D.C. Water Resources Research Institute Annual Technical Report FY 2012

Introduction

This report is a summary of the activities of the District of Columbia (DC) Water Resources Research Institute (WRRI) for the period of March 1, 2012 through February 28, 2013. Housed in the College of Agriculture, Urban Sustainability and Environmental Sciences (CAUSES), the DC WRRI (the institute) is one of the 54 such institutes network at the land-grant universities in the nation. The mission of the institute is to provide DC with interdisciplinary research and training support to address all water issues; identify city water and environmental resources and problems and contribute to their solution. The institute continues to build internal and external research collaboration and partnerships among departments and universities to support the DC water projects. The institute conducts relevant applied water related researches and transfer information to assist water and environmental regulators and policy makers. Improving the quality of DC waterways is strongly related to improving the DC residents' quality of life. The institute provides seed grants to water related research and training projects that improve the quality of DC water ways. The seed grant is awarded to faculty members or researchers from the consortium of universities. The consortium universities include the University of the District of Columbia, Howard University, George Washington University, the Catholic University, Georgetown University, George Mason University, Gallaudet University and American University. The institute has funded 7 projects for FY12 at American University, University of DC, George Washington University and Catholic University of America.

As part of the only urban land-grant units of CAUSES, the institute continued to coordinate water related research, training and outreach activities in DC. The Institute has funded about 70 research projects from 2002 through 2012 which has trained about 220 graduate and undergraduate students. The seed grant creates the opportunity to train students and new faculty in water science and technology research project and leverage extramural funding. Seed grant has enabled some faculties to leverage substantial new grant from the National Science Foundation and DC Department of Environment. Within the last three years, the University of DC alone received about $2 million financial support for research and building research laboratories. In the FY12, about 20 graduate and undergraduate students were trained from various majors such as biology, environmental science, engineering, computer sciences and water resources. In FY2012, The new Environmental Quality Testing Lab of the institute has provided access to about 45 undergraduate and graduate students to be trained on the new analytical technologies, including Inductive Couple Plasma Mass Spectrophotometer and Gas Chromatograph Mass Spectrophotometer. These analytical technologies are crucial for advancing water research and training at the UDC.

In collaboration with other land grant units of CAUSES, the institute conducts outreach and information transfer activities by organizing workshop or symposium and disseminating fact sheets and newsletter. In this FY12, the institute together with Cooperative Extension Service distributed about 1500 hard copies of Water Highlight. In March and April, the institute has co-organized two big symposiums in collaboration with the Anacostia River Toxics Alliance and American Water Resources Association in the National Capitol Region (AWRA-NCR). The institute also collaborates with the DC Department of Environment in environmental outreach activities such as providing hands-on outdoor activities to elementary and middle school students. Such activities play an important role in attracting and preparing underrepresented minority students to succeed in water or environmental science and technology studies. The institute continued to lead the outreach activities in water-related programs at the University of DC to prepare our new scientist for the 21st century water resources management which is actually managing extreme events (too much or too little) and water quality, including emerging contaminants of concern.

For the last 7 years, the institute was focusing on building environmental and water research capacity building. Through the seed grants and extramural funding leveraged by the seed grants, as described in the FY 2011 annual report of the institute, the institute has successfully established two state-of-the-art laboratories: Environmental Quality Testing Laboratory and Environmental Modeling and Simulation Laboratory. The

Environmental Quality Testing Lab is equipped with DR2800 spectrophotometer through Total Organic Carbon and Total Organic Nitrogen Analyzer, a Gas Chromatograph Mass Spectrophotometer, Inductive Couple Plasma Mass Spectrophotometer, and a Time of Flight Liquid Chromatograph Mass Spectrometer with a Direct Sample Analyzer. These nano-analytical technologies are crucial in training and preparing our future scientist while making our underrepresented students, faculty members and researchers to compete for larger external research grants. By providing hands-on demonstration, the testing lab becomes an integral part of our teaching and outreach activities of our college, CAUSES. As indicated herein, the mission of the institute is to provide unbiased water quality monitoring to environmental agencies in the Districts, which requires EPA certification of our testing lab. The institute is completing the necessary steps to apply for the EPA certification of the lab, including hiring more qualified lab technicians. The EPA certification of the lab will create more opportunities for attracting and preparing our students in majoring water related studies. To provide equal access to this new lab for all UDC students, we implemented a new urban water quality management course designed for all majors and non-majors. The new course was part of the NSF funded project lead by Dr. Tolessa Deksissa to foster deep learning. In spring semester 16 students completed this course with significant change in critical thinking. Further, the lab has a potential to provide the DC residents with analytical service in identifying and quantifying chemical of concern in their environment, including soil, water, food and air.

The Environmental Modeling and Simulation lab is equipped with the latest desk top computers with state of the art environmental or water quality models for ranging from basic water quality (eutrophication) and wastewater treatment process through ecological, GIS based and ecotoxicological models. This lab is open to all UDC students from all majors and serving as both a research and teaching lab for graduate and undergraduate students, including Professional Science Master's in Water Resources Management, Environmental Science and Civil Engineering. A new GIS course was proposed for the undergraduate students to be taught in this lab. Finally, the modeling and simulation lab creates research and training opportunities for all UDC students and faculties.

In conclusion, the DC water Resources Research Institute will continue to take the lead in coordinating, facilitating and supporting innovative research and training activities pertaining to the DC water issues, while building partnership along with research infrastructure to analyze problems and identify solutions.

Research Program Introduction

The DC Water Resources Research Institute provides a seed grant to faculty of DC consortium of universities to conduct applied research that address water issues in the District of Columbia. According to Mayor Vincent Gray¡¦s Sustainable DC Plan, all DC water ways will be 100% fishable and swimmable by using 75% of the District¡¦s landscape to capture rainwater for filtration or reuse. The institute funded 10 innovative research and educational projects in FY2012 and this report summarizes their findings.

Dr. Pradeep Behera¡¦s final report on ¡§Anticipating Climate Change Based on Precipitation Analysis for the District of Columbia¡¨ shows the importance of a technical analysis of long-term rainfall record for determining potential climate change trends. Climate change and water resources management are closely related as it affects the hydrologic cycle and results in frequent occurrence of too little water (drought) or too much water (flooding). The analysis of potential climate change based on a storm event and its characteristics helps one understand and make informed decisions on climate change adaptation related issues. In this approach, the long-term rainfall record is divided chronologically into lengths of 20 year of segments. For each of these segments, a storm event analysis is performed for different inter-event time definition. The preliminary results indicate that over the last two decades, generally, the number of larger sized storm events have increased in the Washington DC region. Such information is very critical for our water resources professionals, engineers and regulatory authorities.

Dr. Massoudieh of Catholic University and Dr. Pradeep Behera (UDC) submitted a progress report on the ¡§Monitoring of the Van-Ness UDC Campus Green Roof System to Evaluate Runoff Quantity Control Performance¡¨. It was noted that like any other old city, stormwater management in the District of Columbia has been a very critical issue. The older metropolitan cities face severe stormwater quantity and quality problems including flooding, sewer back up, stream bank erosion, combined sewer overflows, and water pollution in the receiving waters. Aging of drainage infrastructures and high impervious areas are the causes of these problems. To address these problems, the implementation of low impact development projects is part of the DC Water long-term control plan approved by the EPA in 2004. The goal of this research project is to develop a modeling framework to evaluate the performance of green roof system in controlling stormwater runoff volume, and peak flow. The objective of this research project is to develop an analytical model that applies to the green roof systems. They await the final installation of the green roof to complete their project.

Drs. Inder Bhambri and Pradeep Behera¡¦s final report on the ¡§Development of Porous Driveway System for the District¡¦s Residential Lots¡¨ noted that urban stormwater runoff due to air increase of impervious surface contributes to a number of water quantity and quality problems in DC. An increase of impervious surface results in an increase of runoff volume. The higher runoff rate is resulting in flooding and pollution from urban anthropogenic activities which contribute to water quality problems. The objective of this seed grant research project focuses on two-folds: (i) analysis of effectiveness of porous pavement in DC from climatological and hydrological viewpoint, and (ii) Conceptual and experimental proof of concept. The required compressive strength and infiltration capacity were tested through the optimal mix of different types of aggregates, cement and water. It was noted that the porous pavement systems can be implemented in residential lots. In this project, two sets of porous pavement mixes were designed and tested for comprehensive strengths. The results showed that up to 2300 psi can be obtained, but more design and testing are required to achieve up to 3000 psi. From the rainfall analysis it was found that the proposed porous pavement is suitable for regions with storm events dominated by smaller size rainfall events like in DC.

Dr. David Culver provided a progress report on the ¡§Biological Inventory of Seepage Springs and Vernal Lools; Small Isolated Wetlands in Parks of National Capital East (National Park Services)¡¨. The purpose of this project is to (1) inventory small surface waters of the park lands of National Capital East (National Park Service), and (2) to determine if there is a chemical signature that differentiates different communities. Both vernal pools and seepage springs are inhabited by distinct fauna at risk, such as amphibians and crustaceans in vernal pool, and eyeless, depigmented amphipods in seepage springs. In this project, in collaboration with the National Park Service, more than 70 walking transects were identified and over 50 transects have been completed. About 75 potential seepage springs and vernal pools have been located. For each of these sites, a series of basic physic-chemical measurements have been taken using the YSI multiprobe and Hach nitrate/nitrite test strips: temperature, pH, conductivity, dissolved oxygen, nitrate and nitrite. The sites have been visited only once and more site visits are anticipated and species identification is to be completed.

Drs. Tolessa Deksissa, Heidi Moltz and Mr. James Palmer¡¦s final report on ¡§Evaluating Water Management Alternatives in the Upper Potomac River Basin for the District of Columbia Source Water Protection¡¨ depicts the importance of proactive adaptive management plans of water resources management. This project is a collaborative interdisciplinary research project implemented by University of the District of Columbia and the Interstate Commission on the Potomac River Basin. The Potomac River is the sole source of water for the residents of the District of Columbia. Protection of the upper Potomac River Basin is crucial to sustain continuous development of the District as well as the upper region of the basin. The Marsh and Rock Creek watersheds are parts of the Upper Potomac River Basin, and water resources management of this sub basin can affect the District of Columbia¡¦s Source Water Protection. Further, the water resources problem is also exacerbated due to climate change. The study included a graduate student intern from the UDC¡¦s Water Resources Management to 1) evaluate management alternatives recommended by the Marsh and Rock Creek Critical Area Advisory Committee, 2) present the research results to the advisory committee; 3) prepare a technical report on the findings of the project; and 4) assist in preparations to the draft and final Critical Area Resource Plan. This study identified seven water resources issues including availability, water storage, water quality, stormwater, policy and management, data availability, and communication.

Dr. Stephen MacAvoy¡¦s progress report on ¡§Constructing a Chemical Hydrograph of an Urban Stream's Response to Periodic Rainfall¡¨ indicates that the main source pollution for the Anacostia River may be due to stormwater runoff. The Anacostia River has been characterized as one of the most heavily polluted waterways in the United States. The river is heavily impacted by the surrounding urban watershed; however, the source of pollution is not yet well characterized. Previous studies showed that during low flow period, the Anacostia River quality is within the range of normal to less impacted urban river in nitrate and phosphate. During the wet season, stormwater flow may flush PCBs, heavy metals and PAH into the river. The objective of this study is to characterize a pollutant hydrograph. This will be conducted by collecting and analyzing hourly water samples and precipitation events. The project will then determine the nutrients delivered per unit volume of water to the river. This project will generate a chemical response profile to heavy run off and further examine if the geochemistry of the Anacostia River is related to the impervious land cover of the city.

Dr. Arash Massoudieh¡¦s progress report on the ¡§Development of a Physically-based Model for Performance Evaluation Optimization of Green Roof Systems¡¨ noted that the need of mathematical models that can be applied to evaluate the effectiveness of green infrastructures, including green roofs. The goal of the project is to perform a green roof simulation using a mechanistic model that studies different prototype parameters and runoff data to generate a design for future green roof projects. Important factors in retaining stormwater runoff include plant type, soil type, and the slope and depth of green roof. Selection of these factors to get optimum level of water retention may require a physical based mathematical model. The outcome of this research project is useful in selecting appropriate design and implementation of green roof projects.

Brenda Platt¡¦s final report on ¡§Composting Makes Sense¡¨ indicates the application of compost on watershed protection. The purpose of the composting makes sense project was to (1) explore watershed and other community benefits of composting organic discards to the District and the surrounding region, and (2) to identify specific policies for implementation that will help expand the use of compost as a watershed protection method. Compost is a valuable soil conditioner made from the natural decomposition of organic materials such as food scraps, animal manures, and yard trimmings. The benefits of composting include improving soil structure, soil water holding capacity, and reducing stormwater runoff and soil erosion. Other benefits of using composting include reducing solid waste management and land requirement for landfill. It is also noted that avoiding landfills for natural organic materials such as food scraps, animal manures and yard trimming can eliminate methane and other greenhouse gas emission. Soil amendment with compost restores soil organic matter content while serving as an alternative for carbon sequestration. It was also noted that composting has local economic benefit in creating jobs while protecting the watershed by reducing soil erosion and nutrient load into the Chesapeake Bay. Further, advancing composting and compost use can help the environment as well as local economy.

Dr. Iveracottis Short¡¦s progress report on a ¡§Performance-based Review of World-wide Water Reuse Facilities in Support of DC Water Policy¡¨ reviewed world-wide best management practices of water reclamation or reuse policies. Fresh water resource is limited and advancing water reuse is crucial to address world-wide water insecurity. There is no single water reuse policy that applies to all states or nations. Even within the US, different states have different water reuse policies. It is also noted that implementing water reuse projects is difficult in cities where there is no appropriate regulatory water reuse policies. Nevertheless the need for water reuse policy are increasingly crucial to cities where water scarcity eminent. The main goal of this project is to review world-wide water reuse related policy. The European water reuse policy is regulated by the European Water Framework Directives. According to EU Directives, every water treatment plant must meet stringent water quality standards. In Hungary for example, the water reclamation unit must meet the arsenic concentration of 10 Ýg/l. Further, water reuse can provide up to 27% of water supply in Tianjin, China. The finding of this project includes, in the absence of appropriate policy, a collaborative agreement among public, regulators and project managers must be made. Water reuse organization that operates worldwide is expected to see collaborative ways to make policy instead of top down approaches. Drs. Nian Zhang and Pradeep Behera¡¦s final report on ¡§Water Pollution Modeling and Prediction using Computational Intelligence Methods¡¨ noted the need of appropriate mathematical model to optimize Total Maximum Daily Load (TMDL) estimation. The main goal of this research project is to assist in developing an innovative computational intelligence based approach for optimizing TMDL. Their approach comprises of runoff quantity and quality prediction using Back Propagation Recurrent Neural Networks (BP-RNN). The neural networks model was trained by particle swarm optimization and evolutional algorithm to forecast the stormwater runoff discharge. The USGS real-time water data at Four Mile Run station in Alexandria, VA were used to demonstrate the usefulness of this modeling approach. The results show that the proposed method provides a suitable prediction tool for the stormwater runoff monitoring. The finding of this project was presented at 5 workshops and published in 3 conference proceedings.

Biological Inventory of Seepage Springs and Vernal Pools; Small Isolated Wetlands in Parks of National Capital East (NPS)

Basic Information

Title:	Biological Inventory of Seepage Springs and Vernal Pools; Small Isolated Wetlands in Parks of National Capital East (NPS)
Project Number:	2012DC135B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	DC
Research Category:	Biological Sciences
Focus Category:	Ecology, Wetlands, Conservation
Descriptors:	None
Principal Investigators:	David Culver

Publications

There are no publications.

Biological Inventory of Seepage Springs and Vernal Pools

Progress Report

David C. Culver, Principal Investigator

Department of Environmental Science, American University

May, 2013

Progress

The purpose of this project is to (1) inventory small surface waters of the park lands of National Capital East (National Park Service), especially with respect to vernal pools and seepage springs and (2) to determine if there is a chemical signature that differentiates different communities, especially those of vernal pools and seepage springs. Vernal pools and seepage springs are especially interesting habitats because their fauna is both distinctive and at risk—amphibians and crustaceans in the case of vernal pools, and eyeless, depigmented amphipods in the case of seepage springs. One of the species of amphipod found in Rock Creek Park is on the U.S. Endangered Species List.

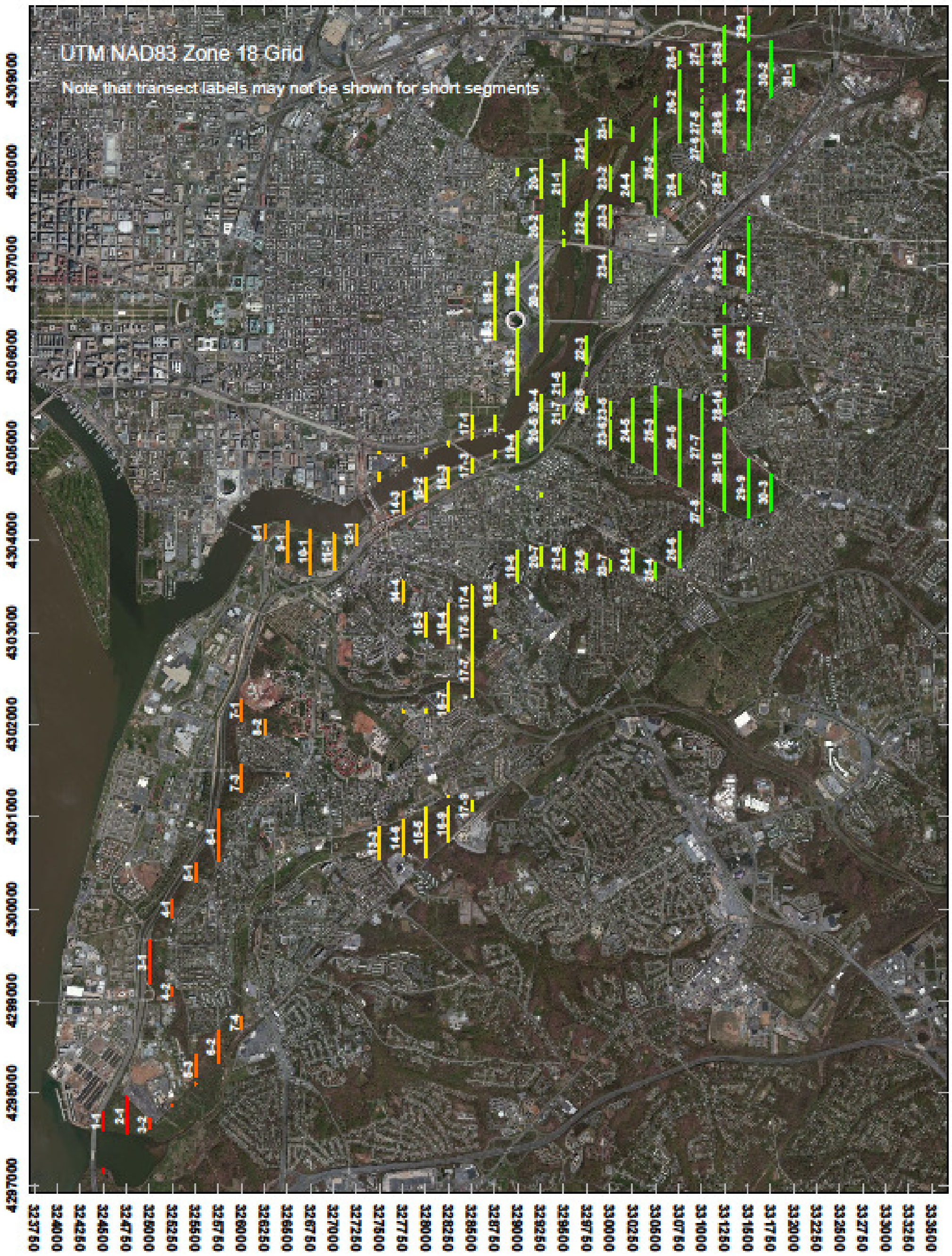
With the cooperation and participation of National Park Service personnel, especially Mikaila Milton of the National Capital East, we have been identifying sites by walking transects 250 m apart for all NACE property within the District of Columbia. There are more than 70 such transects (see map below), and we have completed over 50 transects, and have located 75 potential seepage springs and vernal pools. For each of these sites, a series of basic physic-chemical measurements have been taken using a YSI multiprobe and Hach nitrate/nitrite test strips:

- Temperature (^{o}C)
- pH
- Conductivity (mS/cm)
- Dissolved Oxygen (percent saturation and mg/L)
- NO_3 (mg/L)
- NO_2 (mg/L)

One characteristic of the chemical signature of this water is its large variation, as can be seen the following table.

	Temperature (^{o}C)	Conductivity (mS/cm)	Dissolved Oxygen (mg/L)	pH
Mean	11.0	380	2.54	7.4
Standard Deviation	4.9	276	2.59	1.2
Minimum	3.4	17	0	4.2
Maximum	24	1826	10.9	4.2
N	69	56	67	62

Variability is the result of several factors, including the temporary nature of the water, its small volume, and the diversity of settings, ranging from mature forest to roadsides to industrial sites. Work is not yet complete on differentiating sites into clusters based on faunal composition.



Biological sampling at these sites is challenging because of their small size and water volume, their transitory presence (typically most disappear from May to October when evapotranspiration is high water flow is low or nonexistent), and because of difficulties in locating animals. So-called "false negatives" are common and thorough sampling requires multiple visits (Culver, Holsinger and Feller 2012). At present sites have only been visited once. Four of the sites have obligate seep-dwelling species in the genus *Stygobromus*. Species identification is not yet complete. Another four sites have species in the amphipod genus *Crangonyx* and the isopod genus *Caecidotea* that are common facultative inhabitants of seepage springs. No sites have been found where obligate vernal pool invertebrates were found (species in the Crustacean order Notostraca) and our sampling technique, using small nets and sorting through decaying leaves is unlikely to yield any amphibians (by design).

A complete one time inventory of the National Capital East parklands should be complete by January of 2014, assuming that we have a normal or wet fall. Then, repeat sampling of sites will commence and continue as long as funding permits.

Reference

Culver, D.C., J.R. Holsinger, and D.J. Feller. 2012. The fauna of seepage springs and other shallow subterranean habitats in the mid-Atlantic Piedmont and Coastal Plain, U.S.A. **Northeastern Naturalist** 19 (Monograph 9):1-42.

Anticipating Climate Change based on Precipitation Analysis for the District of Columbia

Basic Information

Title:	Anticipating Climate Change based on Precipitation Analysis for the District of Columbia
Project Number:	2012DC136B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	DC
Research Category:	Climate and Hydrologic Processes
Focus Category:	Methods, Climatological Processes, None
Descriptors:	None
Principal Investigators:	Pradeep K. Behera

Publications

There are no publications.

Anticipating Climate Change based on Precipitation Analysis for the District of Columbia

Final Report

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May 2013

Content

Abstract

Since the publication of the Intergovernmental Panel on Climate Change documents (IPCC, 2007), there has been a growing interests among scientists, engineers, governments and public to understand climate change issues and its associated impacts. Climate change and water resources management are closely related because climate change affects the hydrologic cycle directly. The potential climate change can have significant impacts on our water resources and related sectors such as water availability, flooding, urban infrastructures, water quality, ecosystems, coastal areas navigation, hydropower, economy and other energy (USGS, 2009). As a results water resources managers who play an active role in planning, designing, operating and maintaining these water resources related systems will also be impacted by climate change (Brekke, et. al, 2009).

To understand and in support of informed decision for adaptation climate change related issues, a number of federal, state and local government agencies have launched several evaluations of vulnerability of their critical infrastructures to the potential climate change. Climate change has the potential to increase the variability in extreme weather events. In this regard, the evaluation of impact of climate change on our critical aging infrastructures, most importantly water infrastructures (i.e., water supply systems, sewer systems, drainage systems, hydraulic structures including bridges, culverts and dams) of the nation's capital, Washington DC, is very important because the city houses a significant number of federal agencies, several national monuments, international embassies and serves as a major economic center for the Washington Metropolitan area.

To support the information on climate change to the water resources professionals, engineers and other officials, this project proposes to conduct a technical analysis of the long-term point rainfall data for determining the potential climate change trend. The analysis is based on the definition a storm event and its characteristics. The long-term rainfall record will be divided chronologically into lengths of 20 year of segments. For each of these segments, storm event analysis was performed for different inter event time definitions. The preliminary results indicates that over last two decades, generally the number of higher size storm events have increased in the Washington DC region. Such information is very critical for our water resources professionals, engineers and regulatory authorities.

1.0 Introduction

Since the publication of the Intergovernmental Panel on Climate Change documents (IPCC, 2007), there has been a growing interests among scientists, engineers, governments and public to understand climate change issues and its associated impacts. Climate change and water resources management are closely related because climate change affects the hydrologic cycle directly. The potential climate change can have significant impacts on our water resources and related sectors such as water availability, flooding, urban infrastructures, water quality, ecosystems, coastal areas navigation, hydropower, economy and other energy (USGS, 2009). As a results water resources managers who play an active role in planning, designing, operating and maintaining these water resources related systems will also be impacted by climate change (Brekke, et. al, 2009).

To understand and in support of informed decision for adaptation climate change related issues, a number of federal, state and local government agencies have launched several evaluations of vulnerability of their critical infrastructures to the potential climate change. Climate change has the potential to increase the variability in extreme weather events. In this regard, the evaluation of impact of climate change on our critical aging infrastructures, most importantly water infrastructures (i.e., water supply systems, sewer systems, drainage systems, hydraulic structures including bridges, culverts and dams) of the nation's capital, Washington DC, is very important because the city houses a significant number of federal agencies, several national monuments, international embassies and serves as a major economic center for the Washington Metropolitan area.

To support the information on climate change to the water resources professionals, engineers and other officials, this project proposes to conduct a technical analysis of the long-term point rainfall data for determining the potential climate change trend. Given the climate variability and change throughout the world, local level continuous assessment of storm event characteristics is critical for analyzing adequacy of existing urban drainage infrastructures and for updating the critical rainfall information for future hydrologic designs. The analysis of extreme events is important for hydraulic and hydrology studies, and it is usually been performed using a moving window analysis (i.e. a pre-selected duration at a filter). But based on the Inter-event Time Definition (i.e., minimum dry period between storm events, or IETD) a long-term point rainfall record can be analyzed for different storm event characteristics such as event volume, event duration, event average intensity and inter-event time. Using such new information, it is important to analyze this key input to most of the storm water management planning, analysis, design and operation; such analysis will provide valuable information to our engineers, water resources professionals, and regulatory authorities about the change in storm event characteristics (storm event volume for different durations) over time at a specific location. This study evaluates storm event characteristics based on varying IETDs for Washington DC. The available long-term hourly rainfall records at the representative station, Washington DC Ronald Reagan Airport, within the District of Colombia climatic regions have been used to perform the analysis.

