitor <u>urea</u> concentrations and any appearance of <u>harmful algal blooms</u> (HABs) that may have an impact on the ecosystem heath of the Anacostia River. Measurements of physical factors (e.g. temperature, precipitation, dissolved oxygen), inorganic nutrients (e.g. NO_3^-, NH_4^+, TDP), nitrogen utilization rates (e.g. NH_4^+, urea uptake, and urease activity) were also taken to better understand urea and HAB dynamics in the Anacostia River.

3. <u>Methodologies</u>

Water samples were collected bi-weekly starting in March 2013 until November 2013. Sampling began again in March 2014 and is currently on-going. Dr. Solomon and/or students collected samples from designated sites on the Anacostia River (Fig. 3) in partnership with the Anacostia Riverkeeper (AK). The Anacostia Watershed Society (AWS) and the DC Department of Environment (DC DOE) also monitor these sites, allowing for comparison with current and historical data. Additional sites were added to monitor certain locations such as near RFK where they are building storage tanks to hold the overflow (site 6A; began on 8/21/13) and Pennsylvania Avenue Bridge near a CSO (site 7B; began on 5/29/13). The original site 7 is noted as 7A in the data, while site 6 remains recorded as the original site 6.

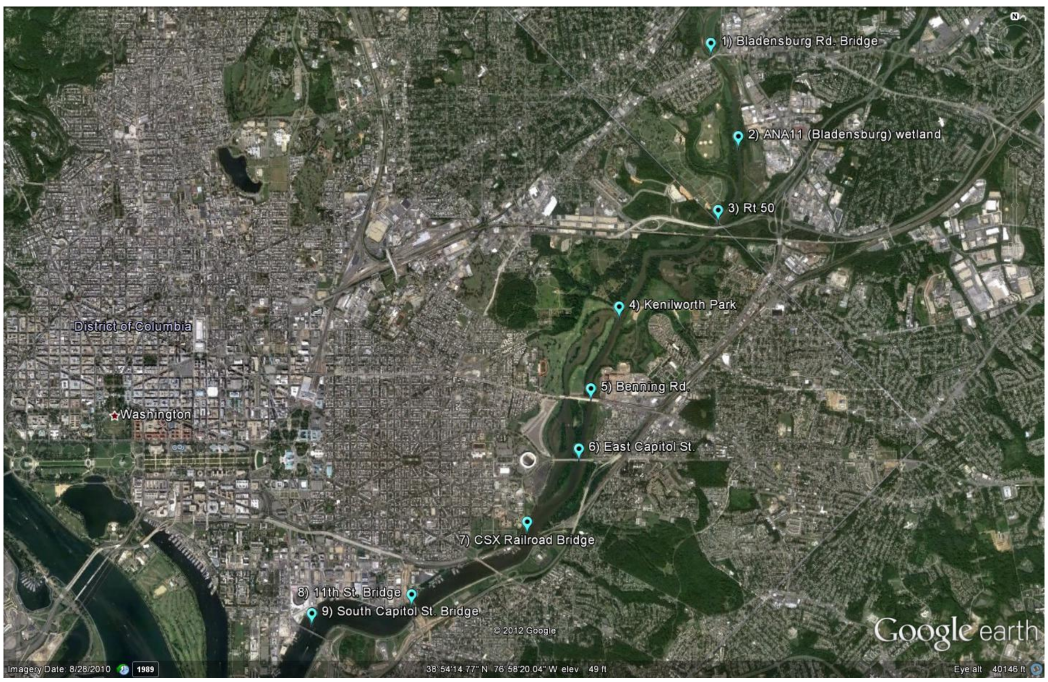

Figure 3: Sampling sites on the Anacostia River (as shown by the blue dots)

Samples were analyzed for (1) concentrations of nutrients such as NO_3^-, NH_4^+, urea and total dissolved phosphorus (TDP) (2) chlorophyll *a* (3) nitrogen uptake and enzymatic activity and (4) phytoplankton and bacterial composition. Due to a collaboration with the University of Maryland that began during summer 2013, natural $^{15}N\text{-}NH_4^+$ samples were also collected and analyzed.

(1) Nutrients: NO_3^- were analyzed according to the resorcinol method (Zhang et al. 2006), NH_4^+ by the method of Parsons et al. (1984), urea by the method developed by Revilla et al. (2005), and total dissolved phosphorus (TDP) by APHA (1998) using an automatic Shimadzu UV-1800 spectrophotometer at Gallaudet.

(2) Chlorophyll *a*: Chlorophyll *a* was measured using a modified protocol of Parsons et al. (1984) on a Turner 10-AU flourometer at Gallaudet.

(3) Uptake and enzymatic activity: Nitrogen (NH_4^+ and urea) uptake rates were analyzed according to Glibert and Capone (1993). Enzymatic activity such urease (Solomon et al. 2007) was also measured to better understand how rapidly phytoplankton utilizes urea.

(4) Phytoplankton and bacterial composition: Samples for phytoplankton and bacteria enumeration was collected and preserved with 4% glutaraldehyde, stored at 4°C until stained with DAPI (4'-6-Diamidino-2-phenylindole) and counted on an epiflourescent microscope at Gallaudet. Some samples were also preserved in Lugol's solution for better resolution for further DNA identification or microscopy.

