D.C. Water Resources Research Institute
Annual Technical Report
FY 2014

Introduction

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

For the last 10 years, the Institute has provided seed grants for 81 research projects and trained more than 200 graduate and undergraduate students. The seed grants created opportunities for students and new faculty in creating innovative researches and getting trained in water technologies. The seed grant also helped new faculty leverage extramural funding. Through the Institute, the University of the District of Columbia has received about $2 million in financial support to build state-of-the-art research and training laboratories for environmental and water quality testing, as well as modeling and simulation.

In 2014, the Institute funded and implemented seven research projects to address water issues in the District. The overarching goal of this project includes identifying city water resources and environmental problems, and contributing to their solutions. About 10 graduate and undergraduate students directly involved in the research projects, but more than 100 students were trained in the water quality testing technologies through lab course, as well as a lab tour as part of the general education courses. These students were from various majors such as water resources, environmental science, civil engineering, computer science and food science.

Funded through the administrative project, the Institute also manages two state-of-the-art water resources laboratories: water and environmental quality testing laboratory, and water and environmental quality modeling and simulation laboratory. The water and environmental quality testing laboratory is in the process of getting accredited by the National Environmental Laboratory Accreditation Program (NELAP). The lab was recently audited by the NELAP representative from New Hampshire. This lab accreditation is the 1st in its kind in DC and can make a significant impact not only in enhancing the research capacity of UDC, but also in increasing program visibility through training and community services. During this reporting period, the Institute has provided free soil quality testing for about 400 garden or garden plots. This month, the Institute launched another set of free soil quality testing service for DC urban gardeners. The purpose of this free lab service is to assess best management practices in integrating urban gardening and urban storm water management as a green infrastructure. The Institute has managed to build the capacity of monitoring both water and soil quality to enhance the urban environment and waterways in DC.

The institute has no funded project for information transfer, but continued building collaboration within the hosting institution and beyond for conducting information transfer activities. The Institute has been working closely with other water organization in the District and other land grant and academic programs at UDC/CAUSES to conduct information transfer activities. In collaboration with the American Water Resources Association in the National Capitol Region (AWRA-NCR), the Institute organized the 3rd Annual Water Symposium on April 10, 2015, at the University of DC. This one day symposium sought to bring together experts from governmental agencies, academia, the private sector, and non-profits to present and discuss challenges and opportunities for water management and resilience in the region, as well as national and international scope. In close collaboration with other land-grant centers in CAUSES, such as the Center for Sustainable Development, the Center for Urban Agriculture and gardening education, the Institute continued in conducting outreach activities by organizing training workshop, distributing newsletters, media releases and fact sheets.

Research Program Introduction

In FY 2014, the Institute funded seven research projects that address three areas: hydrology and flooding, water quality, policy and green infrastructure. The progress report of Dr. MacAvo s project introduces geochemical/nutrient data and land use patterns in the Anacostia River and its tributaries in order to identify the impact of urbanization on water chemistry. The objectives of this research are 1) to determine concentrations of nutrients in this anthropogenically influenced river in the United State's capital, 2) characterize relationships among geochemical components to assess the importance of concrete versus natural geochemical controls and 3) test the hypothesis that urban areas have higher ionic strength derived from Ca and Mg than suburban areas (Ca and Mg are two dominant cations associated with concrete).

The progress report of Dr. Zhang introduces the application of a least-squares support vector machine (LS-SVM) model to improve the accuracy of stream flow forecasting. In this project, the cross-validation and grid-search methods were used to automatically determine the LS-SVM parameters in the forecasting process. To assess the effectiveness of this model, stream flow records from Geological Survey (USGS) gaging station 1652500 on Four Mile Run of the Potomac River, were used as case studies.

The progress report of Dr. Massoudieh s introduces a mathematical model that can assess different prototype parameters and runoff data to automatically generate a design for future green roof projects. In this project, the built green roof as a prototype was applied to collect runoff data in the Washington, DC metro area. The simulation model was applied to optimize the parameters of a built green roof. These parameters were tested running the simulation model using historical rain data in order to make further recommendations for future builds of green roofs for the area or areas of similar climate and precipitation records.

Mr. Brown s progress report introduces the feasibility of using a green stormwater infrastructure at the parcel or site level in an incentive-based framework through the use of agent-based modeling to simulate the Stormwater Retention Credit trading program developed by the District of Columbia District of the Environment.

Dr. Behera s project focuses on a web-based interface for rain fall analysis. This innovative analytical tool can assist engineers and water professionals in analyzing hourly precipitation data at a given location. The long-term precipitation data is analyzed based on the inter event time definition which provides the time series of storm events and their characteristics such as event volume, duration and intensity.

Dr. Bejleri s progress report introduces the application of Bayesian network and time series analysis in stormwater flood prediction and mitigation. The main objectives of this project are to provide a statistical modeling framework that allows for collecting and investigating behavioral, mitigation, accident-prevention, and financial data, and model accident data associated with flooding in the subject area.

The progress report of Dr. Song s work focuses on the monitoring of uptake of water soluble phosphorus in wastewater samples by algae using 31P nuclear magnetic resonance (NMR) Spectroscopy. The preliminary result of the study shows that there are four major phosphorus species in the sediment samples with various concentrations, including inorganic phosphate, DNA, pyrophosphate and phosphate monoesters based on comparison with reported phosphorus NMR chemical shifts. More NMR data will be collected for all the sediment samples cultivated with algae to decide the rate of phosphorus uptake by the algae.

Listed below are the eight grants awarded to researchers for FY 2015 104B grants and associated Principal Investigator.

Title: Urban Stormwater Runoff Prediction Using Computational Intelligence Methods, Dr. Nian Ashlee Zhang, Assistant Professor, Dept. of Electrical and Computer Engineering - University of the District of Columbia.

Title: Evaluating Long-term water quantity and quality performance of Bioretention systems in Washington, DC using monitoring and modeling; Dr. Arash Massoudieh, Associated Professor, Catholic University of America.

Title: Does hydraulic fracturing pose a threat to DC's water supply? A field and modeling study, Dr. Karen L. Knee, Assistant Professor, Department of Environmental Science, American University.

Title: Evaluation of green roof effectiveness for nitrogen, phosphorus and suspended solid reduction in runoff from precipitation events. Dr. Stephen E. MacAvoy, Associate Professor, Department of Environmental Science, American University.

Title: A Novel Water Treatment Solution Using Hybrid Mesoporous Materials Embedded with Metallic Oxide Nanoparticle, Dr. Stephen E. MacAvoy, Department of Environmental Science, American University. Dr. Xueqing Song, Associate Professor, Department of Chemistry, University of the District of Columbia.

Title: Water Pollution Prevention and Removal Using Nanostructured Smart Fluid with Switchable Surfactants. Dr. Jiajun Xu, Assistant Professor, Department of Mechanical Engineering, University of the District of Columbia.

Title: Evaluating Impacts of Urban Water Ways on the Transportation Networks for the District of Columbia. Dr. Yao Yu, Assistant Professor, Department of Civil Engineering, University of the District of Columbia.

Title: Potomac River Stage Forecasting Using a Hybrid Particle Swarm Optimization and Evolutionary Algorithm (PSO-EA) Algorithm with LS-SVM; Dr. Nian Ashlee Zhang, Assistant Professor, Dept. of Electrical and Computer Engineering - University of the District of Columbia.

Title: Identifying Sources of Chlordane Contamination in Anacostia River Food Fish, Dr. Harriette Phelps, Professor of Emirates, Department of Biology and Environmental Sciences University of the District of Columbia.

Development of software Analytical Tool to conduct storm Event Analysis

Basic Information

Title:	Development of software Analytical Tool to conduct storm Event Analysis
Project Number:	2014DC155B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	DC
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Models, Methods
Descriptors:	None
Principal Investigators:	Pradeep K. Behera

Publication

1. Suribhatla, Geetanjali, Bharath Kumar, Reddy Arikatla, Pradeep Behera,Dong H Jeong (2015) Development of a Storm Event Analysis Software Tool for Water Resources Engineering, 2015 Annual NCR-AWRA Water Symposium, Poster Presentation.

Development of Software Analytical Tool to conduct Storm Event Analysis

Progress Report

Dr. Pradeep K Behera, PE
Department of Civil Engineering
Dr. Dong Jeong
Bharath K Reddy Arikatla, CS Major
Department of Computer Science and Information Technology

Submitted to DC Water Resources Research Institute,
University of the District of Columbia

1. Executive Summary

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. In order to manage the exsting stormwater related infrastructures as well as planning and design of new infrastructures, precipitation is the key input. Based on the precipitation information, the stormwater management and flood control, and drainage infrastructures are planned and designed.

To support the information on precipitation and related climate change to the water resources professionals, engineers and other officials, this project developed a storm event analysis of the long-term point rainfall data. Based on the previous research work conducted by PIs at UDC, this project developed a software tool to conduct storm event analysis which is based on the database server system and user friendly GUIs. The current proposal is built upon the previous works conducted by the PI and supported by DC WRRI.

2. 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).

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This research project mainly concerns on designing the user interface for the analysis of hourly precipitation data at a location. The long-term precipiatation data is analyzed based on the inter event time definition (IETD) which provides the time series of stom events and thei charactersitcs such as event volume, duration and intensity [1]. As web-based interface appeals to a broader audience, and requires no additional software to be installed on the engineer's or researcher's computer, we decided to develop a web-based interface for the rainfall analysis. Since the goal of this project is to help relieve some difficulty in rainfall analysis, it was important to account for the user-friendliness of the web-based interface application (website). Scholars in [4] have come up with some guidelines to design the web-based interface and we have applied these guidelines for the development of the web-based interface in this project. Some of those guidelines are:

Accuracy A high quality web-based interface source contains accurate information. The information should be free of spelling, grammar, and punctuation mistakes. There should be evidence of an editor or fact checker who is responsible for making sure that the information is correct.

Accessibility It is important that a website should be as universally accessible as possible. For a website to be highly accessible, it will load quickly, and be viewable in different browsers, operating systems andmonitor resolutions.

Design The design of a website is a very important element to be considered when judging the overall quality. Good websites have a design that is visually appealing, readable, easy to navigate, and fortify the purpose of the site while giving it a unified look and feel.

Technological Aspects Technological Aspects and Interactivity: A websites should be developed by using new technologies and the multimedia nature to allow user interactivity which makes the user different experience from reading a book.

3. Methodology

There are many traditional ways of doing IETD analysis calculation and displaying the results on the webpage. One of the traditional ways is to import the rainfall records [5] from the database to the webpage and then performIETD analysis on those data. By doing so, the network traffic between the web browser and the web server is much more and hence it degrades the performance of the application. So it violates the accessibility design principle as explained in the introduction section. The normal transaction processing is shown in Figure 1. To overcome the performance issue, we have developed a stored procedure [3] in mysql database for calculating the IETD analysis. A stored procedure is a group of Transact-SQL statements compiled into a single execution plan.The transaction using stored procedure is shown in Figure 2. Performing the IETD analysis using stored procedure possesses the following advantages:

Performance Stored Procedures are compiled once and stored in executable form, so stored procedure calls are quick and efficient. Executable code is automatically cached and shared among users. This lowers memory requirements and invocation overhead.

Scalability Stored Procedures increase scalability by isolating application processing on the server. In addition, automatic dependency tracking for stored procedures aids the development of scalable applications.

Security One can restrict access to data by allowing users to manipulate the data only through stored procedures that execute with their definerâ˘A ´Zs privileges. For example, you can allow access to a procedure that updates a database table, but deny access to the table itself.

Maintainability Once it is validated, a stored procedure can be used with confidence in any number of applications. It its definition changes, only the procedure is affected, not the application that calls it. This simplifies maintenance and enhancement.

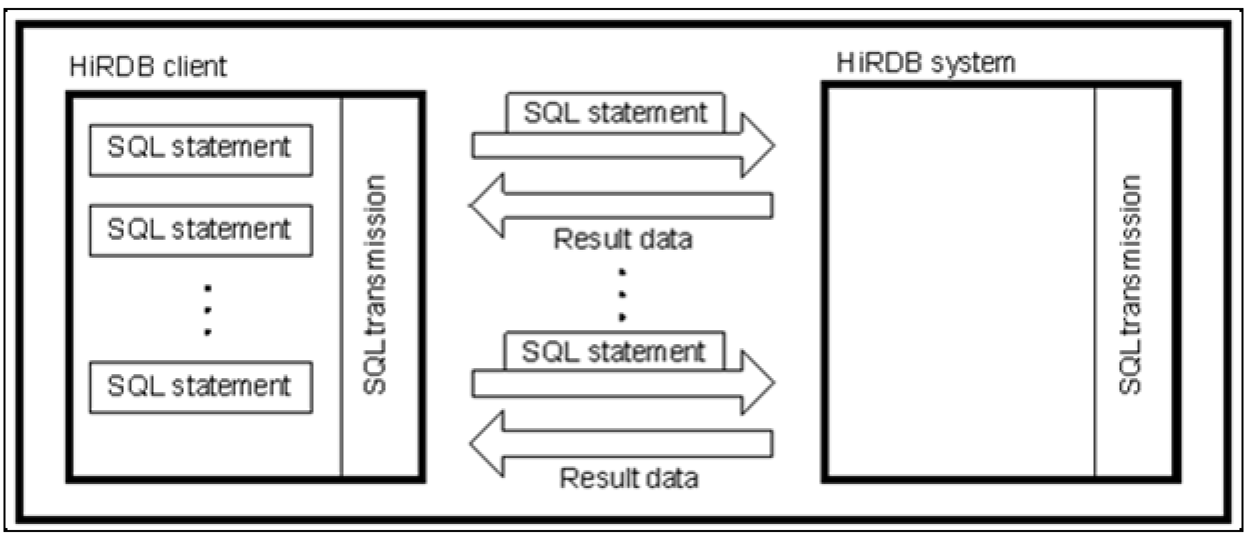


Figure 1: Normal Transaction Processing

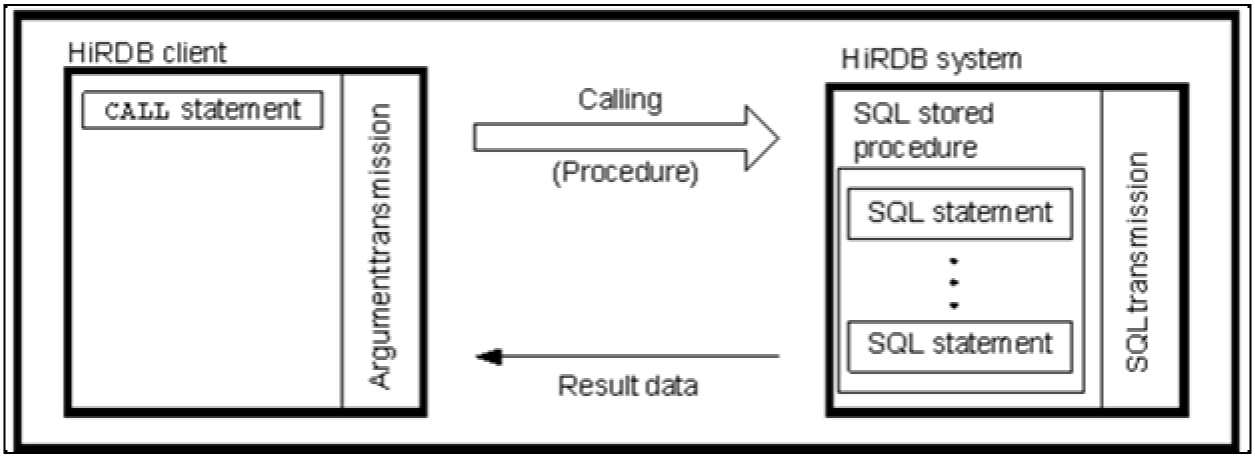


Figure 2: Transaction using Stored Procedures

To represent the results of IETD analysis, we used two kinds of representations, tabular representation and the Bar graph representation. Bar graph are a type of graph that are used to display and compare the number, frequency, or othermeasure (e.g., mean) for different discrete categories of data. We also created a tool tip on top for the Bar graph to provide more interactivity to the user.

In order to develop the rainfall statistical analysis tool, the input, an isolated meteorological event [1], at one point in space as described as a hyetograph must first be defined. The storm event can have both internal and external characteristics (Adams et al., 1986). The external characteristics are the total stormevent volume, the duration of the storm, the average intensity of the stormand the interevent time or duration since the last storm. The internal characteristics are both numerous and complicated such as number of peaks and time to peak etc. stormwater model typically use the external characteristics of rainfall events which are used for this analysis.

The following sections will describe the details derived from the rainfall records which will be analyzed by the tool.

4.1 The Rainfall Event

A chronological rainfall record may be split up into two distinct groups of time periods: peiod with rainfall events, and the intervening times between rainfall events. Here, a rainfall event is characterized by some measurable precipitation. The available 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 characteristics, from which histograms are developed. Probability density functions are then fitted to these histograms. The intensity parameter is a calculated value given by: $i = v/t$.

Once one has defined an event delimiter (in this case an IETD), each event can be scrutinized to determine the following additional characteristics:

1) the volume of precipitation recorded for the event,

2) the duration of the event, and

3) the intensity of the event (volume per unit time).

Thus, each rainfall event that is found within the record may be described by these four parameters (volume *v*, duration *t*, average intensity *i*, interevent time *b*). The following Figure 3 helps to depict the role of the IETD in determining the boundary between events and the time between the events:

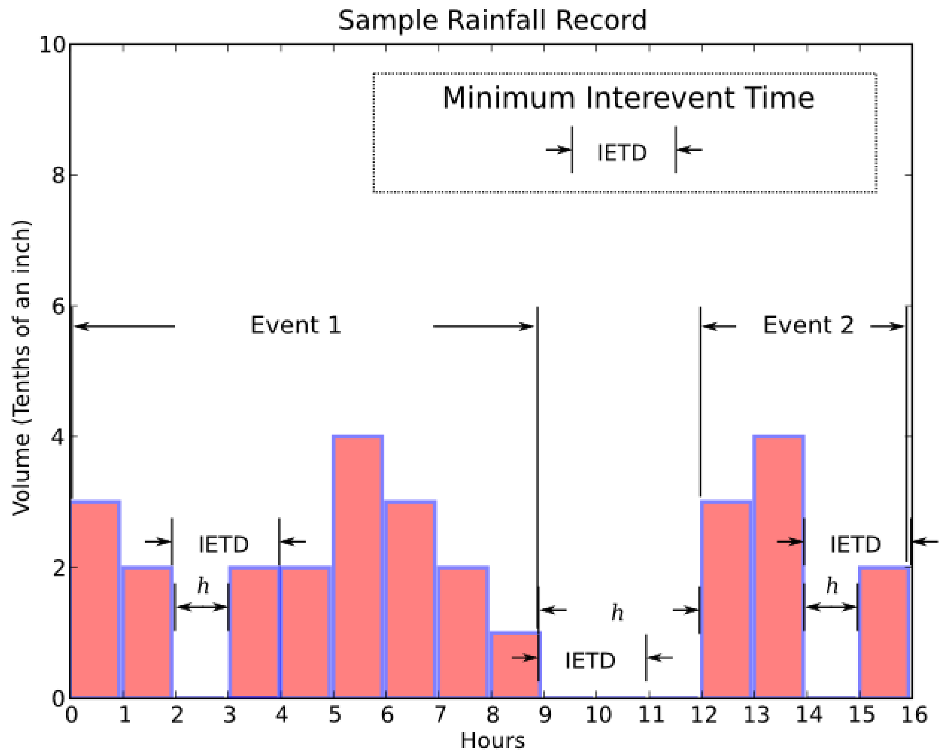
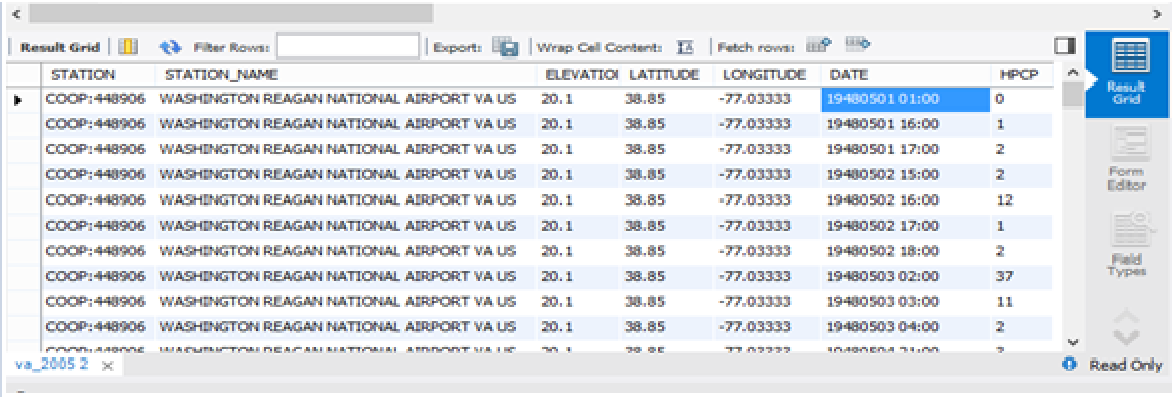


Figure 3: Delineation of Long-term Rainfall Records through IETD

In this example, the rainfall record granularity was given in one-hour intervals, and the volume measurements were given in tenths of inches. The IETD was defined to be two hours. The volume and duration parameters are simply the sum of the volume of rain recorded during the event, and the number of hours that the event lasted respectively. The intensity parameter is therefore given by volume divided by duration of the event. :

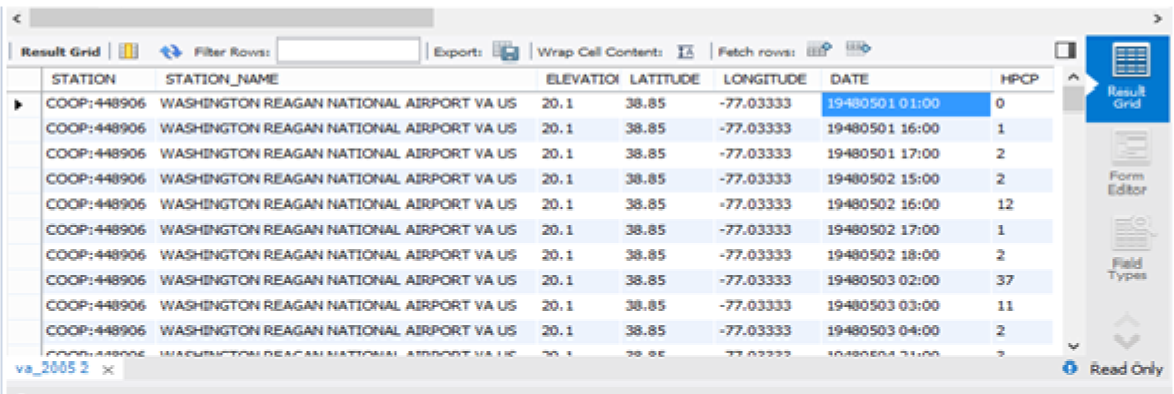
4.2 The Rainfall Record

The first and most important thing when designing the user-interface for performing the IETD analysis [2] is to acquire the data for rainfall records [5]. The data used in the analysis comprised of rainfall records obtained from the National Climatic Data Center [5], NOAA website. These records catalog hourly precipitation information, and present the records in a comma-delimited ASCII text file. The advantage of fetching files from the NCDC [5] is that there is a great deal of coverage, both geographically and historically, in their database; a disadvantage is that the actual formatting of the data within each file is somewhat cumbersome to perform IETD analysis effectively (e.g., DATE field in each record is in text format that cannot be used directly to perform IETD analysis, it is shown in the Figure 4). To overcome this problem, we decided to develop a stored procedure to perform some preprocessing techniques on raw data. The results of performing some preprocessing techniques using stored procedure are shown in the Figure 5.