The analysis is based on the definition a storm event and its characteristics. Following the definition, two sets of analysis has been conducted and primary focus on the storm event volume characteristic. The first set includes the analysis of entire 60 years of record. The second set include the long-term rainfall record will be divided chronologically into lengths of 10-20 year of segments. For each of these segments, storm event analysis, will be performed. A comparative analysis of design storm event volumes for various return periods and volumes for extreme event storms will be performed to see the trends in different time period segments. Such information is very critical for our water resources professionals, engineers and regulatory authorities. Such information is very useful for volume based hydrology for managing urban storm water management systems.

2.0 Data

The available hourly rainfall data from NCDC (National Climatic Data Center) for Washington Reagan National Airport Station (ID 448906) from 1948-2009 was obtained from http://www.ncdc.noaa.gov/oa/ncdc.html and used in this analysis. These files catalog hourly precipitation information, and present the records in a comma-delimited ASCII text file.

Below are the first two lines of data from a sample rainfall record from the NCDC, along with the header rows which contain the column descriptions:

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COOPID,CD,ELEM,UN,YEAR,MO,DA,TIME,HOUR01,F,F,TIME,HOUR02,F,F,TIME,HOUR03,
F,F,TIME,HOUR04,F,F,TIME,HOUR05,F,F,TIME,HOUR06,F,F,TIME,HOUR07,F,F,TIME,HOUR
08,F,F,TIME,HOUR09,F,F,TIME,HOUR10,F,F,TIME,HOUR11,F,F,TIME,HOUR12,F,F,TIME,HO
UR13,F,F,TIME,HOUR14,F,F,TIME,HOUR15,F,F,TIME,HOUR16,F,F,TIME,HOUR17,F,F,TIME,
HOUR18,F,F,TIME,HOUR19,F,F,TIME,HOUR20,F,F,TIME,HOUR21,F,F,TIME,HOUR22,F,F,TI
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448906,00,HPCP,HI,1948,05,02,0100, 00000, , ,0200, 00000, , ,0300, 00000, , ,0400, 00000, , ,0500, 00000, , ,0600, 00000, , ,0700, 00000, , ,0800, 00000, , ,0900, 00000, , ,1000, 00000, , ,1100, 00000, , ,1200, 00000, , ,1300, 00000, , ,1400, 00000, , ,1500, 00002, , ,1600, 00012, , ,1700, 00001, , ,1800, 00002, , ,1900, 00000, , ,2000, 00000, , ,2100, 00000, , ,2200, 00000, , ,2300, 00000, , ,2400, 00000, , ,2500, 00017, ,

Figure 1: NCDC Precipitation Data File

It was found that about .2 % of the record length of 62 year of data was missing. For the missing period, zero value was assumed because it constitutes a significantly small fraction compared to entire record.

3.0 Methodology

The storm event analysis begins with the definition of a storm event. Next, based on the definition of a storm event, the historical rainfall records have been analyzed to identify the size of the storms and their probability of occurring over time. In this study, two key parameters, volume and duration are emphasized over many parts of the country that represents different climatic regions.

Definition of a Storm Event: Adams et al (1986) provided a distinction between a meteorological event and a statistical event. A natural isolated meteorological storm event, at a point in space as described by a hyetograph, that has both external and internal characteristics. The external characteristics are attributed to measured quantities such as total volume of the storm, total duration of the storm, the inter event time or time period since the last storm and calculated quality such as rainfall intensity. Whereas the internal characteristics could be many and complex such characteristics include time to peak intensity, number of peaks, distribution of volume within those peaks etc. From practical point of view, we are generally interested in the external characteristics which are used for the estimation of key design parameter, event runoff volume. A long-term hyetograph consists of a series of natural meteorological events which are measured as rainfall pulses through time at a point in space. The meteorological events are measured by public agencies such as NOAA and NCDC at various locations. They provide the continuous record of rainfall over time which has been used to develop intensity-duration-frequency curves for a specific location. These records could also be analyzed in a different way from event perspective, such as runoff event arising form rainfall event.

On the other hand, a statistical event in hydrology is typically defined by a random variable equaling or exceeding certain magnitude (Adams et al., 1986). In order to define a statistical storm event, it is required to identify when the event begins and ends. Two consecutive storm events are separated by a time period of without rainfall (i.e., dry period). Depending on the weather system, a meteorological event could be one rainfall pulse of any duration or many rainfall pulses with different durations occurred continuously. From practical viewpoint, if the time period between two consecutive events is 'short', it is generally considered as same event. On the contrary, if the time period between the events is 'long', it can be considered as they are belong to two separate event. The stormwater management systems that process runoff from the storm event are affected by the size of the event (one event or a group of events). Accordingly, a meteorological long-term hyetograph could be discretized into individual statistical storm events by defining an inter event time definition (IETD) that represents minimum dry period between two independent storm events. Following Figure 2 presents the illustration of statistical storm events based on IETD.

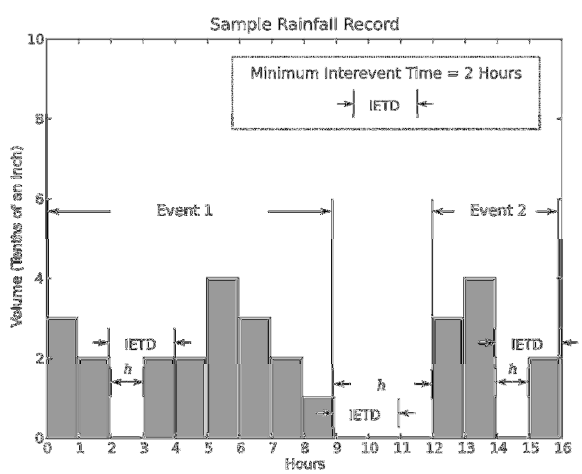

Figure 2: IETD and Separation of Storm Events

From practical viewpoint, IETD duration could also be few minutes to several hours, however it is governed by the applications and watershed characteristics. For smaller watersheds, IETD duration could be shorter (i.e., fraction of an hour to few hours) if the there are small storages and low depression storages. Whereas for larger watersheds on which natural routing of runoff takes place, or with large storage reservoirs, a longer IETD duration (few hours to days) is desirable. For urban watersheds, typical IETDs range from 2 hrs to 6 hours (Guo, 1996, and Wanielista and Yousef, 1993).

Based on the definition of IETD, the available continuous chronological rainfall record has been discretized into individual storm events. If the time interval between two consecutive rainfalls is greater than the IETD, the rainfall events are considered as two separate independent events. Once this criterion is established, the rainfall record is transformed into a time series of individual storm events and each storm event can be characterized by its volume, duration, interevent time and average intensity. The general statistics of the time series of storm events can be obtained. In this research volume and duration of the storm are considered.

4.0 Results and Analysis

We developed a computer code to process the downloaded data. Based on the IETD the code parses into individual storm events. The discretized long-term rainfall for Reagan Airport Station for any IETD is given below in Figure 3.

First Rain	Last Rain	Volume	Duration	IE Time	Intensity
05/01/1948 @ 03:00	05/01/1948 @ 04:00	0.03	2	0	0.015
05/02/1948 @ 02:00	05/02/1948 @ 05:00	0.17	4	21	0.0425
05/03/1948 @ 01:00	05/03/1948 @ 03:00	0.5	3	7	0.166667
05/04/1948 @ 08:00	05/05/1948 @ 02:00	0.82	7	40	0.117143
05/07/1948 @ 12:00	05/07/1948 @ 07:00	0.69	8	45	0.08625
05/07/1948 @ 02:00	05/07/1948 @ 02:00	0.01	1	6	0.01
05/07/1948 @ 06:00	05/07/1948 @ 06:00	0.08	1	3	0.08
05/12/1948 @ 09:00	05/13/1948 @ 07:00	1.61	11	122	0.146364
05/13/1948 @ 10:00	05/13/1948 @ 01:00	0.8	4	2	0.2
05/13/1948 @ 06:00	05/13/1948 @ 08:00	0.21	3	4	0.07
05/14/1948 @ 01:00	05/14/1948 @ 02:00	0.16	2	16	0.08
05/16/1948 @ 12:00	05/16/1948 @ 03:00	0.22	4	45	0.055
05/16/1948 @ 10:00	05/17/1948 @ 01:00	1.03	4	6	0.2575
05/17/1948 @ 03:00	05/17/1948 @ 03:00	0.01	1	13	0.01
05/30/1948 @ 01:00	05/30/1948 @ 02:00	0.06	2	309	0.03
05/30/1948 @ 05:00	05/30/1948 @ 09:00	1.54	5	2	0.308
05/31/1948 @ 07:00	05/31/1948 @ 07:00	0.01	1	9	0.01
06/03/1948 @ 07:00	06/04/1948 @ 12:00	0.08	6	83	0.013333
06/04/1948 @ 03:00	06/04/1948 @ 03:00	0.01	1	2	0.01
06/04/1948 @ 09:00	06/04/1948 @ 09:00	0.02	1	5	0.02
06/07/1948 @ 01:00	06/07/1948 @ 02:00	0.11	2	63	0.055
06/07/1948 @ 01:00	06/07/1948 @ 02:00	0.93	2	10	0.465
06/16/1948 @ 02:00	06/16/1948 @ 02:00	1.07	13	203	0.082308
06/18/1948 @ 06:00	06/18/1948 @ 09:00	0.44	4	51	0.11
06/19/1948 @ 05:00	06/19/1948 @ 09:00	1.63	5	19	0.326
06/20/1948 @ 12:00	06/20/1948 @ 01:00	0.55	2	2	0.275
06/24/1948 @ 05:00	06/24/1948 @ 05:00	0.1	1	111	0.1
06/29/1948 @ 07:00	06/29/1948 @ 07:00	0.32	1	121	0.32
06/30/1948 @ 06:00	06/30/1948 @ 07:00	0.04	2	22	0.02
06/30/1948 @ 10:00	07/01/1948 @ 12:00	0.17	3	2	0.056667
07/06/1948 @ 04:00	07/06/1948 @ 05:00	0.12	2	135	0.06
07/13/1948 @ 03:00	07/13/1948 @ 04:00	0.55	2	165	0.275
07/14/1948 @ 11:00	07/14/1948 @ 02:00	1.06	4	18	0.265
07/14/1948 @ 06:00	07/14/1948 @ 06:00	0.01	1	3	0.01
07/15/1948 @ 12:00	07/15/1948 @ 12:00	0.04	1	5	0.04
07/17/1948 @ 04:00	07/17/1948 @ 05:00	0.05	2	51	0.025
07/19/1948 @ 02:00	07/19/1948 @ 02:00	0.2	1	56	0.2
07/23/1948 @ 10:00	07/23/1948 @ 11:00	0.12	2	91	0.06
07/27/1948 @ 02:00	07/27/1948 @ 03:00	0.42	2	98	0.21
07/27/1948 @ 06:00	07/27/1948 @ 09:00	0.14	4	2	0.035
07/28/1948 @ 01:00	07/28/1948 @ 03:00	0.07	3	3	0.023333
07/28/1948 @ 04:00	07/28/1948 @ 04:00	0.02	1	12	0.02
07/31/1948 @ 01:00	07/31/1948 @ 07:00	1.46	7	68	0.208571
08/01/1948 @ 01:00	08/01/1948 @ 06:00	2.84	18	5	0.157778
08/03/1948 @ 04:00	08/03/1948 @ 05:00	0.14	2	33	0.07
08/03/1948 @ 03:00	08/03/1948 @ 08:00	0.15	6	9	0.025
08/03/1948 @ 11:00	08/03/1948 @ 11:00	0.01	1	2	0.01
08/04/1948 @ 02:00	08/04/1948 @ 02:00	1.26	13	2	0.096923
08/11/1948 @ 05:00	08/11/1948 @ 10:00	1.74	6	170	0.29
08/12/1948 @ 01:00	08/12/1948 @ 06:00	0.22	6	2	0.036667

Figure 3: Output of individual storm event characteristics

Following Figure 4 presents the analysis of Reagan Airport data for 2006 with an IETD of 6 hour. It is noted that in 2006, Washington DC experienced severe flooding which in The extensive flooding shut down operations at four key federal office buildings—IRS Headquarters, the Commerce Department, the Justice Department, and the National Archives. Several Smithsonian museums along Constitution Avenue also closed their doors. The National Gallery of Art closed due to a weather-related steam outage, and the National Zoo banned cars because of flooding in the parking lot. Rock Creek Parkway became impassable and had to be closed when Rock Creek overflowed its banks and flooded the road (NCPC, 2008).

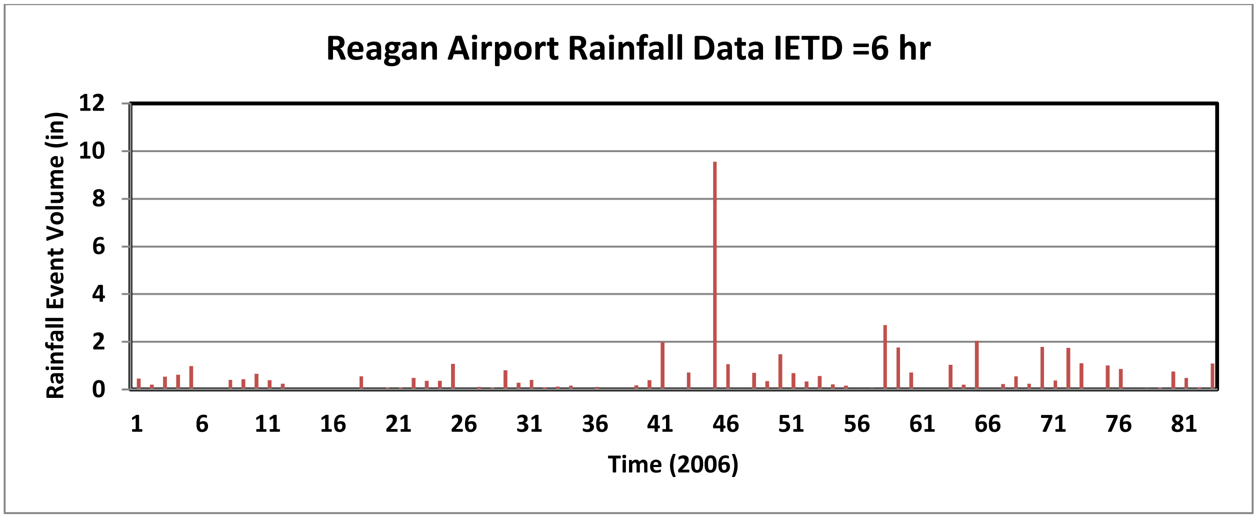

Figure 4: Storm Event Volumes for 2006 at the Reagan Airport Station with an IETD of 6 h

The summarized storm event volume analysis of 60 years Reagan Airport data is presented in Table 1. The table presents the maximum storm event volume in inches for a set of IETDs which ranges from 1 hour to 24 hour. For example, in 1952, the maximum storm event volume for an IETD of 6 hour is 3.89 inches and for an IETD of 24 hour is 4.61 inches.

Table 1: Maximum Storm Event Volumes for Different IETDs at the Reagan Airport Station

YEAR	Maximum Storm Event Volume (inches)									
	IETD 1	IETD 2	IETD 3	IETD 6	IETD 9	IETD 12	IETD 15	IETD 18	IETD 21	IETD 24
1948	1.86	2.84	2.84	4.3	4.3	4.3	4.3	4.3	4.3	4.3
1949	1.68	1.76	1.76	1.77	2.42	2.42	2.42	2.42	2.42	2.42
1950	3.85	3.86	3.86	3.86	3.86	3.86	3.86	5.13	5.13	5.13
1951	2.75	2.75	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
1952	3.11	3.11	3.24	3.89	4.61	4.61	4.61	4.61	4.61	4.61
1953	3	3.01	3.01	3.24	3.65	5.5	5.6	5.6	5.68	5.68
1954	1.68	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73
1955	6.39	6.39	6.39	6.6	6.6	6.6	6.6	6.6	6.6	6.6
1956	1.9	1.9	1.9	1.9	1.9	1.99	1.99	1.99	2	2
1957	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14

YEAR	Maximum Storm Event Volume (inches)									
	IETD 1	IETD 2	IETD 3	IETD 6	IETD 9	IETD 12	IETD 15	IETD 18	IETD 21	IETD 24
1958	3.69	3.69	3.7	3.75	3.75	3.77	3.77	4.24	4.24	4.24
1959	2.74	2.74	2.76	2.76	2.76	2.76	2.76	2.8	2.8	2.89
1960	2.72	2.72	2.83	2.83	2.83	3.25	3.25	3.25	3.25	3.65
1961	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
1962	1.49	1.49	1.49	1.68	1.7	1.7	1.7	1.7	1.75	1.75
1963	3.9	3.9	3.9	3.9	3.9	3.9	3.9	6.28	6.28	6.28
1964	1.17	1.17	1.17	2.11	2.11	2.11	2.11	2.11	2.11	2.11
1965	1.69	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94
1966	4.08	4.15	4.28	4.29	4.29	4.29	4.29	4.29	4.29	4.29
1967	2.85	3.66	3.66	3.66	3.66	4.94	4.94	4.94	4.94	4.94
1968	2.08	2.08	2.09	2.26	2.26	2.51	2.51	2.51	2.51	2.51
1969	4.35	4.35	4.35	4.4	4.4	4.4	4.4	4.4	4.4	4.4
1970	4.69	4.69	4.69	4.69	4.69	4.69	4.69	4.69	4.69	4.69
1971	3.79	3.79	3.79	3.79	3.85	3.85	3.85	3.85	3.85	3.85
1972	6.28	7.15	7.21	7.21	7.46	8.16	8.16	8.16	8.16	8.16
1973	3.26	3.28	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
1974	2.13	2.26	2.27	2.27	2.27	2.28	2.28	2.28	2.28	2.28
1975	3.13	5.32	5.32	6.13	9.08	9.08	9.08	9.08	9.08	9.08
1976	2.84	2.84	2.87	2.96	5.83	5.83	5.83	5.83	5.83	5.83
1977	2.22	2.32	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.65
1978	2.1	2.42	2.42	2.84	2.84	2.84	2.84	2.84	2.84	2.84
1979	3.68	3.68	3.68	3.69	3.69	3.69	3.69	3.69	3.69	3.69
1980	1.47	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61
1981	1.59	1.59	1.59	1.59	1.72	1.73	1.81	2.29	2.29	2.29
1982	1.79	1.8	1.8	1.8	1.87	1.87	1.87	1.87	2.75	2.75
1983	2.31	2.31	2.31	2.44	2.44	2.44	2.61	2.94	2.94	3.04
1984	1.7	2.53	2.53	2.53	2.53	2.54	2.54	2.54	2.54	2.54
1985	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96
1986	2.3	2.33	2.33	2.36	2.36	2.36	2.36	2.36	2.36	2.36
1987	1.73	1.81	1.88	2.26	2.66	2.66	2.66	2.66	2.66	2.66
1988	1.5	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	2.56
1989	1.75	1.75	1.75	2.71	2.71	2.71	2.71	3.35	3.35	3.35
1990	2.17	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
1991	1.37	1.37	1.59	1.64	1.64	1.64	2.62	2.62	2.62	2.62
1992	1.83	1.84	1.84	1.84	1.84	1.84	1.84	2.32	2.32	2.32
1993	4.03	4.03	4.03	4.03	4.03	4.03	4.03	4.03	4.03	4.03
1994	1.85	1.87	2.07	2.39	3.68	3.68	3.68	3.68	3.68	3.68
1995	2.2	2.21	2.21	3.36	3.36	3.36	3.36	3.36	3.36	3.36

YEAR	Maximum Storm Event Volume (inches)									
	IETD 1	IETD 2	IETD 3	IETD 6	IETD 9	IETD 12	IETD 15	IETD 18	IETD 21	IETD 24
1996	2.14	2.43	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
1997	2.71	2.71	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72
1998	2.33	2.33	2.35	2.37	2.37	2.37	2.37	2.37	2.37	2.37
1999	4.54	4.54	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
2000	2.05	2.06	2.06	2.14	2.14	2.14	2.14	2.14	2.14	2.94
2001	1.41	1.57	1.57	1.64	1.64	1.64	1.84	1.84	1.84	1.96
2002	1.82	1.84	1.84	2.17	2.17	2.36	2.36	2.36	2.36	2.36
2003	2.45	2.45	2.45	2.61	2.61	2.74	2.74	3.13	3.13	3.13
2004	2.43	2.46	2.46	2.46	2.71	2.71	3.05	3.05	3.05	3.87
2005	6.07	6.07	7.3	7.3	7.3	7.34	7.34	7.34	7.34	7.34
2006	6.23	6.33	6.33	9.55	10.62	10.62	10.62	10.62	10.65	11.37
2007	4	4	4	4	4	4	6.18	6.18	6.18	6.18
2008	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95
2009	1.77	2.54	2.54	2.54	2.6	2.6	2.6	2.6	2.6	3.23

Table 2 presents the number of storm events having different threshold amounts for different IETDs. For examples, with an IETD of 6 hour, there were 5546 events with an amount less than one inch volume and 6091 events with an amount less than two inch volume, and the difference between these two sets, a total of 545 events were occurred with a size between 1 inch to 2 inch volume. Table 3 presents the percent of storm events having different threshold amounts for different IETDs.

Table 2: Number of storm events with different threshold amounts

Event Size (in)	IETD 1	IETD 3	IETD 6	IETD 12	IETD 24
Total # Events	10445	7467	6221	5286	4363
< 0.5"	8925	5841	4556	3591	2692
< 1.0"	9915	6843	5546	4577	3586
< 2.0"	10352	7357	6091	5141	4192
< 3.0"	10420	7437	6187	5246	4311
< 4.0"	10434	7454	6207	5268	4342
< 5.0"	10441	7462	6216	5278	4351
< 6.0"	10441	7463	6216	5281	4356
< 7.0"	10445	7465	6218	5282	4359

Table 3: Percentage of storm events with different threshold amounts

Event Size (in)	IETD 1	IETD 3	IETD 6	IETD 12	IETD 24
Total # Events	**10445**	**7467**	**6221**	**5286**	**4363**
<.5	0.854	0.782	0.732	0.679	0.617
<1	0.949	0.916	0.891	0.866	0.822
<2	0.991	0.985	0.979	0.973	0.961
<3	0.998	0.996	0.995	0.992	0.988
<4	0.999	0.998	0.998	0.997	0.995
<5	1.000	0.999	0.999	0.998	0.997
<6	1.000	0.999	0.999	0.999	0.998
<7	1.000	1.000	1.000	0.999	0.999

5.0 Climate Change Analysis

In order to understand change in storm event volume over time, a simple analysis was conducted. The entire 60 year of rainfall records was divided chronologically into time segments of 20 years, time period 1950-1969, 1970-1989, and 1990-2009. For each of the 20 year time period storm event analysis was conducted for different IETDs. Tables 5 to 7 presents the results of storm event analysis for different IETDs of 6 hr, 12, hr and 24 hr respectively. The number of storm events having different threshold amounts of 0.5 inch and 1 inch onwards at the increment of 1 inch were obtained for each of the time period. For example, it may be seen that there were 191 events greater than 1 inch rainfall events occurred between 1950-1969, whereas between 1970-89 and 1990-2009, the number of events generally increased to 222 events (16% increase) having a storm volume greater than 1 inch.