(5) Natural abundance of $^{15}N\text{-}NH_4^+$. Samples for natural abundance of $^{15}N\text{-}NH_4^+$ in the particulate and dissolved fraction were collected and prepared by the method of Glibert et al. (unpublished) and analyzed via mass spectrometry to better understand the origins and sources of NH_4^+ to the Anacostia River.

4. Results and Discussion

a. Physical data:

The year 2013 was a wet year with high total precipitation in June and July, and later again in October and December (Figs. 4A & B). Many sampling dates were preceded by one or more rainy days. Average temperatures ranged from 6.97 to 29.3°C (Fig. 5), while dissolved oxygen was the lowest in June and July and highest in March and early April (Fig. 6).

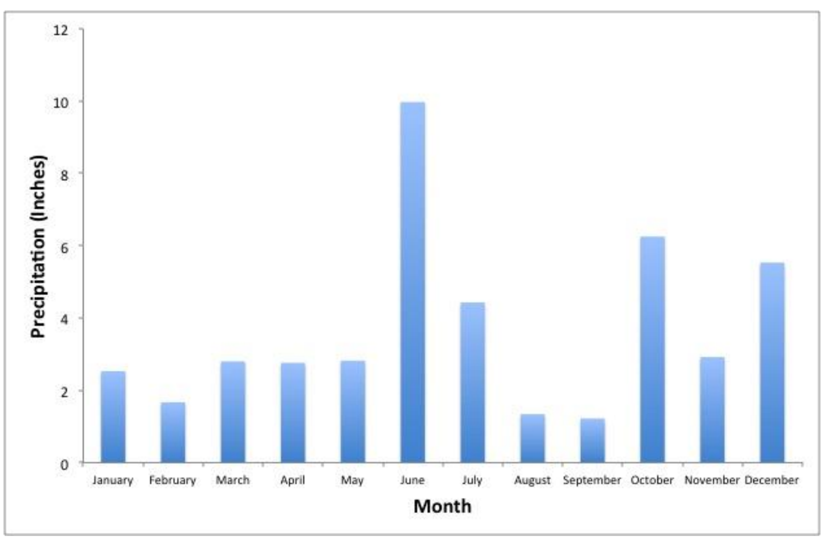

Figure 4A: Monthly precipitation during 2013 (data from the National Weather Service).

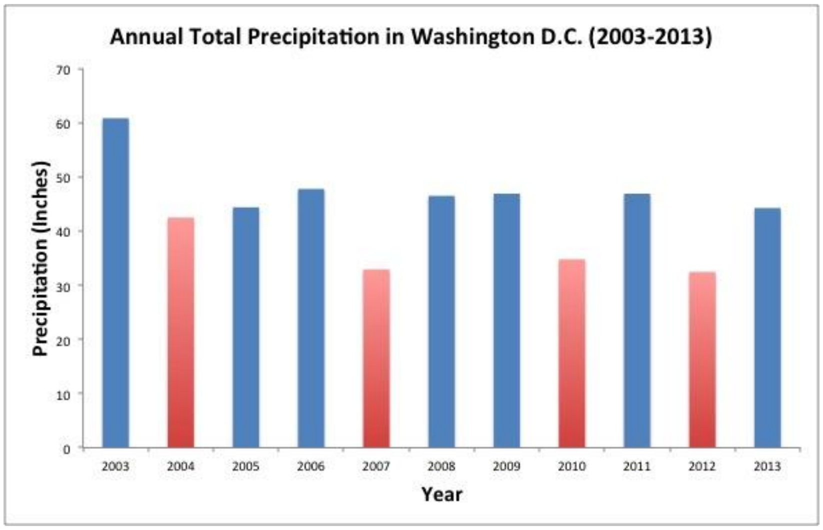

Figure 4B: Yearly precipitation in Washington, D.C. from 2003-2013. The red bars represent total rainfall less than average, while the blue bars represent total rainfall greater than average (data from National Weather Service).

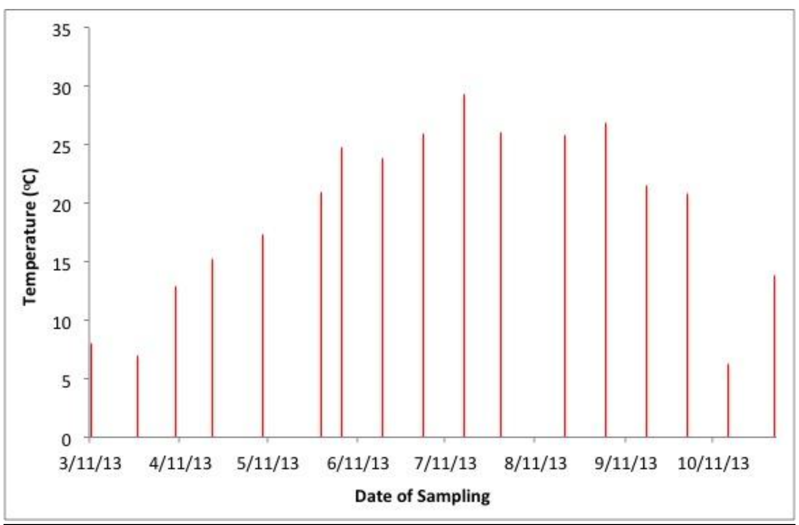

Figure 5: Average temperature of all sites on each sampling date during 2013.