STATION	STATION_NAME	ELEVATIO	LATITUDE	LONGITUDE	DATE	HPCP
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480501 01:00	0
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480501 16:00	1
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480501 17:00	2
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 15:00	2
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 16:00	12
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 17:00	1
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 18:00	2
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480503 02:00	37
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480503 03:00	11
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480503 04:00	2

Figure 4: Before applying preprocessing on DATE column



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COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480501 16:00	1
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480501 17:00	2
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 15:00	2
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 16:00	12
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 17:00	1
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480502 18:00	2
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480503 02:00	37
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480503 03:00	11
COOP:448906	WASHINGTON REAGAN NATIONAL AIRPORT VA US	20.1	38.85	-77.03333	19480503 04:00	2

Figure 5: After applying preprocessing on DATE column

After performing some preprocessing techniques on raw data, the next step is to develop a stored procedure that performs IETD analysis. After performing the IETD analysis, we need to design the user-interface from which user requests to performIETD analysis.

4.3 Designing the User-Interface

Since the goal of the utility is to help engineers and water resources professionals in developing effective solutions to storm water management problems, it was important to account for the user-friendliness of the application. In the stormwater management analysis, the precipitation is the key input to the models. The initial design considerations for the Rain Event Parser were to either build a Graphical User Interface (GUI) or a web-based interface; the web-based interface eventually took precedence, as it appeals to a broader audience, and requires no additional software to be installed on the researcher's computer. In order to provide a scalable application, it was decided to use a Web Application Framework to build the Rain Event Parser. This application allows the engine of the Rain Event Parser to be run in a browsing session; it handles user input/output routines, builds customized HTML pages, and allows for simple database access (note: a database feature was not part of the original specification, but the chosen framework enables one to be used in the future with a minimum impact). As a web-based application, the Rain Event Analysis is extremely simple to use. Once a researcher decides for which station and state of the rainfall record, choose the IETD value (ranging from 2 to 24) whichever they want, and hit the 'Submit Query' button. Then he will be able to get the rainfall events for that particular station for a given IETD value. The User-Interface is shown in the Figure 6.

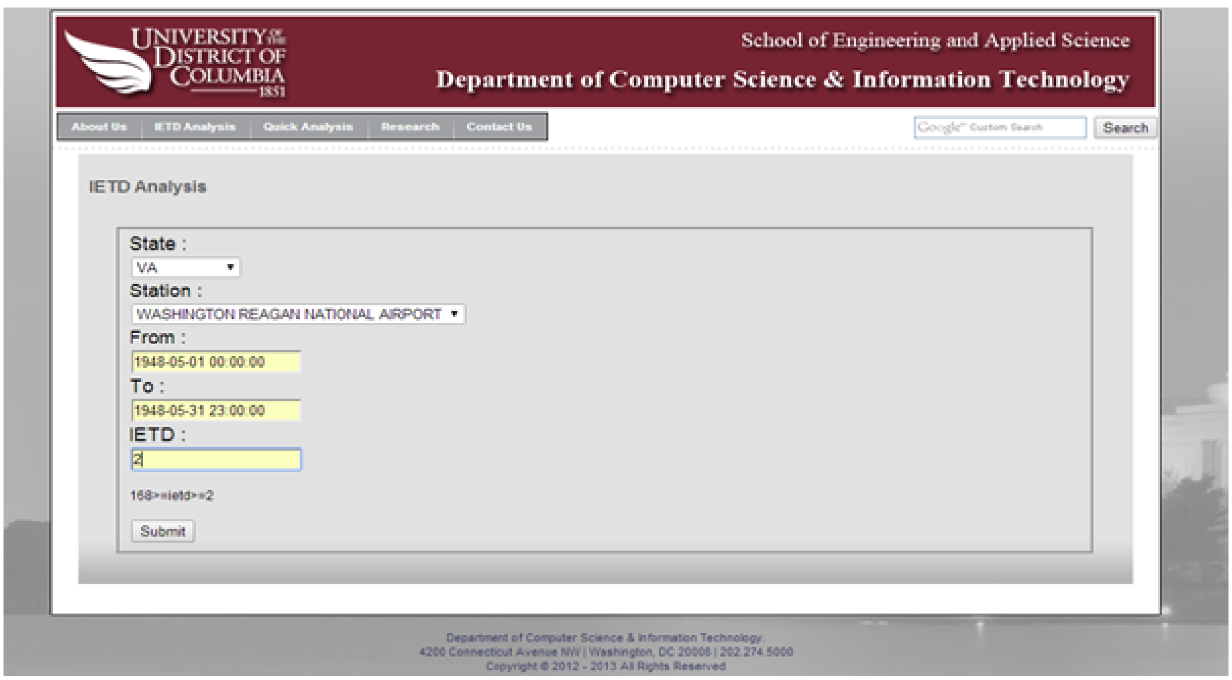

Figure 6: Tab Delimited representation of IETD analysis results.

4.4 Output

The web-based interface is capable of generating different types of representation on the results of IETD analysis. In order to best serve the needs of useers, currently we are providing the Tab-delimited and Graphical representation such as Bar Graphs, Line Charts. The tab-delimited result provides a comprehensive list of all events. This kind of representation will help the engineers to analyze each and every event thoroughly. Figure 7 show the tab-delimited results of IETD analysis.

Event Number	Rain Starts	Rain Ends	IE Time	Volume (inches)	Duration (hours)	Intensity (inches/hours)
1	1948-05-01 15:00:00	1948-05-01 17:00:00		0.03	2	0.015
2	1948-05-02 14:00:00	1948-05-02 18:00:00	21	0.17	4	0.043
3	1948-05-03 01:00:00	1948-05-03 04:00:00	7	0.5	3	0.167
4	1948-05-04 20:00:00	1948-05-05 03:00:00	40	0.82	7	0.117
5	1948-05-07 00:00:00	1948-05-07 08:00:00	45	0.69	8	0.086
6	1948-05-07 14:00:00	1948-05-07 15:00:00	6	0.01	1	0.01
7	1948-05-07 18:00:00	1948-05-07 19:00:00	3	0.08	1	0.08
8	1948-05-12 21:00:00	1948-05-13 08:00:00	122	1.61	11	0.146
9	1948-05-13 10:00:00	1948-05-13 14:00:00	2	0.8	4	0.2

Figure 7: Tab Delimited representation of IETD analysis results.

We have represented Graphical representation of IETD analysis results such as Bar Graph. It helps the researchers to analyze the results quickly, for example the event that has maximum volume, the event that has more IE time and so forth. We developed these kinds of output results using D3 JavaScript [6]. D3 stands for Data-Driven-Documents is a JavaScript library that uses digital data to drive the creation and control of dynamic and interactive graphical forms which run in web browsers. It is a tool for data visualization in W3C-compliant computing, making use of the widely implemented Scalable Vector Graphics (SVG), JavaScript, HTML5, and Cascading Style Sheets (CSS3) standards. We also provided a tool-tip for the bar graph to provide more interactivity to the user. The below Figure 8 shows the bar graph with tool-tip on IETD analysis results.

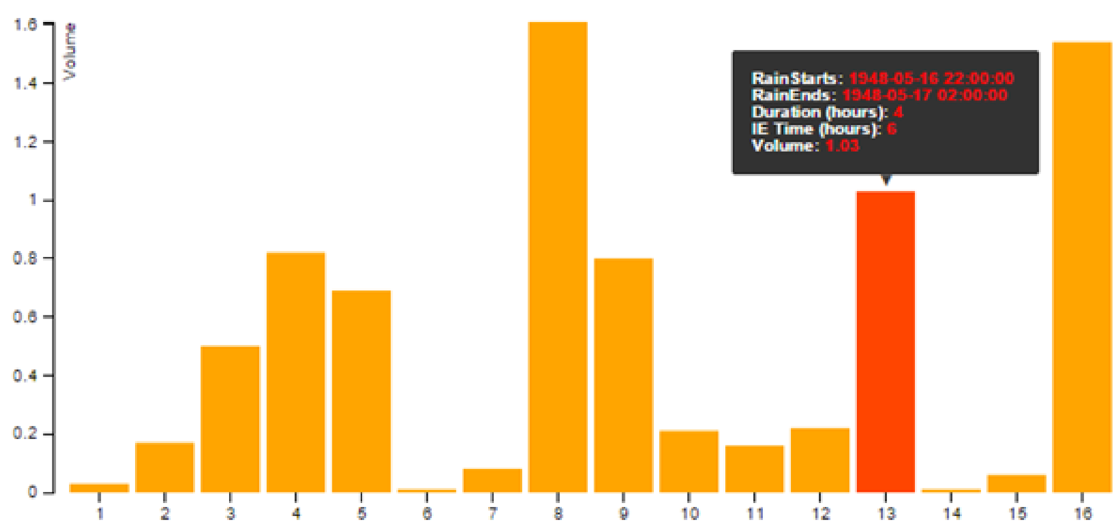

Figure 8: BarGraph representation of IETD analysis results.

4.5 Testing

The core engine of the complete application has gone through several phases of testing to ensure accuracy at all levels. Initially, the program was given extremely short duration data files (2 to 3 months worth of data) which were also parsed by hand in a spreadsheet application. Each test file was parsed (in both ways) for IETD's ranging from 1 hour to 24 hours, and the summary statistics were calculated. It should be noted, however, that there are still several outstanding issues in generating accurate statistical events. Specifically, there are some compelling reasons to remove certain intervals of time from the historical record; dry summer seasons, or winter snowfall seasons can be problematic when trying to determine the likely rainfall parameters for a given location. The parsing utility in [5] allows an individual to select specific months to be removed from a given rainfall record. This functionality comes at a price, however, when analyzing the interevent time parameter. As months are removed from the historical record, the first event immediately following a removal must have a null value stored for the interevent time in order to prevent errors in calculation, since it is clearly impossible to know the actual duration since the true previous event. Care has been taken to ensure that the summary statistics do not factor in these values as zero, which would skew the results; instead, they have been removed from the calculations entirely by being treated as null values.

Conclusion

In this project, a web-based interface for the stom event analysis is developed that will be extremely useful for urban storm water management analysis. By using this tool, engineers or researchers could conduct rainfall analysis for any station within the United States. Even though the application provides accurate results, some effort to be done to increase the robustness and efficiency of this tool which include among them is working on the missing data. Currently we are considering the missing values as 0's, but this assumption may not vadid which requires more analysis.

References

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Appendix

1. Student Support

Category	Number of Students Supported
Undergraduate	
Master	1 Computer Science Major
Ph.D.	
Post Doc.	
Total	1

2.. List of publications (APA format)

- Peer reviewed journal article
- Conference proceeding
- Poster presentation (attach poster): Title, Author, and title of the symposium or conference
  2015 National Capital Region Water Resources Symposium: Urban Water Management and Resilience in Uncertain Times, April 10, 2015, Washington DC
  "Development of a Storm Event Analysis Software Tool for Water Resources Engineering"
  Bharath Kumar Reddy Arikatla, and GeetanjaliSuribhatla, Computer Science Major, Pradeep K. Behera, Professor,and Dong H. Jeong, Assistant Professor, University of the District of Columbia, Washington, D.C.

Prediction of Surface Water Supply Sources for the District of Columbia Using Least Squares Support Vector Machine (LS-SVM)

Basic Information

Title:	Prediction of Surface Water Supply Sources for the District of Columbia Using Least Squares Support Vector Machine (LS-SVM)
Project Number:	2014DC157B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	DC-001
Research Category:	Climate and Hydrologic Processes
Focus Category:	Education, Water Supply, Hydrology
Descriptors:	None
Principal Investigators:	Nian Zhang, Pradeep K. Behera

Publications

1. Zhang, Nian, Tilaye Alemayehu, and Pradeep Behera (2015). Nonlinear Autoregressive (NAR) Forecasting Model for Potomac River Stage Using Least Squares Support Vector Machines (LS-SVM) , International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol. 4, no. 9, pp. 1-9, 2015.
2. Zhang, Nian and Sasan Haghani, (2015). Wind Speed and Energy Prediction Using Least Square Support Vector Machine Trained by Particle Swarm Optimization and Evolutionary Algorithm, The 19th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2015), Orlando, Florida, July 12-15, 2015.
3. Alemayehu, Tilaye, Nian Zhang, and Pradeep K. Behera (2015). Water Quality Classification of Potomac River Using Principal Component Analysis Method, National Capital Region Water Resources Symposium, Washington D.C., April 10, 2015.
4. Kamaha, Rousseland, Nian Zhang (2015). Amelioration of an ECG Signal Using Noise Neutralizer Adaptive Filtering Algorithms, The 72nd Joint Meeting BKX and NIS, Jackson, Mississippi, March 11-14, 2015.
5. Zhang, Nian, Roussel Kamaha, and Pradeep Behera (2015). Prediction of Surface Water Supply Sources for the District of Columbia Using Least Squares Support Vector Machines (LS-SVM) Method , Advances in Computer Science: an International Journal (ACSIJ), vol. 4, issue 1, no.13, pp. 47-51, 2015.
6. Zhang, Nian, Charles Williams, and Pradeep Behera (2015). Water Quantity Prediction Using Least Squares Support Vector Machines (LS-SVM) Method , Journal on Systemics, Cybernetics and Informatics (JSCI), vol. 12, no. 4, pp. 53-58, 2014.
7. Kamaha, Rousseland Nian Zhang, Performance Study of Adaptive Filtering Algorithms for Noise Cancellation of ECG Signal (2015). Emerging Researchers National (ERN) Conference in STEM , Washington, D.C., February 19-21, 2015.
8. Kamaha, Roussel and Nian Zhang, Investigation of Fault-Tolerant Adaptive Filtering for Noisy

ECG Signals, (2014) Annual Biomedical Research Conference for Minority Students (ABRCMS), San Antonio, Texas, November 12-15, 2014.

9. Zhang, Nian, Charles Williams, and Pradeep Behera, (2014). Water Quantity Prediction Using Least Squares Support Vector Machines (LS-SVM) Method, The 18th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2014), Orlando, Florida, July 15-18, 2014.
10. Zhang, Nian, Juan F.R. Rochac, Esther T. Ososanya, Wagdy H. Mahmoud, and Samuel Lakeou, (2014). VLSI Design and Verification of a CMOS Inverter Using the Tanner EDA: A Case Study, The 7th International Multi-Conference on Engineering and Technological Innovation (IMETI 2014), Orlando, Florida, July 15-18, 2014.

Potomac River Stage Forecasting Using a Hybrid Particle Swarm Optimization and Evolutionary Algorithm (PSO-EA) Algorithm with LS-SVM

Progress Report

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Submitted to DC Water Resources Research Institute, University of the District of Columbia

May, 2015

1. Executive Summary

This research project investigates the ability of a least-squares support vector machine (LS-SVM) model to improve the accuracy of streamflow forecasting. Cross-validation and grid-search methods are used to automatically determine the LS-SVM parameters in the forecasting process. To assess the effectiveness of this model, streamflow records from Geological Survey (USGS) gaging station 1652500 on Four Mile Run of the Potomac River, were used as case studies. The performance of the LS-SVM model is compared with the recurrent neural networks model trained by Levenberg-Marquardt backpropagation algorithm. The results of the comparison indicate that the LS-SVM model is a useful tool and a promising new method for streamflow forecasting.

2. Introduction

In regard to stormwater runoff, how urbanized a watershed is or how developed a watershed is can be characterized by the degree of imperviousness found in the watershed [1]. A more urbanized watershed will have a greater percentage of area covered by impervious structures, i.e., roadways, rooftops, sidewalks, parking lots, etc. The effects of these impervious areas create higher peak flows and lower base flows in the watershed tributaries. These effects are most evident in the higher frequency rain/flood events, and they diminish as the range of magnitudes increases, i.e. the initial abstractions (infiltration, interception, and surface storage) become less significant when measured against rainfall for a large event, e.g. a 100-year rainfall event.

Potomac 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. This highly urbanized Potomac River watershed suffers from serious water quantity problems including flooding and stream bank erosion. Of approximately 10,000 stream miles assessed in the watershed, more than 3,800 miles were deemed “threatened” or “impaired”. The middle Potomac sub-watershed, including Washington, DC, contains both the greatest percent impervious area and the greatest population density, which is home to 3.72 million 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.

In this regard, it is imperative to provide a reliable streamflow forecasting tool at various locations on the middle Potomac sub-watershed. Engineers, water resources professionals, and regulatory authorities need this streamflow information for planning, analysis, design, and operation & maintenance of water resources systems (e.g., water supply systems, dams, and hydraulic structures). Currently USGS provides the streamflow data at various locations in the form of gage height and discharge volume at specific locations, and we used this input to design a reliable prediction model.

Recently a variety of computational intelligence has been proposed to address the water quantity prediction problem. In [2][3][4], a predictive model based on recurrent neural networks with the Levenberg-Marquardt backpropagation training algorithm to forecast the stormwater runoff. In [5], a recurrent neural network based predictive model was trained by a combination of particle swarm optimization and evolutionary algorithm to forecast the stormwater runoff discharge. Recent developments of least squares support vector machine (LS-SVM) has attracted an increasing attention in the fields of time series prediction [6]-[17]. However the investigation of the LS-SVM method on water quantity prediction has been very limited. Therefore, this paper will present a promising nonlinear autoregressive (NAR) model optimized by the LS-SVM using the previous discharge time series.

3. Method

3.1 NAR Model with Time-Delay

In the nonlinear autoregressive model (NAR) time series predictive model, the output is feedback to the input and the future values of time series y(t) could be predicted from past values of that time series, as shown in Fig. 1. Extending backward from time t, we have time series (y(t), y(t-1), y(t-2), · · ·).

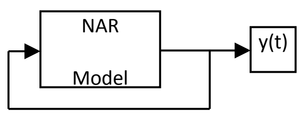

Fig. 1. The NAR based prediction model. The future values of y(t) can be predicted from past values of y(t).

This form of prediction can be written as follows:

$$y(t+s) = f(y(t-1),\ldots,y(t-d))$$

where s is called the horizon of prediction. If s = 1, then this prediction is called one time step ahead prediction; otherwise, it is called multi-step ahead prediction. d is the time delay, giving the number of past predictions fed into the model.

3.2 Least Squares Support Vector Machine Regression with Symmetry Constraints

Least Squares Support Vector Machines (LS-SVM) is a powerful nonlinear kernel methods, which use positive-definite kernel functions to build a linear model in the high-dimensional feature space where the inputs have been transformed by means of a nonlinear mapping $\emptyset$ [18]. This is converted to the dual space by means of the Mercer's theorem and the use of a positive definite kernel, without computing explicitly the mapping $\emptyset$. The LS-SVM formulation solves a linear system in dual space under a least-squares cost function [19], where the sparseness property can be obtained by sequentially pruning the support value spectrum [20] or via a fixed-size subset selection approach. The LS-SVM training procedure involves the selection of a kernel parameter and the regularization parameter of the cost function, which can be done e.g. by cross-validation, Bayesian techniques [21] or others. Given the sample of N points $\{x_i, y_i\}_{i=1}^{N}$, with input vectors $x_i \in \mathbb{R}^p$ and output values $y_i \in \mathbb{R}$, the goal is to estimate a model of the form:

$$y_i = w^T \emptyset(x_i) + b + \varepsilon_i (i=1,2,\ldots,l) \qquad (1)$$

where $\emptyset(\cdot): \mathbb{R}^p \longrightarrow \mathbb{R}^{n_h}$ is the mapping to a high dimensional (and possibly infinite dimensional) feature space, and the residuals e are assumed to be independent and identically distributed with zero mean and constant and finite variance.