Table 4: Number of Events exceeded with different threshold amounts of storm volume

Year Interval	>0.5"	> 1"	> 2"	> 3"	> 4"	> 5"	> 6"	> 7"	> 8"	> 9"
1950-1969	510	191	41	14	4	1	1	0	0	0
1970-1989	533	221	37	10	4	2	2	1	0	0
1990-2009	531	222	46	9	4	2	2	2	1	1

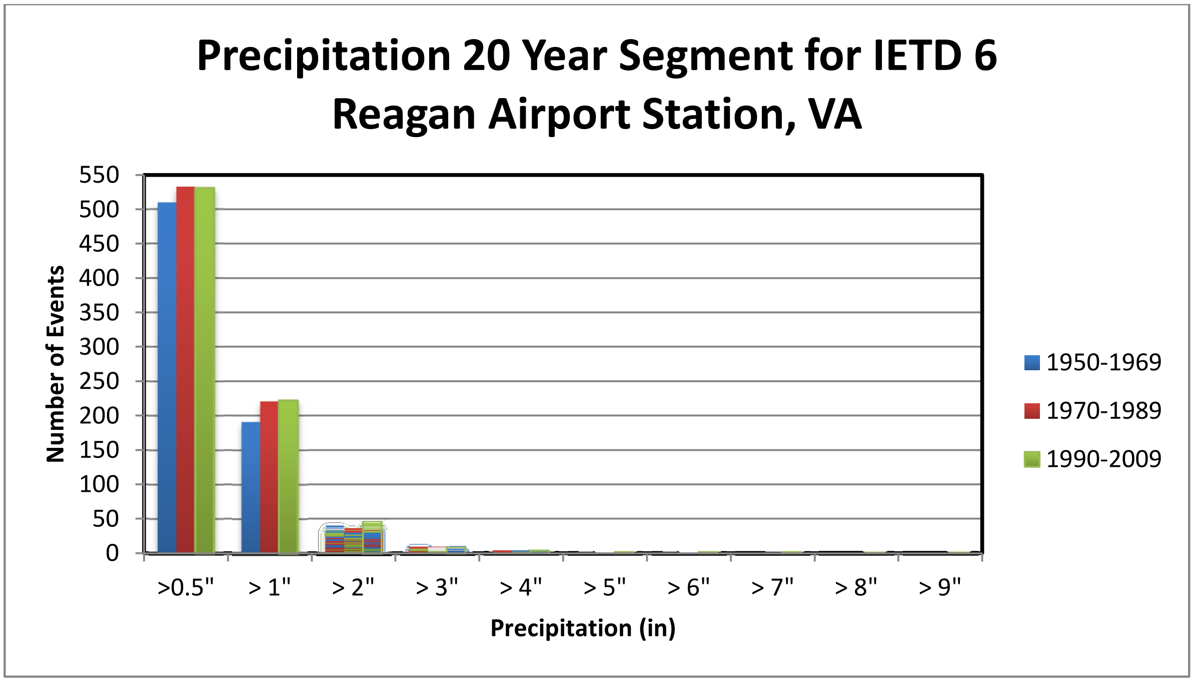

Figure 5: Graphical representation of number of events with different thresholds

Table 5: Number of Events exceeded with different threshold amounts of storm volume

Year Interval	>.5"	<1"	>1"	>2"	>3"	>4"	>5"	>6"	>7"	>8"	>9"	>10"
1950-1969	519	1480	199	44	17	7	2	1	0	0	0	0
1970-1989	539	1473	234	42	12	5	3	2	2	2	1	0
1990-2009	547	1497	234	51	10	4	2	2	2	1	1	1

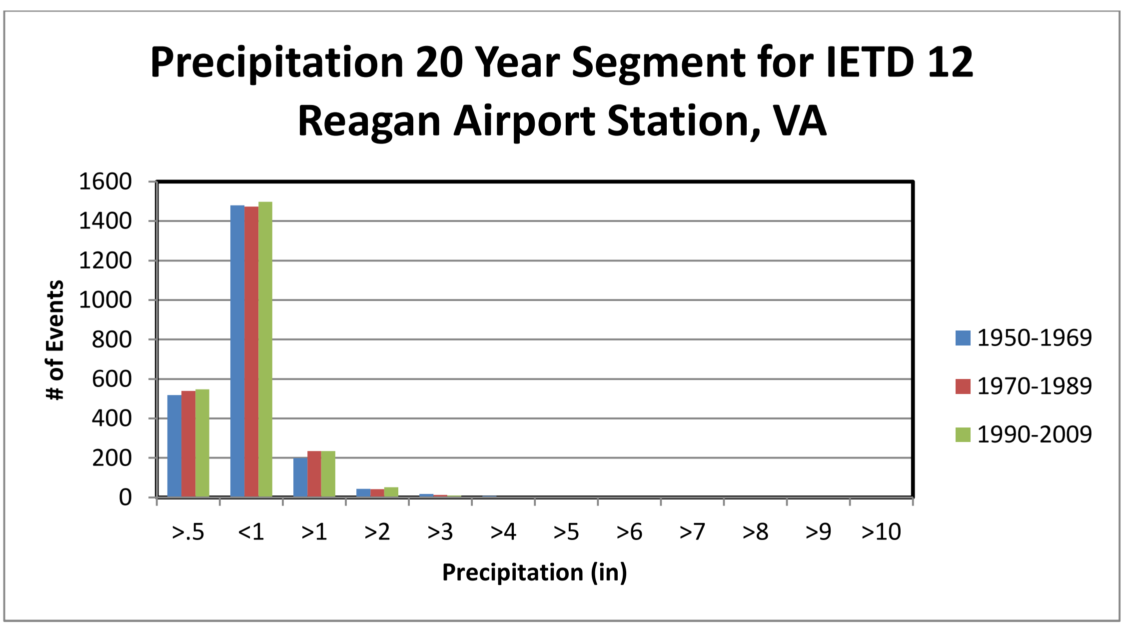

Figure 6: Graphical representation of number of events with different thresholds

Table 3: Number of Events exceeded with different threshold amounts of storm volume

Year Interval	>.5	<1"	>1"	>2"	>3"	>4"	>5"	>6"	>7"	>8"	>9"	>10"
1950-1969	513	1172	226	47	22	10	4	2	0	0	0	0
1970-1989	524	1148	254	55	15	5	4	2	2	2	1	0
1990-2009	546	1169	250	59	14	5	3	3	2	1	1	1

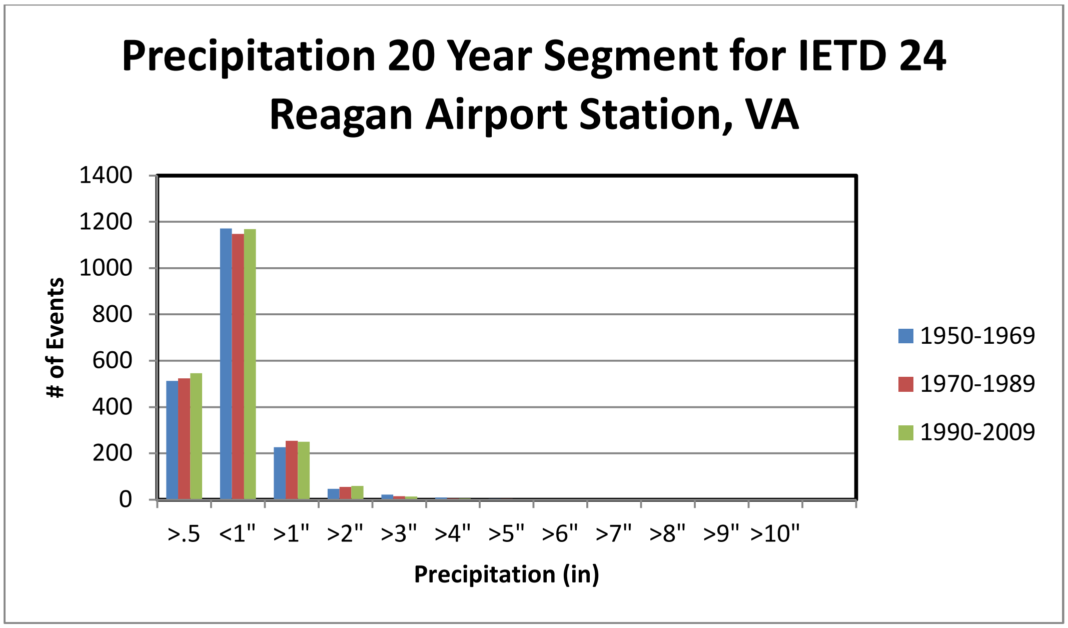

Figure 7: Graphical representation of number of events with different thresholds

From the above storm event analysis it may be found that over last two decades, generally the number of higher size storm events have increased in the Washington DC region.

6.0 Research Outcome

The outcome of this research seed grant is as follows:

1. Three undergraduates students from the School of Engineering and Applied Sciences participated and got the training for research
2. Asteway Ribbiso presented the paper entitled "Long-term Precipitation Analysis for Mid-Atlantic Region for Evaluating Climate Variability and Change", at the 2013 Emerging Researchers National (ERN) Conference in STEM February 28-March 2, 2013, Washington DC
3. Asteway Ribbiso presented the paper entitled "Precipitation Analysis for Mid-Atlantic

Region based on Storm Event Analysis", at the 70th Joint Annual Meeting of BKX/NIS, March 13-17, 2013, Reston VA,

7.0 Acknowledgements

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8.0 References

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Development of a physically-based model for Performance Evaluation Optimization of Green Roof Systems

Basic Information

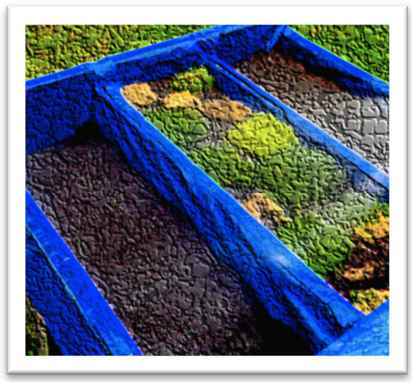
Title:	Development of a physically-based model for Performance Evaluation Optimization of Green Roof Systems
Project Number:	2012DC138B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	DC
Research Category:	Engineering
Focus Category:	Education, Hydrology, Non Point Pollution
Descriptors:	None
Principal Investigators:	Arash Massoudieh, Pradeep K. Behera

Publications

There are no publications.

Development of a physically-based model for performance evaluation optimization of green roof systems

Progress Report



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Introduction

Our team designed and built a green roof prototype that would establish design guidelines for future green roofs in Washington DC area. The prototype allowed us to gather observed run-off data from current rain profiles in the DC area in different types of performance parameters. Our design team also performed a simulation using a mechanistic model that studies past and present runoff data to give insight when predicting outputs for future green roofs of different sizes, slopes, and make ups.

DC has a combined sewer system which allows for the sanitary wastewater and stormwater run-off to flow together in the same line. The problem occurs during heavy rainfall events where the combined water line is at capacity. Blue Plains does not have a backup facility, so the excess water in the combined sewer line is pushed out into the Potomac River, Rock Creek, and Anacostia River. Blue Plans calls this discard Combined Sewer Overflow (CSO). The discharge outlets have prevented home and street flooding, but have caused several environmental problems. As of right now the District bans swimming in any creek or river that is near the CSO outlet (DCwater, online). The District's website sends out a warning saying. "Potentially harmful substances may also be present in these discharges. The public is advised to stay away from any sewer pipe discharge" (DCwater, online). As of right now there are fifty three CSO outlets in the DC stormwater management system. DC is trying to install infaltiable and perminate dams that will trap the over flow wastewater and stop directly pouring wastewater into the surrounding rivers and creeks (DCwater,online).

DC is also trying to promoto the idea of installing green roofs to decrease the amount of stromwater entering the combined system. The Anacostica Watershed Society is giving away a rebate to residental, institutional, and commerical building owners that have a green roof system installed on there building (ddoe, online) .

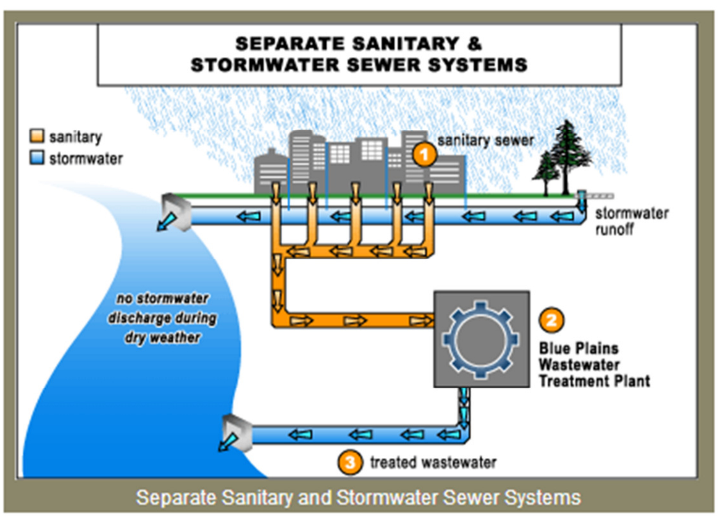


Figure1: Blue Plains Waste Water Treatment Plants – Combined Sewer System

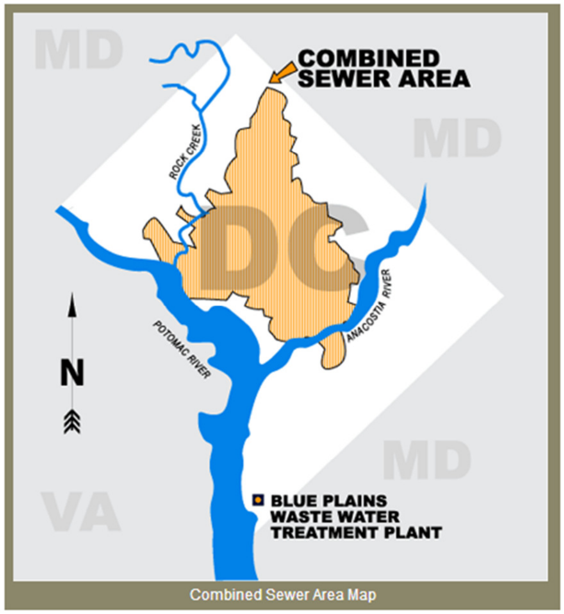


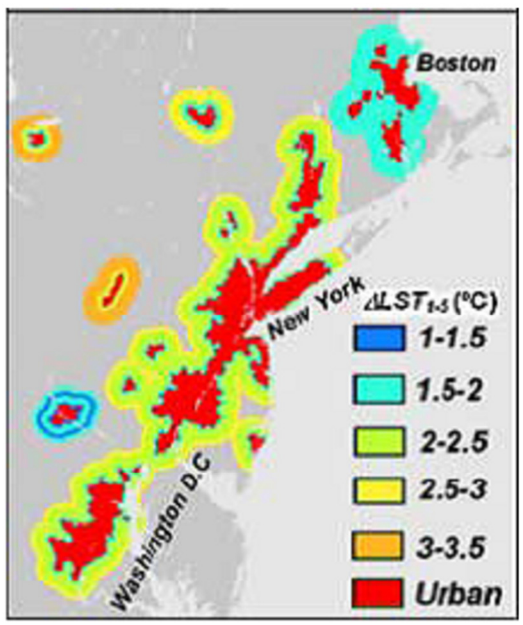
Figure 2: DC Combined Sewer Area

Figure 3: Pollution during Rainfall Warning

Impervious surfaces such as roads, pavements, and roofs are one of the major causes of storm water runoff in most urbanized areas. Without any water retention or absorption flooding and erosion can occur. Although a good drainage system can mitigate these environmental issues, some of these urban areas do not have enough space to construct drainage infrastructures. Developers, engineers, and environmental agencies are trying to implement a green roof system that is designed to store storm water above street level. Some countries in Europe, for example Germany have already discovered the many benefits on installing green roofs. Green Roofs not only mitigate storm water but also conserve energy by providing extra insulation layer for buildings. By installing green roofs storm water can slowly move through the plant, soil, and landscape fabric layers and come out filtered instead of directly flowing off the roof and into the sewer lines.

Another environmental issue that is of major concern to many engineers and developers today is the heat Island, also known as Urban Heat Island. This is because many cities are getting much warmer than their surrounding rural areas due to rise in temperature. Heat Island effect occurs when changes in landscape such as constructed buildings, roads, affect the air temperature of that area. In other words, surfaces that were once vegetation, or streams but replaced by hard surfaces are now exposed directly to the sun. This light rays from the sun heats up this surfaces dry thereby causing an increase in air temperature of that area. Compared to the cities, the rural areas do not have this problem because some of its surfaces are still covered up with vegetation and streams. Besides the increase in air temperature, the heat island also encourages other environmental issues such as "elevating emissions of air pollutants and greenhouse gases, impairing water quality, enhance storm water management and water quality" (E.P.A, online*)*.

In 2001, a group of researchers from Boston University showed the urban heat effect from Washington DC to Boston using satellite measurements (City of Boston, online). Colors were used to indicate how much cooler average land surface temperatures from January through May were in non-urban areas than in urban centers.



The result was alarming because it was showed that the urban areas temperature at Washington, DC was steadily increasing compared the non-urban areas.

There are many ways of which the heat island effect can be reduced. This includes growing more trees, using cool pavements etc. However, one of the cost effective and environmentally friendly ways of mitigating heat island is the use of green roofs. With their vegetative layer, green roofs provide shade and remove heat from the air through evapotranspiration, reducing temperatures of the roof surface and the surrounding air (E.P.A, online). Green roofs reduce heat by adding mass and thermal resistance value. In other words, green roofs help by reducing heat transfer through the building roof, improve indoor comfort and lower heat stress associated with heat waves since the thermal properties of buildings add heat to the air by conduction (Ackerman, online). By lowering air conditioning demand, green roofs can decrease the production of associated air pollution and greenhouse gas emissions. Their vegetation can also remove air pollutants and greenhouse gas emissions through dry deposition and carbon sequestration and storage (E.P.A online). Although the initial costs of green roofs are higher than those of conventional materials, building owners can help offset the difference through reduced energy and storm water management costs, and potentially by the longer lifespan of green roofs compared with conventional roofing materials (E.P.A, online).

Katherine Alfredo and Nicholas VanWoert have both written articles describing how green roof experiments are conducted. The articles illustrate the simulation prototype parameters and models performed. The results show that the prototypes retained different amounts of water and had varying outflow values (Nicholaus et al, 1036). The green roof experiment conducted by Alfredo consisted of four prototypes. One prototype consisted of standard roof membrane materials, while the other three sections had green roof media with depths of 2.5cm, 6.3cm, and 10.1cm. These prototypes were subjected to specific rain intensity phases and data collection. Alfredo stated that the green roof prototypes delayed the drainage process longer than the standard roof membrane materials. Alfredo also observed that the 10.1cm media depth prototype had the longest drainage period, thus requiring the longest hydrograph. Alfredo concluded that the 10.1cm was the best green roof media type to install to reduce rainwater runoff. VanWoert tested three different kinds of roofs. The roof types varied from the standard roof with gravel blast, an extensive green roof system without vegetation, and a green roof system with vegetation. All these prototypes where assembled in a wooden box each having a 2.44cm by 2.44cm section. Two studies were performed to quantify the effects of various storm water retention treatments of the different prototypes. The first study was to find the difference in water retention of all prototypes without a slope. His hydrograph results showed that overall the green roofs retained 82.8% of water compared to the gravel blast roof which only retained 48.7%. The second study was to analyze how the same types of materials would retain water with larger depths and a slope. The depths were increased to 2.5cm, 4.0cm, and 6.0cm while the slope was raised to 2%. According to VanWoert, the results showed that the green roof prototype with the 2% slope and 4 cm media had the greatest water retention of 87%. The other two prototypes had minimal increase in retention from the first study (Nicholaus et al, 1036).

Objectives

The goal of the project is to perform green roof simulation using a mechanistic model that studies different prototype parameters and runoff data to generate a design for future green roof projects.

We created this model by experimenting with our green roof prototype's soil depths, growing media, and slope. The different prototype sections allowed us to create the simulation's parameters. With the gathered observed rainfall and runoff data the simulation was able to generate the different parameters' hydrograph. Hydrographs display the runoff flow from the prototype's section over the rainfall duration and allow for rain intensity to be measured. With the rain intensity and runoff flow we were able to calculate the prototype's section water retention efficiency. By studying the outputs future project teams will be able to pick a green roof design that matches their project's storm water retention goal.

Model Setup

From analyzing both of the articles it is clear that green roofs are a great method to limit the amount of storm water runoff. Alfredo's experiments showed how effective green roofs are by varying the depths of different prototypes. She also illustrated each prototype's drainage, retention, and precipitation results in a hydrograph that showed green roofs can prolong and reduced water discharge by 22-70% (Alfredo and Montalto, 445). However, she advised that more research should be done on the green roofs soil type, climatic condition, and how green roofs may be able to reduce stress on sewer systems. On the other hand, VanWoert's approach on green roof systems showed how the change in slope can affect water retention. With the combination of reduced slope and deeper media depth, it is clear that total quantity of storm water runoff can be reduced (Nicholaus et al, 1037).

With the knowledge from the two articles we knew what parameters we should test in our prototypes, but we wanted to improve the study to implement vegetation that was known to grow well in saturated soil conditions. Irish and Scotch moss were selected for the planted prototype section. Irish and Scotch moss prefer most soil, sunlight, and does not need to be cut, so it is an ideal plant for a green roof. Irish and Scotch mosses are actually not a moss at all because mosses never bloom. Irish and Scotch moss both produce a small white flower, which is preferable for a green roof plant because brightly colored plants attach birds and insects causing more maintenance and care for the green roof (C. Colston Burrell, online). We also wanted to decrease the weight of the green roof system so we researched soil add mixtures in other green roof projects. During our exploration we found that pumice was a popular add mixture for soil that have an organic base. Pumice is a porous light weight rock that allows for some drainage when mixed with the heavier organic soil (Encyclopedia of New Zealand, online). Making our materials list we knew that we may not find pumice, but we still wanted pumice like properties.

Looking at a more local level we researched several of the Washington DC green roof projects like the U.S. Department of Transportation to find what the major components of a green roof were. The Department of Transportation layered its roof with a root barrier, filter fabric, and plants that are acceptable to the DC climate (DDE, Ward 6). Researching what materials would work best for our group's project we layered all purpose stone, filter fabric, combined organic soil, and Irish and Scotch moss to create our green roof prototype.

Using Alfredo and Montalto studies along with local green roof models we designed our prototype frame to be three 3 ft by 1 ft sections. The dividers were made out of timber and the bottom panel was made out of plywood to support the loads of green roof prototype's media. To ensure minimum error in the runoff data collection the frame was covered with a blue trap and all seams were either caulked or made on top of the section dividers. A one inch layer of all purpose stone was used to create a water retention layer below the green roof outlets in each one of the prototype's sections. We then placed the weed blocking landscape fabric on top of the gravel in the soil and gravel sections of the prototype to make sure no soil erosion would occur. The Miracle –Gro moisture control potting mix was distributed evenly to a depth of either six or three inches in the allotted sections. Miracle – Gro moisture control potting mixture was chosen because it was tested by Scotts® to absorb thirty three percent more water than other gardening soils. The soil also prevents over or under watering which is perfect for the mosses' growing needs. The Irish and Scotch moss was planted with some space in between to allow for soil expansion and plant growth. Each section of the prototype has a hose guide and vinyl tube placed

7/8 of an inch from the bottom of the basin to allow the gravel retention layer to have an overflow outlet. As the water level surpasses capacity in the gravel retention layer the water is pushed into the outlet and travels down the vinyl tube into the rain gauge where the flow rate is recorded.

Illustrated Summary of the Construction Procedure

1) Two 3ft x 3ft green roof frames were constructed using timber.
2) Each frame was divided in three equal sections of 1 ft x 3 ft using timber dividers.
3) Plywood was placed at the bottom of the frames.
4) Timber and plywood were covered and sealed tightly with tarp.

5) Outlets were placed 7/8 of an inch from the bottom using spray hose guides and caulk.

6) Gravel was added to each compartment and it was covered by filter fabric

7) Each section was filled with a different type of media as shown in the following table.

	Media - Prototype 1 – Slope: 11%		**Media - Prototype 2 – Slope: 8%**	
Section	**Type**	**Total Depth**	**Type**	**Total Depth**
1	Gravel	1 in	Gravel + Soil	3 in
2	Gravel + Soil + Vegetation	6 in	Gravel + Soil + Vegetation	6 in
3	Gravel + Soil	3 in	Gravel + Soil	6 in

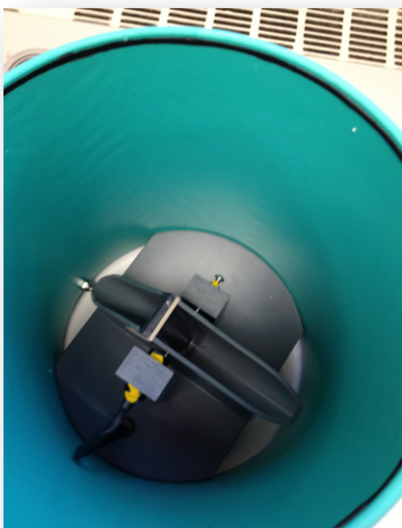
Prototype 1:

Prototype 2:

Data Collection

The rain gauge that was used to monitor runoff from our prototypes was the Rain101A, which operates on a simple “tipping bucket” principle. The Rain101A is comprised of an eight inch funnel that collects water runoff and passes it to the calibration bucket. The calibration bucket work continuously. After one bucket fills to about 0.01’’ of an inch of water the caliber tips over to one side of the gauge having a seesaw like motion. A sensor is connected to the bucket that records each time the bucket tips.

The tipping bucket system has a five second reading rate that is used to ensure the sensor captures each one of the bucket’s tips even in the heaviest water runoff conditions. Before taking readings from the sensor, the Rain101A rainfall recorder software must be installed on a computer. The software program is setup by entering units for the water collection and time duration of the rain study period. A USB cable collects readings from the sensor and stores it in a data logger software program. A hydrograph is then generated to show the time of each bucket tip.