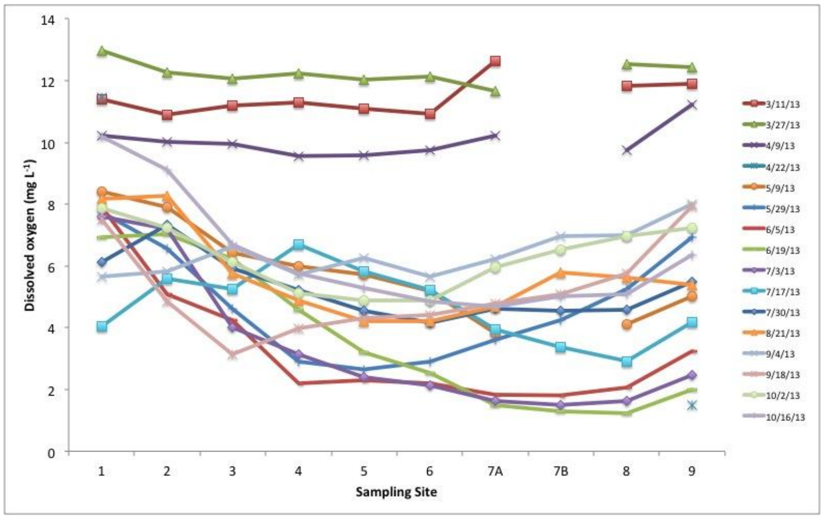

Figure 6: Dissolved oxygen concentrations at each site for each sampling date with the exception of 11/1/13 during 2013.

b. <u>Biological data:</u>

Most of the biological activity occurred during the late summer months into the early fall months in the Anacostia River. Chlorophyll *a* (chl *a*) concentrations increased in late June and remained high until mid-October (Fig. 7). The chl *a* concentrations during this period were within range of historical chl *a* concentrations recorded from 2002-2006. For instance, average chl *a* concentrations were 12.2 $\mu g\ L^{-1}$ during 2002-2006 with the highest recorded chl *a* concentration of 61.8 $\mu g\ L^{-1}$ in August 2002 (Chesapeake Bay Program, 2014), while chl *a* concentrations on average for 2013 was 32.5 $\mu g\ L^{-1}$ with the highest average chl *a* concentration of 62 $\mu g\ L^{-1}$ during August 2013. A closer resolution to the summer months reveals two dates when chlorophyll levels were higher relative to other times and those were bloom conditions (Fig. 8). Further investigation via microscopy and consultation with a phytoplankton taxonomist, Steve Morton, from NOAA revealed that the bloom on June 13 was of the cryptophyte, *Cryptomonas ovata* while the bloom on July 17 was of the dinoflagellate, *Scrippsiella* spp (Fig.9).

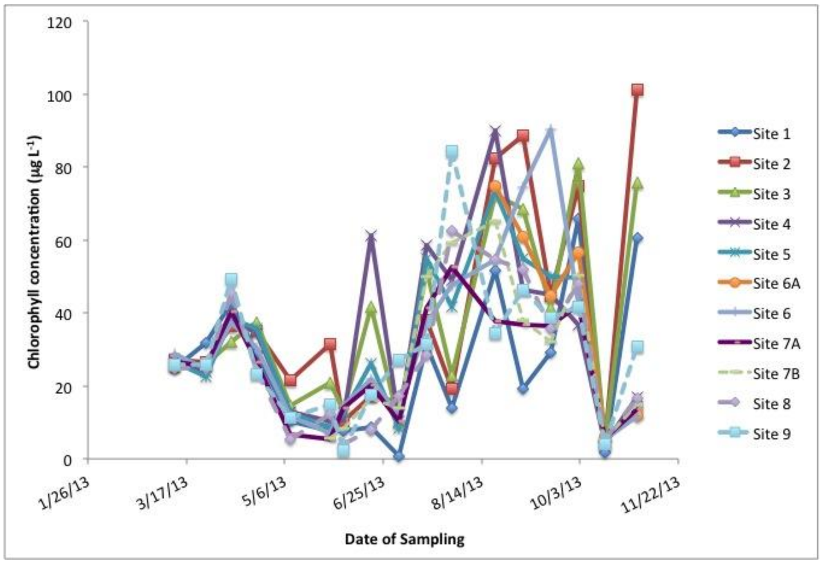

Figure 7: Chlorophyll concentrations in the Anacostia River during 2013.