Least squares support vector machine (LS-SVM) formulates a regularized cost function and changes its inequation restriction to equation restriction. As a result, the solution process becomes a solution of a group of equations which greatly accelerates the solution speed [19]. The following optimization problem with a regularized cost function is formulated:

$$min_{w,b,\varepsilon_i} \frac{1}{2} w^T w + \frac{C}{2} \sum_{i=1}^{l} \varepsilon_i^2 \qquad (2)$$

The solution of LS-SVM regressor will be obtained after we construct the Lagrangian function. The extreme point of Q is a saddle point, and differentiating Q can provide the formulas as follows, using Lagrangian multiplier method to solve the formulas. The conditions for optimality are

$$\frac{\partial Q}{\partial w} = w - \sum_{i=1}^{l} \alpha_i \emptyset(x_i) = 0 \qquad (3)$$

$$\frac{\partial Q}{\partial b} = -\sum_{i=1}^{l} \alpha_i = 0 \qquad (4)$$

$$\frac{\partial Q}{\partial \alpha} = w^T - \emptyset(\mathrm{x_i}) + \mathrm{b} + \varepsilon_i - y_i = 0 \qquad (5)$$

$$\frac{\partial Q}{\partial \varepsilon_i} = C\varepsilon_i - \alpha_i = 0 \qquad (6)$$

where $\alpha \in \mathbb{R}$ are the Lagrange multipliers. From formulas above, we can obtain:

$$\frac{1}{2} \sum_{i=1}^{l} \alpha_i \emptyset(x_i) \sum_{j=1}^{l} \alpha_j \emptyset(x_j) + \frac{1}{2C} \sum_{i=1}^{l} \alpha_i^2 + b \sum_{i=1}^{l} \alpha_i = \sum_{i=1}^{l} \alpha_i y_i \qquad (7)$$

The formula above can be expressed in matrix form:

$$\begin{bmatrix} 0 & e^T \\ e & \Omega + C^{-1} I \end{bmatrix} (\mathrm{l}+1)(\mathrm{l}+1) \begin{bmatrix} \mathrm{b} \\ \alpha \end{bmatrix} = \begin{bmatrix} 0 \\ \mathrm{Y} \end{bmatrix} \qquad (8)$$

In this equation,

$$e = [1, \dots, 1]_x^T$$

$$\Omega_{ij} = K(x_i, x_j) = \emptyset(x_i)^T \emptyset(x_j) \qquad (9)$$

Formula (7) is a linear equation set corresponding to the optimization problem and can provide us with α and b. Thus, the prediction output decision function is:

$$\bar{y}(x) = \sum_{i=1}^{l} \alpha_i K(x_i x) + b \qquad (10)$$

where $K(x_i, x)$ is the core function.

3.3 Practical Implementation

The training process of LS-SVM involves the selection of kernel parameter: the squared bandwidth, $\sigma 2$ (sig2) and the regularization constant, γ (gam). The regularization constant, γ (gam) determines the trade-off between the training error minimization and smoothness A good choice of these parameters is crucial for the performance of the estimator. The tuning parameters were found by using a combination of coupled simulated annealing (CSA) and a standard simplex method. The CSA finds good starting values and these values were passed to the simplex method in order to fine tune the result. We use 10-fold cross-validation for selecting these parameters.

Another important choice is the selection of regressors, i.e., which lags of inputs and outputs are going to be included in the regression vector. This selection is done by using a large number of initial components and then performing a greedy search to prune non-informative lags on a cross-validation basis. Therefore an initial model containing all regressors is estimated and optimal choices for the parameters are made. On each stage of the greedy backwards elimination process, a regressor is removed if the cross-validation mean absolute error or mean squared error improves. For the purpose of model estimation, all series are normalized to zero mean and unit variance. Once the parameters are calculated, the final set of regressors is then used for the predictions. By using only a subset of the total data available, we can compare the predictions against real values to see how accurate the prediction is.

4. Results

4.1 Study Area

The study area will focus on the Four Mile Run at Alexandria, VA, as shown in Fig. 2. The US Geological Survey (USGS) gaging station 1652500 on Four Mile Run located at the Shirlington Road Bridge has collected stream flow data since 1951 [1]. The Four Mile Run is 9.2 miles long, and is a direct tributary of the Potomac River.

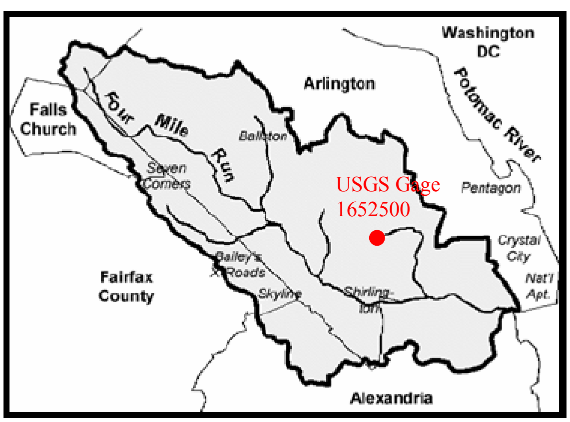

Fig. 2. Four Mile Run at Alexandria, VA is a nine-mile long stream located in a highly urbanized area in Northern Virginia. It is a direct tributary of the Potomac River, which ultimately carries the water flowing from Four Mile Run to the Chesapeake Bay.

The entire watershed can be classified as highly urbanized, which ultimately flows through some of Northern Virginia's most densely populated areas to the Chesapeake Bay. In addition, because of the highly urbanized nature of the Four Mile Run watershed, the neighborhoods and businesses adjacent to this portion of the run were subjected to repeated flooding, beginning in the 1940s. Therefore, the flood-control solutions are the major concern. Runoff prediction would provide a promising solution for flood-control.

4.2 Time Series Data from USGS

The real-time USGS data for the Four Mile Run station include the discharge data, which is useful for investigating its impact to the long-run discharge forecast. The discharge is the volume of water flowing past a certain point in a water-flow. For example, the amount of cubic feet passing through a drain per second is a measure of discharge. The discharge data was retrieved for 120 days between August 28, 2010 and December 4, 2010. Because the real-time data typically are recorded at 15-minute intervals, the runoff discharge (cubic feet per second) data plots 34721 data during the 120 days, as shown in Fig. 8. The discharge will be presented to the system as an input. It is a 34721x1 vector, representing dynamic data, i.e. 34721 time steps. It is challenging that these discharge values vary significantly over time. As shown in Fig. 3, the baseline is at around 4 on the Y-axis, with peaks reaching 8, with very little repetition to the pattern, making it more difficult to predict future values.

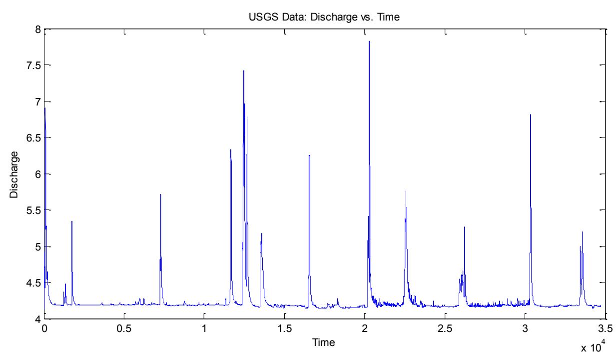

Fig. 3 Plot of entire discharge data set vs. time.

4.3 Training Data and Time Delays

The first 500 time series data from the original sample of about 34,721 were used for our analysis. To determine an appropriate time delay or lag, we increase the number of delays lags until the network performed well. After a number of experiments, 80 is determined to be the smallest lag number that ensures a good performance. That means the model will use the past 80 input data to predict a future data.

Before parameter tuning and network training, we should use the function *windowize* to convert the time-series into a Hankel matrix useful for training a nonlinear function approximation [22]. For example, assume there is a matrix X which is defined below.

$$X = \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \\ d_1 & d_2 & d_3 \\ e_1 & e_2 & e_3 \\ f_1 & f_2 & f_3 \\ g_1 & g_2 & g_3 \end{bmatrix}$$

1st window

Now we want to convert matrix *X* to a new matrix *Xu* by running the Matlab command:

Xu = windowize(X, [1 2 3])

This command will select 3 rows of data (i.e. circled by the blue dashed line) from matrix *X* to make a window, and pout this window in a row of matrix *Xu*. For example, row 1 to 3 from matrix *X* will be selected to make the 1st window, and put in the 1st row of matrix Xu. Similarly, row 2 to 4 from matrix X will be selected to make the 2nd window, and put in the 2nd row of matrix Xu. Thus, the matrix Xu will look as follows.

1st window

$$W = \begin{bmatrix} a_1 & a_2 & a_3 & b_1 & b_2 & b_3 & c_1 & c_2 & c_3 \\ b_1 & b_2 & b_3 & c_1 & c_2 & c_3 & d_1 & d_2 & d_3 \\ c_1 & c_2 & c_3 & d_1 & d_2 & d_3 & e_1 & e_2 & e_3 \\ d_1 & d_2 & d_3 & e_1 & e_2 & e_3 & f_1 & f_2 & f_3 \\ e_1 & e_2 & e_2 & f_1 & f_2 & f_3 & g_1 & g_2 & g_3 \end{bmatrix}$$

In our case, Xu = windowize(X, 1:lag+1) will convert the discharge data set into a new input vector including the past measurements and the future output by *windowize*.

The size of the discharge data set contains 500 data points, which consists of 500 rows. With the 80 lags, it will generate 420 rows and 81 columns. The last column of the resulting matrix *Xu* contains the future values of the time-series, and the previous 80 columns contain the past inputs. The first 340 data points (i.e. 70%) will be used as training data, and the remaining 160 data (i.e. 30%) will be used as test data. Xtra = Xu(1:end-lag,1:lag) will generate 80 past inputs, i.e. x(t-1), x(t-2), … x(t-80), while Ytra = Xu(1:end-lag,end) contains their actual future value, x(t). Ytra will be used as the target for those past inputs.

4.4 Tuning the Parameters

In order to build an LS-SVM model, we need to tune the regularization constant, *gam* and the kernel parameter, *sig2*. γ (gam) determines the trade-off between the training error minimization and smoothness. In the common case of the Gaussian RBF kernel, the kernel parameter, *sig2* is the squared bandwidth. We use the following statement to tune these parameters:

```
[gam,sig2] = tunelssvm({Xtra,Ytra,'f',[],[],'RBF_kernel'},...
'simplex','crossvalidatelssvm',{10,'mae'})
```

Where *f* stands for function estimation. The Kernel type is chosen to be the default RBF kernel. The optimization function is specified as simplex. The simplex is a multidimensional unconstrained non-linear optimization method. Simplex finds a local minimum of a function starting from an initial point X. The local minimum is located via the Nelder-Mead simplex algorithm [23]. The model adopts *crossvalidatelssvm* as the cost function. It estimates the generalization performance of the model. It is based upon feedforward simulation on the validation set using the feedforwardly trained model.

In addition, 10 means 10-fold. We use 10-fold cross-validation because the input size is greater than 300 points. Otherwise, leave-one-out cross-validation will be used when the input size is less or equal than 300 points. The 10-fold cross-validation method will break data (the size of the data is assumed to be *n*) into 10 sets of size n/10, then train on 9 datasets and test on 1, and then repeat 10 times and take a mean accuracy. *mae* is the mean absolute error and is used in combination with the 10-fold cross-validation method. It is the absolute value of the difference between the forecasted value and the actual value. It tells us how big of an error we can expect from the forecast on average.

The tuning of the parameters is conducted in two steps. First, a state-of-the-art global optimization technique, Coupled Simulated Annealing (CSA) [24], determines suitable parameters according to some criterion. Second, these parameters are then given to a second optimization procedure *simplex* to perform a fine-tuning step. The parameter tuning results are shown in Fig. 4. Coupled Simulated Annealing chosen the initial *gam* to be 1364.706, and *sig2* to be 13.989. They serve as the starting values for the *simplex* optimization routine. After 11 iterations, the *gam* and *sig2* are optimized to be 83.2188 and 15.298, respectively.

4.5 Network Training and Prediction

Once the *gam* and *sig2* parameters were tuned, we should train the network. It will train the support values and the bias term of an LS-SVM for function approximation. The Matlab command is

```
[alpha,b] = trainlssvm({Xtra,Ytra,'f',gam,sig2,'RBF_kernel'})
```

Xtra and Ytra are the training data we defined before. *f* stands for function estimation. The Kernel type is chosen to be the default RBF kernel. Because the network has 80 lags, it helps generate 80 past inputs. For each iteration, the past 80 Xtra data points will be used to predict the 81th data point. Ytra is the desired target. The 340 samples in the Xtra and Ytra will be used to train the network.

After the network has been well trained, we can test the prediction performance by testing on the new data, which have never been seen by the network. We will use the remaining 160 data points as the testing data. The Matlab command is

```
prediction = predict({Xtra,Ytra,'f',gam,sig2, 'RBF_kernel'},Xs,500)
```

Xtra and Ytra are the training data we used before. ‘f’ stands for function estimation. The Kernel type is chosen to be the default RBF kernel. Xs is the starting point for iterative prediction. Since we want to check both the training performance and prediction performance, we set Xs=X(1:end-lag,1). The model will start predicting from the 1st data point, and will predict the next 500 points from the start point.

The predicted discharge value and the actual discharge value were shown in Fig. 5. The prediction is shown in the red dashdot while the real USGS discharge data points are shown in blue line. The first 340 samples are training data, and the remaining 160 samples are testing data. As shown in Fig. 5, the prediction on the training data matches the actual values perfectly. This makes sense because these training samples have been seen by the network during training. The prediction on these data should have already been trained to be very close to the actual value. In addition, when we test the new data from time step 341 to 500, we find the predicted values match very well with the actual values. This demonstrated that the LS-SVM model has excellent prediction ability.

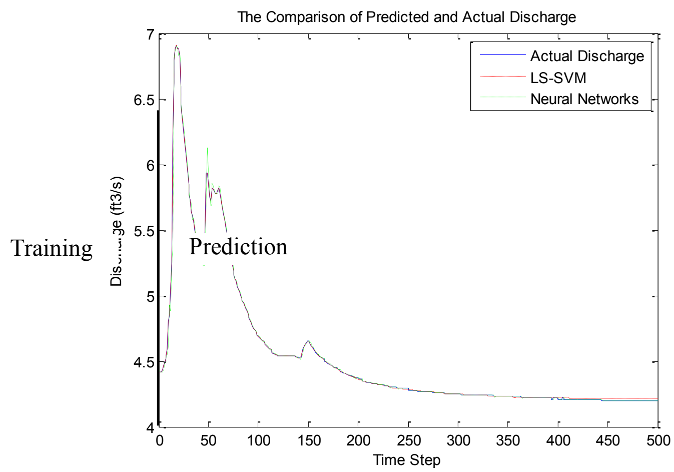

Fig. 4 The LS-SVM prediction is shown in red dashdot, the USGS discharge is shown in blue line, and the recurrent neural networks model trained by Levenberg-Marquardt backpropagation algorithm is shown in green dash colon. The first 340 samples are training data, and the remaining 160 samples are test data.

In order to further evaluate the performance of the proposed LS-SVM method, we compare the results with the recurrent neural networks model trained by Levenberg-Marquardt backpropagation algorithm [4]. The simulation result is shown in Fig. 5. The USGS discharge is shown in blue line, the LS-SVM prediction is shown in red dashdot, and the recurrent neural networks model trained by Levenberg-Marquardt backpropagation algorithm is shown in green dash colon. The first 340 samples are training data, and the remaining 160 samples are test data.

5. Conclusions

In this research project, the least squares support vector machine (LS-SVM) based algorithm is developed to forecast the future streamflow based on the previous streamflow. The first 340 data points are used as training data, and the remaining 160 data are testing data. First we convert the time-series into a Hankel matrix useful for training a nonlinear function approximation. Next we build an LS-SVM model by tuning the regularization constant, *gam* and the kernel parameter, *sig2*. A Gaussian Radial Basis Function (RBF) kernel framework was built on the data set to optimize the tuning parameters. The 10-fold cross-validation method is used to estimate the generalization performance of the model. Then we train the LS-SVM network. It trains the support values and the bias term of an LS-SVM for function approximation. We developed an effective training scheme. After the network has been well trained, we test the prediction performance by predicting new values on the testing samples, as well as the training samples.

The performance of the LS-SVM model is compared with the recurrent neural networks model trained by Levenberg-Marquardt backpropagation algorithm. The excellent experimental results of the comparison indicate that the LS-SVM model is a useful tool and a promising new method for streamflow forecasting. The excellent experimental results demonstrated that the proposed LS-SVM based predictive model has superior prediction performance on not only the training samples, but also the testing samples. In addition, the proposed parameter tuning method and the training scheme worked effectively, which ensure an accurate prediction of streamflow.

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Appendix

1. Student Support

Category	Number of Students Supported
Undergraduate	1
Master	0
Ph.D.	0
Post Doc.	0
Total	1

2.. List of publications (APA format)

- Peer reviewed journal article

- **Nian Zhang**, Tilaye Alemayehu, and Pradeep Behera, "Nonlinear Autoregressive (NAR) Forecasting Model for Potomac River Stage Using Least Squares Support Vector Machines (LS-SVM)", *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, vol. 4, no. 9, pp. 1-9, 2015. (DCWRRI student co-author)
- **Nian Zhang**, Roussel Kamaha, and Pradeep Behera, "Prediction of Surface Water Supply Sources for the District of Columbia Using Least Squares Support Vector Machines (LS-SVM) Method", *Advances in Computer Science: an International Journal (ACSIJ)*, vol. 4, issue 1, no.13, pp. 47-51, 2015. (DCWRRI student co-author)
- **Nian Zhang**, Charles Williams, and Pradeep Behera, "Water Quantity Prediction Using Least Squares Support Vector Machines (LS-SVM) Method", *Journal on Systemics, Cybernetics and Informatics (JSCI)*, vol. 12, no. 4, pp. 53-58, 2014. (DCWRRI student co-author)

- Conference proceeding

- **Nian Zhang** and Sasan Haghani, "Wind Speed and Energy Prediction Using Least Square Support Vector Machine Trained by Particle Swarm Optimization and Evolutionary Algorithm," *The 19th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2015)*, Orlando, Florida, July 12-15, 2015. (Accepted)
- Tilaye Alemayehu, **Nian Zhang**, and Pradeep K. Behera, "Water Quality Classification of Potomac River Using Principal Component Analysis Method," *National Capital Region Water Resources Symposium*, Washington D.C., April 10, 2015. (DCWRRI student co-author)
- Roussel Kamaha and **Nian Zhang**, "Amelioration of an ECG Signal Using Noise Neutralizer Adaptive Filtering Algorithms," *The 72nd Joint Meeting BKX and NIS*, Jackson, Mississippi, March 11-14, 2015. (DCWRRI student co-author)
- Roussel Kamaha and **Nian Zhang**, "Performance Study of Adaptive Filtering Algorithms for Noise Cancellation of ECG Signal," *2015 Emerging Researchers National (ERN) Conference in STEM* , Washington, D.C., February 19-21, 2015. (DCWRRI student co-author)

- Roussel Kamaha and **Nian Zhang**, "Investigation of Fault-Tolerant Adaptive Filtering for Noisy ECG Signals," *2014 Annual Biomedical Research Conference for Minority Students (ABRCMS)*, San Antonio, Texas, November 12-15, 2014. (DCWRRI student co-author)
- **Nian Zhang**, Charles Williams, and Pradeep Behera, "Water Quantity Prediction Using Least Squares Support Vector Machines (LS-SVM) Method," *The 18th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2014)*, Orlando, Florida, July 15-18, 2014. **(Best Paper Award)** (DCWRRI student co-author)
- **Nian Zhang**, Juan F.R. Rochac, Esther T. Ososanya, Wagdy H. Mahmoud, and Samuel Lakeou, "VLSI Design and Verification of a CMOS Inverter Using the Tanner EDA: A Case Study," *The 7th International Multi-Conference on Engineering and Technological Innovation (IMETI 2014),* Orlando, Florida, July 15-18, 2014.
- **Nian Zhang**, Charles Williams, Esther Ososanya, Wagdy Mahmoud, "Streamflow Prediction Based on Least Squares Support Vector Machines," *ASEE-2013 Mid-Atlantic Fall Conference*, Washington, D.C., October 11-13, 2013. (DCWRRI student co-author)
- Wagdy H. Mahmoud and **Nian Zhang**, "Software/Hardware Implementation of an Adaptive Noise Cancellation System," *120th ASEE Annual Conference & Exposition*, Atlanta, GA, June 23-26, 2013.
- **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) - Special Session "Cyber-Physical Systems and Autonomic Management"*, Orlando, Florida, April 15-18, 2013. (DCWRRI student co-author)
- Lalindra Jayatilleke and **Nian Zhang**, "Landmark-Based Localization for Unmanned Aerial Vehicles," *2013 IEEE International Systems Conference (IEEE SysCon 2013) - Special Session "Cyber-Physical Systems and Autonomic Management"*, Orlando, Florida, April 15-18, 2013. (DCWRRI student co-author)
- **Nian Zhang**, Pradeep K. Behera, and Charles Williams, "Streamflow Prediction Based on Least Squares Support Vector Machine," *National Capital Region Water Resources Symposium*, Washington D.C., April 5, 2013. (DCWRRI student co-author)
- 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. (DCWRRI student co-author)

- Poster presentation (attach poster): Title, Author, and title of the symposium or conference

Stormwater Flood Prediction and Mitigation in Bloomingdale and Ledroit Park Using Bayesian Network and Time Series Analysis

Basic Information

Title:	Stormwater Flood Prediction and Mitigation in Bloomingdale and Ledroit Park Using Bayesian Network and Time Series Analysis
Project Number:	2014DC158B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	DC
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Water Quantity, Surface Water
Descriptors:	None
Principal Investigators:	Valbona Bejleri

Publication

1. Allen, Timothy Chen, Kevin Bembridge , and Valbona Bejleri (2015. Identifying Factors that Contribute the Most to Flooding Conditions of Washington, DC s Bloomingdale and Ledroit Park Neighborhoods A General Linear Modeling Approach, 2015 NCR-AWRA Annual Water Symposium, Washington, DC. Poster Presentation.

STORMWATER FLOOD PREDICTION AND MITIGATION IN BLOOMINGDALE AND LEDROIT PARK USING BAYESIAN NETWORK AND TIME SERIES ANALYSIS

Progress Report

Valbona Bejleri
Division of Sciences and Mathematics

Submitted to DC Water Resources Research Institute,
University of the District of Columbia

May, 2015

1. Executive Summary

Residents and businesses of Washington, DC's Bloomingdale and LeDroit Park neighborhoods have historically experienced severe flooding during large storms. In August 2012 the District appointed a Flood Prevention Task Force of experts and residents and has undertaken construction projects to alleviate some flooding problems in principal roadways, but longer term solutions are currently not scheduled to begin until 2022. A deeper understanding of factors that contribute to flooding conditions in the area is necessary to ensure that the District invests its resources most effectively to address this problem.