Rain gauges used for data collection

The following figures illustrate how the data collection worked for each compartment:

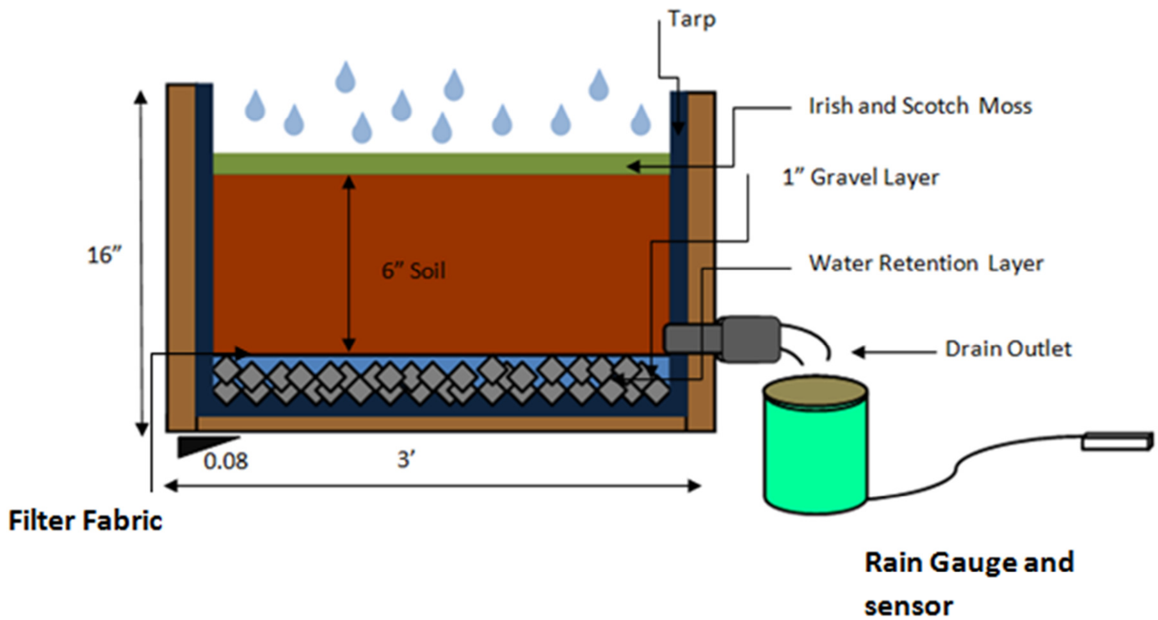


Figure 4: six inch deep with vegetation - low slope

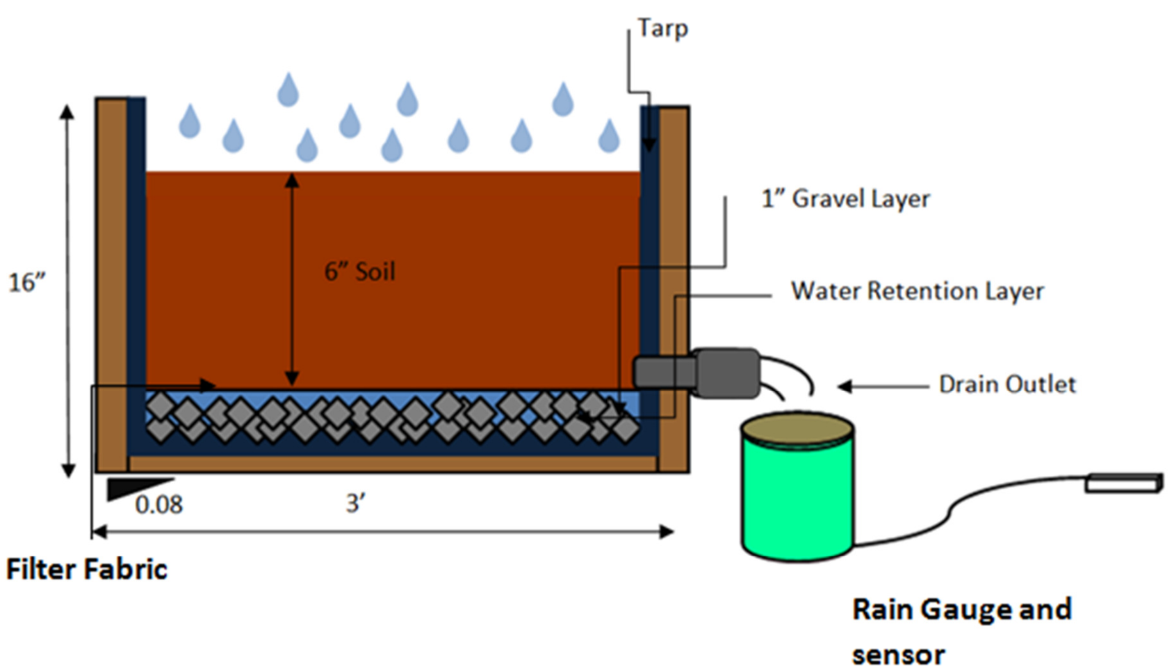


Figure 5: six inch deep without vegetation - low slope

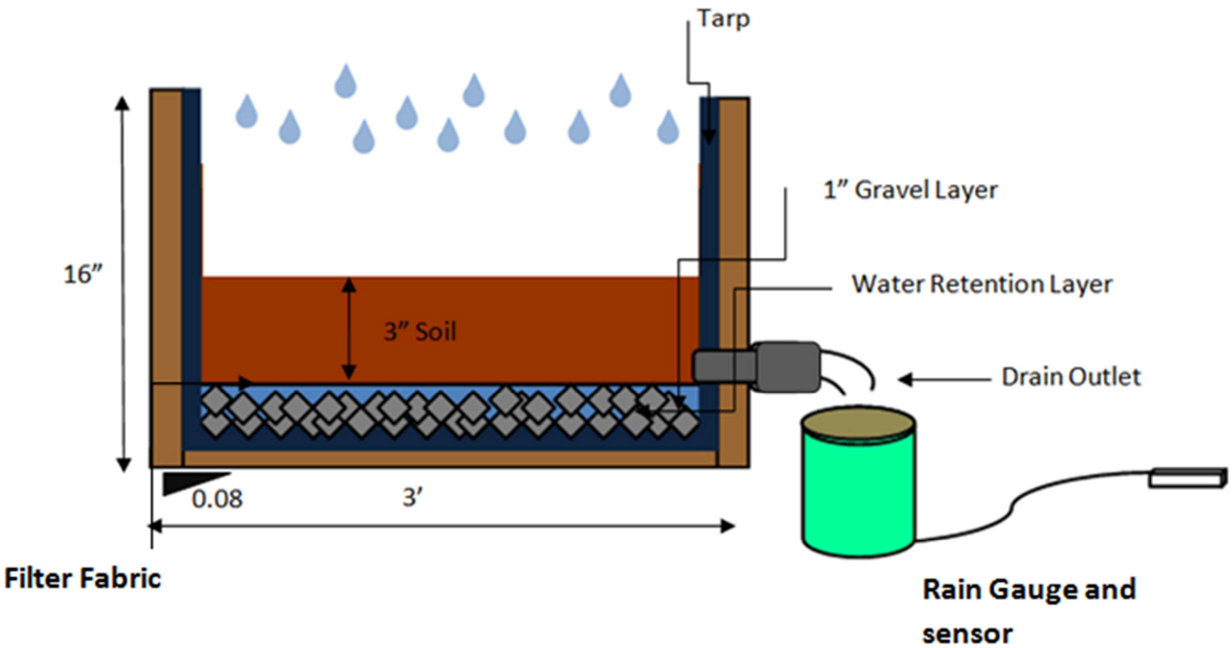


Figure 6: three inch deep without vegetation - low slope

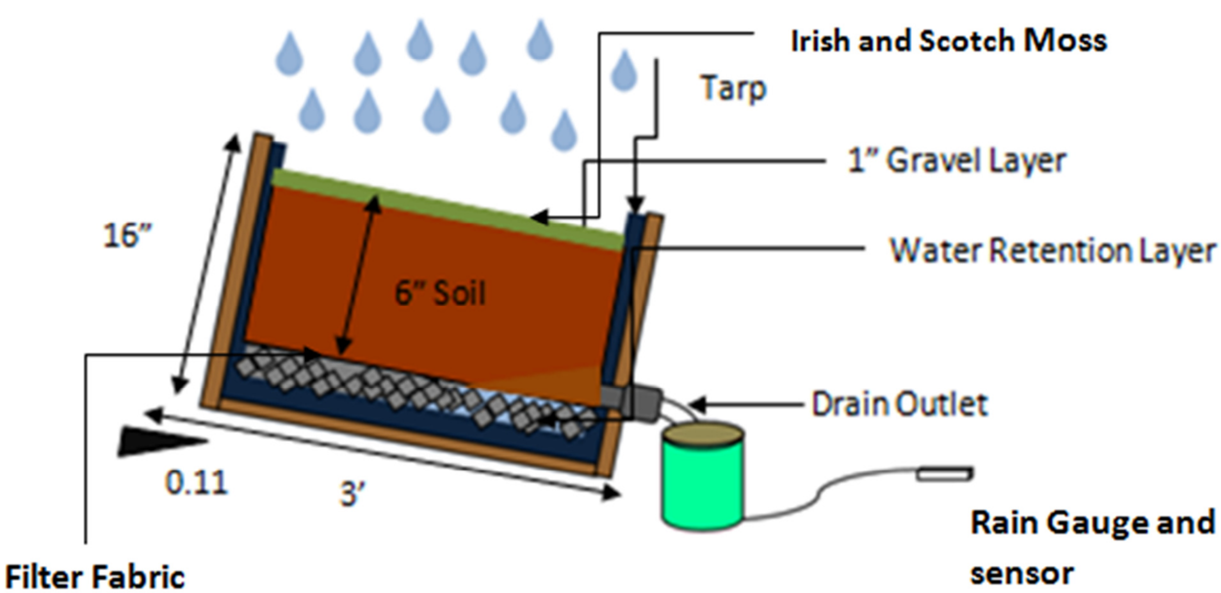


Figure 7: six inch deep with vegetation - high slope

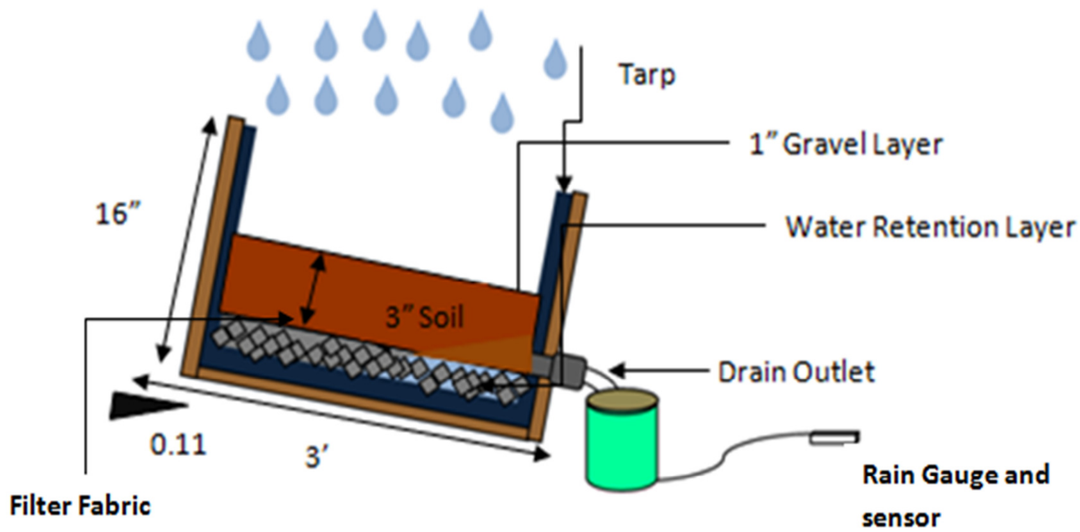


Figure 8: three inch deep without vegetation - high slope

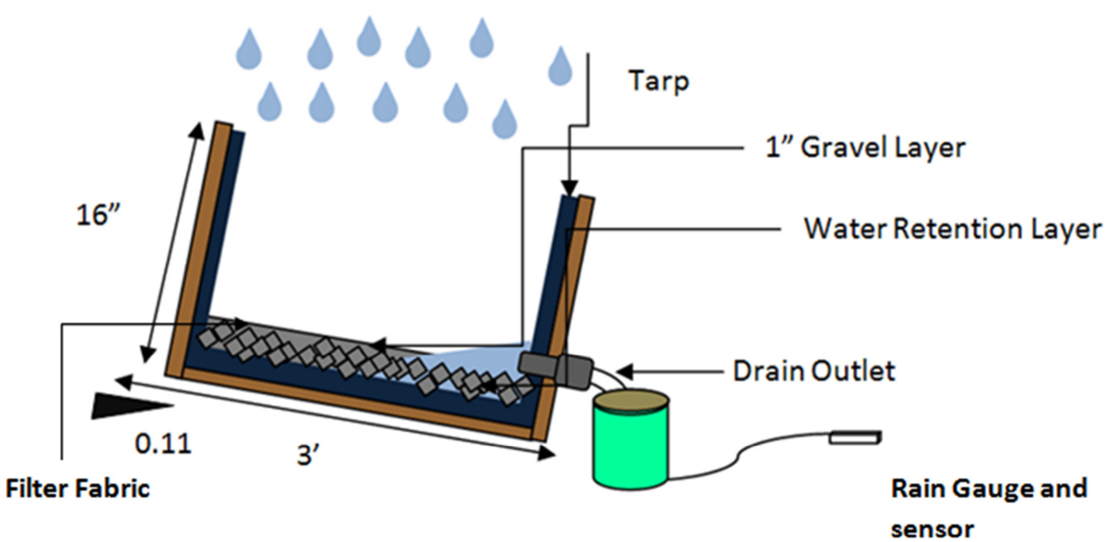


Figure 9: Just gravel - high slope

A moderate rain was needed in order to collect data and test the green roof prototypes using the rain gauges. However, there were not enough rainfall during the month of April, which was the month corresponding to the performance of the experiment. There were only two light precipitations from which all of the storm water was retained in the green roof's media; therefore, no runoff was able to be collected in the rain gauges. Since the project was executed within a tight schedule, a second step needed to be taken. Therefore, the idea of working with natural rain was discharged, and it was decided to work with synthetic rain instead. The test was then performed using a hose and the data collected from the gauges was simulated and analyzed using the mechanistic computer simulation model.

Simulation and Results

Once the data was collected, it had to be analyzed. By manipulating the input parameters, the outputs of the model could be compared to the outputs from the collected data. Once calibrated, the model could then be used with rain data from the past to predict how the prototypes (or any theoretical prototypes) would behave as far as water retention and decreasing runoff flow. Once these simulations were run, actual effectiveness could be analyzed, and the design could be modified again if the models were determined ineffective.

The model simulates the inflow and outflow from each layer (designated in the input parameters) and can show what is going through each layer as well as the outflow, which is also at a designated height from the input parameters.

There were many inputs to the computer simulation that were necessary in order to have a modeled output that would be accurate (See Table A). These included soil parameters, such as hydraulic conductivity (Ks) and moisture contents (θ_0, etc). Other inputs were drainage coefficient of the outlet pipe (C_D), the area of the prototype, the slopes of each prototype, and the storage volumes at the surface and the gravel layers.

The model simulation gave multiple outputs. The main outputs that were studied were the modeled runoff flow rate against the actual observed runoff flow from the prototype (Figure C).

Figure A shows how much rain water has accumulated at the bottom of the green roof over time, and levels out at the height of the outflow, or as the model is concerned, the bottom threshold.

In order to calibrate the model so that the modeled output matched closely with the observed output, a few of the input parameters had to be manipulated and therefore the models would then be rerun. The particular inputs that we were changing to do the calibration were: hydraulic conductivity, moisture contents, and the bottom threshold. Some guess work was involved in the moisture contents and bottom threshold because of the nature of the prototype. Rains from prior dates and previous tests may have left some water in the soil and pooled in the gravel layer.

The tricky part of this was that all of the models had to manually be calibrated to the same parameters. It was not as difficult to calibrate one particular prototypes data to match the modeled output, but this did not necessarily work for the other prototypes. After much trial and error, one particular set of input parameters were found to be the ideal set, although the matches between the different observed and modeled charts were imperfect (Figure A-O). This set of parameters that was chosen can be seen in Table A.

Inputs and Outputs

Table A: Inputs used in the computer simulation

```
path, C:\Users\Pete\Dropbox\Greenroof_Senior_Designgroup\1stSim_ThreeinchHighslope\
rainfilename, rain.txt
soil_ks, 5
soil_alpha, 12.4
soil_n, 2.28
soil_m, 0.56
soil_theta0, 0.2
soil_theta_r, 0.057
soil_theta_s, 0.51
soil_nz, 5
soil_dz, 0.015
drain_coeff, 4E5
bot_tresh, 0.012
top_tresh, 0.1
dt, 0.000015
area, 0.27
width, 0.3
slope, 0.11
```

Output for 6 inches, no vegetation, low slope compartment – The one used for calibration

Fig. A: Accumulated Water at Bottom vs. Time

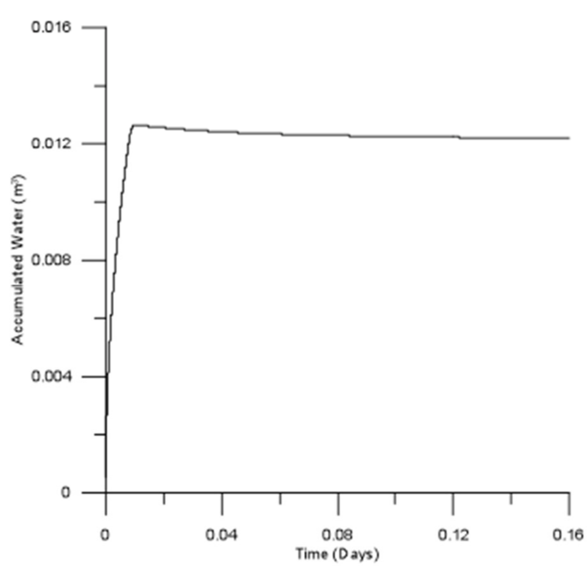


Fig. B: Flow per Layer vs. Time

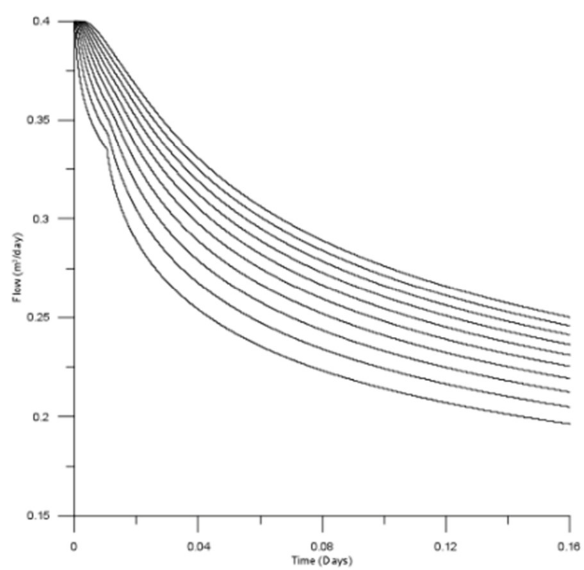
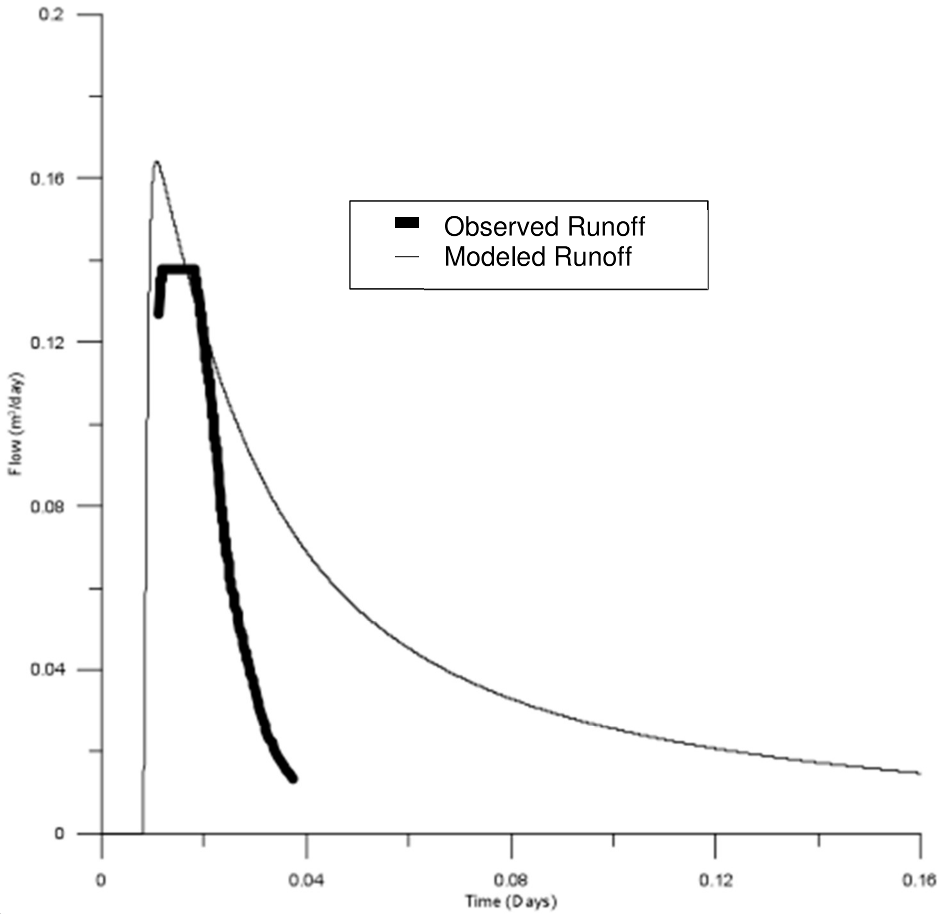
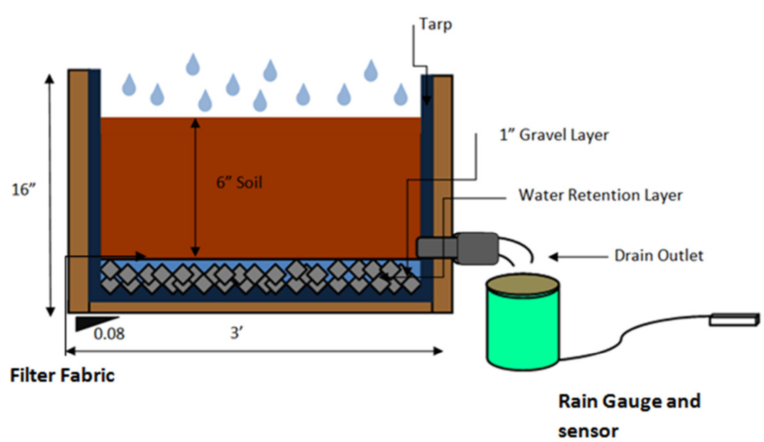


Fig. C: Runoff Flow vs. Time



C



Output for 3 inches, no vegetation, high slope compartment

Fig. D: Accumulated Water at Bottom vs. Time

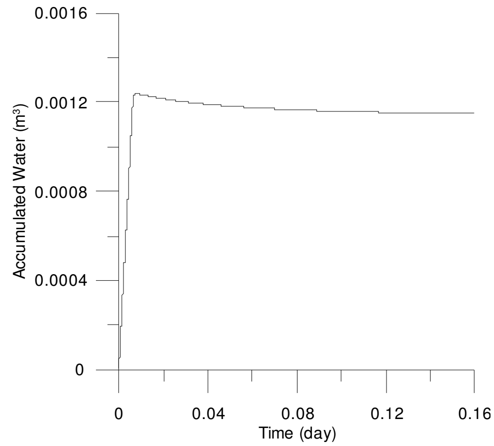


Fig. E: Flow per Layer vs. Time

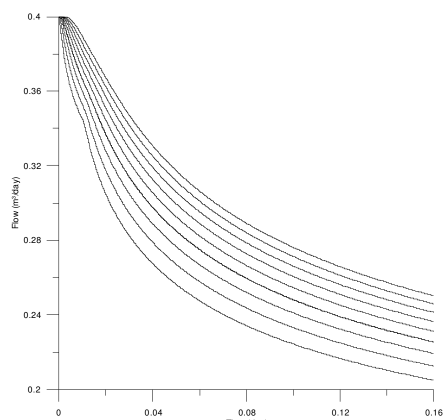
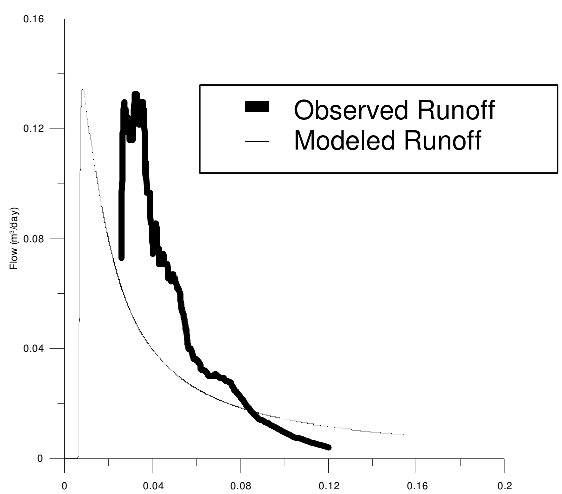


Fig. F: Runoff Flow vs. Time



Output for 6 inches, vegetation, high slope compartment

Fig. G: Accumulated Water at Bottom vs. Time

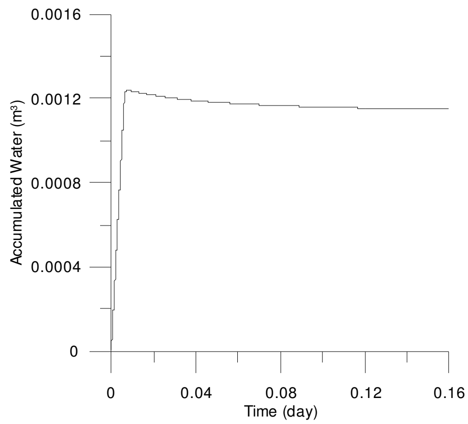


Fig. H: Flow per Layer vs. Time

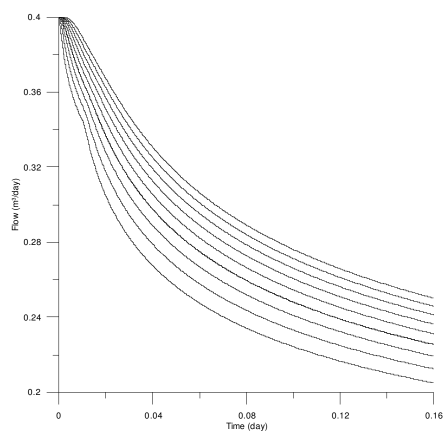
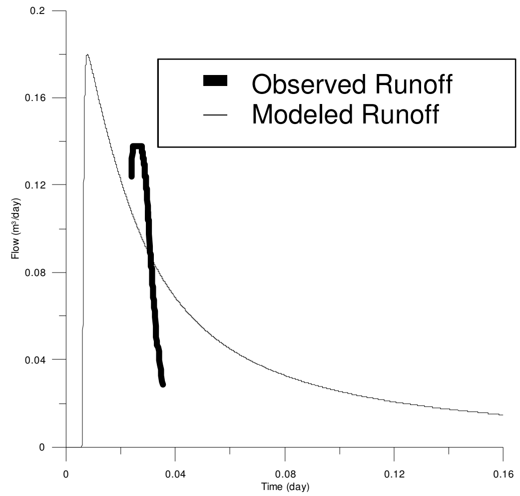


Fig. I: Runoff Flow vs. Time



Output for 6 inches, vegetation, low slope compartment

Fig. J: Accumulated Water at Bottom vs. Time

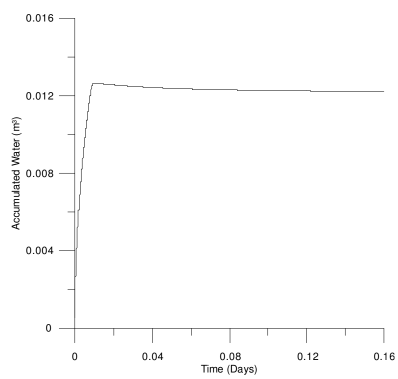
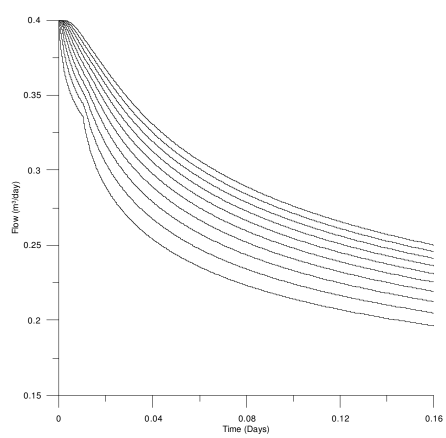


Fig. K: Flow per Layer vs. Time



Evaluating Water Management Alternatives in the Upper Potomac River Basin for the District of Columbia Source Water Protection

Basic Information

Title:	Evaluating Water Management Alternatives in the Upper Potomac River Basin for the District of Columbia Source Water Protection
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End Date:	2/28/2013
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Congressional District:	DC
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Focus Category:	Hydrology, Management and Planning, Water Quantity
Descriptors:	None
Principal Investigators:	Tolessa Deksissa, Heidi Moltz, James Palmer

Publications

There are no publications.