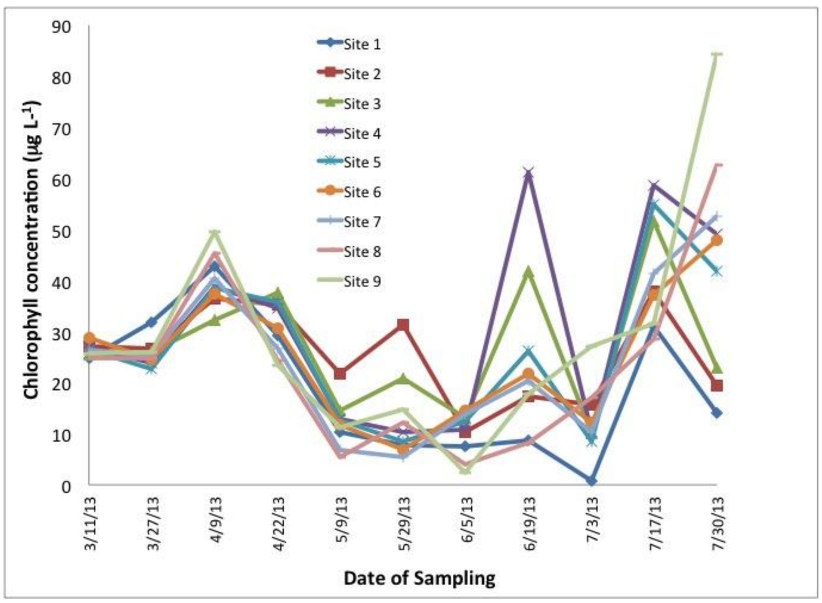

Figure 8: Chlorophyll concentrations during the spring and summer months in Anacostia River during 2013.

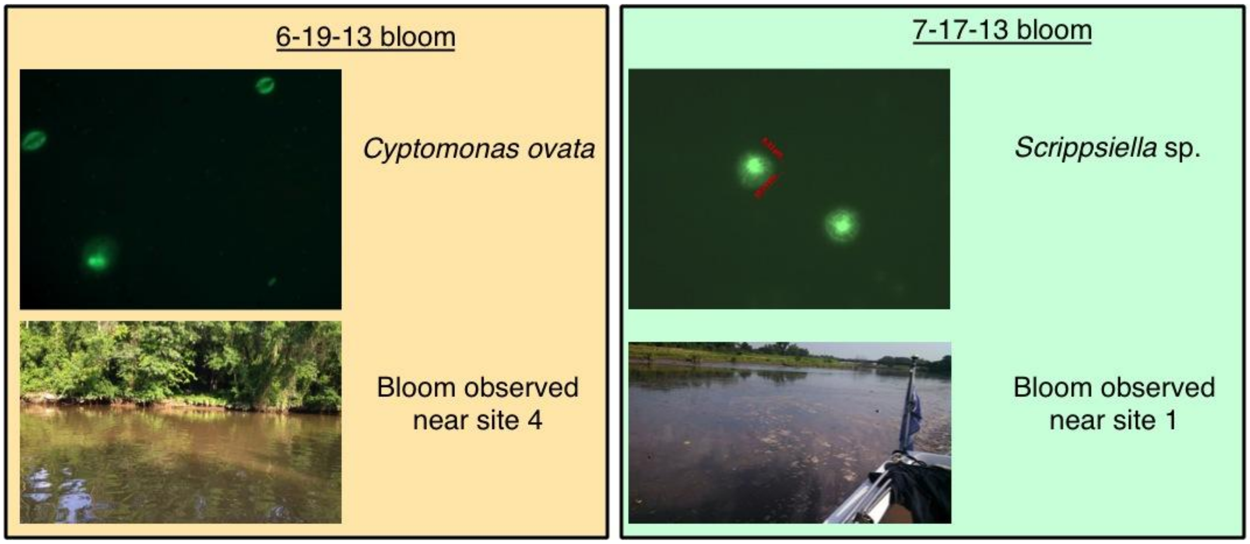

Figure 9: Epiflourescent and bloom pictures of phytoplankton species present on two dates: June 13 and July 17, 2013.

c. Nutrient concentrations (NH_4^+, urea, TDP)

Nitrogen concentrations, especially for NH_4^+, were high during the *Cryptomonas ovata* bloom. Comparisons with historical NH_4^+ data from 2002-2006 that was available via the Chesapeake Bay Program (2014) revealed that the highest concentration was 13 μM-N during July 2003. The NH_4^+ concentrations observed during May-July 2013 were six-fold of historical concentrations (Fig. 10) For the first time according to our knowledge, urea concentrations were measured for the Anacostia. Urea concentrations were never higher than 10 μM-N (Fig. 11) and decreased starting on July 17 and remained low the rest of the year. These concentrations are similar to what has been observed in the Chesapeake Bay mainstem (Table 1). Analysis of NO_3^- is currently on-going.

TDP concentrations were higher during the early months of the year then again in late summer (Fig. 12). TDP concentrations were higher during the *Scrippsiella* spp. Bloom than during the *Cryptomonas ovata* bloom, which suggests that these two species required different nutrient conditions. The TDP concentrations from the last two sampling dates of 2013 have not yet been analyzed.