2. Introduction

Stochastic processes considered include environmental, behavioral, mitigation, prevention, and financial data related to storm and flooding events and related traffic accidents and fatalities. Time Series Analysis and Poisson regression were used to evaluate the behavior of flooding events and contributing factors. The objectives of this project are to provide a statistical modeling framework that allows for:

- Collecting and investigating behavioral, mitigation, accident-prevention, and financial data;
- Model accident data associated with flooding in the subject area;
- Offering the opportunity for training students and District experts on how to use (and extend the use of) the model developed.

3. Method

Two graduate students worked under supervision of Dr. Bejleri on the following tasks:

1. Model Specification

- Searched and explored the literature related to our problem; conducted meta-research of current prediction and mitigation methodologies used by the District to better understand how the District is addressing the problem.
- Graphed time plots of the series
- Computed statistics from the data
- Used time series analysis and Poisson regression to evaluate the behavior of flooding events and contributing factors.

Model specification is the first approach to building the model. Later in the analysis, this step will be revised again.

2. Model Fitting

- Performed General Linear Modeling (GLM) techniques considering a dichotomous response variable (flood/no flood)
- Modeled the chances of flood occurrences

3. Diagnostics (ongoing work)

- Assess the quality of the model.
- How well does the model fit the data?
- Are all the assumptions of the model reasonably satisfied by our data?

4. Results

Storms that originate off the coast of Cape Verde tend to be stronger (http://www.aoml.noaa.gov/hrd/tcfaq/A2.html). Higher Sea Surface Temperatures in the Caribbean Sea and Gulf of Mexico tend to strengthen storms as well (http://www.nhc.noaa.gov/aboutsst.shtml). It has been observed that El Niño winds tend to weaken Atlantic storms (Elsner, James B. and Bossak, Brian H. (2001), http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/hurr/enso.rxml, and Bell, G. D., and M. Chelliah (2006)).

Three different data sources were considered: OpenData DC, FEMA OpenData, and NOAA. Exploring data using a probability plotting technique, students concluded that flood occurrences fit a Poisson distribution. Based on the “resistant line” technique, which is a method that considers fitting medians instead of the averages, we estimated about 19% annual rate of occurrence within DC boundaries.

5. Conclusions

This is an ongoing project. Some preliminary results were organized in the poster attached with this report.

- Identify most influential factors that contribute to flooding in Washington, DC
- Explain relationships between these factors
- Assess the model
- Estimate the uncertainty associated with model's parameter estimates
- Allow predictions

6. References

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Appendix

1. Student Support

Category	Number of Students Supported
Undergraduate	NA
Master	2 (expected)
Ph.D.	NA
Post Doc.	NA
Total	

2.. List of publications (APA format)

Bejleri, V. and Deksissa, T. (2014). A Bayesian Technique for Estimating the Uncertainty Associated with Parameters of Effluent Flow Rate of the Hydraulic Model. International Journal of Social Health Information Management, Vol. 7, Issue 15, 16-23.

Poster (please see attached)

Monitoring of Uptake of Water Soluble Phosphorus in Wastewater Samples by Algae Using 31P Nuclear Magnetic Resonance (NMR) Spectroscopy

Basic Information

Title:	Monitoring of Uptake of Water Soluble Phosphorus in Wastewater Samples by Algae Using 31P Nuclear Magnetic Resonance (NMR) Spectroscopy
Project Number:	2014DC159B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	DC
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Toxic Substances, Education
Descriptors:	None
Principal Investigators:	Xueqing Song

Publications

There are no publications.

Monitoring of Uptake of Water Soluble Phosphorus in Wastewater Samples by Algae Using ^{31}P Nuclear Magnetic Resonance (NMR) Spectroscopy

Progress Report

Xueqing Song

Division of Sciences and Mathematics
College of Arts and Science

Submitted to DC Water Resources Research Institute,
University of the District of Columbia

May 4, 2015

Abstract
A series of ^{31}P NMR samples were obtained including extracts with NaOH-EDTA of inorganic and organic phosphorus from sediment samples collected in the Reflecting Pool located in front of the Lincoln Memorial in Washington, DC. NMR sample were also prepared for these sediment samples after cultivated with algae for 4 weeks. The ^{31}P NMR studies shows that there are four major phosphorus species in these sediment sample with various concentration, including inorganic phosphate, DNA, pyrophosphate and phosphate monoesters based on comparison with reported phosphorus NMR chemical shifts. More NMR data will be collected for all the sediment samples cultivated with algae to decide the rate of phosphorus uptake by the algae.

Key words: Harmful algal blooms (HABs); Phosphorus; Nuclear Magnetic Resonance Spectroscopy; Sediment Sample

Introduction
Phosphorus (P) is an element that is essential for all life forms which cannot be substituted by any other element. It is a key element in many physiological and biochemical processes, like the formation of DNA and within photosynthesis. The element of phosphorus does not occur in nature as a free element due to its high reactivity. Phosphorus is always combined with other elements, like oxygen, to form phosphates which occur in many different complex forms. It is not a rare element, being the eleventh most abundant element in the lithosphere. However, the form in which it is present in the biosphere is often a form that is unavailable for plants. Plants can only absorb the soluble inorganic form of phosphorus, orthophosphate (PO_4^-), dissolved in soil solution. This form of phosphorus is an essential nutrient for plant growth; hence it is a vital element for the Harmful Algae Bloom.

Excessive phosphorus in a freshwater system increases plant and algal growth. This can lead to: changes in number and type of plants and animals; increases in animal growth and size; increases in turbidity; more organic matter falling to the bottom of the system in the form of dead plants and animals; and losses of oxygen in the water. When there is no oxygen at the bottom of a freshwater system, phosphorus that previously had been locked in the sediment can be released back into the water. Elevated phosphorus levels, however, can increase a freshwater system's productivity and result in large amounts of organic matter falling to the bottom. Bacteria and other organisms decompose this matter and in the process use a lot of oxygen. In very productive freshwater systems, the oxygen levels can be in such short supply that fish kills occur. A type of algae, called cyanobacteria, grows particularly well in high levels of phosphorus.

Treating the water with chemical algaecides may provide short-term relief but does not control the source of the problem, requiring repeated treatments that are expensive and may have adverse effects on our environment. An effective, long-term and cost-efficient approach to controlling algae includes reducing the amount of phosphorus entering our waters.

Since algae have to utilize phosphorus from wastewater for their growth, this project is designed to collect some preliminary data to investigate the possibility of using algae as a method for phosphrous removal from wastewater. Moreover, algae can also fix carbon dioxide from atmosphere as in photosynthesis, thus reducing green house gas emission. Also, algal biomass can be used for biofuel which is considered as renewable energy. The objectives of this project are to develop analytical method able to provide rapid, sensitive, easy and reliable detection of soluble inorganic and organic phosphorus in sediment samples in Lincoln Memorial

Reflecting Pool in Washington, DC and to monitor the uptake of phosphorus by algae collected from the Lincoln Memorial Reflecting Pool by using phosphorous-31 NMR spectroscopy. This project is also designed to involve undergraduate students at the University of the District of Columbia in research. Undergraduate students in this project have the chance to learn analytical skills by collecting 31NMR data on NMR spectrometer and analyzing the data.

Materials and methods

Site description and sediment sampling

The sediment samples were collected from the four corners of rectangular shaped reflecting pool by the Lincoln Memorial in Washington, D.C. (Fig. 1) Sediment samples were collected from surface sediments in clean glass bottles as recommended by the Environmental Protection Agency (EPA) method 3050 “Acid Digestion of Sediments, Sludges, and Soils”. The samples were then separated into two 250mL beakers for phosphorus content analysis and for algae cultivation experiment, respectively. The samples were free-dried in beakers into powder. For algae cultivation experiment, the dried sediment sample (20 g) was placed in bottles and 1 gram dry algae collected from the reflecting pool are added. Aliquot of 0.1M HCl or 0.1M NaOH will be added to make the 100 mL water solution with pH of 4, 7 and 10, respectively. The beakers are then placed in the incubator at 28^{o}C with a humidity of 80% for 4 weeks. An auto-timer was used to control the light used in the experiment.

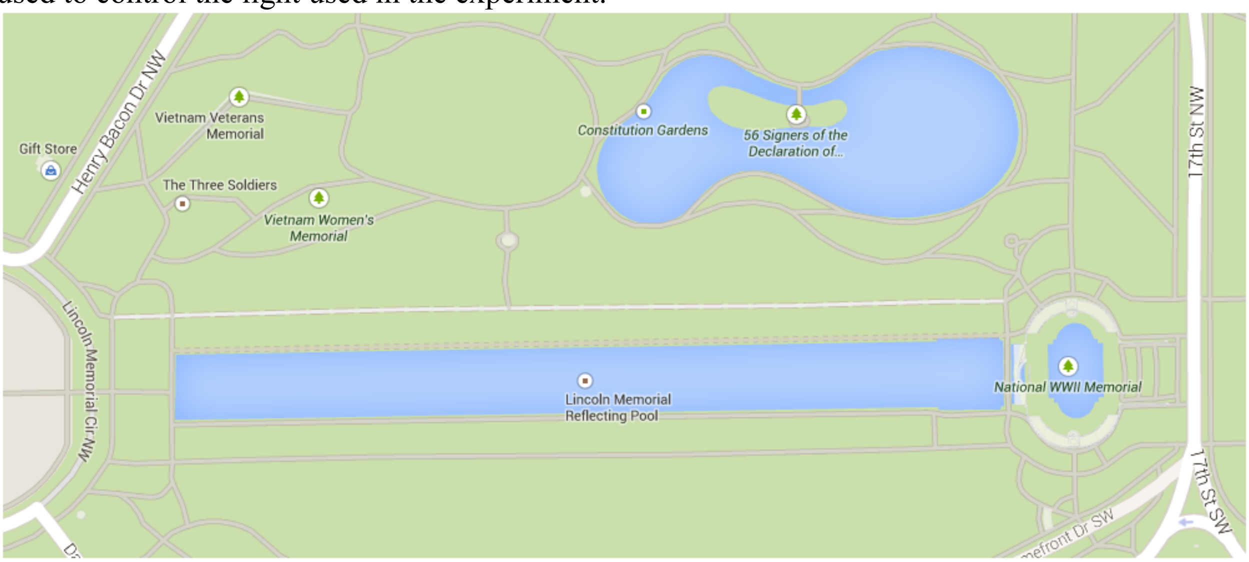

Fig. 1 Locations of sample collection sites in the Reflecting Pool

Fig. 2 The South-East corner of the reflecting Pool

Table 1. NMR Samples prepared for phosphorus NMR analysis

*	PH= 4	PH=7	PH=10
SE	SEA4	SEA7	SEA10
SW	SWA4	SWA7	SWA10
NE	NEA4	NEA7	NEA10
NW	NWA4	NWA7	NWA10

SE: Sediments collected from South-East corner of the Reflecting Pool; SW: Sediments collected from South-West corner of the Reflecting Pool; NE: Sediments collected from North-East corner of the Reflecting Pool; NW: Sediments collected from North-West corner of the Reflecting Pool

Sediment sample extraction:

Preparation of soil and sediment samples for ^{31}P NMR analysis was done according to the procedure in the literature. According to this method, a 20-g soil sample was extracted with 200mL of demineralized water by shaking in an end-over-end shaker for 18 h at 25 ^oC. The extracts were centrifuged for 40 min at 10,000 g and the supernatant was discarded. Soil and/or sediment residue were then extracted twice with 0.25 M NaOH and 50 mM Na_2EDTA (1:20 solid to solution ratio) with a 16 hours shaking time at ambient laboratory temperature, and the extracts were combined. After each extraction, the samples are centrifuged for 40 min at 10,000 g. The supernatants from each sample were treated with gel filtration to remove NaOH. Typically, a G-25 Sephadex column (with a fractionation range of 100–5,000 mol wt, dry bead diameter of 20–80 mm, volume of 4–6 mL g^{-1}, column volume of 75.0 mL) was used. Twenty mL of the extract were then pipetted onto the top of the column and eluted with demineralized water by pumping at a rate of 0.6 mL min^{-1}. Leachate is then collected until litmus paper indicated an alkaline pH, suggesting that NaOH was passing through the column. A total of 110mL of the leachate, free from NaOH, was then freeze-dried for subsequent use for ^{31}P NMR analysis. Same method was used to prepare NMR sample for the sediment residual after algae cultivation at PH value of 4, 7 and 10. Total 16 NMR samples were prepared, as shown in Table 1.

NMR experiments and Instrumentation:

All measurements will be conducted on a Bruker Avance III Ultrashield 400-MHz NMR spectrometer equipped with a 5-mm inverse z-gradient broad-band probe head at 298 K. Topspin (Bruker) is used for data processing and analysis with further data analysis carried out in Microsoft Excel and Graph Pad Prism. All spectra will be collected without X nucleus decoupling to prevent sample heating during the measurement influencing the enzymatic reaction and causing drifts in the chemical shifts.

^{31}P NMR spectroscopy:

^{31}P is a spin 1/2 nucleus with 100% natural abundance, and reasonably good natural receptivity, 391 times larger than ^{13}C. The chemical shift range covered by ^{31}P-containing compounds covers more than 700 ppm, from 500 to -200, with 85% H_3PO4 used as the reference at 0.0 ppm. The high sensitivity of ^{31}P NMR makes the technique a reliable analytical tool similar to 19F and ^{1}H NMR.

The 31P-NMR signals of P compounds (both organic and inorganic) of interest in environmental studies generally fall between 25 and −25 ppm. These includes: phosphonates, with a C P bond, at 20 ppm; orthophosphate at 5–7 ppm; orthophosphate monoesters, with one C moiety per P, at 3–6 ppm; orthophosphate diesters (two C moieties per P), including phospholipids and deoxyribonucleic acid (DNA), at 2.5 to −1 ppm; pyrophosphate at −4 to −5 ppm; and polyphosphate at −20 ppm. Although rarely reported for environmental samples, a peak for the terminal P group in the polyphosphate chain should also be present at −4 to −5 ppm. (Fig. 1)

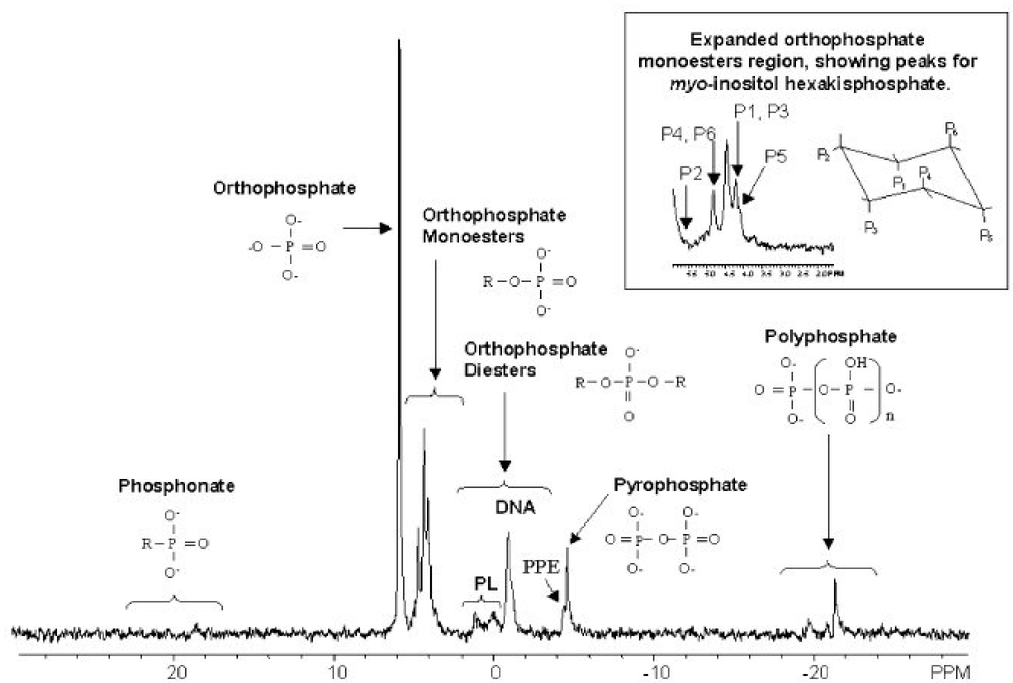

Fig. 3. A solution 31P-nuclear magnetic resonance (NMR) spectrum of a forest floor sample extracted with NaOH–EDTA [24], produced on a Varian Unity INOVA 500MHz spectrometer equipped with a 10mm broadband probe, using a 90◦ pulse, 0.68 s acquisition, 4.32 s pulse delay, 25 ^{o}C temperature, and 7Hz line-broadening. This spectrum shows the diversity of P species in natural samples, including phosphonates, orthophosphate, orthophosphate monoesters, orthophosphate diesters such as phospholipids (PL) and deoxyribonucleic acids (DNA), pyrophosphate and polyphosphate, with the terminal P in the polyphosphate chain indicated by PPE. The inset shows the expanded orthophosphate monoesters region, indicating the peaks and structure for *myo*-inositol hexakisphosphate (phytic acid).

Solution NMR spectroscopy

NMR Sample preparation

For NMR spectroscopy, a 20 ml aliquot of soil extract was spiked with 1 ml ofmethylene diphosphonic acid (MDPA) solution as an internal standard (either 50 or 67 mg P kg-1 soil), frozen at -35°C, lyophilized (~ 48 hours), and homogenized by gently crushing to a fine powder. Each lyophilized extract (~ 100 mg) was re-dissolved in 0.1 ml of deuterium oxide and 0.9 ml of a solution containing 1.0 M NaOH and 100 mM Na_2EDTA, and then transferred to a 5-mm NMR tube.

31P-NMR analysis

The P containing solutions were analyzed by a 400-MHz Bruker Avance spectrometer (Bruker AXS, Inc., Madison, Li et al. Chemical and Biological Technologies in Agriculture (2015) 2:7 Page 2 of 7 WI, USA), equipped with a 5-mm Bruker broadband inverse (BBI) probe, operating at 31P resonating frequency of 161.81 MHz, applying 6 s initial delay and a 45° pulse length ranging between 8.5 and 9.5 μs (−2 dB power attenuation). The 31P-NMR spectra of sample solutions were acquired from 5, 10, and 15 h of acquisition time. The 5 h of acquisition time comprised 3,000 transients and 5,461 time domain points, while the 31P spectra for the 15-h acquisition time consisted in 9,000 transients, 16,384 time domain points, and a spectral width of 250 ppm (40,650 Hz). Except for the samples used to determine the best acquisition time, the rest of the 31P-NMR spectra of this study were acquired with 15 h of acquisition time. An inverse gated pulse sequence, with 80-μs length Waltz16 decoupling scheme, with around 15.6 dB as power level, was employed to decouple phosphorous from proton nuclei. All spectra were baseline-corrected and processed by TopSpin software (v. 3.2). The free induction decays (FID) for solution-state 31P-NMR spectra were transformed by applying a fourfold zero filling and a line broadening of 6 Hz. Signals were assigned according to literature [1-4]. The relative proportions of P species were estimated by integration of 31P-NMR spectral peaks and expressed in respect to the concentration of total P in extracts (TPE).

Preliminary Results

Preliminary NMR data show that the sediment sample collected from the Reflecting Pool contains four inorganic and organic phosphorus species Chemical shifts of signals were identified as follows: inorganic phosphate, 6.41ppm; DNA, -0.14 ppm; pyrophosphate, -3.92 ppm; phosphate monoesters, between 4.0 and 6.0 p.p.m., with prominent signals at 5.70 ppm (Fig. 4) As more ^{31}P NMR data are collected, the concentrations of phosphorus compounds will be calculated from the integral value of the MDPA internal standard at 17.63 ppm. Comparison of the concentration of phosphorus species will be given, and the factors such as PH value and length of cultivation, and temperature on the uptake rate of phosphorus will be discussed.

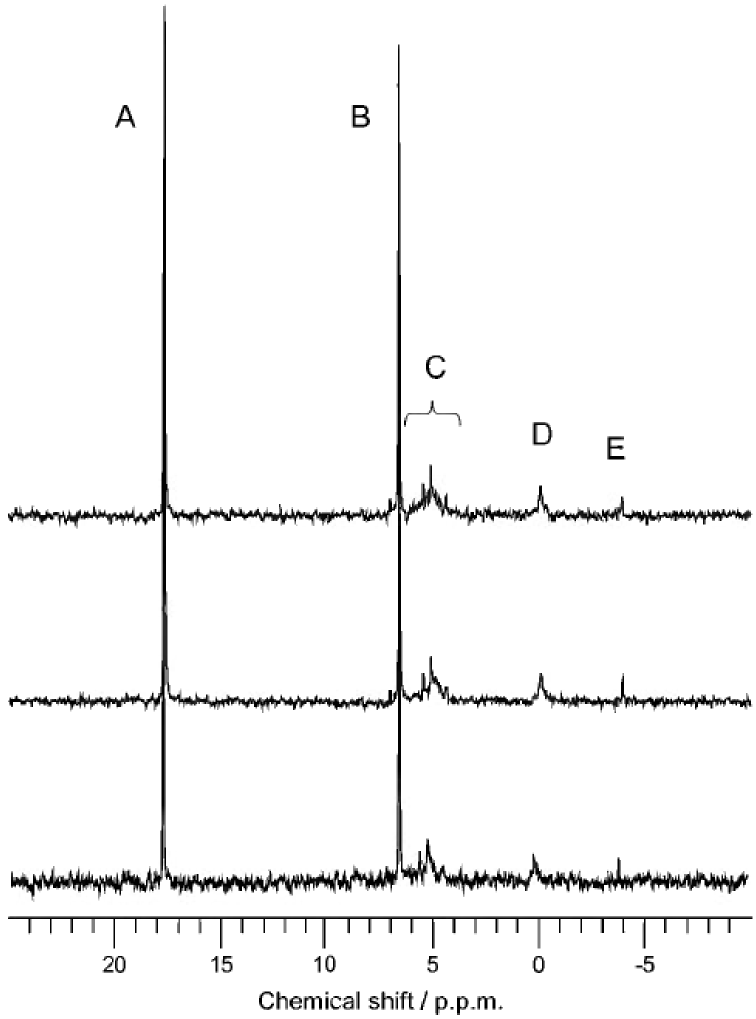

Figure 4. Replicate solution 31P NMR spectra of 0.25 M NaOH + 50 mM Na2EDTA extracts of a sediment sample (SE). The spectra are scaled to the height of the internal MDPA standard (66.7 mg P kg-1 soil) at 17.6 p.p.m. (signal A). Other signals were assigned as follows: B, phosphate; C, phosphate monoesters; D, DNA; E, pyrophosphate.