Evaluating Water Management Alternatives in the Upper Potomac River Basin for the District of Columbia Source Water Protection: Final Report

Submitted to the DC WRRI

By

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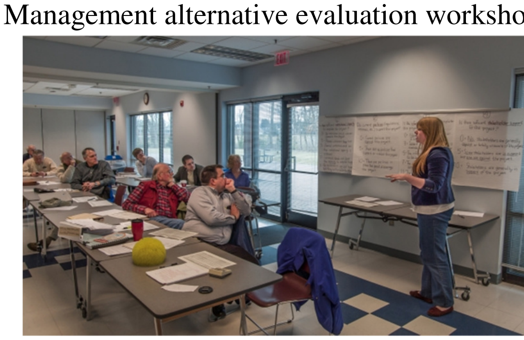
University of the District of Columbia

Dr. Heidi Moltz (Co-PI)
Interstate Commission on the Potomac River Basin

Mr. James Palmer (Collaborator)
Interstate Commission on the Potomac River Basin

Flooding on Rock Creek (left) and low flow at Natural Dam on Marsh Creek (right)

Management alternative evaluation workshop.



May, 2013

Abstract

The Marsh and Rock Creek watersheds are parts of the Upper Potomac River Basin, which were designated as the "Critical Water Planning Areas" (CWPA) by the Department of Environmental Protection (DEP) under the Act 220. The Act 220 requires development of the Critical Area Resource Plan (CARP) which was developed by the Interstate Commission of the Potomac River Basin (ICPRB) following guidance from the act Potomac Regional Committee, the local Critical Area Advisory Committee (CAAC), and DEP. The CARP process has identified 7 issues related to water resources management in the CWPA such as water availability, water storage, water quality, stormwater, policy, data availability, and communication. The main purpose of this study is to evaluate management alternatives recommended by the Marsh and Rock CAAC utilizing principles of surface hydrology, hydrogeology, hydraulics, and engineering. The result shows that both Marsh and Rock Creeks are headwaters, and there is no inflow into these sub-watersheds, and the amount of available water is extremely limited. Water demand often exceeds water availability under low-flow condition using a common 7Q10 indicator. The evaluation of management alternatives were presented to the committee and the recommendation were given herein based on feasibility and technical merit. Finally, the result of this study shows that sustainable upstream management of water resources is essential to long-term adequate public water supplies in D.C.

Introduction

The Potomac River is the sole source of water for the residents of the District of Columbia (D.C.). Further, protection of the source waters is crucial for sustainable development of the city. A holistic, integrated, and adaptive approach to water resources planning is necessary in these dynamic times with, for example, increasing demand for clean water supplies and the impacts of climate change on water resources. Utilizing this type of approach, the purpose of this study was to evaluate water resources management alternatives towards long-term water resources sustainability in the Marsh and Rock creek watersheds. These adjacent watersheds are located in the Monocacy watershed of the upper Potomac River Basin above the D.C. water supply intakes.

Pennsylvania shares the Potomac River basin with D.C., Maryland, Virginia, and West Virginia. Degradation of water quantity and quality in the Pennsylvania portion of the basin can affect the quantity and quality of water supply in D.C. If not managed, degradation of Potomac headwaters upstream of the D.C. water intakes may ultimately affect the quality of life of the residents in the nation's capital. A collaborative effort amongst the Potomac River basin jurisdictions is, therefore, crucial to protecting and preserving the source water. Further, clean, sustainable water supplies in the nation's capital are necessary for economic development, human health, and ecosystem resilience.

Act 220 Water Resources Management in the Marsh and Rock Creek Watersheds

The Marsh and Rock creek watersheds comprise 143 square miles in Adams County Pennsylvania, the headwaters of the Monocacy River, a major tributary of the Potomac River. In January 2011, the

Pennsylvania Department of Environmental Protection (PADEP) designated the combined Marsh and Rock watersheds as a Critical Water Planning Area (CWPA) under Act 220 of 2002 – one of only three designations in the Commonwealth. The designation resulted from a screening process indicating that the demands in Marsh and Rock creek watersheds may exceed supply under certain conditions.

After designation as a CWPA, the process of developing a Critical Area Resource Plan (CARP) began, as specified by the legislation and PADEP guidance documents. Collaborative management of basin-wide water supplies is a priority for the Interstate Commission on the Potomac River Basin (ICPRB), the Potomac Drinking Water Source Protection Partnership (DWSPP), and PADEP. In alignment with this priority, the ICPRB assisted in development of the CARP for the Marsh and Rock creek watersheds in Adams County, Pennsylvania, funded by PADEP and ICPRB. The goal of the CARP planning process was to identify a detailed list of water availability issues in the watersheds and develop practical, implementable solutions to identified issues. ICPRB's work included both technical and participatory aspects.

A list of management alternatives was developed through the CARP process that is appropriate given the watersheds' existing governmental, political, and financial constraints. Management alternatives were proposed by the Critical Area Advisory Committee (CAAC – a committee of over 50 local stakeholders representing diverse interests and water use sectors), technical staff, PADEP, and concerned local citizens. This study evaluated the management alternatives for technical merit and feasibility. The final list of alternatives became part of the CARP for voluntary implementation through local groups (municipalities, landowners, etc.).

Study Objectives

The purposes of this study were to 1) evaluate management alternatives recommended by the Marsh and Rock CAAC utilizing principles of surface hydrology, hydrogeology, hydraulics, and engineering; 2) present the research results to the advisory committee; 3) prepare a technical report on the findings; and 4) assist in preparations to the draft and final CARP. These tasks were conducted by a graduate student in UDC's Professional Science Master's in Water Resources Management under consultation and with oversight by ICPRB. This project provided a graduate student with real-world project experience with on-the-ground implications for water availability in Adams County, Pennsylvania and the larger Potomac basin. Finally, this project provided an opportunity for thoughtful, proactive (rather than reactive) management of water supplies to ensure that water is available to meet the long-term needs of the local community.

Project Description and Results

At the time this project began, the CAAC was brainstorming management alternatives to address identified water resources issues in the watersheds. Seven water resources issues were identified including availability, water storage, water quality, stormwater, policy and management, data availability, and communication. Availability is an issue because the average amount of water withdrawn in each CWPA sub-watershed on a daily basis in every season is greater than what would be present under low flow conditions. Further, there are only four days of average use available in storage capacity in the watersheds. This causes concern about the availability of water supplies during times when surface and ground water is not readily available. Impaired waters exist in all sub-watersheds in the CWPA, potentially threatening human and ecosystem uses. Stormwater causes flooding, erosion, and transportation of pollutants to the waterways in the CWPA. There is a lack of integrated, coordinated oversight and management of water resources that includes authority for implementation. Data is currently limited for water resources decision-making. Finally, there is a need for a strategic water resources communication effort.

Approximately 59 management alternatives were brainstormed by the committee to address these water resources issues. The complete list of management alternatives is documented in the draft CARP (Moltz and Palmer 2012). To determine which management alternatives were most applicable to the watersheds, they were quantitatively scored for feasibility and technical merit.

The first scoring approach, utilized to determine feasibility of management alternatives, was based on the Integrated Lentic/Lotic Basin Management (ILBM) methodology (RCSE-Shinga University and ILEC 2011). ILBM is an internationally recognized approached developed by the International Lake Environment Committee (ILEC). The method consisted of an evaluation and scoring on six governance pillars (information, funding, policies, institutions, stakeholders, and timeframe) for each management alternative. The pillars were scored using the following questions and a numeric ranking from 1 to 10 for each.

- Is the information needed to complete this project available?
- Are there known funding sources which can support this project?
- Do current policies (regulations, ordinances, etc.) support this project?
- Does the institutional framework exist to complete this project?
- Is there sufficient stakeholder support for this project?
- In what timeframe is the project likely to be complete?

The methodology is based on the assumption that strength in these pillars facilitates successful integrated water resources management. This scoring process was implemented at a CAAC workshop in February 2012. Additional information provided by the intern's evaluations elaborated on the initial scores.

The second, or technical, scoring approach was developed to determine whether each management alternative has the potential to solve identified water resources issues in the CWPA. Technical scoring was conducted for groups of management alternatives, organized by the water resources issue they are meant to address. Each water resources issue, therefore, has a distinct set of evaluation criteria. This scoring process was implemented by ICPRB with assistance from the UDC intern and utilizing information from the associated evaluations. Questions utilized to score the management alternatives for each water resources issue are:

- Availability and storage: Will this management alternative reduce the calculated deficit in a quantifiable way?
- Water quality: Will this management alternative protect or improve water quality conditions in a quantifiable way?
- Stormwater: Will this alternative manage stormwater in such a way to improve water quality and/or reduce the water deficit in a quantifiable way?

- Policy/Management: Will this management alternative assist in the coordinated management of water resources in the CWPA in order to effectively implement CARP recommendations?
- Data availability: Will this management alternative result in the collection and availability of additional data necessary for improved management of the water resources?
- Communication: Will this management alternative engage stakeholders in the community and yield behavioral changes that will result in better management of water resources?

As described, the UDC intern assisted in developing the information necessary to expand on the initial feasibility scoring and conduct the technical scoring for the management alternatives. Specifically, the examination included an evaluation of local implementability; costs; data, tools, and technical assistance necessary for implementation; quantification of water conserved; and identification of permits required. The rationales behind these analyses are provided below. The complete results of this effort were outlined in the final report to the Department of Water Resources Management (Senic 2012).

- Although management alternatives may have been successfully implemented elsewhere, local conditions may not be conducive for successful implementation in the Marsh and Rock creek watersheds. For each management alternative, feasibility for local implementation was evaluated.
- The purpose of the CARP is to plan to meet the water needs of the community for current and anticipated future water uses. A quantification of the potential water deficit was developed by ICPRB. For each management alternative, the amount of additional water made available (thereby reducing the deficit) was calculated.
- Implementation of a particular management recommendation may be technically feasible but cost prohibitive. Therefore, determining the approximate cost of each management alternative will be an important project component. To this end, a literature review and communication with practitioners was conducted.
- Each management recommendation may have several approaches for implementation. For example, the addition of agricultural ponds may enhance water supplies and reduce the potential agricultural water shortfall under low flow conditions. However, implementation of agricultural ponds in the watersheds could proceed in different ways. The technical implications of the different approaches was explored and, where possible, quantified.

Presented here are the results for one management alternative to illustrate the nature of the investigation. It was recommended that community water supply systems perform a water audit at least once a year to control water loss. To determine if the water audit was locally feasible, conversations were held with the largest public water supplier, PADEP officials, and a representative from the American Water Works Association (AWWA), the designer of a standardized water audit tool, to ensure that implementation was feasible. It was determined that several water suppliers in the watersheds have experience implementing this particular software elsewhere. It was also determined that this software would be most applicable only for the largest systems in the watersheds as the small systems may not have the resources for implementation and do not have the associated large water conservation benefits. An investigation of the potential benefits of community water supply systems performing an annual water audit found that the water to be conserved from such a practice in the CWPA exceeded 100 Mgal/y. In terms of cost, the water audit software is free. Preliminary data collection will be free, utilizing readily available data; however, long-term improvement of the audit will require more costly data collection. Further, implementation of conservation measures resulting from the audit will have high costs in some systems. Initial steps in implementing the water audit procedure across water suppliers in the watersheds include holding a meeting to demonstrate the use of the tool to those who are not familiar; enumerating an implementation time frame and procedure; and getting the suppliers to make an initial audit using readily available data.

The complete results of the evaluation process for select management alternatives were detailed in the final report to the Department of Water Resources Management (Senic 2012). The evaluation of management alternatives were also presented to the committee, both verbally and in writing. This information was used by the committee to select and prioritize the management alternatives recommended in the CARP (Moltz and Palmer 2012). The CARP management recommendations are provided in Table 1 and 2. The recommendations are divided into two tiers. Tier 1 recommendations are those that had high scores for both feasibility and technical merit (Table 1). Tier 2 recommendations are those that did not score as high, but were considered valuable by the committee to addressing a portion of the respective issue in the watersheds (Table 2).

Table 1. Tier 1 recommendations. The water resources issue the action is meant to address is provided in the first column followed by a brief description of the recommendation.

Issue	Management Recommendations
Availability	Community water supply systems should perform a water audit at least once a year to manage water loss.
Availability	Import water into the CWPA.
Stormwater	Implementation of stormwater management program(s).
Policy/Management	Establish groundwater protection ordinances for well construction and geothermal wells.
Policy/Management	All municipalities in the CARP area should adopt and enforce ordinances regarding private well construction standards, including geothermal systems.
Policy/Management	All municipalities in the CARP area should adopt and enforce ordinances regarding on-lot septic system maintenance and the establishment of sewage management districts.
Policy/Management	All municipalities in the CARP area should adopt and enforce ordinances regarding protecting and creating riparian buffers.
Policy/Management	Encourage land preservation (purchasing conservation easements) targeting the Marsh and Rock creek watersheds.
Policy/Management	Establish groundwater protection ordinance for yield analysis (for large wells); need common methodology for municipalities to determine sustainable groundwater yields.
Policy/Management	Establish groundwater protection ordinance for water quality protection; need inspections to ensure proper construction and testing of finished water to make sure treatment is adequate and well is functioning properly.
Policy/Management	Encourage the adoption of a wellhead protection ordinance to protect community water supply sources within the CWPA.

Issue	Management Recommendations
Policy/Management	Prepare a Joint Comprehensive Plan for the CWPA that includes sound land use policies and a strong water supply and protection component.
Policy/Management	Foster implementability of recommendations - develop a list of projects requiring additional funding for future grant-seeking efforts.
Policy/Management	Establish a water conservation program that can respond to water supply/demand conditions, especially for businesses and institutions affected by an influx of tourists during summer months when water supply typically is low.
Data Collection	Mason Dixon Utilities to fund a USGS (or similar) stream gage.
Data Collection	Installation of additional stream or staff gages and continued maintenance and operation of existing gages.
Data Collection	Community systems in the CWPA should prepare and get DEP approval for Source Water Protection Plans for all wells and surface intakes.
Data Collection	Monitoring to evaluate the effectiveness of implemented management recommendations.
Communication	Encourage communication between large water users on conservation measures being used within the community to foster idea sharing and long-term sustainability.
Communication	Develop a Strategic Communication Plan for the general public and targeted stakeholders (including all levels of education: school districts, colleges, universities), a marketing plan.
Communication	Enhance water resources education in the CWPA.

Table 2. Tier 2 recommendations. The water resources issue the action is meant to address is provided in the first column followed by a brief description of the recommendation.

Issue	Management Alternatives
Availability	Implement more water efficient irrigation practices.
Availability	Seek, promote, and implement wastewater treatment system reuse, beneficial reuses of wastewater.
Availability	Investigate use of quarries as water storage facilities, particularly in the diabase.
Availability	Creation of a new or rehabilitation of an old reservoir in/near the CWPA (ex. Birch Run).
Availability	Creation of additional agricultural ponds.
Availability	New developments should include/incentivize water conservation equipment in homes when built.
Availability	New developments need to provide additional storage capacity.
Availability	Percolate water back into the ground from sewage treatment plants where feasible.
Availability	Enhanced or additional treatment mechanisms should be developed to provide additional sources of water.
Quality	Quantify maximum contaminant loads for pollutants of concern in impaired waterways by developing TMDLs.

Issue	Management Alternatives
Quality, Communication	Public water suppliers in the CWPA should participate in the Potomac Drinking Water Source Protection Partnership to leverage resources and enhance communications with other suppliers in the basin.
Stormwater, Availability	Implementation of stormwater and gray water reuse program(s).
Policy/Management	Foster implementability of recommendations - develop incentives or credits for implementation of practices.
Policy/Management	Develop a sub-committee of WAAC to coordinate volunteers to implement improvement projects in the CWPA.
Policy/Management	Implement local drought preparedness activities including establishment of a CWPA drought advisory group.
Policy/Management	Encourage the development and maintenance of riparian buffers along designated greenways (including the Rock and Marsh creek greenways) as specified in the County Greenway Plan.
Policy/Management	Create a Marsh and Rock Creeks Water Management Council.
Data Collection	Encourage/increase water use registrations and/or metering.
Data Collection	Encourage identification and documentation of delineated wetlands.

Internship Details

The UDC intern worked 20 hours per week on-site at ICPRB in Rockville, MD from mid-February 2012 through the end of August 2012. The intern participated in the CAAC workshop to evaluate management alternatives, a CAAC quarterly meeting, and a combined Potomac Regional Committee and CAAC meeting. The intern conducted site visits to GMA, Knouse Foods, and Hundredfold Farms to understand on-site activities as well as participated in a number of conference calls to gain stakeholder input on the feasibility of implementing various management alternatives. The intern also provided general assistance in developing CARP materials such as GIS mapping and analysis, groundwater availability assessments utilizing hydrogeologic principles, and summarizing CARP findings for communication with the general public.

The results of this work included 7 blog postings[1], a final report to UDC, assistance with a technical report to the CAAC, and editorial proofing of the draft CARP.

Effect on DC Source Water

The outcomes of the CARP project in the Marsh and Rock watersheds included a more detailed understanding of the uses and availability of water resources in the watersheds as well as recommendations for water management actions that can be taken to minimize water resources problems. The results of this study were a technical evaluation of management alternatives under consideration for inclusion in the CARP. The evaluation is an important part of the process and informed the advisory

[1] http://www.marshrockwaterplan.blogspot.com/

committee of the effectiveness of each measure in terms of ensuring water supplies. The finding of this study will benefit the downstream communities in Maryland and D.C. as the downstream water quantity and quality depends on upstream management actions. Further, the outcome of this study enhanced the knowledge and stewardship of D.C's source waters, specifically in the Marsh and Rock creek watersheds.

Implications to D.C.'s source waters from implementation of the management alternatives are numerous. Two examples include implementation of stormwater management practices and additional stream gages in the watersheds. Effective upstream stormwater management would have the following potential benefits to D.C.'s source waters: reduction in non-point source pollutants such as nutrients and sediments, decreased peak streamflows, and decreased erosion. Additional USGS stream gages in the Marsh and Rock creek watersheds would also assist D.C. in the management of water supplies by providing additional real-time data, further enhancing understanding of water resources for long-term planning, drought forecasting, and flood preparedness to name a few.

Sustainable upstream management of water resources will be essential to long-term adequate public water supplies in D.C., as it in the downstream portion of the Potomac basin and dependent on clean, abundant surface water resources. Implementation of the recommended CARP management actions are one step towards this vision in the Upper Monocacy Watershed, one portion of D.C.'s source waters.

Next Steps

This study establishes a collaborative research project between the land grant institution (College of Agriculture Urban Sustainability and Environmental Sciences, University of the District of Columbia) and the ICPRB. The findings of this study will be useful to preparing a future collaborative research project that benefits source water protection in the Potomac River basin.

At the time of this report, the draft CARP is awaiting final approval from the Potomac Regional Committee. Should the committee approve the plan, it will be forwarded to the Statewide Committee for review. The CARP is scheduled for final review by the Regional Committee around February 2013.

The CARP management alternatives are already being poised for implementation in the Marsh and Rock creek watersheds. The local Water Resources Advisory Committee has been restructured with a focus on data collection and education of local municipalities towards successful implementation of the CARP. Other organizations in the watersheds, such as the Watershed Alliance of Adams County, are also interested in assisting with implementation.

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Episodic ion and nutrient inputs to the Anacostia River: constructing a chemical hydrograph of an urban stream's response to periodic rainfall

Basic Information

Title:	Episodic ion and nutrient inputs to the Anacostia River: constructing a chemical hydrograph of an urban stream's response to periodic rainfall
Project Number:	2012DC140B
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Descriptors:	None
Principal Investigators:	Stephen E. MacAvoy

Publications

There are no publications.

Episodic ion and nutrient inputs to the Anacostia River: constructing a chemical hydrograph of an urban stream's response to periodic rainfall

Progress Report

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May, 2013

Introduction and Scope

The Anacostia River has been characterized as one of the most heavily polluted waterways in the United States. High concentrations of contaminants have been documented in the river's sediments (heavy metals, polycyclic aromatic hydrocarbons (PAHs) and clams (*Corbicula fluminea*) (PCBs, PAHs and chlordane) (Phelps 2005, 2007), plus there is a high incidence of tumors in the resident bullhead catfish (Pinkney et al. 2004). In fact, the Washington DC Department of the Environment has issued advisories against consumption of Anacostia fishes. (http://ddoe.dc.gov/ddoe/cwp/view,a,1209,q,494756.asp). These facts clearly show that the river is heavily impacted by the surrounding urban watershed, however recent studies have found lower nitrate, ammonium and phosphorus at base-flow than would be expected in a polluted river (MacAvoy et al. 2009). In fact, the Anacostia at base-flow seems to be on the high end of "normal" for nitrate (a major form of nitrogen that is usable by plants) in an estuary (between 0.1 and 1.0 mg/l). The fact that base-flow nitrogen conditions are "normal", even in areas adjacent to combined sewage outflows, is very good news for the river and suggests that a cleaner river may be achievable in the future.

However, Hwang and Foster (2008) have shown that storm-water flow after heavy precipitation evens, seem to flush PCB's into the Anacostia. It may be, therefore, that the nutrient loads observed by MacAvoy et al. (2009), which show base-flow conditions, do not reflect the possible periodic flushing of the watershed. Indeed, Miller et al. (2007) showed strong correlations between discharge and total nitrogen in the upper Anacostia watershed, although the correlation was much less significant once discharge was greater than 1000 cubic feet/second (discharge as measured up to 4500 cfs during episodes between 2003 and 2005). Nitrates and other compounds (such as PAHs) emitted through vehicle tailpipes and industrial processes are deposited as "dry-deposition" on impermeable surfaces, where they accumulate. Precipitation may then wash the compounds from the impermeable surfaces into the Anacostia.

In this study, we propose to obtain water samples from the Anacostia hourly following precipitation events (via autosampler). These samples will have their nutrient and geochemical characteristics monitored (nitrite, nitrate, ammonia, phosphorus plus cations and anions). The water will also be examined for fatty acids to help identify bacteria in the water column. These analyses will generate a chemical response profile for the river resulting in a chemical view of the river's response to periods of heavy run off. During the same storm events that the Anacostia is exposed to, we will collect the same type of data for a relatively un-urban (suburban) first order tributary river in Montgomery County MD (Longbranch Cheek) as a contrast. We will determine the nutrients delivered per unit volume to the rivers and, by using flow monitors maintained by the USGS and Montgomery County Department of Environmental Protection we will be able to estimate the total nutrients moving through the rivers. (http://www.montgomerycountymd.gov/dectmpl.asp?url=/content/dep/water/monPhysFlow.asp).

The geochemical data we obtain will allow us to contrast the geochemical controls of each river in order to better assess the impact of urbanization on river chemistry. Previous work has suggested that concrete (essentially a man-made conglomerate rock) has a significant influence on the geochemistry of the Anacostia (Sarrano et al. 2010, 2011). The concrete might be altering the river in ways the river's biology has never experienced.

While it has been shown that the Anacostia has extremely high levels of petroleum-based hydrocarbons in the sediments due to the intense urbanization throughout the watershed (Wade et al. 1994; Velinsky and Ashley 2000—unpublished). Its less urban tributaries maybe considered relatively pristine compared to the Anacostia main-stem, and will offer a natural "control" for comparison. It seems likely that the precipitation episodes that seem to flush PAHs into the area's rivers, also would flush nutrients. During base-flow the Anacostia nitrogen and phosphorus concentrations are on the high side of "normal" for an estuarine system (less than 1 mg/l; MacAvoy et al. 2009). However, no studies have examined the changes in water geochemical/nutrient composition that may occur during episodic high flow events (previous work has focused on contaminants). If researchers or policymakers are going to understand nutrient movement to the Chesapeake estuary, it is vital to understand the importance of high flow episodes for their delivery.

Objectives of the Research

The objectives of this research are to determine: 1) the chemical response of both the Anacostia and a suburban tributary (Longbranch Creek) to precipitation events; 2) compute the storm water delivery of nutrients/geochemical variables to the rivers; 3) test the hypothesis that there is a geochemical difference between the Anacostia and Longbranch creek arising from different degrees of urbanization. This work will involve charactering the inorganic geochemistry of both river systems. Compounds to be examined include nitrate, nitrite, ammonium, phosphorus, calcium, potassium, magnesium, chloride, aluminum, zinc, cadmium, copper, boron, sulfur, lead and tin. ISCO automated samplers (one for each river) will collect hourly samples during high flow (the ISCO is triggered to collect samples automatically when the stream hydrograph begins to arise). The samples will then be collected and analyzed. A principle components analysis will be conducted to determine which environmental variables co-vary. Analysis of Variance and non-parametric methods will be used to differences in the rivers and will compare storm-flow to base-flow data collected in previous studies.

The Longbranch Creek, hypothesized to be less polluted than the Anacostia, will be a good way to critically analyze the Anacostia chemical data.

Methods, Procedures and Facilities

Water Collection- Water will be collected by automated samplers (ISCO samplers), that can be programmed to collect 500ml of water at set time intervals when the stream hydrograph begins to rise. The water will be transported to back to the lab analyzed at American University and Cornell (soil lab). Data to be collected includes nitrate, nitrite, ammonia, phosphate, Mg, Na, Cl, K, Ca, Ni, B, Cd, S, Sr, Pb, and Cr using standard methods.

Geochemical and nutrient analysis: Standard methods will be used for all water geochemical and nutrient analysis. These methods can be found at http://www.standardmethods.org/

Organic contaminant profiling- Different classes of hydrocarbon will be isolated from sediments and water column filtrate using soxhlet extraction followed by saponification and separation of the fatty acids, PAHs, hormones etc. For specific methodology, please see MacAvoy (2000) and MacAvoy et al. (2002, 2003). Hydrocarbon characterization will be accomplished by identified using a Thermo Polaris Q GC-MS (gas chromatography - mass spectrometry).

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Development of Porous Driveway System for Districts Residential Lots

Basic Information

Title:	Development of Porous Driveway System for Districts Residential Lots
Project Number:	2012DC141B
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Descriptors:	None
Principal Investigators:	Inder J. Bhambri, Pradeep K. Behera

Publications

There are no publications.