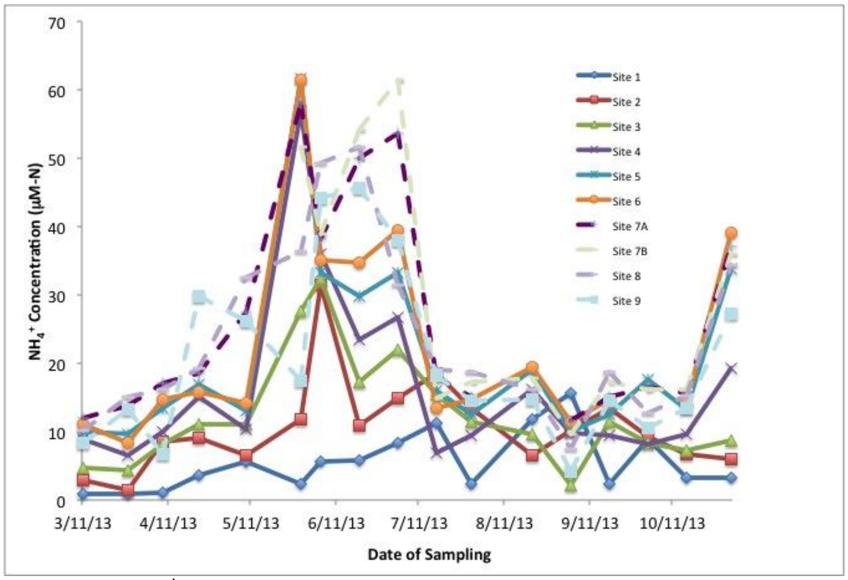

Figure 10: NH_4^+ concentrations in the Anacostia River during 2013.

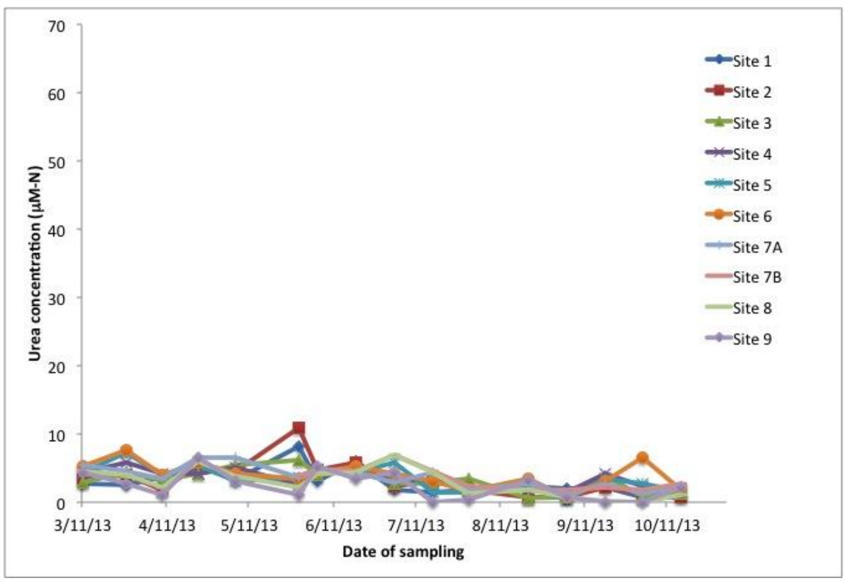

Figure 11: Urea concentrations in the Anacostia River during 2013

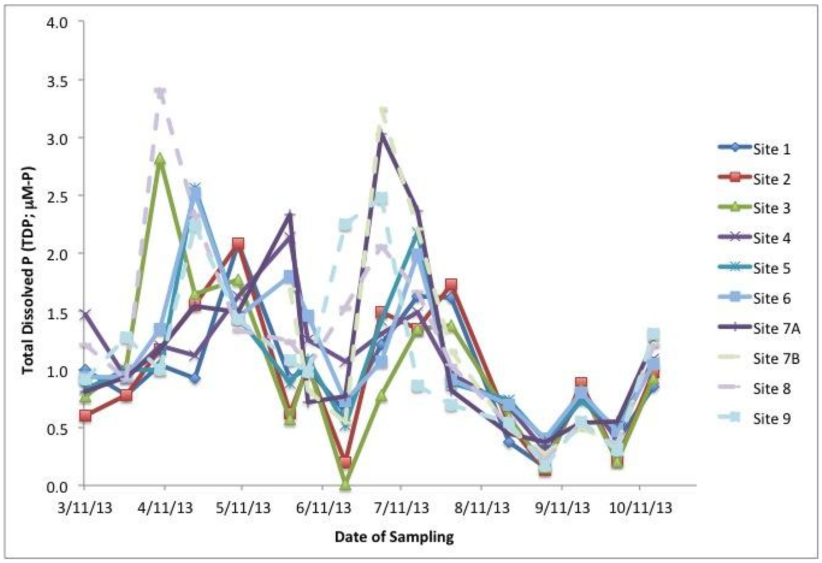

Figure 12: Total dissolved phosphorus (TDP) concentrations in the Anacostia River during 2013.

d. Biochemical rates (NH_4^+ uptake and urease activity)

NH_4^+ uptake was only measured on selected dates after NH_4^+ concentrations were the highest. NH_4^+ uptake rates were similar on three sampling dates, and increased from site 1 to site 9 (Fig. 13). Urea uptake has yet to be analyzed.

Urease activity rates that have been analyzed to date revealed that the highest activity occurred in late May. Urease activity rates tend to be the highest during the summer months (Solomon, 2006), so rates are expected to continue to be high during the rest of the summer.