Reference

1. Cade-Menun BJ (2005) Characterizing phosphorus in environmental and agricultural samples by 31P nuclear magnetic resonance spectroscopy. Talanta 66:359–371
2. Makarov MI, Haumaier L, Zech W (2002) Nature of soil organic phosphorus: an assessment of peak assignments in the diester region of 31P NMR spectra. Soil Biol Biochem 34:1467–1477
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Developing a chance-constraint framework for optimization of long-term hydraulic performance of green roofs

Basic Information

Title:	Developing a chance-constraint framework for optimization of long-term hydraulic performance of green roofs
Project Number:	2014DC160B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	DC
Research Category:	Climate and Hydrologic Processes
Focus Category:	Education, Hydrology, Non Point Pollution
Descriptors:	None
Principal Investigators:	Arash Massoudieh, Pradeep K. Behera

Publications

There are no publications.

Progress Report on Performance evaluation of green roofs in Washington, D.C. using pilot study and modeling

Authors: Peter J. Horgan, MCE, Arash Massoudieh, Ph.D.

Abstract:

Green roof systems are a growing trend worldwide for stormwater management. In a city like Washington, DC, where there is a combined sewer system that leaks thousands of gallons of wastewater in to the local river systems, better management of rain water and the subsequent stormwater runoff is vital to avoiding these problems. Green roofs are one major resource at a city's disposal due to lack of space for other stormwater management systems. Using built prototypes to collect runoff data in the Washington, DC metro area and a simulation model to optimize the parameters of a built green roof. These parameters were tested running the simulation model using historical rain data in order to make further recommendations for future builds of green roofs for the area or areas of similar climate and precipitation records.

Table of Contents

Introduction

New development and urbanization has led to a large decrease in the quality of surface water as well increasing the amount of runoff that must then go through the public water system. For this reason, stormwater is managed in a variety of ways, with focuses on both quality of water (pollutant and sediment reduction) and quantity of water (flow mitigation and runoff retention).[1] The major pollutants as far as water quality is concerned are the nutrients of Phosphorus and Nitrogen. These come from developed sites, but also from fertilizers and multiple other sources. Street runoff is an issue in regards to the fact that solid particles like heavy metals will be picked up by rainwater and are attached partly to the suspended solids and eventually reach surface water. Roof runoff, depending on the material and condition of the roof, can also add significant pollutants into the watershed.[2] On the quantity front, peak runoff flows and total volume of runoff for any rain event will be larger with constructed areas, due to lack of infiltration, evaporation, and transpiration opportunities. To deal with both quality and quantity issues, stormwater must be managed. The best way to do this is through Best Management Practices of stormwater, or BMPs. Some

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[1] Joong Gwang Lee, Ariamalar Selvakumar, Khalid Alvi, John Riverson, Jenny X. Zhen, Leslie Shoemaker, Fu-hsiung Lai. "A Watershed-Scale Design Optimization Model for Stormwater Best Management Practices." *Environmental Modelling & Software* 37 (November 2012): 6-18.

[2] Siaka Ballo, Min Lui, Lijun Hou, Jing Chang. "Pollutants in Stormwater Runoff in Shanghai (China): Implications for Management of Urban Runoff Pollution." *Progress in Natural Science* 19, no. 7 (10 July 2009 2009): 873-80.

examples are bio-retentions, rainwater harvesting, stormwater ponds, green roof systems, and many more.

Green roof systems are being implemented across the world in cities to help manage stormwater. In general, a green roof system will consist of a layer of growth media in which plants will be growing above a drainage layer of some type, generally gravel or a similar layer.[3] Green roof systems can be effective in both the quality and quantity aspect of stormwater management. As long as there are not fertilizers in a green roof, the quality of the water will most likely be improved, as opposed to a normal roof system that would add pollutants and nutrients. This is due to the plants and soil using nutrients in the water, thus purifying the outflow and the retention of some of the pollutants as well as water in the medium. The real value to a green roof in regards to stormwater runoff, however, is on the quantity front. Green roofs are able to retain stormwater in the growth media (soil) for an extended period of time, and in doing so will reduce the total volume of runoff, as well as the peak flow

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[3] J Darkwa, G Kokogiannakis, G Suba. "Effectiveness of an Intensive Green Roof in a Sub-Tropical Region." *Building Services Engineering Research and Technology* 34, no. 4 (November 2013 2013): 427-32.

following a storm event.[4] They also are able to allow for more time for evaporation and transpiration in addition to the infiltration that they administer.[5]

When analyzing effectiveness on green roof studies, one way to look at results are with the average retention. This can be broken down by event, month, or any other time frame. If it is analyzed by season, it can be found that the average retention in the systems are highest in the spring, however because storms are larger and more intense in the summer, there is more actual rainfall held, albeit at a lower percentage of average retention. This may not be the case for many other climates or places with different rainfall patters, but this kind of analysis can be used for a study that is using the Mid-Atlantic or even the Northeast United States.

There are many design parameters that are vital to the performance of a green roof system. Each part of a green roof system contributes to the duration that it can retain or use water. One such parameter is the growth media of the green roof. This refers to the top layer of the system that the plants will be place in to grow and help with the efficiency of the roof. After testing and analyzing different types of amounts of growth media, it has been found that while the depth of this layer is important to

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[4] A.F. Speak, J.J. Rothwell, S.J. Lindley, C.L. Smith. "Rainwater Runoff Retention on an Aged Intensive Green Roof". *Science of the Total Environment* 461-462 (September 1, 2013 2013): 28-38.

[5] Virginia Stovin, Gianni Vesuviano, Hartini Kasmin. "The Hydrological Performance of a Green Roof Test Bed under Uk Climatic Conditions." *Journal of Hydrology* 414-415 (January 11, 2012 2012): 148-61.

the effectiveness in retaining water, it was limiting after a certain point.[6] This is important, because future designs can use the minimum amount of growth depth media, thus reducing material cost and load weight, all the while keeping the maximum efficiency of the roof. This sentiment was echoed in other studies that found that the depth of the substrate had no change on the ability of the roof to reduce pollutants and metals.[7] With both of these conclusions, it is found that neither quality nor quantities of runoff are affected by larger growth media. Another piece of a green roof design that can be looked into for effectiveness are the characteristics of the material used in the growth media, particularly their hydraulic retention properties. Different types of plants need differing amounts of water in differing amounts of time. When many different plants were tested to find which green roofs performed best, it was found that grass mixtures performed the best, as opposed to forbs, which were next best. Bare soil proved to be more effective than some sedum mixtures.[8] This study did not take into account, however, the water quality aspect of stormwater management. In general, however, if there is less runoff altogether, there will be less pollutants altogether. Hydraulic conductivity as a soil property proved to be one of

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[6] Abagail Graceson, Martin Hare, Jim Monaghan, Nigel Hall. "The Water Retention Capabilities of Growing Media for Green Roofs." *Ecological Engineering* 61 A (2013): 328-34.

[7] Martin Seidl, Marie-Christine Gromaire, Mohamed Saad, Bernard De Gouvello. "Effect of Substrate Depth and Rain-Event History on the Pollutant Abatement of Green Roofs." *Environmental Pollution* 183 (December 2013 2013): 195-203.

[8] Ayako Nagase, Nigel Dunnett. "Amount of Water Runoff from Different Vegetation Types on Extensive Green Roofs: Effects of Plant Species, Diversity and Plant Structure." *Landscape and Urban Planning* 104, no. 3-4 (March 2012 2012): 356-63.

the most influential pieces of the media mixtures that had an affect on the drainage time of the roof system. Many other inputs for a green roof design are vital to the performance in regards to quality and quantity. One of these could be the slope of the actual roof system, among other aspects of the design.[9]

Washington, DC has a combined sewer system which allots for the sanitary wastewater and stormwater run-off to flow together in the same lines throughout the city. Problems then arise during heavy rainfall events where the combined water line is at capacity. The city's wastewater treatment plant, known as Blue Plains, does not currently have a working backup facility, causing the excess water in the combined sewer line to flow out into the Potomac River, Rock Creek, and Anacostia River. Blue Plans calls this discharge Combined Sewer Overflow (CSO). This is a necessary problem, because the discharge outlets prevent home and street flooding, but at the same time cause several environmental problems, including the dumping of raw sewage into the rivers. Currently, swimming is banned by the District in any creek or river that is near the CSO outlets. The District's website even warns residents and visitors that the sewer pipe discharges can be harmful and dangerous. Currently there are fifty three of these CSO outlets in the DC stormwater management system.[10]

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[9] Morgan, S., S. Celik, and W. Retzlaff. "Green Roof Storm-Water Runoff Quantity and Quality." *Journal of Environmental Engineering* 139, no. 4 (2013): 471-78.

[10] Phong Trieu, Peter Guillozet, John Galli, and Matthew Smith. "Combined Sewer Overflow Rooftop Type Analysis and Rain Barrel Demonstration Project." edited by Department of Environmental Programs. Washington, D.C.: Metropolitan Washington Council of Governments, 2001.

DC is in the process of planning and constructing infaltiable and perminate dams that will trap the over flow wastewater and stop directly pouring wastewater into the surrounding rivers and creeks, as well as building underground storage for the overflow until there is working space in Blue Plains.

DC is also trying to promote the idea of installing stormwater best management practices to decrease the amount of stromwater entering the combined system in the first place. Green roofs are one place that this can be achieved. Other initiatives, like the ones run by The Anacostica Watershed Society, are giving away a rebates to residental, institutional, and commerical building owners that have a green roof system installed on their structure.

Impervious surfaces such as roads, other pavements, and roofs are the major causes of stormwater runoff in most urbanized areas. Without any water retention or the possibility of absorption, the water almost immediately flows to a central drain and into the combined sewer system, picking up pollutants and nutrients along the way. Flooding and erosion can occur if no water is retained or drained into pervious surfaces. Although a good drainage system can begin to mitigate these environmental issues, most urban areas do not have enough space to construct quality drainage infrastructure. This is a major reason why, in urban areas, green roof systems are one of the only options for stormwater best management practices.

Many cities across the world have begun to make green roof systems a priority in their runoff management plans. Cities like Copenhagen and Munich are leaders in utilizing the growing technologies. Washington, DC and neighboring city Baltimore are two of the more progressive cities in the United States as far as implementing these practices, possibly because of their proximity to the ever troubled Chesapeake Bay.

Green Roof systems have other benefits besides water treatment and retention. Due to the extra layer of insulation for a structure, energy can be conserved by using less heating and air conditioning systems. Another environmental issue that green roofs help to mitigate is that of the heat island effect, or urban heat island. Many cities are getting much warmer than their surrounding rural areas due to changing landscapes. Essentially, surfaces that were once vegetation or streams have been replaced by impervious surfaces are now exposed directly to the sun. The sunlight directly heats up these surfaces causing an increase in air temperature of that area. Cities have much more of these paved surfaces and less of the pervious surfaces that rural areas have, showing directly where the increases in temperature are coming from.

In 2001, researchers from Boston University showed the urban heat effect from Washington, DC to Boston using satellite measurements. The result for Washington, DC was alarming because it was showed that the urban area temperature in DC was steadily increasing to potentially unsafe levels compared the surrounding non-urban areas.

There are multiple courses to take for a city to reduce the heat island effect. This includes growing more trees in the urban areas, using cooler pavements when constructing roads and sidewalks, and other best management practices. However, one of the more cost effective and environmentally efficient ways of mitigating heat island effects is the use of green roof systems. Because of the vegetative layer, green roofs provide cool surfaces and remove heat from the air through evapotranspiration, reducing temperatures of the roof surface and the surrounding air. It is almost like simulating a ground surface on top of an existing structure. Green roof systems reduce heat transfer through the building roof, keeping the heat from bouncing back into the surrounding air by conduction. By adding an additional layer of insulation, green roof systems lower air conditioning demand, thus decreasing 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. 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 stormwater management costs, and potentially by the longer lifespan of green roofs compared with conventional roofing materials.

Green roof systems can be studied in different ways. The main ways that green roof systems can be effectively studied and experimented on are through simulation models using prototypes.[11] Past research has shown that prototypes with differing input parameters retained different amounts of water over different amounts of time, with varying outflows.[12] While this may seem obvious, it is an important starting point for current research. The design parameters can be optimized based on the climate and rainfall of any given location. That is the purpose of this research: to optimize the hydraulic performance of the green roof through simulating past rains through a model.

One past green roof system experiment consisted of four prototypes. One prototype consisted of standard roof membrane materials while the other three sections had green roof media with differing depths of 2.5cm, 6.3cm, and 10.1cm. These sections were subjected to specific rain intensity phases. The green roof prototypes delayed the drainage process longer than the standard roof membrane materials. This study also observed that the section with the largest media depth had the longest drainage period. This led to the conclusion that the best green roof media

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[11] Janet Snell, John Compton-Smith, Maureen Connelly. "Performance Evaluation of Green Roof Systems Using the Roof Evaluation Modules (Rem)." Vancouver, BC: British Columbia Institute of Technology Centre for Architectural Ecology, 2010.

[12] A. Palla, I. Gnecco, L.G. Lanza. "Compared Performance of a Conceptual and a Mechanistic Hydrologic Models of a Green Roof." *Hydrological Processes* 26 (2011): 73-84.

type to install to reduce rainwater runoff was that of the largest media depth. This was predicted at the start of the study.[13]

Another study tested three different styles of roof systems entirely; from the standard roof with gravel blast, an extensive green roof system without vegetation, and a green roof system with vegetation. All these prototypes were assembled in a wooden box each having equal 2.44cm by 2.44cm sections. 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. The hydrograph results showed that overall the green roof systems 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%. 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. This showed that even though there were deeper roofs, with a slope, this might not be helpful to the overall water retention of the system.[14]

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[13] Katherine Alfredo, et al. "Observed and Modeled Performances of Prototype Green Roof Test Plots Subjected to Simulated Low and High Intensity Precipitations in a Laboratory Experiment." *Journal of Hydrologic Engineering* (2005): 444-54.

[14] Nicholaus VanWoert et.al. "Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth." *Journal of Environmental Quality* 34 (2005): 1034-44.

Methods

Experimental Work

The research objective is to create a green roof simulation using a model that studies different prototype parameters and runoff data to automatically generate a design for future green roof projects.

Green roof system prototypes were designed and built with the goal of taking runoff data directly from the prototype. The prototype allowed for the gathering of observed runoff data from current rain profiles in the DC. A simulation using a mechanistic model that studies past and present runoff data was used to predict outputs for future green roofs of different sizes, slopes, and make ups.

The model was created by experimenting with the green roof prototype's soil depths, growing media, and slope. The different prototype sections allowed for the creation of the simulation's input parameters. With the gathered observed rainfall and runoff data the simulation is to generate the different parameters' hydrographs. The hydrographs are to display the runoff flow from the prototype's section over the rainfall duration, as well as allow for rain intensity to be measured. With the rain intensity and runoff flow we were able to calculate each prototype section's water retention efficiency. With these outputs, suggestion for future designs can be made to match any project's stormwater retention goal.

Prior research makes it is clear that green roofs are a great method to limit the amount and slow the process of storm water runoff. One of the articles stresses that more research should be done on the green roofs for the purposes of finding optimal soil type, climatic condition, and how green roofs may be able to reduce stress on sewer systems. With the combination of reduced slope and deeper media depth, it is clear that total quantity of storm water runoff can be reduced.[14] It was determined from the literature review research what parameters should be tested in the constructed prototypes.

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. The mosses 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. In order to decrease the weight of the green roof system it was found that pumice was a popular add mixture for soil that has an organic base. Pumice is a porous light weight rock that allows for some drainage when mixed with the heavier organic soil. Pumice was not able to be found for use in the soil mixture of the prototypes.

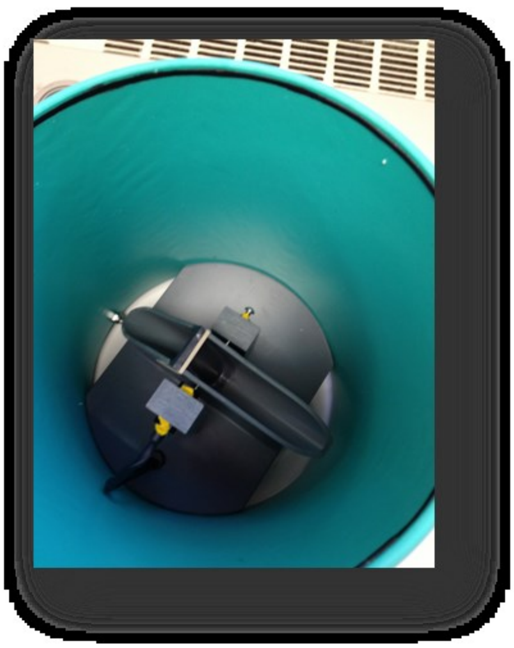
Locally, there are many green roof projects in the city of Washington, DC. The U.S. Department of Transportation is one agency that is actively trying to implement the technology wherever possible. The Department of Transportation has one example that layered its roof with a root barrier, filter fabric, and plants that are acceptable to the DC climate. Adding this local usage research to literature review research, the constructed prototypes were layered with, in order from bottom to top, all-purpose stone, filter fabric, combined organic soil (Miracle-Gro), and Irish moss and Scotch moss.

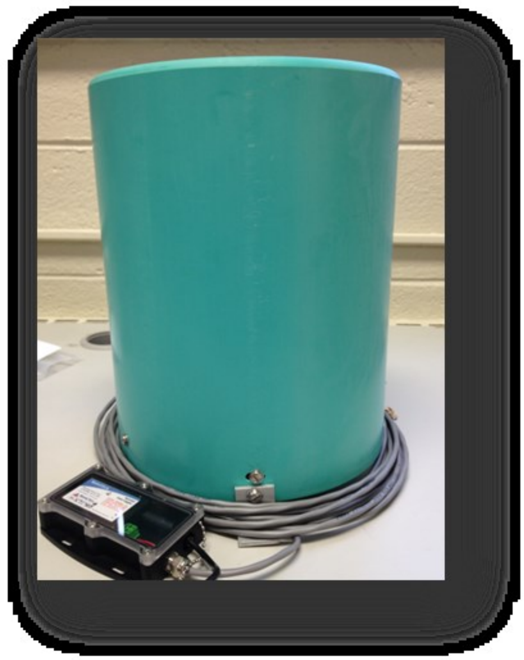
Using past studies along with local green roof models the prototype frame was designed to be three separate 3 foot by 1 foot sections. The frame and dividers were made out of 2x10 timber pieces and the bottom panel was made out of plywood to support the loads of green roof prototype's gravel and media. To ensure minimum error in the runoff data collection the frame was covered with a blue tarp and all seams were either caulked or glued on the top of the section dividers. A one inch gravel 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. A weed blocking landscape fabric was placed on top of the gravel in the soil to ensure 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. This particular mixture was chosen because it was tested by the manufacturer to absorb thirty three percent more water than other gardening soils. The soil also helps to prevent over or under watering which is perfect for the mosses' growing needs. The mosses were planted with space between each plant 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 a flow outlet.

The photograph shows the sections of the roof prototype as they stack up. The section on the left is the lowest level, the gravel. The section on the right shows just added soil layer. The middle section shows the completed overall section including the aforementioned gravel and soil, as well as the mosses.

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 runoff is recorded in a volumetric tipping bucket system. The bucket in the rain gauge is designed to tip and record after .01 inches of rain. With this, the flow rate of the runoff was able to be calculated and used in the simulation model.

The rain gauges that were used to monitor runoff from our prototypes are called the Rain101A, which operates on a simple "tipping bucket" principle. The Rain101A system is comprised of an eight inch funnel that collects water runoff and passes it to the calibration bucket that works continuously. After one side of the bucket fills to 0.01 inches of water, the bucket tips over to one side of the gauge, in a sort of 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 rain and water runoff conditions. The accompanying software program is set up prior to use of the system, and automatically puts the collected data into a simple table showing the time of each bucket tip of .01 inches. 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.

Three separate rain events were chosen to be used in the simulation. All of the rain events are from the year 2013. The first was a rain event beginning on June 28th and lasting until June 29th before picking back up on July 1st. This event was able to be split into two separate events when charted to better show how the model matched the prototype runoff; however, it only gave one data set output for the parameters because it was still modeled as one long event. The second event observed and then modeled was on July 3rd only. The third was on July 12th only.

The green roof prototype that was analyzed for each rain event was the prototype that was at an eleven percent grade. Two separate sections of this prototype were analyzed: the six inch media depth section and the three inch media depth section. This was the different identifier in the input of the simulation.

Simulation modelling is vital to a study of this nature. Running a model to match up with the real data that the roof prototypes are will calibrate the model, thus enabling the model to be used with any chosen inputs and it will give an accurate portrayal as to what that particular system will be able to accomplish.[15]

[15] M. Carbone, G. Garofalo, G. Nigro, P. Piro. "A Conceptual Model for Predicting Hydraulic Behaviour of a Green Roof." *Procedia Engineering* 70 (2014): 266-74.