Development of Porous Driveway System for Districts Residential Lots Final Report

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Abstract

Urban stormwater runoff contributes to a number of water quantity and quality problems of many receiving waters (i.e., rivers, streams and lakes). The impervious surface from the developments increase the runoff volume and higher runoff rate resulting in flooding and erosion and pollution from the urban anthropogenic activities contribute to water quality problems. Therefore, reduction of stormwater impacts is a very important issue in many urban areas in the United States. This is more emphasized for many older metropolitan areas such as the District of Columbia which are serviced by mostly combined sewer system in addition to separate storm and sanitary sewer systems. For example, the impact of the urban stormwater discharges from highly urbanized areas has been more pronounced on the Chesapeake Bay ecosystem [1-3]. Anacostia River has been recognized as one of the most polluted water bodies in the nation which is primarily attributed to combined stormwater runoff and municipal wastewater treatment discharges [4]. To address stormwater pollutions over last two decades several best management practices including detention basins, rain barrels, green roofs, and bioretention ponds have been proposed and implemented throughout the watersheds. These are not only cost effective, but also sustainable way to reduce the stormwater and to remove the pollutions from urban runoff. However due to the high cost of land in dense urban areas such as the District of Columbia it is highly desirable to minimize the land occupied by these facilities by optimizing their performance.

This seed grant research focused on the (i) Analysis of effectiveness of porous pavement in DC from climatological and hydrological viewpoint, and (ii) Conceptual and experimental proof of concept by focusing on developing an effective porous pavement which will provide required compressive strength and infiltration capacity through the optimal mix of different types of aggregates, cement and water. The porous pavement systems can be easily implementable into residential lots. The methodologies of the research include literature review, rainfall characteristics within the District of Columbia, conceptual porous pavement design, experimental design, and performance assessment. From the rainfall analysis it is found that a significant percentage of storm events are smaller size rainfall events in Washington DC region which are very suitable to porous pavements. Two sets of porous pavement mixes were designed and tested for comprehensive strengths which resulted in up to 2300 psi. More design and testing are required to achieve up to 3000 psi.

1. Introduction

Stormwater runoff quantity problems (i.e., flooding, erosion and sewer backup) and quality problems (i.e., pollutant loads, aquatic health of receiving waters) are the important issues the District of Columbia faces. Due to the limited capacity of the combined sewer system and the wastewater treatment plant, a large amount of combined storm-water and raw municipal wastewater is discharged into the local receiving waters that include Potomac River, Anacostia River, and Rock Creek [4]. Anacostia River has been identified as one of the most polluted water bodies in the nation and a number of efforts have been implemented to reduce the amount of pollution in this water body. The highly impervious areas within the District also contribute to highly polluted with various toxic organic compounds, metals, nutrients and pathogens [5, 6]. It has been observed that an half inch of rainfall can cause overflows to local receiving waters. To address the above mentioned stormwater problems, one of the goal of the District is to reduce the stormwater runoff volume, peak flow rate and associated pollutant load as much as possible. The runoff quantity and control strategies that are cost-effective and a sustainable way of reducing the adverse effects of stormwater is to use Low Impact Development (LID) practices such as but not limited to retention, detention, bioretention ponds, green roof, permeable pavements, and constructed wetlands.

2. Research Objectives

The overall goal of the proposed study is to develop a porous driveway system to provide lot-level runoff quantity and quality control within residential lots thereby reducing the overall urban runoff volume and number of overflows to the receiving waters (i.e., Potomac River, Anacostia River and Rock Creek). This seed grant research will focus on the (i) Analysis of effectiveness of porous pavement in DC from climatological and hydrological viewpoint, (ii) Conceptual and experimental proof of concept by focusing on developing an effective porous pavement which will provide required compressive strength and infiltration capacity through the optimal mix of different types of aggregates, cement and water. The next task would be selection of right design of porous pavement and performance evaluation of the systems from both the design criteria of strength and infiltration capacity. Infiltration of rainfall into the porous pavement systems is controlled by three mechanisms – the maximum possible rate of entry of water through the driveway and sub-grade, the rate of movement of water through the vadose (unsaturated) zone and the rate of drainage through the bottom of the vadose zone. The infiltration rate and storage capacity of the proposed sub-grade will be evaluated for their performance. The goal is to use the outcomes of this research to write a proposal to local and external agencies such as EPA and/or

NSF to provide funding for a large scale, integrated assessment of the impact of such technique on the storm-water quality and quantity control in the District of Columbia. The objectives of the research include:

- Evaluation of effectiveness of porous pavement in DC from climatological and hydrological viewpoint
- Development of optimal combination of concrete and aggregate and/or recycled materials to create a driveway system which is structurally sound to carry the loads from vehicles (i.e., compressive strength) while allowing infiltration of rainfall and runoff.
- Develop a lab-scale model to demonstrate the rate of infiltration through the system.

3. Literature Review

Most cities in the world have storm water conveyance systems that were built in the early 1900s which provide a conventional capture of the storm water runoff. With land development and population growth in the oldest cities in North America, the existing storm water management systems are ineffective and inefficient to manage the runoff due their design adequacy and design philosophy. These systems were planned, designed and build over time with different design criteria and philosophy. After the 1983 EPA NURP study, the urban stormwater management has been included source control, conveyance control and end-of-the-pipe storage and treatment control. Several best management practices including stormwater management pond and infiltration basins were developed and implemented. However, over last decade more emphasis has been placed on the eco-system approach which includes both water quantity and quality control at the watershed and sub-watershed level. As a part of eco-system approach low impact development (LID) systems have been emphasized to treat runoff on site. On-site treatment systems such as infiltration basins, porous concrete, porous asphalt, swales, filter strips have been in research and found effective and cheap to mitigate the growing problem in our cities. Articles such as, "Review of permeable pavement systems", "Improvement of porous pavement systems for onsite storm water management", and "Long term storm water quantity and quantity performance of permeable pavement systems" were reviewed for perspective and understand on the current trend of porous pavements.

Scholz and Grabowiecki (2006) summarized the wide range of topics in the permeable pavement systems in the article *Review of Permeable Pavement Systems*. Even though the permeable pavement systems have limitation due to urbanization and climate change, they offer economical water cycle and reduction of pollutant. Permeable pavements are the most efficient way to manage pollutions in surface runoffs. Research has shown that the structure can be used as an effective in-situ aerobic bioreactor. The life span of porous pavement depends on the size of the air voids in the media. It is usually shorter than the typical pavement, but in most cases after many years of usage the pavements were effective in containing and infiltrating the runoff. Consequently, the pavement reduced zinc and copper levels while infiltrating the runoff. While impervious surfaces have a high potential for introducing pollution to our water ways, it is in fact stated that porous pavement have a great record in reducing pollutants. Permeable pavements that do not have underline filtration system will not be successful in removing pollutants. It is still unclear the long term effect of permeable pavement in regard to it maintenance, operation, and cost. But porous pavements meet their primary object in removing pollutant. Further research is needed to improve the systems. Porous pavements are suitable for lot level runoff quantity and quality control and these systems can be implemented for a wide variety of residential, commercial and industrial settings.

4. Understanding hydrology through Precipitation Analysis

Development of stormwater management systems requires hydrologic and hydraulic analysis. For source control systems, specifically porous pavement systems, hydrologic analysis is required to understand the rainfall-runoff processes, infiltration processes. Therefore, in order to understand effectiveness of the porous pavement within any jurisdiction from runoff quantity control viewpoint it is necessary to understand the climate, specifically precipitation, which is the key input to hydrology.

A storm event analysis is conducted to understand the magnitude and frequency of storm event volume. In this regard, the volume of the storm event is emphasized as key parameter. The available local continuous chronological rainfall record is first discretized into individual rainfall events separated by a minimum period without rainfall – termed the interevent time definition (IETD). If the time interval between two consecutive rainfalls is greater than the IETD, the rainfall events are considered as two separate events. Once this criterion is established, the rainfall record is transformed into a time series of individual rainfall events and each rainfall event can be characterized by its volume (v), duration (t), interevent time (b) and average intensity (i). Next, a frequency analysis is conducted on the magnitudes of the time series of rainfall event volume.

The available hourly rainfall data from the National Climatic Data Center (NCDC) for

Washington Reagan National Airport Station (ID 448906) from 1948-2009 was obtained from http://www.ncdc.noaa.gov/oa/ncdc.html and used in this analysis. These files catalog hourly precipitation information, and present the records in a comma-delimited ASCII text file. We developed a computer code to process the downloaded data. Based on the IETD the code parses into individual storm events. After the processing the data, the data file is imported into excel for further analysis.

Table 1 presents the number of storm events having different threshold amounts (i.e., rainfall volume) for different IETDs. For examples, with an IETD of 6 hour, there were 5546 events with an amount less than one inch volume and 6091 events with an amount less than two inch volume, and the difference between these two sets, a total of 545 events were occurred with a size between 1 inch to 2 inch volume. Table 2 presents the percent of storm events having different threshold amounts for different IETDs.

Table 1: Number of storm events with different threshold amounts

Event Size (in)	IETD 1	IETD 3	IETD 6	IETD 12	IETD 24
Total # Events	**10445**	**7467**	**6221**	**5286**	**4363**
< 0.5"	8925	5841	4556	3591	2692
< 1.0"	9915	6843	5546	4577	3586
< 2.0"	10352	7357	6091	5141	4192
< 3.0"	10420	7437	6187	5246	4311
< 4.0"	10434	7454	6207	5268	4342
< 5.0"	10441	7462	6216	5278	4351
< 6.0"	10441	7463	6216	5281	4356
< 7.0"	10445	7465	6218	5282	4359

Table 2: Percentage of storm events with different threshold amounts

Event Size (in)	IETD 1	IETD 3	IETD 6	IETD 12	IETD 24
Total # Events	**10445**	**7467**	**6221**	**5286**	**4363**
<.5	0.854	0.782	0.732	0.679	0.617
<1	0.949	0.916	0.891	0.866	0.822
<2	0.991	0.985	0.979	0.973	0.961
<3	0.998	0.996	0.995	0.992	0.988
<4	0.999	0.998	0.998	0.997	0.995
<5	1.000	0.999	0.999	0.998	0.997
<6	1.000	0.999	0.999	0.999	0.998
<7	1.000	1.000	1.000	0.999	0.999

The appropriate IETD for a highly urbanized area such as Washington DC will be approximately between 1to 3 hours. That is the runoff will be drained to the outlet within 3 hours to distinguish between two storm events. Considering an IETD of 3 hours, 78.2% of the storm events are having less than 0.5 inch of rainfall volume and 91.6% of storm events are having less than 1.0 inch of rainfall volume. Such high percentage of small events is very useful for porous pavements.

5. Development of Porous Pavement Mixes

As previously mentioned the overall goal of the proposed study is to develop a porous driveway system to provide lot-level runoff quantity and quality control within residential lots thereby reducing the overall urban runoff volume and number of overflows to the receiving waters (i.e., Potomac River, Anacostia River and Rock Creek). This section presents the conceptual and experimental proof of concept by focusing on developing an effective porous pavement which will provide required compressive strength and infiltration capacity through the optimal mix of different types of aggregates, cement and water.

Infiltration of rainfall into the systems is controlled by three mechanisms – the maximum possible rate of entry of water through the driveway and sub-grade, the rate of movement of water through the vadose (unsaturated) zone and the rate of drainage through the bottom of the vadose zone. The infiltration rate and storage capacity of the proposed sub-grade will be evaluated for their performance.

In the experimental design, two concrete mixes were considered which noted as:
Pavement Concrete Mix I and Pavement Concrete Mix II. For each of the mixes different proportion of aggregates were selected.

Materials: The pervious concrete also known as porous, gap-graded, permeable mainly consists of normal portland cement, course aggregate and water. In regular concrete mixes, the fine aggregates generally fills in the voids between the course aggregates, thereby making the bulk concrete impervious. Whereas in porous concrete fine aggregates are non-existent or added in very low quantities. In this research, aggregates grading used in porous concrete are experimented with a set of course aggregates grading between ¾ inch and 3/8 inch (19 mm and 9.5 mm). Our experiment assumed such grading will provide a porosity anywhere between 15% to 35%. The details of aggregates fro proposed two mixes are given in the Table 3. It is noted that no chemical admixtures were added in the concrete mixes.

Table 3 : Concrete Mix – aggregate proportion and water cement ratio

Design Mix	**Crushed Stone Particle Size**	**Proportion**	**Water- Cement Ratio**
Pavement Concrete Mix I	Passing Sieve #1” and Retained in 3/4”	50%	0.36
	Passing Sieve # 3/4” and Retained in 1/2”	25%	
	Passing Sieve # 1/2” and Retained in 3/8”	25%	
Pavement Concrete Mix II	Passing Sieve #1” and Retained in 3/4”	33.3%	0.35
	Passing Sieve # 3/4” and Retained in 1/2”	33.3%	
	Passing Sieve # 1/2” and Retained in 3/8”	33.3%	

Figure 1: Aggregates of different sizes

Figure 2: Preparation of sample mix

Properties

The porous concrete mixture is stiff compared to traditional concrete. The slumps, when measured are generally between less than ¾ in (20 mm), although slumps as high as 2 in (50 mm) have been used (Obla, 2007). Porous concrete mixes can develop comprehensive strengths in the range between 500 psi and 4000 psi.

Figure 3: concrete mix preparation

Figure 4: Sample preparation for compressive strength testing

6. Analysis & Results

Two sets of mixes were prepared. Concrete mixtures were casted in the 4 inch and 3 inch diameter cylinderical samples. The mixes are cured for 28 days. Before the testing the samples, the samples were caped.

Testing of concrete cylinders:

Figure 5: Testing of Samples from Pavement Mix II (unloaded and loaded)

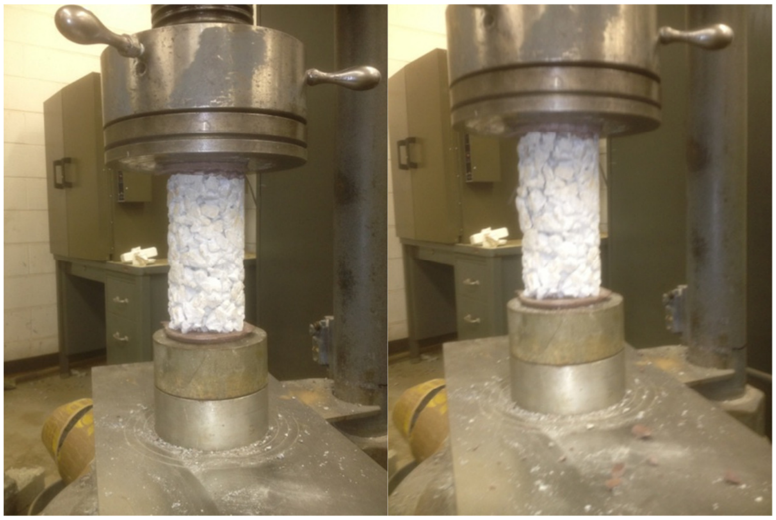

Figure 6: Testing of Samples from Pavement Mix II (unloaded and loaded)

Figure 7: Testing of Samples from Pavement Mix I and II – showing deformation

It may be noted that from the testing (Figure 7) and breakage lines were at approximately 60^o which depicts the strength of the concrete. Table 4 presents the comprehensive strengths of the design mixes.

Table 4: Comprehensive Strength Results

Design Mix	Particle Size	Proportion	Water-Cement Ratio	28 Day Compressive Strength
Pavement Concrete Mix I	Passing Sieve #1" and Retained in 3/4"	50%	0.36	**2,300 psi**
	Passing Sieve # 3/4" and Retained in 1/2"	25%		
	Passing Sieve # 1/2" and Retained in 3/8"	25%		
Pavement Concrete Mix II	Passing Sieve #1" and Retained in 3/4"	33.3%	0.35	**1,470 psi**
	Passing Sieve # 3/4" and Retained in 1/2"	33.3%		
	Passing Sieve # 1/2" and Retained in 3/8"	33.3%		

The proposed mixes only achieve a maximum of 2,300 psi which is lower side of expected results. In the future work, different mixes will be designed to achieve at least 3000 psi.

7. Acknowledgement

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Composting Makes Sense

Basic Information

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There are no publications.

INSTITUTE FOR Local Self-Reliance

Composting Makes ene: Final Report

Brenda Platt, Principal Investigator
Institute for Local Self-Reliance

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Abstract

The purpose of the Composting Makes ene project was to research and document the watershed and other community benefits of composting organic discards to the District and the surrounding region, and to identify specific policies for implementation that will help expand the use of compost as a watershed protection method.[1] There is an urgent need for compost utilization to help preserve and restore local waterways, and driving demand for compost can result in economic gains for regional communities.

Despite decades of attention, the Chesapeake Bay watershed suffers from excessive nitrogen and phosphorus levels due to nutrient-laden run-off pollution. Excess fertilizers from farms and suburban lawns, sewage from septic systems, and sediment from construction projects wash off the land and into our waterways every time it rains. About 60% of soil that is washed away ends up in rivers, streams and lakes, contaminating waterways with soil's fertilizers and pesticides. Soil erosion also reduces the ability of soil to store water and support plant growth. Nationally, soil is being swept and washed away 10 to 40 times faster than it is being replenished, destroying acres of cropland, despite the fact that the need for food and other agricultural products continues to grow.[2] The economic impact of soil erosion is enormous, costing society a total of $44 billion each year in America.[3]

Fortunately, a dark, crumbly, earth-smelling and sustainable material called compost can mitigate many of these problems when added to soil. Compost is a valuable soil conditioner made from the natural decomposition of organic materials such as food scraps, animal manures, and yard trimmings. Because these recovered organics cannot be shipped abroad, composting and the use of compost can provide myriad benefits to the local economy and environment. These benefits include reducing stormwater runoff and soil erosion, reducing waste, improving soil properties, protecting the climate (through reduced landfill methane gas emissions as well as carbon sequestration via compost-amended soil), and creating green jobs at compost facilities and on low-impact development projects. Thus, advancing composting and compost use in DC and Maryland is a key sustainability strategy to protect the Chesapeake Bay watershed, reduce climate impacts, improve soil vitality, and build resilient economies.[4]

Through the Composting Makes ene project, staff from the Institute for Local Self-Reliance (ILSR) and three student interns conducted research, documenting how the use of compost can address current water pollution issues in the Bay watershed (namely eutrophication), and to do so, identified model policies implemented elsewhere that could be replicated in the Mid-Atlantic region. Additionally, the team determined that on a per-ton basis, composting alone can create twice as many job positions as landfills and four times as many jobs as incinerators. On a dollar-per-capital-investment basis, the comparison is even more striking, as composting operations sustain three times more jobs than landfills and seventeen more jobs than incinerators. However, investing resources in composting and compost use combined, and promoting policies that support both, will maximize environmental and economic benefits: for every one million tons of material composted, followed by local use of the resulting compost, almost 1,400 new full-time equivalent jobs could potentially be sustained.[5] These key findings and further information can be found in the Institute's booklet titled, *Building Healthy Soils with Compost to Protect Watersheds* and full report titled, *Pay Dirt: Composting in Maryland to Reduce Waste, Create Jobs, and Protect the Bay* available for download at http://www.ilsr.org/paydirt/.

Introduction

In early 2012 the DC Water Resources Research Institute (WRRI) granted $15,000 to the Institute for Local Self-Reliance (ILSR) to support our Composting Makes ene project. The grant largely covered the stipends for university students to provide research assistance under the guidance of Principal Investigator Brenda Platt, director of the Institute for Local Self-Reliance's (ILSR) Composting Makes ene project. The Institute for Local Self-Reliance (ILSR), alike the DC Water Resources Research Institute (WRRI), acknowledges the severe watershed problems in the DC Metropolitan Area (e.g. a polluted and unfishable Anacostia River and Potomac River and an over-capacitated stormwater management infrastructure), and as such, this project focused on identifying the watershed benefits and other benefits of composting organics in the National Capital Region. The project team also undertook the task of identifying model policies regarding composting and the use of compost that could be replicated in the DC region.

While there have been many successful composting programs and operations instituted in the U.S., only 2.8% of all discarded food scraps are being recovered nationally, and the DC-Maryland area follows a similar trend.[6] Though Maryland has a fairly well established infrastructure to compost yard trimmings, most food scraps that are being recovered end up in Delaware, and just the same, material from DC Government's pilot composting program are transferred out of state to Virginia. By doing so, local jurisdictions forego the environmental and economic benefits that accompany a decentralized community-based composting infrastructure, one that embraces composting on a wide range of scales and sizes.[7] From an economic perspective, such communities relinquish the burden of added transportation costs (often the largest cost consideration in a composting infrastructure), and can sustain more jobs than other environmentally benign waste management methods such as landfilling and incineration. What's more, compost itself is an integral component of green infrastructure projects, which is a growing industry with job opportunities. From a watershed protection perspective, composting offers aid to an ailing Bay in many ways. Composting reduces waste that can potentially enter the Chesapeake's tributaries and, in so doing, diverts material from landfills (thus reducing methane gas emissions and material that can potentially contaminate groundwater through leaching). Perhaps, most importantly, composting creates a product that, when applied to soils, can cut irrigation needs by 50%, reduce contamination of urban pollutants by 60-95%, add organic matter to soil, which restarts the soil ecosystem, and can reduce erosion and sedimentation.[8]

Objectives

Our initial proposal identified the following goals: to (1) produce and disseminate information that composting is a key strategy to protect watersheds from nutrient run-off, stimulate sustainable economic growth, reduce pollution, mitigate the detrimental impact of wastes on public health and the environment, and help spur urban food production, and (2) identify key policies that if implemented will increase use of compost as a watershed protection method.[9]

Materials and method

The Composting Makes ene project was completed in two phases. In the first phase of the project, student interns researched and documented the watershed and economic benefits of composting and compost use, while also identifying state and local policies that could serve as a model for the DC-Maryland region. With the support of ILSR staff, our UDC PSM-WRM student intern conducted the watershed-focused work by first reviewing existing literature, such as the US Composting Council's *A Watershed Manager's Guide to Organics: The Soil and Water Connection* to determine how healthy soils contribute to healthier water resources and how steps taken to improve soils leads to improved water quality such as the ability to store water and nutrients, regulate the flow of water, and immobilize and degrade pollutants. This work also required the investigation of programs that have been effective and succussfully implemented such as Washington State's Soils for Salmon, communication with academic and industry experts including Virginia Polytechnic Institute and State University staff, and the review of evidence-based research studies.

Using this information, the ILSR team identified model policies that can be replicated in DC and Maryland to enhance Chesapeake Bay watershed protection, while developing a composting infrastructure that benefits communities and spurs a market for compost. Beginning in the summer of 2012, staff-supported interns posted these policies online to ILSR's Composting New Rules page, establishing new resources including *Compost-Amended Soil Requirements* and *Compost Procurement Policies,* while improving their web page development skills.

ILSR also documented the economic benefits of composting and compost use with the assistance of two American University student interns. We first developed a survey to be distributed to 42 area facilities that we identified that compost, mulch, or recycle natural wood waste. Half of these – 23 – participated in our survey which took place in August 2012.[10] The survey requested pertinent economic information from each facility such as number of full-time equivalent employees, type of job positions, ranges of wages paid, and capital investment in addition to questions that revealed the amount of material being processed.[11] This method established a correlation between the number of jobs at composting facilities and the tonnage of processed material, as well as the number of jobs sustained per dollars invested – thus, providing perspective on potential job creation in the national capital region if DC and Maryland invest in building composting infrastructure and divert more compostable material from the waste stream. By coupling pre-existing, extensive research done by ILSR with information from Maryland's three waste incinerators and six responsive landfills, we were also able to compare the economic benefit of expanding composting to these conventional disposal sites.

In addition to the survey, the team gathered information and hands-on composting experience through tours and in-person interviews at composting facilities and urban farms including ECO City Farms, just outside the District. Attaining data regarding the use of compost also entailed phone interviews with managers of the nation's largest compost utilization program in Texas, President and CEO of Filtrexx International (the industry leading manufacturer of compost-based products for erosion control and stormwater management), and public officials whose jurisdictions have implemented model replicable policies.

Phase two of this project focused on developing the two primary reports detailed below, and creating a dedicated web page, which includes summary documents and supporting information.

Results and Discussion

The proposed project was successfully implemented and met its goals. We have finalized two major reports:

1. *Building Healthy Soils with Compost to Protect Watersheds*: This 12-page booklet highlights the importance of organic matter to healthy soils, and links healthy soils in turn to a healthier watershed. It makes the case that amending soil with compost is the best way to increase the level of organic matter. This report identifies watershed problems, the benefits of compost-amended soils, model initiatives and policies (including DC's RiverSmart Homes initiative), frequently asked questions, and resources for more information.

2. *Pay Dirt: Composting in Maryland to Reduce Waste, Create Jobs, and Protect the Bay:* This 47-page report summarizes the current composting infrastructure in Maryland, compares the number of jobs sustained through composting versus disposal facilities, outlines the benefits of expanding composting and compost use, underscores the importance of a diverse composting infrastructure that includes backyard and community composting, and suggests policies to overcome obstacles to expansion. (A grant from the Town Creek Foundation enabled us to leverage the DCWRRI grant to produce this report.) While this report focuses on Maryland, it will make the case for expanding composting in the District and surrounding region. Due to land limitations, DC's composting's future is in part tied to MD's and the MD capacity to compost. It has particular significance for UDC's Muirkirk Farm and future plans to compost there as the farm is located in Maryland.

We released these reports May 8th during International Compost Awareness Week, May 6th-11th. To publicize the findings, we have and will continue to develop online web pages and social media graphics. One major finding is that on a per-ton basis, composting employs two times more workers than landfilling, and four times more than incineration. But using compost for stormwater management, soil erosion control, and other green infrastructure applications, sustains even more jobs. We estimate that for every 1 million tons of organic material composted at a mix of small, medium, and large facilities followed by local use of the resulting compost, almost 1,400 new full-time equivalent jobs could potentially be supported. These jobs would pay wages ranging from $23 million to $57 million.[12]

Documenting model policies for replication has been an integral facet of our Composting Makes ene project. We added 23 new examples of model rules to promote composting to our searchable Composting New Rules web page. These include performance-based permitting regulations, regulations with exemptions for on-farm and other small-scale composters, state bans on landfilling yard trimmings, compost-amended soil requirements, and compost procurement stipulations. In August, BioCycle journal published our article on "Supportive Rules for Small-Scale Composting." (Available on our web site at: http://www.ilsr.org/supportive-rules-small-scale-composting/)

We have started raising awareness about the connection of compost to water and soil health.