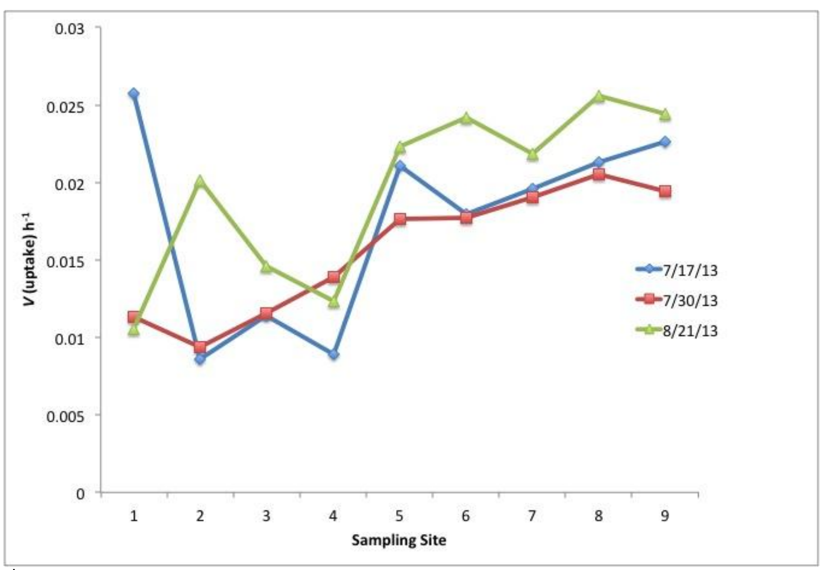

Figure 13: NH_4^+ uptake rates in the Anacostia River during selected dates.

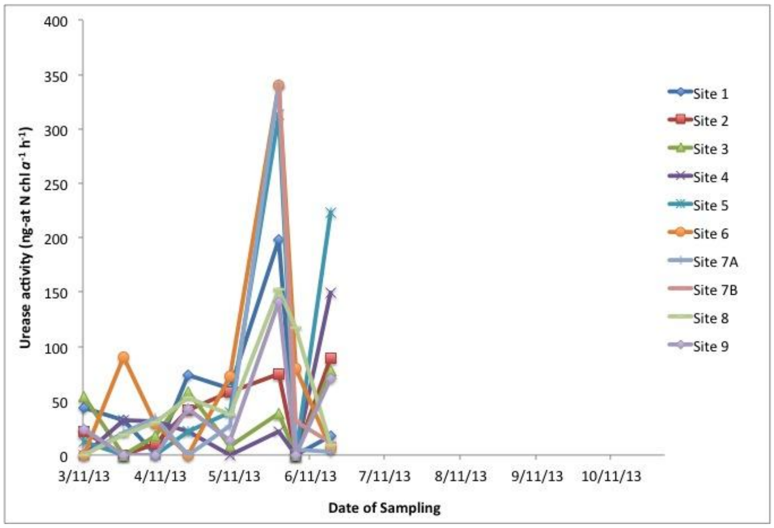

Figure 14: Urease activity rates normalized for chl *a* in the Anacostia River during 2013. Samples still need to be analyzed for the rest of the year.

5. <u>Natural abundance data</u>

Natural abundance of ^{15}N-NH_4^+ revealed that there might be two or three water regimes in the Anacostia River (Fig. 15). The first water regime is from site 1 to 4 with a source of NH_4^+ that originates near site 1, possibly from Quincy Manor Run. The second water regime includes site 5 and 6 that is close to two tributaries, Hickey Run and Watts Branch. Studies of both Hickey Run and Quincy Manor Run have found that those areas have approximately 41% of impervious surfaces (US Army Corps of Engineers, 2009) that may contribute NH_4^+ to these tributary waters that enter the Anacostia River. The third water regime is the area where most of the CSOs exist from sites 7 to 9.

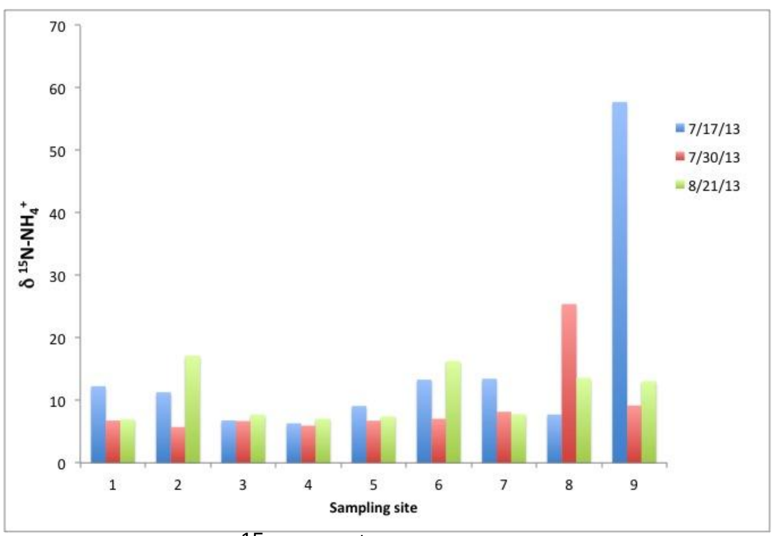

Figure 15: Natural abundance of ^{15}N-NH_4^+ in the Anacostia River during selected dates. Samples were only selected to be analyzed for those dates as NH_4^+ concentrations were high.