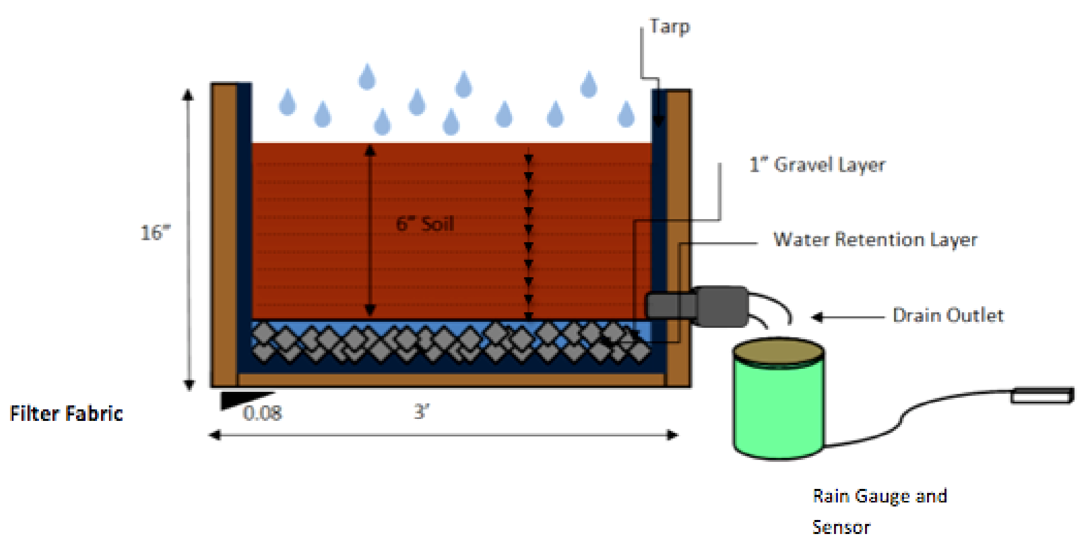
The stoichiastic model that was applied began with a generational model of one hundred generations and fifty sets of data per generation, known as the "population." Each generation optimizes the data to only the extent that it can. The following generation takes that set of changed parameters and automatically continuously calibrates the model to the data until the generations are through. After the one hundred generations, the modeled data should match the data from the prototypes.

The calibrated model will be able to tell give us the optimal parameters for a green roof system when it runs through the deterministic model for any given series of rain events.

Modeling

The figure below shows the schematic of the green roof. The vertical zones can be divided into freeboard, soil column, and gravel base. The one-dimensional model of the green roof has been developed using C++ language. The model considers vertical flow of water in unsaturated soil and the storage of water in the bottom of the green roof system. It also considers the effect of evaporation and transpiration as controlled by temperature and presence of plant roots. Richard's equation will be used to simulate rainfall percolation in the substrate:

$$\frac{\partial \theta}{\partial t} = \nabla \cdot \left[K \nabla \left(\psi + z \right) \right] - E\left(z\right) - T(z) \qquad (1)$$



The schematic of the green roof model

Where θ is the water content, t is time, K is the hydraulic conductivity which is a function of the water content, and ψ is the matric potential, e is the evaporation and T is transpiration. E is assumed to be exponentially decreasing with depth and is proportional to the difference between the saturated vapor pressure and air vapor pressure:

$$E\left(z\right)=k_E e^{-k_{ez}z}(e_s-e_{air}) \qquad (2)$$

Transpiration is also considered to be dependent to root biomass and temperature. The relationship between K and θ and ψ and θ, namely the soil retention parameters are provided by ((van Genuchten 1980, van Genuchten and Parker 1984)). [16] [17]

The storage at the bottom of the green roof is modeled using simple water balance:

$$\frac{\partial V(h_s)}{\partial t}=q_u A-k_d(h_s-h_d) \qquad (3)$$

[16] van Genuchten, M. T. "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils." *Soil Science Society of America Journal* 44, no. 5 (1980): 892-98.

[17] van Genuchten, M. T., and J. C. Parker. "Boundary-Conditions for Displacement Experiments through Short Laboratory Soil Columns." *Soil Science Society of America Journal* 48, no. 4 (1984): 703-08.

where V is the volume of water stored in the bottom of the green roof which depends on the h_s, the stored water depth and the slope of the green roof, q_u is the flow rate from the topsoil which can be negative when the flow is upward due to capillary pressure, k_d is the drainage coefficient of the drain, and h_d the elevation of the drain above the lowest point of the floor of the green roof.

The first objective of this research is to use the data collected during a wide range of weather conditions to estimate the parameters including soil hydraulic retention parameters, evapotranspiration parameters and drainage coefficient. An evolutionary optimization-based code has been developed and linked to the green roof model to perform this task. Also a Markov-Chain Monte Carlo (MCMC) parameter has been developed to perform the parameter estimation stochastically. The parameter estimation will by evaluating the objective function using runoff and soil moisture data collected over the course of multiple rain events by running the model continuously. This allows estimation of the parameters that are effective during dry times such as parameters controlling evapotranspiration. These parameters are very important for realistically predicting the long-term performance of green roofs as the main mechanism of elimination of water over long-run is evapotranspiration.

Results and Discussion

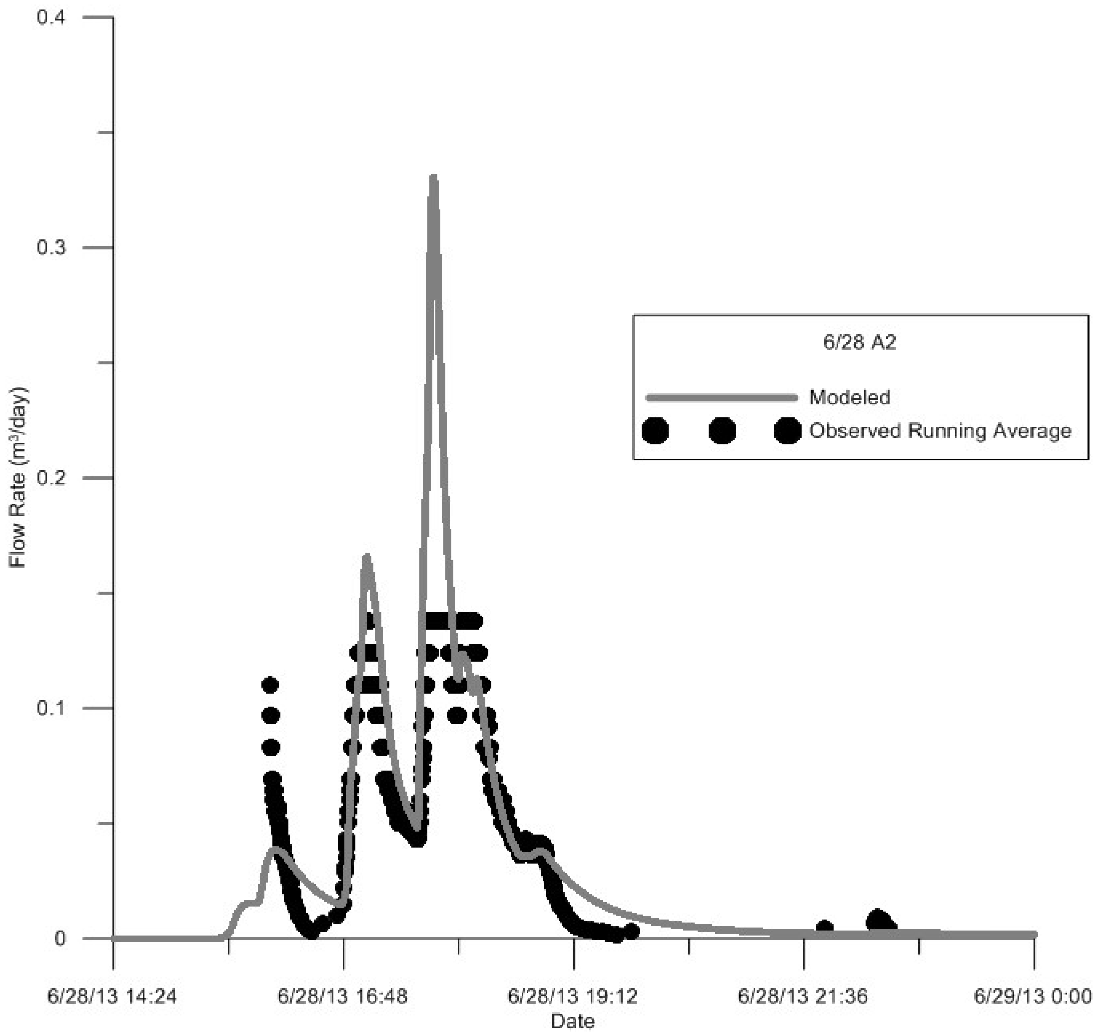
Model Calibration

Once the models were run, the observed runoff was able to be compared with the modeled runoff with adjusted parameters. Each rain event investigated gave slightly different results.

The following charts show the flow rates over time out from the prototype as well as what the model said the prototype's outflow could be.

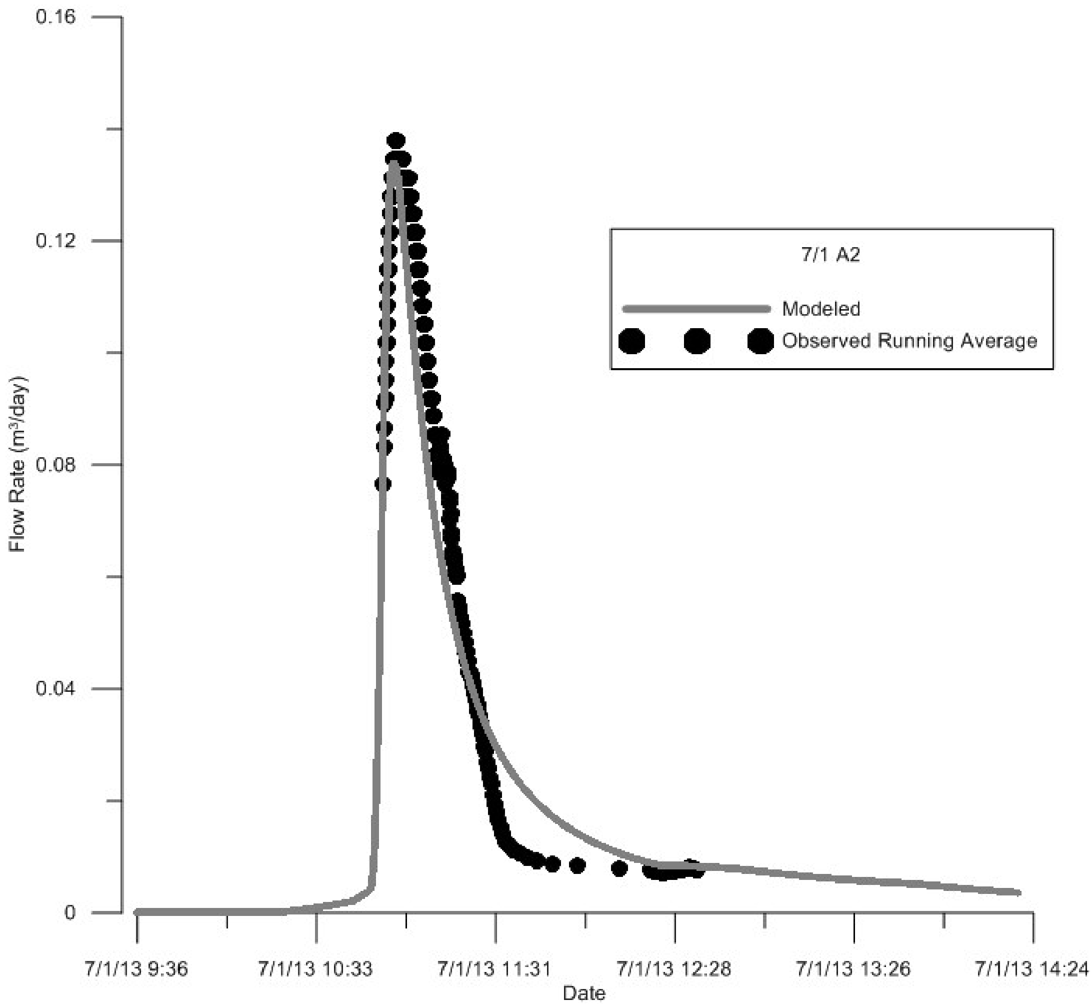
First, the section of the prototype that was examined, and ultimately gave the best and most usable data, had six inches of growth media as well as planted mosses. This section of the prototype is called "A2".

For the rain even on June 28th, the following results were graphed comparing the observed runoff from the rain gauges and the modeled results. In order to get a clearer picture of the observed data, a running average was taken that averaged every five results, thus making a smoother line on the graph:

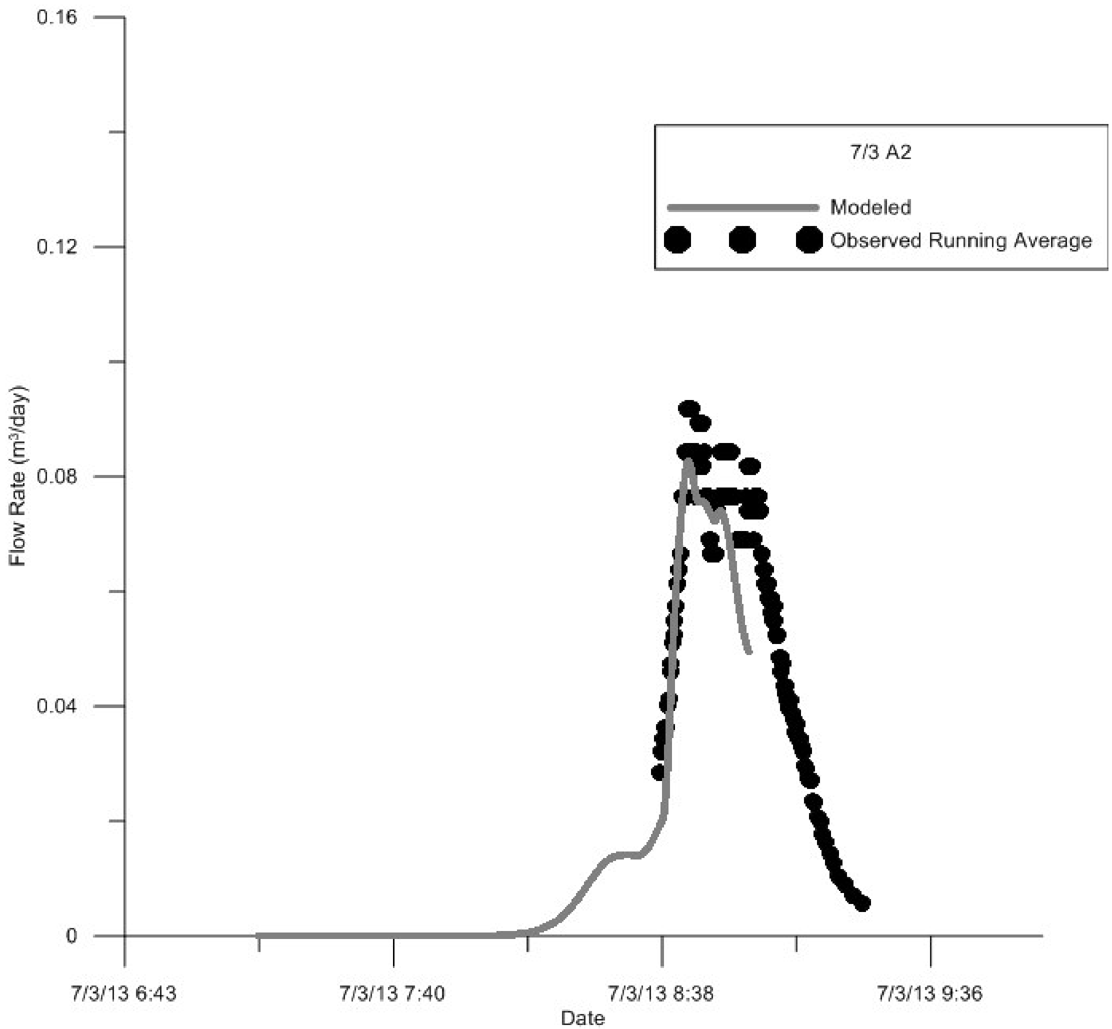


The modeled runoff is potentially even a better representation of reality due to the data logger only being able to record a tip in the bucket once every five seconds. This is the reason for the spike in the modeled line that does not exist with the observed data.

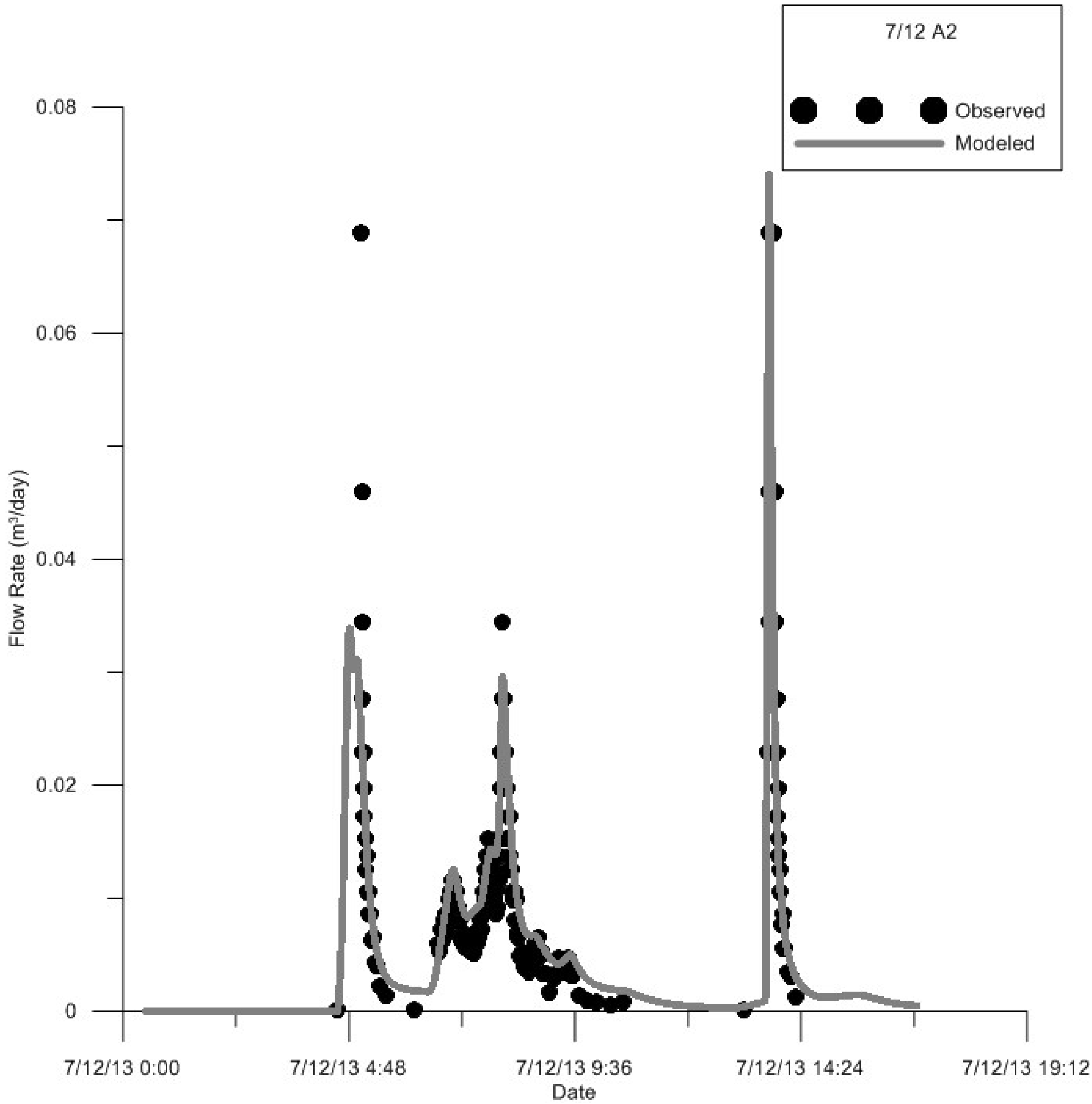
The July 1st rain event showed how one simple rain event would affect the roof system. The model matches with the observations very closely:



The July third rain event had a few intensity spikes that both the model and the observations followed. The discharged maxed out at a small 0.1 cubic meters per day:



July 12th's rain even had multiple spikes which led to the model and the actual runoff to spike in unison, as well. Despite the multiple rain spikes during the event, the model never had a discharge higher than .08 cubic meters per day.



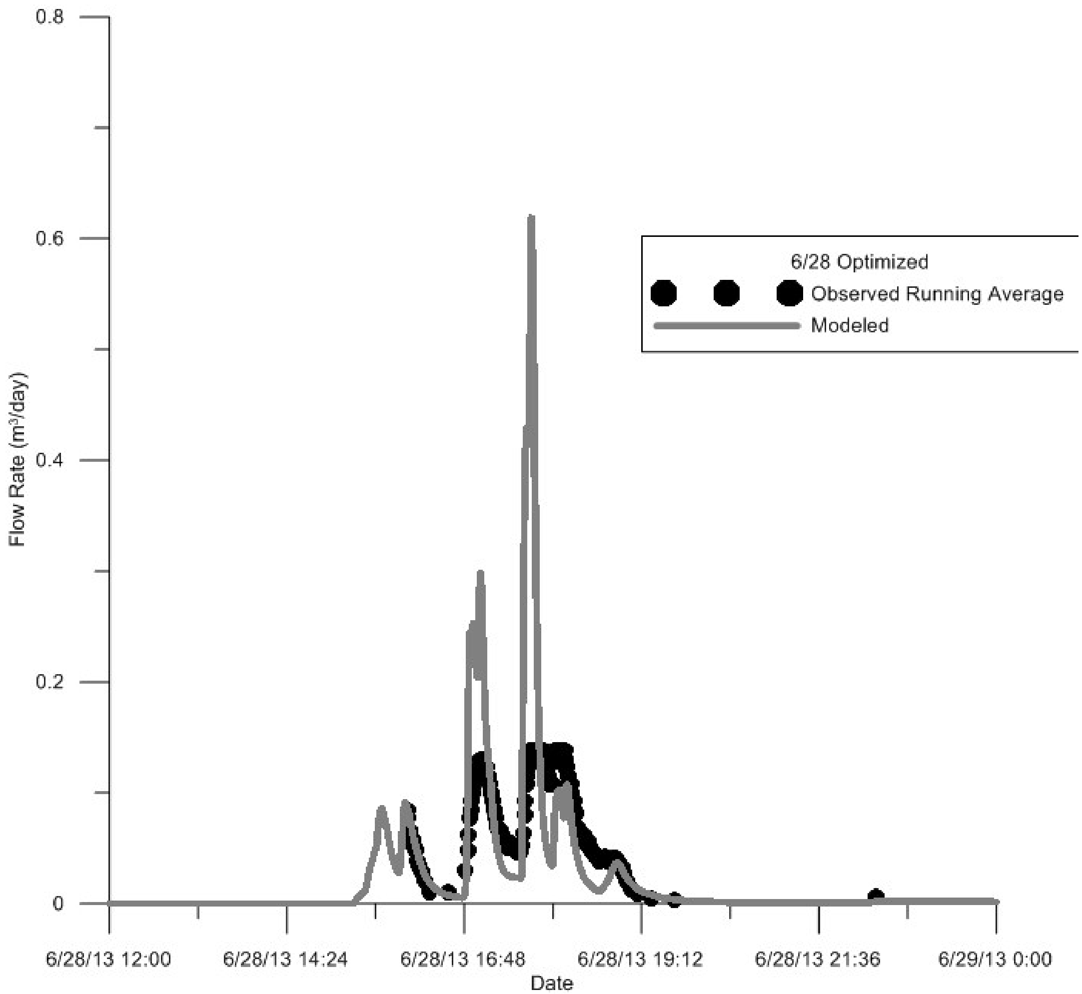
The prototype section that only had three inches of growth media, known as A3, gave less than desirable results in the following charts. The data logger could not log each tip of the bucket fast enough to get the actual runoff. This is due to there being less space in the media for sorption and thus more flow running off at the same time. The simulation still ran to a somewhat effective end.