- In September, we testified before DC Councilwoman Mary Cheh's public hearing on recycling about the many benefits of composting. We provided similar information as part of an expert panel, "Alternatives to Landfilling and Incineration: Turning Waste into a Resource" at a public hearing with the five members of the Prince George's County Council's Committee on Transportation, Housing & the Environment before Committee.
- In October, we made a presentation on "Controlling Roadway Soil Erosion with Compost" to the MD State Highway Administration's Recycled Materials Task Force.
- In November, ILSR submitted comments for the public record to the DC Department of Environment on its "Draft Stormwater Management Guidebook." Our comments focused on strengthening the requirements for use of compost-amended soils and the acceptance of compost-related products such as compost berms, compost filter socks, and compost blankets as best management practices in the Guidebook.
- Also in November, ILSR coordinated and moderated the 2-hour roundtable on "Compost: Protecting Our Watershed," during which participants agreed that promoting compost and compost-related products was important to control stormwater run-off and erosion. (The roundtable was part of the 7th Potomac Watershed Trash Summit, sponsored by the Alice Ferguson Foundation.) An ad-hoc committee formed to continue this effort, which is being modeled after Washington State's successful Soils for Salmon project.

- ILSR nominated the following policy for 2013 priority consideration for the Choose Clean Water Coalition, a multi-state network of organizations working for a cleaner Chesapeake Bay: promoting minimum standards for soil quality and depth as a best management practice to manage stormwater and soil erosion. It is likely this recommendation will be incorporated into the Coalition's work to strengthen policies to address run-off problems.
- As an engaged participant on the MD Department of Environment's Compost Study Group, we have directly influenced and contributed to the content of its programmatic and regulatory recommendations, which now include language to support use of compost and compost-related products as best management practices for stormwater and soil erosion control. ILSR and our work is mentioned several times in the Executive Summary, but perhaps more importantly we played a key role in guiding the recommendations throughout the report.
- To promote compost usage and awareness that amending soils with organic matter can address watershed problems, we co-sponsored and spoke at a March 5th Workshop on compost as a best management practice for stormwater management and watershed implementation plans (WIPs). The workshop was completely full (130 participants) with a substantial waitlist. The response from this event has been extremely positive.
- In March, ILSR returned to the DC Council's chambers and testified again before Councilwoman's Mary Cheh at her hearing on "waste-to-energy." ILSR's comments focused on the importance of comprehensive composting to zero waste planning and how incineration systems compete with the development of composting and aiming for zero waste.
- In April, we presented our findings on the jobs benefits of composting compared to disposal at the National Capital Region Organics Task Force meeting, hosted by the Metropolitan Washington Council of Governments.
- We will present key findings from our *Pay Dirt* report at the upcoming June 6th DC Environmental Network's monthly meeting.

In addition, ILSR successfully facilitated the creation of the MD-DC Compost Council and a listserve for members. We have 29 members and have a 10-member steering committee. At our February 4th meeting, we agreed on our top priorities, which include ensuring the MD Composting Workgroup Report gets to the governor and MD legislature and participating with MDE in the development of the new MD permitting regulations for composting facilities.

Another identified priority was to participate in the February 18th meeting of the MD Horse Council's Farm Stewardship Committee to seek their support for composting. ILSR attended the meeting. The Committee is very supportive of composting, not only on-farm but also the development of additional capacity to handle horse manure. One issue ILSR raised was the use of persistent herbicides on horse pasture, which can be a contaminant in compost at concentrations as low as 1 ppb. ILSR will be working with others to produce a fact sheet on the persistent herbicide issue for MD Horse Famers; the Stewardship Committee wants to make the MD Horse Council a leader on composting and persistent herbicides.

We had one unexpected outcome from our work this year: the decision to foster a regional Master Composter train-the-trainer program in conjunction with UDC. This program will be vital to creating a robust decentralized community-based composting infrastructure. When fully implemented, we envision it enhancing backyard composting efforts, creating community-based composting opportunities, and imbedding a culture of composting and composting know-how in the community. Our initial plans are to adapt the successful NY Compost Project's Master Composter Certificate program. We are actively fundraising to support this work.

Conclusion

The work begun through the Composting Makes ene project demonstrates the enormous opportunity to expand composting in the DC-MD region. Almost one half of typical household garbage is compostable. In Maryland alone, more than one million tons of yard trimmings and food scraps are disposed of each year.[13] What's more, there are significant economic and environmental benefits that can be reaped by dedicating dollars and our compostable "waste" stream to the development of composting facilities and to the compost use industry. Government, institutional, and private entities that implement policies that promote composting and compost use can realize these benefits. Furthermore, coupling composting with the use of compost will optimize benefits. From an economic standpoint, composting employs two times more workers than landfilling, and four times more than incineration, but using compost offers even more economic benefits. Compost is a value-added product, that can potentially sustain one new business for every 10,000 tons of compost used. Many of these businesses are in the growing field of green infrastructure, because compost is such an effective and versatile material, specifically in terms of watershed protection. The many advantages of compost amended soil (e.g., improved water retention, reduced non-point source pollution, reduced erosion and sedimentation) warrant the expansion of composting, especially in the Chesapeake Bay region.

The Composting Makes ene project produced results that many in the composting and water resource management industries have long awaited, but there is a tremendous need to continue this line of work, for example, through outreach and education. This will be a critical factor that will influence whether much needed policies are put in place, and a sustainable and equitable composting infrastructure is developed in the DC region. The Institute for Local Self-Reliance is interested in continuing this work.

The close of this grant period also places its partners in an opportunistic position, as we are now equipped with a body of work that substantiates reason for potential funders and public officials to support swift and direct action that progresses composting in DC. The District of Columbia's College of Agriculture, Urban Sustainability, and Environmental Sciences (CAUSES) can use the resources and findings produced from this grant to better understand, plan, and raise funds for some of its key initiatives such as: composting and agricultural development at Muirkirk Farm, continuously enhancing the Professional Science Masters – Water Resource Management (PSM-WRM) curriculum, efforts to reduce non-point source pollution and improve the city's stormwater management, and its core goal of enahncing health and nutrition in the district through intensive urban organic crop production. Because schools and universities can be a catalyst for community-based composting, we hope the Composting Makes ene project and a continued partnership will facilitate the development of a regional Master Composter program that, as previously discussed, can be a model for urban land grant institutions. We are available to help UDC continue its efforts to become a national academic leader in urban sustainability by partnering on compost-related projects.

Acknowledgement

Howard Ways, former Director of Planning and Sustainability at UDC, was also a principal investigator on this project. Howard remained involved with the project even after leaving UDC and met monthly throughout with principal investigator, Brenda Platt, providing valuable feedback and direction.

This grant report would not be complete without a word about our fabulous interns: Bobby Bell (UDC), Meredith Hollingsworth (AU), and Cameron Harsh (AU). Meredith worked on this project during summer 2012, Cameron came on January 2013, and Bobby has worked with us throughout the grant period. Here again, our Town Creek Foundation grant enabled us to leverage the DCWRRI funds and pay our interns over an extended period of time. Our expectation was that students involved in this project would gain a high level of competency to start or extend their careers in organics management, business and environmental sciences. We have met this expectation. Bobby, in particular, has enhanced his competency in watershed and composting know-how issues. ILSR paid for his registration to attend the 4-day Better Composting School in October 2012. This is the training course offered to operators of commercial-scale composting facilities in Maryland. Bobby continues to learn and hone his research skills and knowledge. We hope to continue working with him in the future.

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[11] Platt et al., Op. Cit. (See Appendix C)

[12] Platt et al., Op. Cit.

[13] Ibid.

Water Pollution Modeling and Prediction Using Computational Intelligence Methods

Basic Information

Title:	Water Pollution Modeling and Prediction Using Computational Intelligence Methods
Project Number:	2012DC144B
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Focus Category:	Hydrology, Non Point Pollution, Water Quality
Descriptors:	None
Principal Investigators:	Nian Zhang, Pradeep K. Behera

Publications

There are no publications.

Water Pollution Modeling and Prediction Using Computational Intelligence Methods

Final Report

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May 2013

Table of Contents

Abstract

To restore and maintain the physical chemical and biological integrity of water bodies in the United States, the Clean Water Act requires the development of Total Maximum Daily Loads (TMDL) for impaired waters [1]. A TMDL is the maximum amount of a pollutant that a water body can receive and still meet water quality standards. In the last decade, several models and methodologies have been proposed emphasizing system wide modeling of the water bodies and the uncertainties associated with TMDL decisions. However, these methods are still evolving and their implementation is very limited. The Environmental Protection Agency (EPA) has been emphasized that there is a need for the development of new and more flexible modeling systems, tools, internet based technologies, integrated modeling systems combining new solution techniques, source representation, new algorithms and decision-making tools to support the development of tens of thousands of TMDLs nationally including a number of TMDLs for Chesapeake Bay [2] [3].

The broader goal of this research project is to assist in developing an innovative computational intelligence based approach for optimizing TMDL. Our approach comprises of runoff quantity and quality prediction using Back Propagation Recurrent Neural Networks (BP-RNN). The prediction of water quantity and quality (e.g. pollutant load) is dependent upon the reliable water quantity prediction (e.g. flow and runoff). A hybrid learning algorithm incorporating particle swarm optimization and evolutional algorithm was presented, which takes the complementary advantages of the two global optimization algorithms. The neural networks model was trained by particle swarm optimization and evolutional algorithm to forecast the stormwater runoff discharge. The USGS real-time water data at Four Mile Run station at Alexandria, VA were used as time series input. The excellent experimental results demonstrated that the proposed method provides a suitable prediction tool for the stormwater runoff monitoring.

1. Introduction

Water pollution is a serious problem for human health and the environment and is one of main threats and challenges humanity faces today [1]. Pollution loading from point and non-point sources continues to have significant impacts on our receiving waters, i.e., rivers, streams and lakes; in spite of massive public investments in drainage infrastructure (i.e., sewer systems and treatment plants) and the implementation of several federal and state regulations. The Nationwide Urban Runoff Program study in 1983 revealed that the non-point source pollution specifically from storm water runoff from urban development can harm our surface water resources and, in turn, cause or contribute to an exceedance of water quality standards by changing natural hydrologic patterns; accelerating stream flows; destroying aquatic habitat; and elevating pollutant concentrations [2]. The pollutants in urban runoff include visible matter, suspended solids, oxygen-demanding materials, nutrients, pathogenic microorganisms and toxicants such as heavy metals, pesticides, and hydrocarbons. In addition, inadequate management of accelerated storm water runoff resulting from development throughout a watershed increases flood flows and velocities, contributes to erosion and sedimentation, overloads the transport capacity of streams and storm sewers, and transports in some instances significant quantities of nutrients (nitrogen and phosphorus) into the receiving water bodies. Anacostia River was determined to be one of the most polluted water bodies in the nation mainly due to the CSOs and stormwater discharges and wastewater treatment plant discharges. These pollutants impose considerable physical, chemical, and biological stresses on the receiving waters that affect aquatic life and human health and impair the designated uses of water resources. Typical urban stormwater-related receiving water quality problems include the degradation of aquatic habitats, degradation in water quality during and after wet weather events, beach closures, accelerated rates of eutrophication in lakes and estuaries, and thermal pollution. These problems have been prevalent in most receiving water systems in the vicinity of urban or urbanizing areas.

To address this stormwater problem the DC Water (previously known as DC WASA) has developed a Long Term Control Plan (LTCP) which would cost several billion dollars. In order to support LTCP a continuous monitoring and modeling of the system is necessary not only to provide technical assessment but also to develop a cost-effective solution. Moreover, evaluations of runoff quantity and quality are necessary to assess the problem and to assess the performance of proposed best management practices.

Over the last decades, a number of computational intelligence techniques have been proposed and applied to hydrological forecasting. The techniques include neural networks [3] - [12], genetic algorithm [13], support vector machine [14], or the combination of neural networks and genetic algorithm [15]. Comparatively, the various runoff forecast models based on neural networks were more accurate than many conventional prediction models [16][17][18]. These techniques can be applied to runoff analysis to improve the prediction of flow and/or fill in the missing data.

However, many other powerful computational intelligence methods have not yet been used on water quantity prediction although they have the most successful applications on time series prediction [19][20][21]. Since water quantity prediction is a kind of time series prediction problem, it is reasonable to expect that these state-of-the-art methods would also provide great promise for meeting the challenge of water quantity prediction.

In this project, we explored a state-of-the-art recurrent neural network based predictive model trained by a combination of particle swarm optimization and evolutionary algorithm to forecast the water flow discharge at a particular section of a stream. The project report is organized as follows. In Section 2, the research objectives are described. In Section 3, the study area and water quantity data are introduced. In Section 4, the research methodology is described. The Elman style recurrent neural network is presented, followed by the description of the evolutionary algorithm (EA), particle swarm optimization (PSO), and the hybrid of these two methods. In Section 5, the analysis and the training method are described. The experimental results are demonstrated including the training error for the PSO-EA method and the predicted values of the training data. Section 6 provides the research outcomes.

2. Research Objectives

The overall goal of the proposed study is to develop computational intelligence methods including recurrent neural networks, wavelet neural networks, particle swarm optimization, fuzzy neural networks, or the combination of these methods to forecast the runoff quantity and quality. Furthermore, the outcomes of this research will be used to write a proposal to federal and state agencies to obtain funding for the development of general-purpose advanced computational intelligence methods on the stormwater quantity data as well as energy data. The specific objectives of the research include:

- Thoroughly investigating the promising recurrent neural networks, wavelet neural networks, particle swarm optimization, fuzzy neural networks methods and their accuracy on time series prediction.
- Tailor the best models, or the combination of these models to runoff prediction problem.
- Test these computational intelligence methods using the real-time runoff data.
- Perform comparisons of the proposed methods with other conventional neural networks methods on runoff prediction.

3. Study Area and Data

A. Potomac River Watershed

The study area is focus on the Potomac River watershed, as shown in Fig. 1. The Potomac is one of the least dam-regulated large river systems in the eastern United States [22]. The Potomac has the highest level of nitrogen and the third highest level of phosphorus of all the major rivers in the Chesapeake Bay watershed. These nutrients can limit the growth of submerged aquatic vegetation, cause low oxygen conditions and create dead zones. Approximately 90% DC area drinking water comes from Potomac. In the last three decades, many areas in the watershed have seen their population more than double. A growing population alters and stresses the natural state of its land and water. The Potomac watershed is expected to add more than 1 million people to its population over the next 20 years. The most densely populated area in the watershed is the Middle Potomac, including Washington, DC, which is home to 3.72 or about 70% of the watershed's population. In the next 20 years, the population of the Potomac watershed is expected to grow 10% each decade, adding 1 million inhabitants to reach a population of 6.25 million [22]. The Potomac River delivers the largest amount of sediment to the Chesapeake Bay each year which can limit the growth and submerged aquatic vegetation and affect populations of all fish, shellfish and birds that depend on this vegetation as a source of food or shelter.

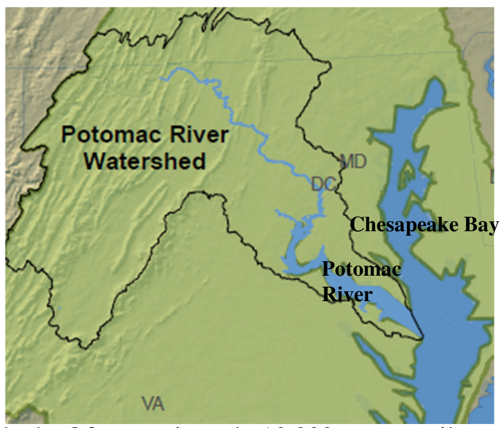

Fig. 1. Potomac River Watersheds. Of approximately 10,000 stream miles assessed in the watershed, more than 3,800 miles were deemed "threatened" or "impaired".

B. Time Series Data

Rea-time stormwater runoff water data are obtained from the U.S. Geological Survey (USGS)'s national water information system at the Four Mile Run stream station, Alexandria, VA. The stream passes from the Piedmont through the fall line to the Atlantic Coastal Plain, and eventually empties out into the Potomac River. Real-time data typically are recorded at 15-60 minute intervals. A time series of the discharge with 34721 discrete points between October 9, 2010 and January 29, 2011 is depicted in Fig. 2.

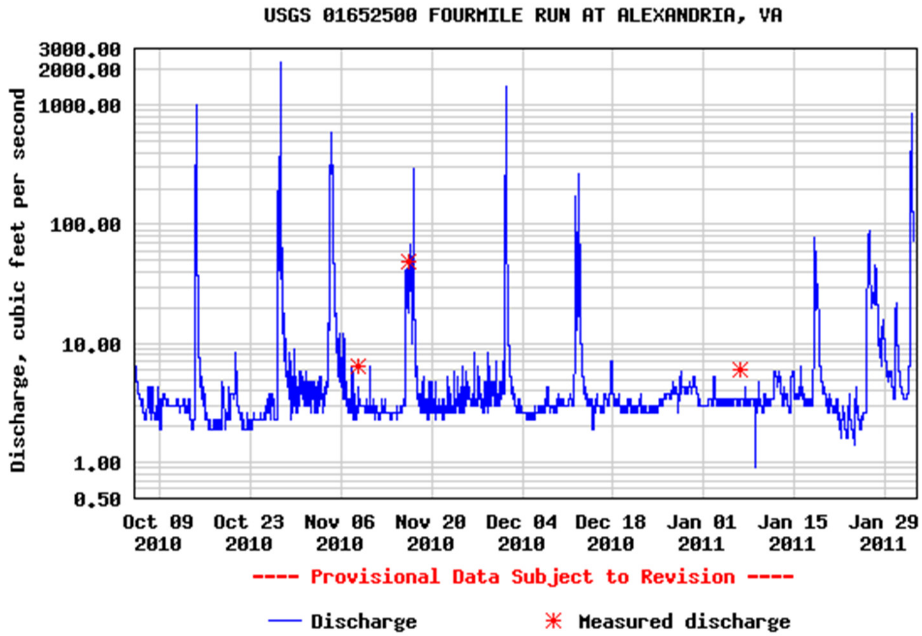

Fig. 2. The 120-day Discharge data (cubic feet per second) collected at the Four Mile Run site at Alexandria, VA during October 9, 2010 to January 29, 2011.

4. Research Methodology

A. Network Architecture

We proposed an Elman based neural network, which is composed of five layers, input layer, hidden layer 1, hidden layer 2, and output layer. There are feedback connections from the outputs of the hidden layer 1 to the inputs of the context layer, as shown in Fig. 3.

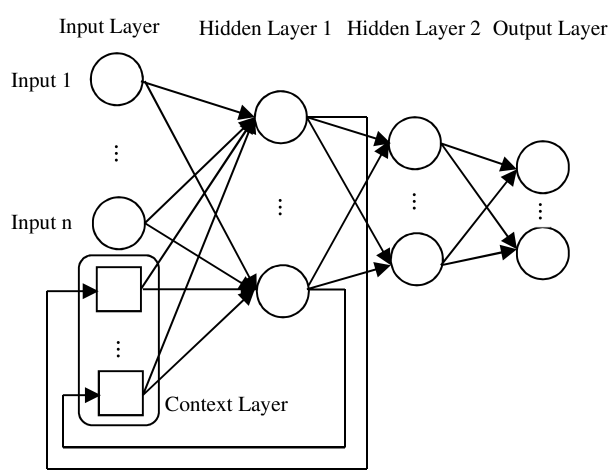

Fig. 3. The topological structure of the Elman neural networks model. The network is composed of five layers, with a feedback connection from the outputs of the hidden layer 1 to the input of the context layer.

In the recurrent neural network model, the input layer has 100 neurons, the context layer has 40 neurons, the hidden layer 1 has 40 neurons, the hidden layer 2 has 20 neurons, and the output layer has 1 neuron. Neurons between adjacent layers are fully connected, as indicated in Fig. 3. The transfer functions of the two hidden layers and the output layer are tansig.

B. Evolutionary Algorithm (EA)

To begin the evolutionary algorithm, a population of n neural networks, , i=1,.., n, defined with weights and bias for each network, was created at random. Each neural network had an associated self-adaptive parameter vector , i=1,…, n, where each component corresponded to a weight or bias and served to control the step size of the search for new mutated parameters of the neural network.

Each parent generated an offsprings strategy by varying all of the associated weights and biases. Specifically, for each parent , i=1,…, n, an offspring , i=1,…, n, was created by

$$\sigma_i^{'}(j) = \sigma_i(j)\exp(\tau N_j(0,1)), \quad j = 1,\ldots,N_w \quad (1)$$

$$w_i^{'}(j) = w_i(j) + \sigma_i^{'} N_j(0,1), \quad j = 1,\ldots,N_w \quad (2)$$

where is the number of weights and biases in the recurrent neural network, , and is a standard Gaussian random variable resampled for every j [23].

C. Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a form of evolutionary computation technique developed by Kennedy and Eberhart [24][25][26]. Similar to Evolutionary Algorithms (EA), particle swarm optimization algorithm is a population based optimization tool, where the system is initialized with a population of random solutions and the algorithm searches for optima satisfying some performance index over generations. It is unlike an EA, however, in that each potential solution is also assigned a randomized velocity, and the potential solutions, called particles, are then “flown” through the problem space.

Each particle has a position represented by a position vector . A swarm of particles moves through the problem space, with the velocity of each particle represented by a vector . At each time step, a function representing a quality measure is calculated by using as input. Each particle keeps track of its own best position, which is recorded by a vector , where is the best fitness it has achieved so far. Furthermore, the global best position among all the particles obtained so far in the population is kept track of as , and its corresponding fitness as .

At each time step t, by using the individual best position, , and global best position, , a new velocity for particle i is updated by

$$\vec{v}_i(t+1) = w \times \vec{v}_i(t) + c_1\phi_1(\vec{p}_i(t) - \vec{x}_i(t)) + c_2\phi_2(\vec{p}_g(t) - \vec{x}_i(t)) \quad (3)$$

where and are positive constants, and are uniformly distributed random numbers in [0, 1] and w is the inertia weight. The term is limited to the range . If the velocity violates this limit, it is set at its proper limit. Changing velocity this way enables the particle i to search around its individual best position, , and global best position, . Based on the updated velocities, each particle changes its position according to the following:

$$\vec{x}_i(t+1) = \vec{x}_i(t) + \vec{v}_i(t+1) \quad (4)$$

Based on (3) and (4), the population of particles tends to cluster together with each particle moving in a random direction. Fig. 4 illustrates the procedure of the PSO algorithm [27].

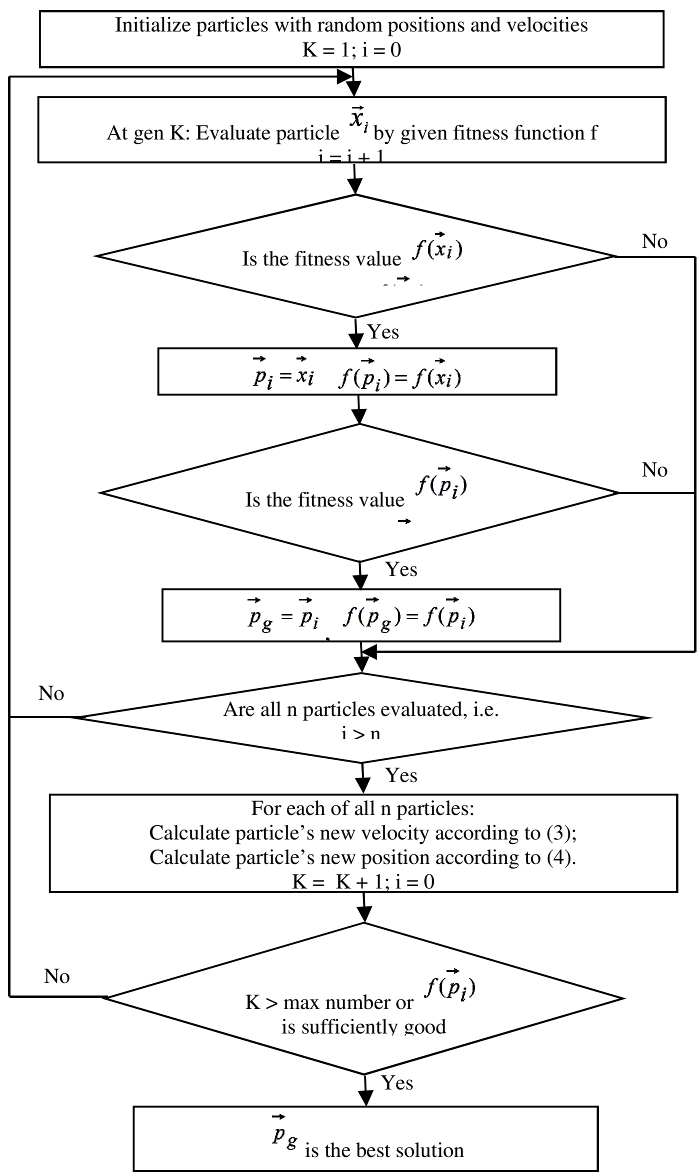

Fig. 4. The flow chart of the PSO algorithm.

D. Integration of EA and PSO

PSO works based on social and cognitive adaptation of knowledge, and all individuals are considered to be of same generation. On the contrary, EA works based on evolution from generation to generation, so the changes of individuals in a single generation are not considered. EA discard valuable information at the end of generation and starts almost randomly at next generation, while PSO keeps such information with the memory of local and global best throughout the entire evolution. On the hand, the property of mutation in EA helps to maintain the diversity of PSO population in "flying" to the new search area.
Based on the complementary property of PSO and EA, a hybrid algorithm is created that combines the concepts of both algorithms. In each generation, the winners, which constitute half of the population, are enhanced by PSO. These winners are sharing information with each other as well as benefiting from their learning history, compared to EA where they are stagnant. The other half of the population which consists of individuals with lower fitness is replaced by the offspring created from the EA process with influence from the PSO enhanced parents. This procedure enhances the entire population.

The pseudo code for hybrid PSO–EA is summarized as follows [20]:

- Initialize a population of individuals with random positions and velocities in an n-dimensional problem space.

- Do

    Evaluate the fitness according to same given fitness function.
    Compare the fitness values to find the winners.
    Enhance the winner with PSO.
    For each elite:

        Update the if the current particle's fitness value
        is better than the ;
        Determine : choose the particle with the best
        fitness value of winners;
        Calculate particle's new velocity according to (3);
        Calculate particle's new position according to (4).