6. Project outcomes and presentations

a. Collaborations

This project resulted in a successful collaboration with the Anacostia Riverkeeper (AK). We often observed situations that resulted in contacting the proper authorities. On one occasion, AK reported workers cleaning one of the bridges and found out that they were working without the correct permits. AK also contacted DC DOE after we observed the *Scrippsiella* spp.bloom. DC DOE went out to look at the bloom the next day and was in touch with us regarding whether it was a health hazard and whether an advisory needed to be issued.

This project also allowed Dr. Solomon and personnel in her laboratory to interact and network with other people who are working on the Anacostia River including Anacostia Watershed Society, AK, WaterCat consulting and researchers at University of DC and University of Maryland. Through DCWWRI, both Dr. Solomon and her colleague, Dr. Daniel Lundberg, learned about two workshops or symposiums that focused on DC water issues and were able to attend.

b. Presentations

Summer 2013 interns, Kody Schouten and Anna McCall ’15, presented their results to the campus community including several Anacostia River stakeholders (e.g. Anacostia Riverkeeper, WaterCat Consulting) at the end of the summer as part of their internship. They also presented at ASLO (see next section).

Giovanna Vasquez ‘16 and lab technician, Muhammad Rubaiyat, prepared materials to educate the Gallaudet community about the Anacostia River research during Earth Day 2014.

c. Weaving the project into the curriculum

Data from the study was used in courses taught by Dr. Solomon to spread awareness among students and the campus community during the Spring 2013, Fall 2013, and Spring 2014 semesters. During the spring semesters, Dr. Solomon co-taught a course on socio-environmental synthesis that utilized the Anacostia River as a case study. Students from these courses visited the Blue Plains Treatment Plant and the Anacostia River to better understand the socio-environmental system. Many students later signed up for clean-up days through the Anacostia Watershed Society and AK as part of their sorority or fraternity community service efforts. Other efforts included sharing research results with the Gallaudet University Sustainability Council, and one graduating senior decided to do a grant proposal on studying how much litter enters the Anacostia River as part of her capstone project.

d. Additional funding
Data from the study allowed us to apply for further funding from Maryland Sea Grant and receive funding from an anonymous donor to continue our work on the Anacostia River.

7. Student support

Over the course of one year, **six** deaf and hard-of-hearing undergraduate and **one** graduate student were involved with the project. Brandon McMillian ’13 and Justin Christian ‘14 were involved in getting the project started during the Spring 2013 semester. Brandon was involved with the sampling as well as measuring TDP. Justin joined on one sampling trip and helped with sample preparation.

Two interns, Kody Schouten (Tarleton State University, TX) and Anna McCall (Gallaudet ’15) were involved with the project during Summer 2013. They were involved with all sampling trips and all the nutrient analyses. Both students won scholarships to attend and present their poster at the Association for the Sciences of Limnology and Oceanography (ASLO) conference in Honolulu, Hawaii in February, 2014. They had the opportunity to be part of the ASLOMP program that matched them with a mentor during the meeting.

Giovanna Vasquez ’16 and Sheena O’Donnell ’14 worked on the project during Fall 2013 and Spring 2014 semesters. The experience helped Giovanna land an internship interview with MarineLab in Key Largo, Florida for Summer 2014. Learning how to do nutrient analyses benefitted Sheena as she progressed through her senior honors capstone project on designing a sustainable turtle aquarium.

Melanie Jackson, a PhD student at University of Maryland, became involved with the study starting in March 2014. She will be looking at the natural abundance of $^{15}N\text{-}NH_4^+$ to investigate potential sources of NH_4^+ to the Anacostia River as part of her dissertation research.

8. Conclusion

The aim of this project was to investigate the role of organic nitrogen, especially urea, and its potential relationship with harmful algal blooms in the Anacostia River. It was predicted that urea would be higher closer to the CSOs on the lower part of the Anacostia River (sites 6-9) which may lead to occasional harmful algal blooms, but that did not occur. Both NH_4^+ and urea concentrations were highest upriver between sites 3-6 which is located along marshland, National Arboretum and Langston golf course while the two blooms were observed between sites 1-4.

The two phytoplankton blooms observed during the summer included a dinoflagellate and a crytophyte. These two blooms occurred under different nutrient conditions. The *Cryptomonas ovata* bloom that occurred on June 19, in the middle of the rainiest month of 2013, happened when there was high NH_4^+ but low TDP concentrations. Urea concentrations ranged from 3.5-5.9 μM-N, and urease activity was higher than the previous sampling dates (with the exception of late May) suggesting that urea may have been utilized in addition to NH_4^+. However, crytophytes have a lower urea activity per cell than dinoflagellates (Solomon 2006), so it may have utilized NH_4^+ more than urea. NH_4^+ and urea uptake rates need to be analyzed for this date to test this prediction and better nitrogen physiology of this bloom.