Model Application

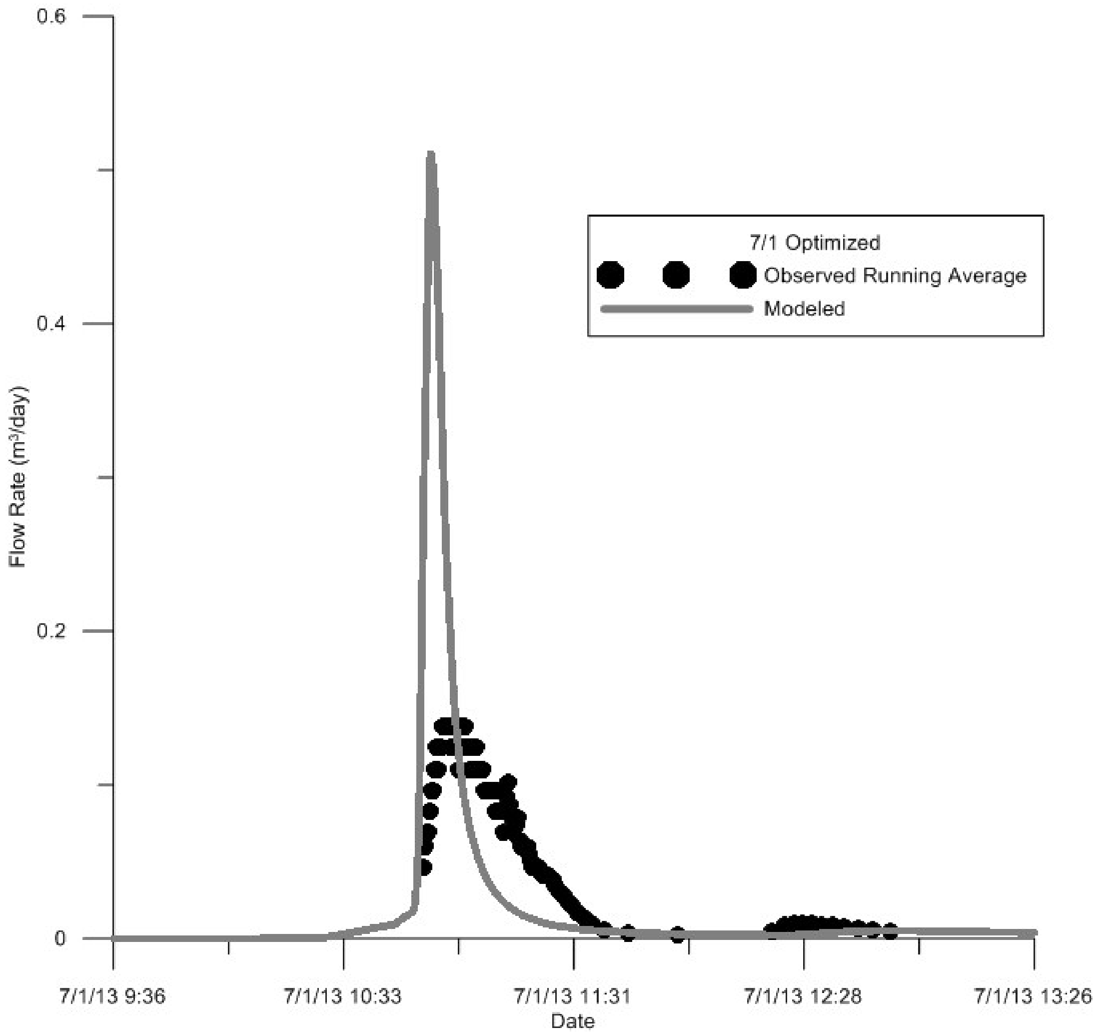
The parameters that were optimized by the simulations are summarized in the following chart. Each rain event for the A2 prototype gave a different set of parameter results. In order to use one set for an optimized parameter set, the three results were simply averaged. This averaged set of parameters became the set that could be used to rerun the models and recommend for future design.

A2	Ks	alpha	n	theta0	theta_r	theta_s	bot_thresh	drain_coeff	std
1-Jul	247508.6	0.2747	8.3021	0.4552	0.0771	0.7067	0.0504	30000.0	0.5270
3-Jul	147747.6	3.5764	5.0806	0.2154	0.1370	0.6387	0.0198	162749.2	1.0618
12-Jul	691889.7	3.6334	4.2507	0.1798	0.1470	0.8312	0.0221	448583.8	1.1294
Average	362382.0	2.4948	5.8778	0.2834	0.1204	0.7255	0.0308	213777.7	0.9061

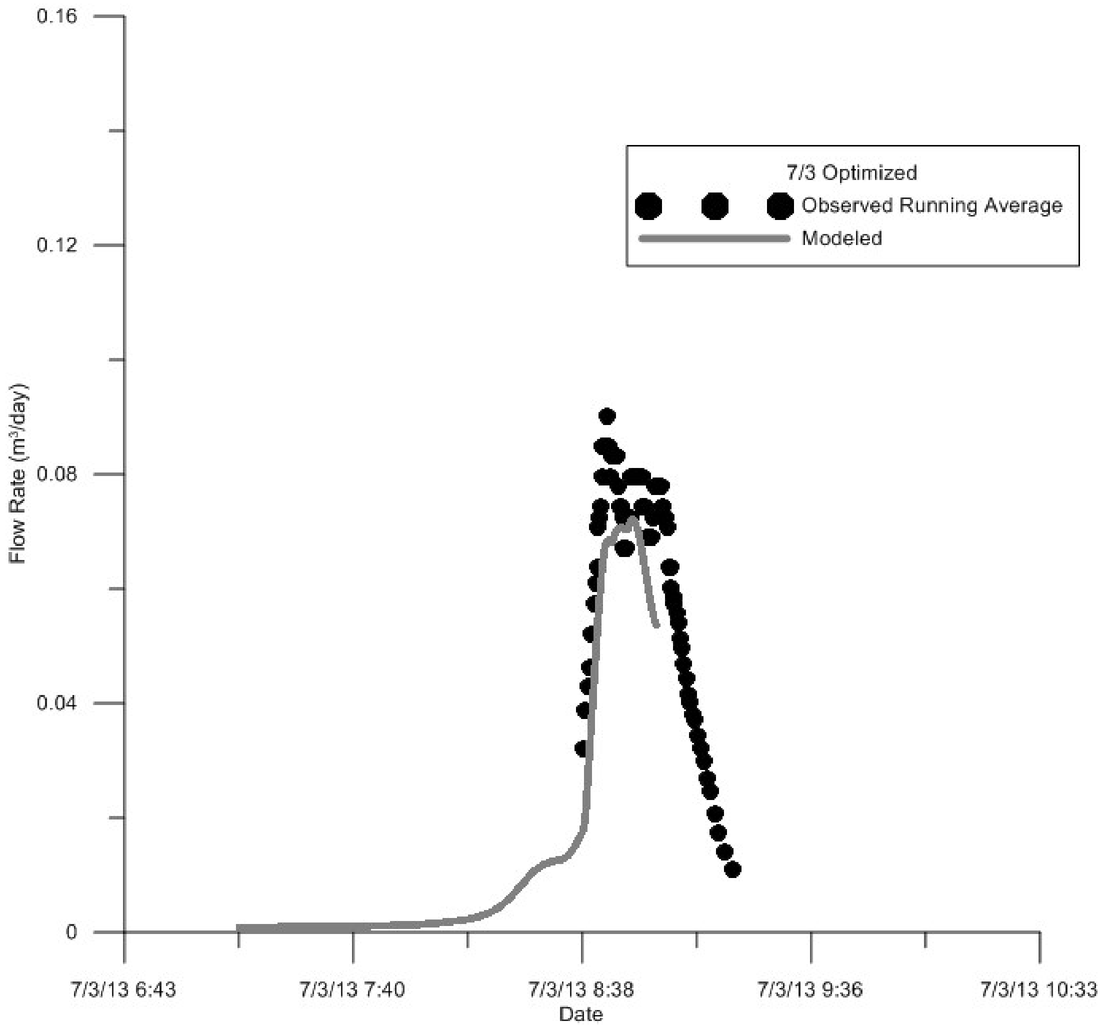
Using this set of parameters gives the following charts for the same data series that were shown above. The optimized set should theoretically improve them all, but because the relatively small sample of three was averaged, there are points in which the flow is actually higher than the previous sets of data.



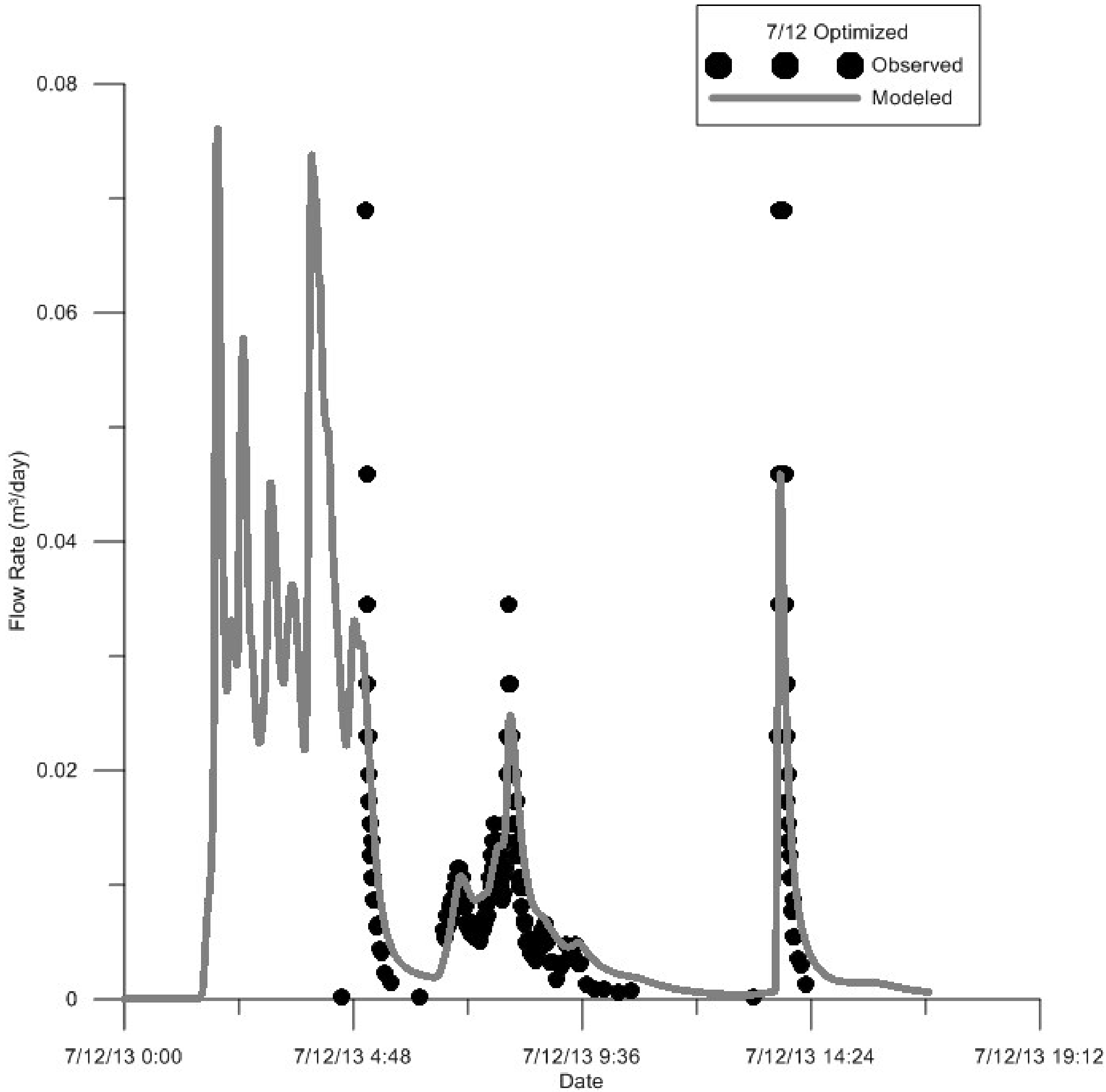
The optimized model for the June 28th rain event mimics the observations, but at the same time increases the maximum discharge. When compared to the non-averaged optimized model that ran originally, this simulation actually had close to two times as large of a maximum discharge, meaning that the optimized averaged parameter set did not help for this rain event. This could be due to a larger hydraulic conductivity of the soil in the averaged parameter set.



The July first event in the optimized model had about half of the maximum flow rate that the non-optimized model proved to have. In this case, the model was helped by the averaging of the three optimized parameter sets.



The event on July third showed that the model was effective in lowering the maximum flow rate compared to the observed data. When compared to the non-averaged optimal parameters, which had a maximum flow rate above .08 cubic meters per day, this model stayed just under .08 cubic meters per day.



The July 12th event had discrepancies at the start of the event with the model spiking, but stayed consistent for the rest of the event with the observations. Aside for the possible error in the model at the start of the ev3ent, the maximum flow rate determined by the model is less than the max flow rate from the non-optimized model. For this event, the optimized average parameters were effective.

The averaged optimized series of parameters was able to then be used as a baseline for a potential design. To test this, rain event data from the past sixty-two years, starting in May of 1948 and going until June of 2010 was used and simulated using the same model, running forwards. The rain data was taken from the Ronald Reagan International Airport collections.

Each month's total rain aggregate was found and the months were then sorted from the lowest total rainfall to the highest. Representative months were chosen out of these data series to be examined. In order to get a good representation, instead of just using the months with the most or least overall rain, months that were closest to the fifth percentile and the ninety-fifth percentile were used. The "wet" month in the fifth percentile that was used was May of 1971 with 6.8 total inches. The "dry" month in the ninety-fifth percentile that was used for the model was September of 1990 with only .87 inches of rain. The month that was directly in the fiftieth percentile of all of the months, March of 1973 with 2.93 inches, was also further examined to see how the model and optimized parameters would do during an average month of rain events.

Each month was separately run through the model using the optimized parameters that were found. To evaluate the overall effectiveness of the optimized roof system in that particular month, an efficiency index was created. The purpose of this index would be to compare tinkered iterations of the optimized parameter set in order to further the effectiveness of the proposed green roof system. The index was simply the squared integral with respect to time of the out flow from the model divided by the squared integral with respect to time of the actual rain itself from the month in question. This simply gives a unit-less number between zero and one that shows how much of the water was retained (or the peaks have been reduced by) in the roof while otherwise it would have been immediate runoff flow.

$$Efficency\ Index = (\int f\,(t)^2 dt)/(\int f_b\,(t)^2 dt)$$

The first set of tinkered parameters in the optimized model was to lower the initial moisture content of the soil to assume that the roof was relatively dry prior to the upcoming month of precipitation. This was done throughout.

The next set of parameters that were slightly changed to further the effectiveness of the green roof system in the model was the depth of soil. The simulation looks at the soil media in layers, putting together the depth of the layers and the number of layers to form the total media. The original parameter set had a soil media of six inches and by changing the depth of each layer, the months were each run again with roof soil depths of twelve inches and twenty-four inches.

The average rain month of March, 1973 was the month chosen for being in the middle of all the examined months as far as total precipitation. The efficiency of the roof systems with differing media depths are summarized in this chart, showing that the increases in media depth certainly help the system retain more water for longer:

Media (inches)	Efficiency Index
6	0.08795
12	0.08460
24	0.08041

The examination of the month with high precipitation (May, 1971) led to similar overall results. As expected, the efficiency index lowers with larger media depth, to an even more drastic end than when compared to the month with less rain overall:

Media (inches)	Efficiency Index
6	0.09292
12	0.09092
24	0.06431

It can also be noted from these particular simulations that the efficiency index of roof system is higher and therefore less effective when dealing overall with the higher amounts of rain that were seen in May of 1971.

September of 1990 was the month examined that had minimal rain. The original roof model had no outflow to begin with, and this was mirrored when the media was expanded and the underdrain height was elevated.

The next parameter from the optimized model that was changed to see if it would improve the model was the bottom threshold of the system. This was doubled from .03 meters in the automatically optimized parameter set to .06 meters for the following simulations, and again doubled to .12 meters. Theoretically, putting the underdrain higher would increase the roof's efficiency due to the increase in available volume for storage of rainwater.

March of 1973 had efficiency indexes decrease as the underdrain height was increased:

Underdrain Height (m)	Efficiency Index
0.03	0.08795
0.06	0.08404
0.12	0.07644

May, 1971 showed similar results when increasing the underdrain height, except when the drain was modeled to the highest .12 meters:

Underdrain Height (m)	Efficiency Index
0.03	0.09292
0.06	0.02351
0.12	0.00000

The storage of the roof took care of all of the water and required no drainage. It could then be assumed that all of that water was still in the roof when the next rain events occurred, or if enough time had passed, that the water in storage evaporated.

September of 1990, with the low rainfall, again had negligible outflow coming from the outflow due to the low amount of overall precipitation.

Conclusions

Green roof systems are an effective way for cities and land developers to manage stormwater runoff. In order to optimize the design of the system so that it manages the most water while at the same time staying at a reasonable construction scope and maintenance cost is a tricky balance. This simulation model takes rain events through a prototype roof system and optimized what that system could do to improve. With optimized parameters as a starting point for design, and with maximum parameter possibility in mind, an optimal design for a green roof system can be made.

By taking the optimal parameters from actual rain events and tinkering with them in the simulation over different periods of time in the past that proved to have much different precipitation levels, it could be found what the effectiveness of the green roof system could be, and how it could easily be improved simply by changing one or more design aspects of the roof itself. The design aspects that were specifically looked into here are the depth of the soil/growth media, as well as the height of the underdrain where the volume of stored water would leave the roof.

The most average month of rain for the region in the time frame looked at was March of 1973. The roof system worked to an extent when using the original optimized parameters that came from averaging the optimized outputs from the model when looking at the July, 2013 rain events. When March, 1973 was run again through the model with larger media depths and higher underdrain heights, the efficiency improved linearly. This linear relationship was expected for the average month of rain. In order to make the best possible roof system looking at the parameters that were tinkered with, one must find the maximum practicable design parameters for the specific design, like how high the underdrain can be and how much weight can be added through extra media depth before the roof would need further structural support. This model series shows that for the average month for the region, the averaged optimized parameters can be improved simply by changing those very simple design inputs.

When examining a month of rain data that was considered to be very high rain, it was found that the optimized parameters could be expanded upon to further improve the roof system's effectiveness. May, 1971 consisted of a high amount of total rainfall, and the original optimized roof system would have done a decent job of slowing down the runoff over time and reducing the peak runoffs. This was furthered when the model added media depth and raised the underdrain. The heavy rain events were able to be offset by the increased storage at the bottom of the roof and increased usage in the soil.

September of 1990's rain was entirely contained by the roof system's original optimized parameters. For this month, adding media depth and underdrain height would have no effect except to add cost to a project. For a climate that is generally dry, where September of 1990 would be an average month with regards to rainfall, the original parameter set would be sufficient.

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Geochemical characteristics of an urban river: detecting the influences of an urban landscape

Basic Information

Title:	Geochemical characteristics of an urban river: detecting the influences of an urban landscape
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Start Date:	3/1/2014
End Date:	2/28/2015
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Descriptors:	None
Principal Investigators:	Stephen E. MacAvoy

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1. Connor NC, Sarraino S, Frantz D, Bushaw-Newton K, MacAvoy SE. (2014). Geochemical characteristics of an urban river: influences of an anthropogenic landscape. Applied Geochemistry 47:209-216.
2. Williamson, G and SE MacAvoy (2014). Comparing Economic and Ecological Benefits of Green Roof Systems. Proceedings of the 12th Annual Green Roof and Wall Conference.

Geochemical characteristics of an urban river: detecting the influences of an urban landscape

Progress Report

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Submitted to DC Water Resources Research Institute, University of the District of Columbia

May 4, 2015

1. Executive Summary:

This progress report describes the current status of the the project "Geochemical characteristics of an urban river: detecting the influences of an urban landscape". The study is examining geochemical/nutrient data and land use patterns in the Anacostia River and its tributaries in order to identify the impact of urbanization on water chemistry. The specific objectives of this research are 1) to determine concentrations of nutrients in this anthropogenically influenced river in the United State's capital, 2) characterize relationships among geochemical components to assess the importance of concrete versus natural geochemical controls and 3) test the hypothesis that urban areas have higher ionic strenght derived from Ca and Mg than suburban areas (Ca and Mg are two dominant cations associated with concrete).

Several months of geochemistry data have been collected and are presented in the report. However, an analysis of the data will need to wait until the project is closer to completion. The project will contine as planned through the summer and into the fall 2015.