    Use the enhanced elites as parents to produce offspring with EA to replace losers for the next generation.
    For each offspring:

        Save parent's as current for further comparison;

Use parent's velocity as self-adaptive parameters;
Calculate the self-adaptive parameter according to (1);
Calculate the position according to (2).

5. Analysis & Results

5.1 Number of Hidden Neurons and Delays

In this section, the proposed particle swarm optimization and evolutionary algorithm are utilized to predict the discharge for the stormwater quantity monitoring.

The input vector is composed of both original samples and the network's previous predictions. The recurrent neural network is not only trained with the original time series, but also trained by the series of sequence differences, represented by, where and are obtained from the given time series data. This dynamic signal is fed into RNN the same way as the original data. Batch training method is adopted, and the weights are updated based on a cumulative error.

The training error for the PSO-EA method is shown in Fig. 5. The actual and predicted values of the first 500 training data are illustrated in Fig. 6. The experimental results demonstrated that the algorithm is performing very well and is suitable for using as a water quantity monitoring tool.

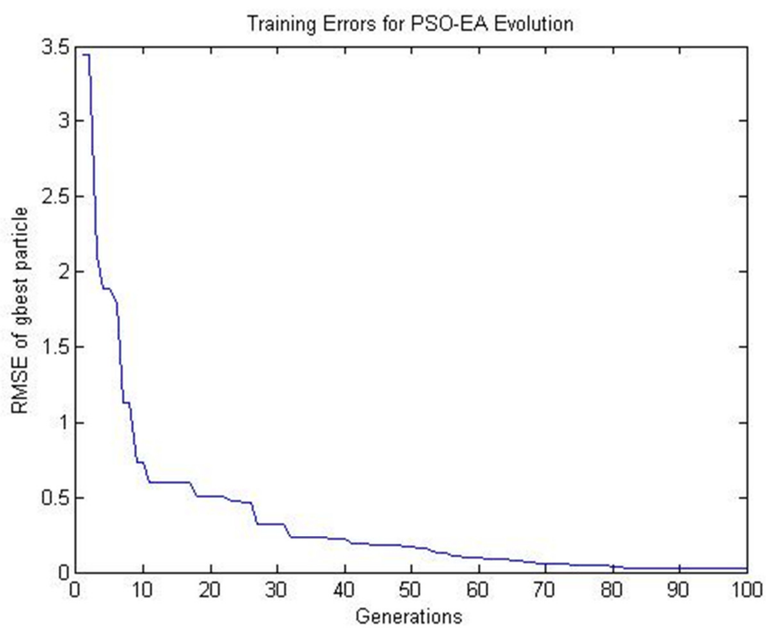

Fig. 5. Training error for the PSO–EA algorithm. The errors reflect the performance of the best particle, i.e. the Pg, at each generation.

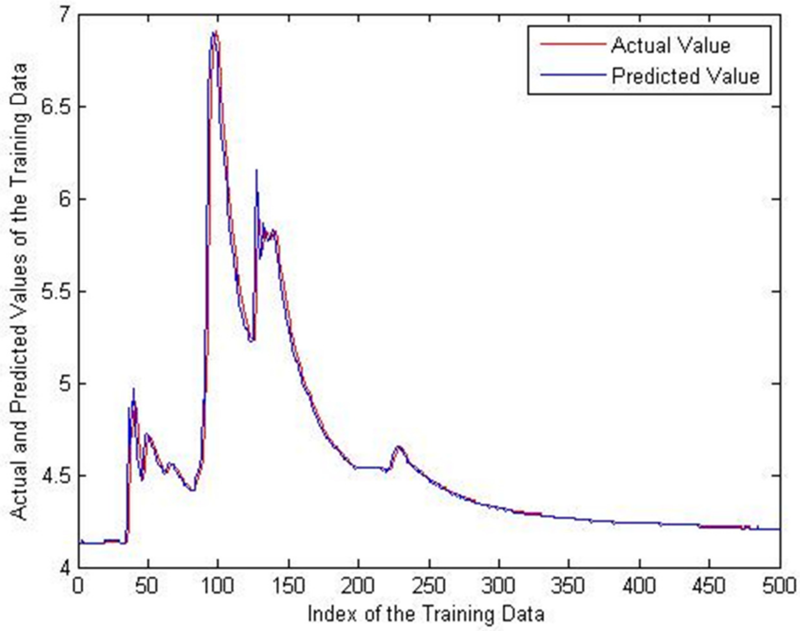

Fig. 6. The actual and predicted values of runoff discharge.

This project provides a recurrent neural network based predictive model trained by a combination of particle swarm optimization and evolutionary algorithm to forecast the stormwater runoff discharge. This method explored a new neural network based solution for monitoring and controlling urban water pollution in the District of Columbia.

In this research project, the stormwater runoff discharge data at the Four Mile Run stream station was studied, because of its impact to the District of Columbia and Potomac River. An Elman style based recurrent neural network was constructed. A hybrid training algorithm incorporating particle swarm optimization and evolutional algorithm was investigated, which takes the complementary advantages of the two global optimization algorithms. PSO keeps valuable information with the memory of local and global best throughout the entire evolution. On the hand, the property of mutation in EA helps to maintain the diversity of PSO population in “flying” to the new search area.

The experimental results demonstrated that the proposed neural network based predictive model and the training algorithm ensure an accurate prediction on the urban runoff quantity. This provides an excellent prediction method for the stormwater runoff monitoring, and has impact to the District of Columbia as well as the Potomac River and the Chesapeake Bay.

6. Research Outcome

The following research paper were published and presented, which were supported by this project (Attached in Appendix A).

1. Nian Zhang, Pradeep K. Behera, and Charles Williams, "Solar Radiation Prediction Based on Particle Swarm Optimization and Evolutionary Algorithm Using Recurrent Neural

Networks," 2013 IEEE International Systems Conference (IEEE SysCon 2013), Orlando, Florida, April 15 - 18, 2013.

2. Nian Zhang, Pradeep K. Behera, and Charles Williams, "Runoff Forecast Using LS-SVM Method," National Capital Region Water Resources Symposium, Washington D.C., April 5, 2013.
3. Charles Williams and Nian Zhang, "Streamflow Prediction Based on Least Squares Support Vector Machine," 2013 Emerging Researchers National (ERN) Conference in STEM, Washington, D.C., February 28 - March 2, 2013.
4. Nian Zhang and Pradeep Behera, "Solar Radiation Prediction Based on Recurrent Neural Networks Trained by Levenberg-Marquardt Backpropagation Learning Algorithm," The Third IEEE PES Conference on Innovative Smart Grid Technologies (ISGT 2012), Washington, D. C., January 16-20, 2012.
5. Nian Zhang and Shuhua Lai, "Water Quantity Prediction Based on Particle Swarm Optimization and Evolutionary Algorithm Using Recurrent Neural Networks," 2011 International Joint Conference on Neural Networks (IJCNN), San Jose, CA, July 31-August 5, 2011.

6. Acknowledgement

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Monitoring of UDC Van-Ness Campus Green Roof System to Evaluate Runoff Quantity Control Performance

Basic Information

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Project Number:	2012DC145B
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End Date:	2/28/2013
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Focus Category:	Education, Hydrology, Non Point Pollution
Descriptors:	None
Principal Investigators:	Pradeep K. Behera, Arash Massoudieh

Publications

There are no publications.

Monitoring of UDC Van-Ness Campus Green Roof System to Evaluate Runoff Quantity Control Performance

Progress Report

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May 2013

Content

Abstract

Urban stormwater management has been a very critical issue for most of the cities in the United States. The older metropolitan cities face severe stormwater quantity problems (i.e., flooding, sewer back up, stream bank erosion) and water quality problems (i.e., CSOs and stormwater discharges, water pollution and receiving water quality problems) due to aging drainage infrastructure and high impervious areas and other factors. Cities pay substantially for the damages when CSOs and polluted stormwater runoff reach local receiving waters. Similar to many older cities in the nation, the sewer system in the District of Columbia is comprised of both combined and separate sewer systems. It has been recognized that these systems contribute significant pollution to the Anacostia and Potomac Rivers and Rock Creek through Combined Sewer Overflows (CSOs) and Storm Sewer discharges during wet-weather (i.e., rainfall and snowmelt) events [Huanxin,et. al, 1997), Hwang and Foster (2006),] These overflows and associated pollutant loads can adversely impact the quality of the receiving waters. Anacostia River was determined to be one of the most polluted water bodies in the nation mainly due to the combined stormwater and municipal wastewater discharged to it during peak runoff [4].

To address the above mentioned stormwater problems, the objectives of overall stormwater management of the District are to reduce the peak stormwater runoff, delay the peak, reduce the runoff volume and reduce the associated pollutant load as much as possible. A low cost and sustainable way of reducing the adverse effects of stormwater is to use Low Impact Development (LID) practices such as but not limited to retention, detention, bioretention ponds, green roof, permeable pavements, and constructed wetlands. However due to the high cost of land in dense urban areas such as the District of Columbia it is highly desirable to minimize the land occupied by these facilities by optimizing their performance. The goal of the proposed research is to develop a modeling framework to evaluate the performance of green roof system in controlling stormwater runoff volume, and peak flow. The research involves development of an analytical model for a LID, thereby green roof system and the installation of equipments to measure the runoff quantity parameters at the newly built green roof systems at the UDC campus. The measured data will be utilized to evaluate the performance of green roof system in controlling runoff. The outcomes of this seed grant research is to develop a larger proposal to Federal agencies such as EPA, USGS, and NSF for external funding for a large scale, integrated assessment of the impact of various green roof systems on the storm-water quantity and quality in the District of Columbia.

1. Introduction

Stormwater management is one of most important issues the District of Columbia faces. The inadequate capacity of the combined sewer system and the wastewater treatment plant, a large amount of combined storm-water and raw municipal wastewater is discharged into the local receiving waters such as Anacostia River, Potomac River and Rock Creek (NRDC). The Anacostia River is identified as one of the most polluted water bodies in the nation and there are many efforts going on to reduce the amount of pollution in this water body. The highly urbanized area of the District and associated anthropogenic activities and vehicular pollution results in storm-water is also highly polluted with various toxic organic `compounds, metals, nutrients and pathogens [EPA, Wade, T., et al, 1994]. The Chesapeake Bay Program estimates that urban and mixed open areas account for 18 % of nitrogen and 29 % phosphorous loadings to the Chesapeake Bay and the share of nutrient loads from urban areas is growing.

To address the above mentioned stormwater problems, the objectives of overall stormwater management of the District are to reduce the peak stormwater runoff, delay the peak, reduce the runoff volume and reduce the associated pollutant load as much as possible. A low cost and sustainable way of reducing the adverse effects of stormwater is to use Low Impact Development (LID) practices such as but not limited to retention, detention, bioretention ponds, green roof, permeable pavements, and constructed wetlands.

Low impact development (LID) is relatively new and promising trend in stormwater management practice that works with the on-site reduction of volume of run-off along with its quality improvement adopting various eco-friendly and cost effective methods such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavements. With rapid urbanization and so caused increase in impervious area in the new development LID‘s significance is being strongly felt. Being an innovative idea its effectiveness is still needed to be proved in the coming days. LID not only helps to solve the pressing problem of stormwater management in developing sites but also adds to the beauty of the landscapes by its aesthetic enhancements. On the top of it, LID helps to control the increasing volume of run-offs and reduce the pollutants load in run-off by incorporating some simple and feasible methods such as bioretention facilities, rain gardens, vegetative rooftops and porous pavements on the existing sites too. LID is a milestone in the scientific innovations that promotes the sustainable development of the land and other facilities since it maintains the balance in hydrologic cycle of watershed if applied extensively. This principle and practice is thus very close to nature in addition to being economically feasible. The benefits of LID are not limited to its effectiveness in stormwater management in terms of cost control and environment preservation. This method additionally boosts property values, improves habitat, adds to the aesthetic quality and over all makes the quality of life better.

The implementation of best LID practices is good for developers, property owners and communities in terms of cost and restoration and preservation of water quality as well. The history of LID dates back to 1990. It began from Prince George's County, Maryland and it is gradually gaining popularity all over the states. The use of LID is still not extensive and this approach is still under consideration.

The implementation of LID systems has been popular over last decade compare to the end-of-the-pipe treatment system. Moreover, the emphasis on the green infrastructure that includes LID system is gaining traction over last couple of years. As a result, several cities are implementing green roof systems for the large buildings. However, there are limited studies are available for the evaluation of the performance of green roof system in controlling the runoff quantity and quality. Having an analytical tool for green roof system that is able to predict the performance of runoff volumetric control that can be useful for water resources engineers, planners and regulators.

The University of the District of Columbia (UDC) Van Ness campus covers approximately nine acres. Over 75 % of the nine acres is impervious area. It contains eleven buildings and is located directly above a metro red line stop. The site is located along an ultra-urban commercial avenue. The corridor was largely built during early 1980s with the completion of the metro line, however lot level development and redevelopment continues. The site drains to the Municipal Separated Sewer System (MS4) and is the largest single land user contributing to the site's two discharge outfalls. These outfalls discharge to the Rock Creek in the Soapstone Valley Park around Audubon Terrace less than half a mile from the campus. Through the funding from the District of Columbia Department of the Environment (DDOE) UDC campus service is retrofitting approximately 130,000 square feet of new green roofs at the UDC Van Ness campus. The green roofs will be integrated with a cistern bioretention system that is anticipated to provide twice the storage required for the 95th percentile event from the managed area. The District has supported significantly for green roof project implementation. This investment provides the platform for a long term green roof research site which is the primary objective of this research.

2. Vegetative Roof Covers

These are also called the green roofs. The roof of the houses and buildings are turned into the green garden like thing by planting the plants and flowers those have shallow fibrous roots. It reduces the impervious area thus is very effective to decimate the volume of runoff that accumulates from the roofs during rainfall. Green roofs could be very effective specially in older urban areas with combined sewer overflow (CSO) problems. Green roofs are usually multi-layered in the green roof that are vegetative layer, media, geotextile layer and a synthetic drain layer. The benefits of green roofs are many like they increase the life of roofs, reduces the energy costs and conserve the valuable land area that would otherwise needed for other stormwater control measures. Green roofs are more popular in Europe while they could be practiced in the older cities of the US where the stormwater infra-structures have been saturated in terms of their capacities.

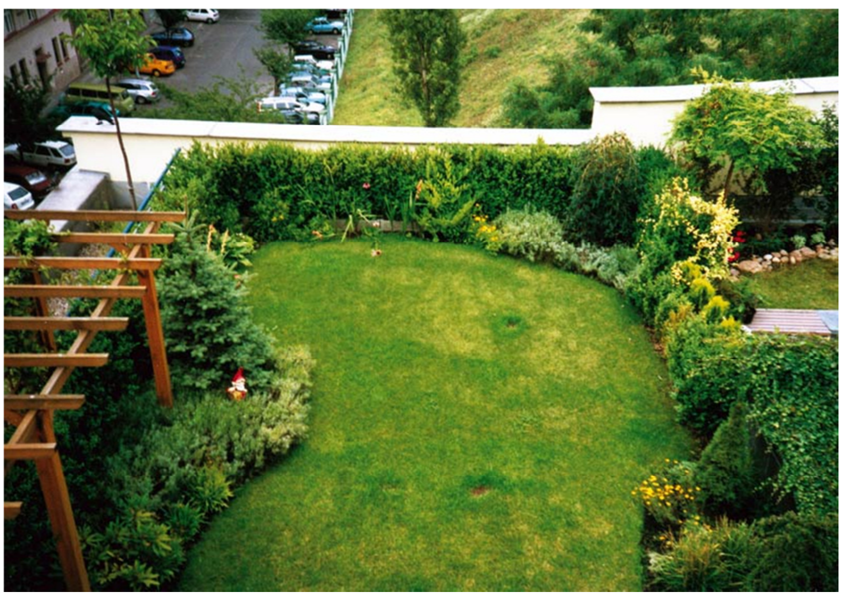

Figure: Example of a Roof Garden

Green roofs are highly effective in reducing total runoff volume. Simple vegetated roofvcovers, with approximately 3 inches of substrate can reduce annual runoff by more than 50 percent in temperate climates (Miller, 2000). However, when creating a roof garden, we must follow slightly different rules than we do when making a ground garden. There are several factors we must consider. It is primarily the bearing capacity of the roof structure, prevention from roots and water penetrating the roof structure, inclination of the roof (must not exceed 30°), altitude of the attic, etc. Depending on the bearing capacity, you may choose whether you will design your roof garden as merely ornamental (extensive green coat - in case the bearing capacity is only 100 - 300 kg/m^2) or "stepable"(when the bearing capacity is over 300 kg/m^2).

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3. Development of Analytical Rainfall and Runoff Model

3.1. Modeling Approach

In order to simulate the performance of LID systems civil engineers have been developing methods to analyze and design the LID system which would cost-effectively eliminate or reduce the stormwater impacts from these urban environments. Civil engineers employ a variety of modeling techniques to help plan for future stormwater removal needs, and to address maintenance concerns on the various LIDS. The analysis and modeling of stormwater metrics, during the course of these planning, development, and maintenance projects, can be a costly and time-consuming endeavor. There are three major methods used to model LIDs: event-based models, continuous simulation models, and analytical probabilistic models.

Event-based modeling represents the simplest approach to model and have been commonly used for analysis and design. The costs associated with this modeling technique are extremel minimal; this approach, however, is fairly naïve; there is no way to derive an estimate for future requirements of the system when using this method (Adams and Papa, 2000).

Continuous simulation modeling falls at the other end of the spectrum. The complexity of this method is significant, in contrast to Event-based modeling, but the quality of the information derived from this method is vastly superior in predicting the optimal requirements of the drainage infrastructure required to maintain an acceptable level of performance. Currently, the chief continuous simulation modeling software used by civil engineers is the United States Environmental Protection Agency *Storm Water Management Model* (EPA SWMM). This model requires hundreds of input parameters related to the environment of the area being simulated to provide useful information, and these values must be compiled by engineers in the field. The result of this modeling technique represents a comprehensive analysis of the drainage requirements for the area being simulated (Adams and Papa, 2000).

The analytical probabilistic modeling technique has similar advantages to both other modeling techniques, while having few of the disadvantages. This technique relies on a statistical analysis of the historical rainfall record for the are in question, computing the probability density functions (PDF's) for each of the major rainfall parameters (described below), and deriving a simplified series of parameters which represent the most likely requirements for an effective stormwater management infrastructure in that area. Like the event-based technique, this model is not difficult to implement, however, the information derived from this technique has been shown to be an effective method of depicting continuous performance of urban drainage systems (Adams and Papa, 2000). In terms of drawbacks, this modeling method requires an extensive historical rainfall record for the best predictive results; further, depending on the quality of the historical rainfall record, the probabilistic model may only serve as a means for fine-tuning the input parameters for the more comprehensive continuous modeling technique. The remainder of this report will describe the development of an analytical probabilistic model to simulate LID system.

3.2. Development of Analytical Model for LID System

The estimation of runoff quantity and quality by analytical probabilistic models is primarily based on the probability density function (PDF)s of rainfall characteristics and a rainfall-runoff transformation function employed in the model derivation. From modeling perspective, when rain falls on a catchment, it must satisfy the hydrologic losses including interception, depression storage and infiltration losses, before runoff occurs. If the volume of the rainfall event is sufficient to satisfy these hydrologic losses, then the resulting runoff from various pervious and impervious surfaces makes its way to the catchment outlet either through a drainage system or through natural channels. Processes that transform rainfall to runoff are many and they vary spatially and temporally. It is difficult to accommodate all of them in deterministic models and even more so in analytical probabilistic models.

A number of analytical models have been proposed to estimate runoff volume from rainfall (Adams and Bontje, 1984; Guo and Adams, 1998). Most of these models are event-based and employ simple system representations. Typically, the event runoff volume is calculated as the difference between the volume of the input rainfall event and the total hydrologic losses throughout the duration of the event. The rainfall-runoff model used in this study follows the system representation presented by Adams and Bontje (1984) which employs a depression storage volume and a runoff coefficient to evaluate the resulting event runoff volume. The continuous simulation model, STORM uses a similar representation for runoff generation. The linear hydrologic model of the rainfall-runoff transformation employed herein is as follows:

$$v_r = \begin{cases} 0 & v \le S_d \\ \phi(v - S_d) & v > S_d \end{cases} \qquad (3\text{-}1)$$

where the rainfall volume, v, must first satisfy the volume of depression storage, S_d (mm), before any runoff can be generated. S_d is the spatially averaged depression storage volume. For a rainfall volume greater than S_d, the runoff volume is determined by the product of a dimensionless runoff coefficient, □, and the excess of rainfall over depression storage. This is illustrated in Figure 3.1.

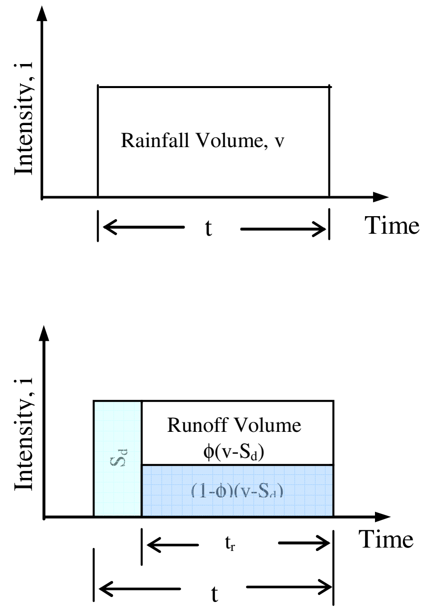

Figure 3.1: Rainfall-Runoff transformation.

The runoff coefficient is a spatially and temporally averaged constant that is selected based on land use, which is generally estimated from the percentage impervious area of the catchment.

It is assumed that the duration of the runoff event is equal to the duration of the rainfall event. Figure 3.2 illustrates the simplified system representation of event-based rainfall-runoff transformation for an urban catchment.

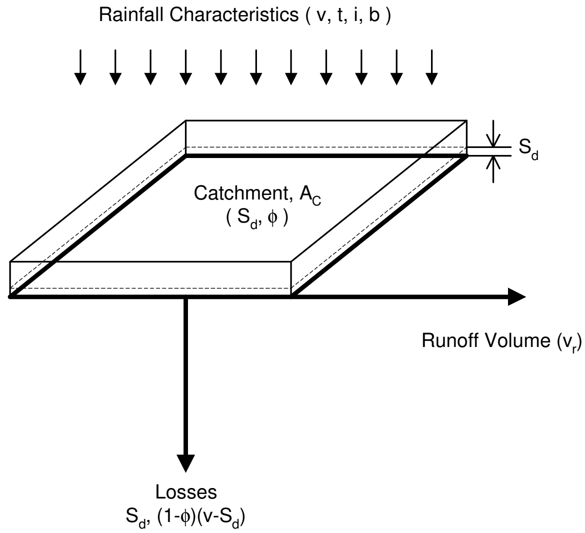

Figure 3.2: Schematic representation of rainfall-runoff process in urban catchments.

As discussed in the previous section, the event rainfall volume can be described by exponential PDF as follows:

$$f_V(v) = \zeta e^{-\zeta v}, \quad \zeta = 1/\bar{v} \tag{3-2}$$

Given the marginal PDF of event rainfall volume and the rainfall-runoff transformation function [Equation (3-1)], the cumulative distribution function (CDF) of event runoff volume, $F_{V_r}(v_r)$ can be obtained using derived probability distribution theory as follows:

$$\begin{aligned} F_{V_r}(v_r) &= \Pr[V_r \le v_r] = \Pr[v_r = 0] + \Pr\left[S_d < V \le \frac{v_r}{\phi} + S_d\right] \\ &= \int_{v=0}^{S_d} f_V(v)\,dv + \int_{v=S_d}^{\frac{v_r}{\phi}+S_d} f_V(v)\,dv = 1 - e^{-\zeta\left(\frac{v_r}{\phi}+S_d\right)} \end{aligned} \tag{3-3}$$

The PDF of event runoff volume, $f_{V_r}(v_r)$, can be obtained by taking the derivative of $F_{V_r}(v_r)$ as

$$f_{V_r}(v_r) = \frac{d}{dv_r} F_{V_r}(v_r) = \frac{d}{dv_r}\left[1 - e^{-\zeta\left(\frac{v_r}{\phi} + S_d\right)}\right] = \frac{\zeta}{\phi} e^{-\zeta\left(\frac{v_r}{\phi} + S_d\right)}, \qquad v_r > 0 \tag{3-4}$$

The expected value of the event runoff volume, $E[V_r]$ is obtained as follows:

$$E[V_r] = 0 \cdot p_{V_r}(0) + \int_0^{\infty} v_r f_{V_r}(v_r) dv_r = \int_{v_r=0}^{\infty} v_r \cdot \frac{\zeta}{\phi} e^{-\zeta\left(\frac{v_r}{\phi} + S_d\right)} dv_r = \frac{\phi}{\zeta} e^{-\zeta S_d} \tag{3-5}$$

Equation (3-5) represents the model for expected runoff volume per event from urban catchments. It shows that it is a function of the rainfall volume PDF parameter (ζ) and catchment land use characteristics (ϕ and S_d).

Once the distribution of event runoff volume is derived, other information can be obtained. The average annual runoff volume, R, can be found as

$$R = \theta \cdot E[V_r] = \theta \frac{\zeta}{\phi} e^{-\zeta S_d} \tag{3-6}$$

where θ is the average annual number of rainfall events. Strictly, the average annual number of runoff events, n_r, is given by the product of the average annual number of rainfall events and the probability that a rainfall event produces runoff (i.e., $v > S_d$) as follows:

$$n_r = \theta \cdot \Pr[V > S_d] = \theta \cdot \int_{v=S_d}^{\infty} f_V(v)\, dv = \theta \cdot \int_{v=S_d}^{\infty} \zeta e^{-\zeta v}\, dv = \theta \cdot e^{-\zeta S_d} \tag{3-7}$$

The expected value of event runoff volume, the average annual runoff volume, and the average annual number of runoff events constitute the runoff quantity assessment performance measures for urban catchments utilized herein.

4. Future Work

This proposed seed grant research depend upon several factors such as installation of green roof systems and UDC, procurement of equipment, installation of equipment and measurement of runoff volume for few storm events, which is beyond the control of the PI. If the above mentioned tasks cannot happen the future work would involve the verification of green roof performance based on a hypothetical case study and Washington DC metrology and hydrologic analysis.

5. Acknowledgements

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Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	17	0	0	0	17
Masters	6	0	0	0	6
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	23	0	0	0	23

Notable Awards and Achievements

Publications from Prior Years