The *Scrippsiella* bloom that occurred on July 17 differed than the *Cryptomonas ovata* bloom because by this time NH_4^+ concentrations had decreased, and TDP concentrations increased. The NH_4^+ uptake rates on this date showed similar rates on later dates, suggesting NH_4^+ was utilized by the dinoflagellate resulting in lower concentrations than earlier in the summer. Urea and urease activity rates have not yet been analyzed for this date, but previous information about urea uptake and urease activity by dinoflagellates suggests that it will be high during this bloom (Solomon, 2006; Solomon et al. 2010). However, there is not much known about the urea physiology of *Scrippsiella* compared to other dinoflagellates. If this is a common dinoflagellate in the Anacostia River that could be improperly identified as a harmful phytoplankton, further taxonomic and physiological studies are warranted.

The six-fold concentrations of NH_4^+ observed than historical levels needs to be further investigated. The PhD student will continue to investigate different sources of NH_4^+ by measuring natural abundance of $^{15}N\text{-}NH_4^+$. We obtained additional funding to continue monitoring the Anacostia River for another year and to continue to analyze samples from 2013 to further investigate the role of NH_4^+ and urea in relation to potential harmful algal blooms.

9. Acknowledgements

Our work on the Anacostia River was supported by grants from the DC Water Resources Research Institute and Maryland Sea Grant. We also want to thank an anonymous donor who also supported our project. Our collaboration with the Anacostia Riverkeeper allowed us to go out bi-weekly on their boat. They donated their staff time so that one staff person could accompany us and drive the boat. Last but not least, we want to thank Dr. Daniel Lundberg for his assistance with analyzing TP and TDP concentrations, sampling the River and working with students.

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Information Transfer Program Introduction

The Institute has no funded Information Transfer Project, however it conducts outreach and training activities in close collaboration with other landgrant centers in CAUSES, such as the Center for Sustainable Development, the Center for Urban Agriculture, and 4-H and Youth Development by distributing newsletters, media releases and factsheets, and training and attracting youth to prepare them to the water sciences and technologies.

In addition, the Institute has also established a strong collaboration with the regional water and environmental organization to conduct major outreach and environmental education. Every year, in collaboration with DC Environmental Film Festival, the Institute screens two water related films at UDC. For more information about the films, please follow the links:

1.http://www.dcenvironmentalfilmfest.org/films/show/1257

2.http://www.dcenvironmentalfilmfest.org/films/show/1258

3.http://www.dcenvironmentalfilmfest.org/films/show/833

4.http://www.dcenvironmentalfilmfest.org/films/show/829

5.http://www.americantowns.com/dc/washington/events/environmental-film-festival-thursday-screenings-at-university

In colaboration with NCR-AWRA, we organize annual water symposium at UDC. This year we organized the 2nd Annual water symposium on April 4. Please follow the following links for more information about both 1st and 2nd annual water symposiums:

1.http://www.udc.edu/docs/causes/WaterHighlights%202013.pdf

2.https://www.udc.edu/docs/causes/Just%20CAUSES%20April.pdf

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	4	0	0	0	4
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Publications from Prior Years

1. 2008DC92B ("Modeling of Integrated Urban Wastewater System in the District of Columbia (Pase II)") - Dissertations - Rahham, A., 2008, Master in Public health, Effect of Combine Sewer Over flows on Rock Creek water quality and implication of human health, MS Dissertation , Environment and Occupation health, George Washington University, Washington, DC
2. 2008DC92B ("Modeling of Integrated Urban Wastewater System in the District of Columbia (Pase II)") - Water Resources Research Institute Reports - Deksissa, T. and P. Behera, 2008, Modeling of Integrated Urban Wastewater System in the District of Columbia (Phase II), DC Water Resources Research Institute, University of the District of Columbia, Washington, DC, pp17.
3. 2008DC93B ("Development of Web-based Rainfall Statistical Analyisis Tool for Urban Stormwater Management Analsis") - Conference Proceedings - Behera P.K. and T. Branham, "Development of a Rainfall Statistical Analysis Tool for Analytical Probabilistic Models for Urban Stormwater management Analysis", Proceedings World Environmental & Water resources Congress 2010, Providence, RI, May 16-20, 2010 pp. 3281-3290.
4. 2008DC93B ("Development of Web-based Rainfall Statistical Analyisis Tool for Urban Stormwater Management Analsis") - Conference Proceedings - Behera P.K. and Y. Guo and R. Teegavarapu, "Evaluation of Antecedent Storm Event Characteristics for different Climatic Regions based on Interevent Time Definition (IETD)" Proceedings World Environmental & Water resources Congress 2010, Providence, RI, May 2010, pp. 2441-2450.
5. 2008DC93B ("Development of Web-based Rainfall Statistical Analyisis Tool for Urban Stormwater Management Analsis") - Conference Proceedings - Ramesh Teegavarapu, A Aneesh Goly, Chandramouli Viswanathan, and Pradeep Behera, Precipitation Extremes and Climate Change: Evaluation using Descriptive WMO Indices , Proceedings, World Environmental and Water Resources Congress 2012: Crossing Boundaries, ASCE, Albuquerque, NM, May 2012, pp. 1927-1936.