2. Introduction

The Anacostia River contains a variety of contaminants from various sources including road runoff, atmospheric deposition of contaminants, millions of gallons of raw waste and treated water from purification plants (which may contain hormones or hormone mimicking organics). These contaminants have a documented impact, with organisms from clams to fish experiencing poor health (Washington Post 2005). While progress is being made to ameliorate some of the pollution problems in the river, the long-term changes to basic water chemistry have been overlooked. The stream is urban and cannot avoid expressing the chemical fingerprint of its altered watershed. This watershed contains a great deal of concrete, an artificial conglomerate rock that dissolves under acidic precipitation. The "extra" ions that are presumably released could create conditions of high ionic strength waters, which will impact invertebrates and fishes living in them. One of the goals of the DC government is to make the Anacostia swimmable and fishable by 2030. Understanding the extent of chemical change resulting from an urban location is an important but largely overlooked feature of the river. We have a good understanding of toxic effects associate with organic chemical contaminants, however we do not know the chronic effects of water chemistry change for these systems.

For example, the literature bears multiple examples of the dramatic effects that impervious surfaces can have on watersheds. Those effects may be chemical as well as hydrological. Specifically, runoff from urban areas (where concrete is a major conglomerate rock) can lead to increased pH, conductivity, and modified ionic composition (Gaillardet et al. 1999; Gallo et al. 2013; Hasenmuller and Criss 2013; Wright et al. 2011). For example, a 2011 study examining the influence of concrete drainage systems on streams in Sydney, Australia found that, in comparison to reference streams, urban streams showed increases in alkalinity/buffering capacity and pH, as well as Na. Cl, and Ca. (Wright et al. 2011). Additionally, they suggest that significant amounts of Ca, HCO_3, and K ions in urban streams could originate from contact with concrete drainage pipes (Wright et al. 2011). Also a critical issue for the river is nitrogen concentrations (nitrate and ammonium in particular). While urban streams generally have less nitrogen than agricultural streams, the Anacostia's can be high and should be monitored (MacAvoy et. al. 2009; Connor et al. 2014). Clearly, the altered urban landscape can influence the geochemistry and nutrients of natural river systems; examining the geochemical controls of urban rivers could be an important factor in fully understanding how development impacts their health and biodiversity.

The document is a progress report on our project examining geochemical and nutrient data from water column samples in order to identify controls on the Anacostia River, Washington DC, and compare that data to the more sub-urban/ex-urban Northwest Branch in Maryland. The specific objectives of this research are 1) to determine concentrations of nutrients in this anthropogenically influenced river in the United State's capital, 2) characterize relationships among geochemical components to assess the importance of concrete versus natural geochemical controls and 3) test the hypothesis that urban areas have higher ionic strenght derived from Ca and Mg than suburban areas (Ca and Mg are two dominant cations associated with concrete).

To date, we have collected water chemstry from 6 sites during 3 months (November, January and February). A fourth field collection from the sites is scheduled for May 8th. Each water sample has 32 chemical characteristcs examined, from inorganic cations (Ca, Mg etc), metals (Pb, Cu etc), and nutrients (nitrate etc.).

3. Method

Water Collection:

There are 6 water collection points. These are made monthly or bimonthly. The six sites are dived between 3 in suburban Maryland (along the Western Branch: Greenbelt, Paint Branch and Long Branch) and 3 in the Anacostia mainstem: Bladensburg, Kenilworth Aquatic Gardens and Navy Yard). The water is transported to back to the lab analyzed at American University, Cornell (water/soil lab) and the University of Alaska. Data to be collected includes nitrate, nitrite, ammonia, phosphate, conductivity, pH, Mg, Na, Cl, K, Ca, Ni, B, Cd, S, Sr, Pb, and Cr (among others) using standard EPA 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/.

Total Suspended Solids (TSS): Collected water will be filtered using 47mm glass as per EPA method 340.2.

Land use patterns: Data from the District Department of the Environment and US Geological Survey will be used to create maps of land use and geology. These will be converted into data to be examined alongside the aqueous geochemistry to test for trends.

Statistical Analysis: Principle Components Analysis (PCA) is a powerful method for analyzing co-variation among many variables in large data sets, and will be used to examine the 32 water chemical variables analyzed in this study. When considering relationships among geochemical or nutrient variables indicated by the PCA, the subjective practice of only considering loadings of greater than 0.5 as qualifying for interpretation will be used (Puckett and Bricker 1992). Those over 0.75 will be interpreted as additionally important. As Puckett and Bricker (1992) point out, this is more conservative than criteria by some other researchers (for example: 0.4 for Miller and Drever (1977), and < 0.4 for Reeder et al. (1972)). Data will not be transformed (log or otherwise) prior to the PCA. The PCA can be thought of as a way of linearly transforming the data as it is arranged in three-dimensional space. Since the results of the PCA are a way of organizing the data and were only to be used to examine relationships, as opposed to generating models (regressions for example), raw data were used (Jolliffe, 2002).

4. Results

The two tables of geochemical data (from November 2014 (Table 1) and January 2015 (Table 2) below are representative of information collected thus far in the study. The data have not been analyzed for trends or correlations among the variables because it would be premature to do so.

Date reported: 11/19/2014			Greenbelt	Paint Branch	Bladensburg	water park	navy yard	longbranch
samples ID			117141	117142	117143	117144	117145	117146
pH			7.33	7.26	7.41	7.20	7.42	7.01
soluble salts	mmho/cm		0.48	0.25	0.32	0.34	0.31	0.33
hardness	mg eq CaCO3 /L		85.49	70.10	109.73	117.16	109.64	105.43
SAR	mmol/L		10.18	4.05	3.65	3.77	4.26	3.25
Cations								
Ca	mg/L		22.92	17.88	30.61	34.58	29.57	28.07
Mg	mg/L		6.86	6.18	8.08	7.48	8.69	8.58
Na	mg/L		216.98	78.26	88.08	94.06	102.72	77.00
K	mg/L		6.15	7.24	7.74	11.01	8.33	8.72
Fe	mg/L		0.47	0.29	0.04	1.60	0.57	0.15
Mn	mg/L		0.00	0.00	0.00	0.00	0.00	0.01
Zn	mg/L		0.00	0.01	0.00	0.01	0.00	0.01
Al	mg/L		0.02	0.00	0.00	0.00	0.00	0.00
Total elements & anions								
As	mg/L		0.01	0.02	0.02	0.02	0.01	0.02
Ba	mg/L		0.00	0.00	0.00	0.00	0.00	0.01
B	mg/L		0.01	0.01	0.01	0.08	0.02	0.01
Cd	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Cl	mg/L		188.97	90.45	109.22	86.41	118.36	106.05
Cr	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Co	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Cu	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Mo	mg/L		0.00	0.01	0.00	0.00	0.00	0.00
Ni	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
P	mg/L		0.01	0.02	0.02	0.07	0.03	0.03
Pb	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
S	mg/L		3.54	2.87	4.60	8.14	5.50	2.60
Se	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Si	mg/L		2.30	3.05	3.31	3.92	3.52	3.89
Sr	mg/L		0.12	0.07	0.12	0.15	0.13	0.16
Ti	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
V	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
NN4-N	mg/L		0.00	0.00	0.02	0.50	0.15	0.00
NO3-N	mg/L		0.00	0.24	0.01	0.08	0.41	0.07

Table 1. Geochemical and nutrient concentrations collected November 2014.

			010815Green Belt	010815Paint Branc	010815Longbrar	010815Blad	010815waterpark	010815Navy yard
samples ID			108201501	108201502	108201503	108201504	108201505	108201506
pH			7.17	7.38	7.20	7.37	7.48	7.44
soluble salts	mmho/cm		1.34	1.62	5.18	1.84	1.91	0.42
hardness	mg eq CaCO3 /L		325.23	116.20	313.42	123.96	221.15	99.69
SAR	mmol/L		53.50	42.27	120.32	47.79	36.08	7.51
Cations								
Ca	mg/L		97.61	30.92	86.00	34.37	67.53	28.11
Mg	mg/L		19.79	9.47	23.97	9.26	12.76	7.16
Na	mg/L		2223.43	1050.53	4910.24	1226.47	1236.30	172.87
K	mg/L		12.61	9.01	17.35	8.56	14.51	5.04
Fe	mg/L		0.59	0.64	0.08	0.37	0.27	0.27
Mn	mg/L		0.70	0.24	0.28	0.18	0.33	0.21
Zn	mg/L		0.04	0.01	0.03	0.01	0.01	0.01
Al	mg/L		0.02	0.10	0.00	0.02	0.13	0.03
Total elements & anions								
As	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Ba	mg/L		0.20	0.10	0.38	0.09	0.09	0.05
B	mg/L		0.03	0.02	0.01	0.01	0.06	0.01
Cd	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Cl	mg/L		1162.08	656.35	1745.60	747.15	768.21	158.68
Cr	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Co	mg/L		0.01	0.00	0.00	0.00	0.00	0.00
Cu	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Mo	mg/L		0.00	0.01	0.00	0.00	0.00	0.00
Ni	mg/L		0.01	0.00	0.00	0.00	0.00	0.00
P	mg/L		0.01	0.02	0.01	0.01	0.01	0.01
Pb	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
S	mg/L		9.48	5.81	11.60	5.52	14.94	5.37
Se	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
Si	mg/L		3.82	3.37	5.40	3.34	4.49	3.14
Sr	mg/L		0.79	0.14	0.57	0.16	0.30	0.12
Ti	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
V	mg/L		0.00	0.00	0.00	0.00	0.00	0.00
NN4-N	mg/L		0.07	0.00	0.01	0.00	0.17	0.25
NO3-N	mg/L		0.08	0.40	1.20	0.37	0.16	0.39

Table 2 Geochemical and nutrient concentrations collected January 2015.

5. Conclusions

There are no conclusions at this time. The project is still in the data collection stage and will be for some months to come.

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Appendix

1. Student Support (for current project)

Category	Number of Students Supported
Undergraduate	1
Master	1
Ph.D.	
Post Doc.	
Total	2

2.. List of publications (APA format) Publications are derived from several years of WRRI funding, not the current project.

- Peer reviewed journal article
- Connor NC, Sarraino S, Frantz D, Bushaw-Newton K, MacAvoy SE. (2014). Geochemical characteristics of an urban river: influences of an anthropogenic landscape. *Applied Geochemistry* 47:209-216.

- Bushaw-Newton KL, Ewers E, Fortunato CS, Ashley JT, Velinsky DJ, SE MacAvoy. (2012). Bacterial community profiles from sediments of the Anacostia River using metabolic and molecular analyses. *Environmental Science and Pollution Research* 19 (4): 1271-1279.

- MacAvoy SE, Ewers E, Bushaw-Newton K. (2009). Nutrients, oxygen dynamics, stable isotopes and fatty acid concentrations of a freshwater tidal system, Washington, D.C. *Journal of Environmental Monitoring* 11:1622-1629.

- Conference proceeding
- G. Williamson, and SE MacAvoy. 2014. Comparing Economic and Ecological Benefits of Green Roof Systems. Proceedings of the 12th Annual Green Roof and Wall Conference.

- SE MacAvoy, E Ewers, and KL Bushaw-Newton. 2007. Biogeochemical snapshot of an urban water system: The Anacostia River, Washington DC. EOS Transactions of the American Geophysical Union 88 (52) B51D-03

- Poster presentation (attach poster): Title, Author, and title of the symposium or conference
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urban stream syndrome" Nicholas P. Connor, Stephanie L. Sarraino, Deborah E. Frantz, Karen Bushaw-Newton, Stephen E. MacAvoy

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  S.L. Sarraino, D.E. Frantz, K Bushaw-Newton and S.E. MacAvoy

- 12/16/10 American Geophysical Union, Annual Meeting. San Francisco CA. "Seasonal nutrient dynamics in the Anacostia River (D.C., USA): geochemistry and hydrocarbon biomarkers"

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Determining the Feasibility of Simulating the District of Columbia’s Department of the Environment Proposed Stormwater Volume Trading Market Using Agent-Based Modeling

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Determining the Feasibility of Simulating the District of Columbia's Department of the Environment Proposed Stormwater Volume Trading Market Using Agent-Based Modeling

Progress Report

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1. Executive Summary

This document provides an overview of a project funded through the DC WRRI Seed Grant program that focuses on a new and innovative way to simulate the adoption of green stormwater infrastructure (GSI) at the parcel or site level in an incentive-based framework through the use of agent-based modeling (ABM). The information presented in this report reflects aspects of ongoing PhD research by one of the authors to provide background and context for the research efforts, while other information is associated with efforts more directly related to the grant-funded efforts.

The primary purpose of this effort is to investigate the feasibility of using an ABM approach to simulate the Stormwater Retention Credit (SRC) trading program developed by the District of Columbia District of the Environment (DDOE). To support this goal, other tasks are needed, such as identifying and collecting data, reviewing literature on key aspects of the research effort, such as GSI practices and costs, applications of ABMs similar in approach, and behavioral economics in environmental areas. The feasibility of modeling the SRC program will be based upon available data as well as the development of a methodology to synthesize data into quantifiable relationships that can be modeled. A simple generalized model will be developed based upon the findings of this effort, which will help to inform future more complex modeling efforts.

2. Introduction

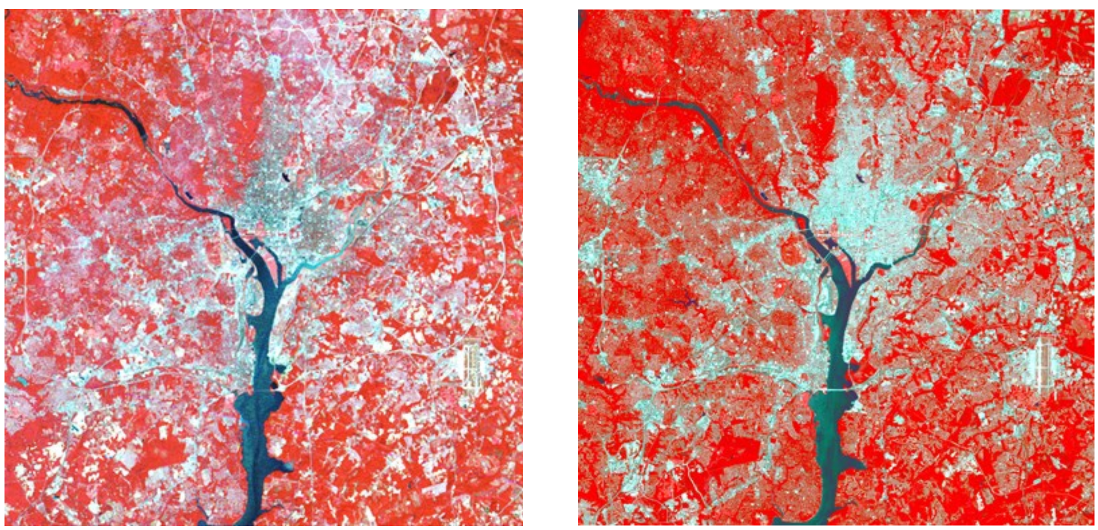
The Rising Challenge of Urban Stormwater Runoff

The physical drivers behind these increasing pollution levels are associated with pollutants that are washed off the landscape by stormwater runoff. Additional impacts are generated when combined sewer systems (CSSs), which are designed to convey both sanitary and stormwater flows concurrently, are overwhelmed and lead to the discharge of raw or partially-treated sewage to receiving waters. In both instances, the underlying cause for increasing runoff is tied to our urban footprint. The United States Environmental Protection Agency (EPA) expects between 800,000 and 1,000,000 acres of newly developed land to be generated annually over the next 25 years (U.S. EPA, 2012a).

While even the low end of this range is a significant amount of developed land area, this represents less than one percent of the current total developed land area in the U.S. (USDA, 2009). Impacts from existing impervious cover have been driving stormwater-related pollution since the onset of urbanization. Regulations addressing urban stormwater runoff were promulgated for the first time in 1990; therefore, a significant portion of existing developed land area continues to discharge stormwater runoff that neither managed nor treated. In the District of

Columbia (DC) and surrounding areas, urbanization has changed the landscape over the past 300 years, but more recently this area has experienced an increased rates of urbanization. Figure 1 shows the increased in urbanized area and associated impervious surfaces between 1972 and 2012.

In recent years, EPA has faced growing criticism about the effectiveness of its stormwater regulatory program to address the corresponding water quality impacts. These impacts are significant and affect all portions of the country. To better assess its existing regulatory program, EPA asked the National Research Council to review the program and provide suggestions for improvement. The Council released its report, Urban Stormwater Management in the United States, in early 2009 and was critical of many aspects of EPA's regulations, and concluded that "[r]adical changes … are necessary to reverse degradation of fresh water resources and ensure progress toward the Clean Water Act's goal of 'fishable and swimmable' waters." The District of Columbia (DC) and surrounding areas have experienced high rates of urbanization, which is the main driver for stormwater runoff impacts. Figure 1 shows the increased in urbanized area and associated impervious surfaces between 1972 and 2012. Over this time, there has been an increase in combined sewer overflows (CSOs) in combined sewer areas and an upward trend in the degradation of headwater streams an urban water quality associated with MS4 areas. These dynamics have also led to a continuous decline in the overall quality of the Chesapeake Bay.



a b

Figure 1 – Impervious Cover Change between 1972 (a) and 2012 (b) (Source: LANDSAT data, NASA) (Red is impervious surface)

Overview of District of Columbia Stormwater Runoff Credit Trading Program

To address the problems cites in the NRC report, the EPA is currently engaged in a rulemaking to update the regulations associated with their stormwater program. A new national performance standard – the first of its kind – was expected to be a central feature in this rulemaking with a central focus on on-site retention requirement, such as the capture/infiltration of certain percentile storms on site. While this rulemaking eventually stalled, it is expected to become revived in the near future. Regarding, the spirit of this retention-based requirement is consistent with the newly-adopted MS4 permit administered by the District of Columbia Department of the Environment (DDOE), which requires the on-site retention of the 90th-percentile storm, which equates to events of 1.2 inches and less. Concerns have been raised by the land development community that this new requirement may significantly increase the cost of developing or redeveloping land in the District. Some fear this new requirement may not only stifle development within the District, but may drive development to suburban "green field" development.

To combat these fears, DDOE has proposed a new regulatory framework that allows owners/developers of regulated sites, after achieving a minimum of 50% of this volume on site, to have the option to use off-site retention in the form of Stormwater Retention Credits (SRCs), purchased from the private market, or in-lieu fee, paid to DDOE. SRCs are expected to be lower-cost and therefore more commonly used than in-lieu fee. DDOE's program is designed to provide flexibility for regulated sites while maximizing the benefit to District waterbodies. It is anticipated that buyers of credits will consist of developers/owners of sites in the urban core/downtown area while credits are expected to be generated outside the urban core area. These roles are defined by the logic that meeting the new on-site retention requirement in the dense urban core using vegetated roofs and cisterns, for examples, is more costly than capturing equivalent volumes in less dense areas outside of downtown by using practices such as porous pavement and bioretention. This redistribution of volume retention will also benefit the environment by providing greater protection to non-tidal headwater streams of the Anacostia River, which are more susceptible to the impacts of flashy urban flows, at the cost of greater discharge of flows to the tidal Potomac River, which can better absorb urban discharges with nominal impacts to water quality or ecology. Similarly, the increased vegetative cover associated with green infrastructure practices expected to be used by SRC-generators will increase property values, reduce urban heat island effects, enhance public health, and provide a greater aesthetic value to these areas.

Overview of Project Concept and Study Goals

The framework proposed by DDOE is both novel and significant; however, it is the first of its kind, so it is unknown how successful and active this "market" will be and what the consequences of it may lead to. One way to simulate and predict how this market may function is through the use of ABM. This is a relatively new approach used in the social sciences and macroeconomic fields to model complex systems to study emergence and behavioral-based patterns. Using this framework, "agents" may be individuals, groups, firms, or companies who are identified and given decision-making properties that affect how various types of agents interact. Helbing and Balietti (2006) state that ABM is a, "method that (is) suited for the computer simulation of socio-economic systems," and that, "the behaviors and interactions of the agents may be formalized by equations, but more generally they may be specified through (decision) rules, such as if-then kind of rules or logical operations...this makes the modeling approach much more flexible." The development of an ABM to simulate the proposed stormwater volume trading market will help to predict how the market may behave and aid in the enhancement of conditions that may help to improve the performance and effectiveness of the framework. Similarly, this process may help to spell out a process that can be used to analyze other urban areas in an effort to determine the feasibility of a similar market-based program for ultra-urban stormwater management that may lead to a more cost-effective outcome.

The overall approach of this research is to analyze the information and data available to determine the feasibility of simulating the DDOE SRC trading market using an ABM approach. The scope of the work will be limited to studying agent identification, key decision making parameters impacting agent interactions, and potential impacts or unintended consequences of a successful and robust stormwater volume trading market.

Available data by local public institutions and beyond will provide a basis for the agent analysis and early model development. Agents will be identified after a review of the DDOE trading program and associated material that informs the key stakeholders identified as drivers of the market. Agent properties will be determined through a combination of a thorough review of the literature, a careful inventory of available data from local public institutions, and possibly an engagement with key stakeholders to survey their motivations regarding decision making involved in the stormwater volume trading market. Interviews with key public staff with DDOE as well as DC Water and other related institutions will be considered in an effort complement the information gathered in related efforts. The target of these efforts will be to:

- Identify and collect spatial GIS-based data, regulatory information through research and attending DDOE trainings, and other data sets that have the potential of being useful to the study;
- Perform a literature review of GSI practices, ABM, and decision-making dynamics and develop a comprehensive list of agents needed to accurately simulate the proposed trading market as well as determine the key decision-making factors used by agents and stakeholders in the modeled market;
- Synthesize a feasibility assessment of the proposed approach based upon the results of the literature review and data gathering efforts;
- Develop a simplified conceptual model based upon feasibility assessment determination output.

As listed above, the ultimate objective of the research will be to determine the feasibility of modeling the proposed stormwater volume trading market using the ABM approach. Assuming this objective is met and the determination is positive, other secondary and supporting objectives include the development of an initial ABM including a comprehensive set of agents, environmental constraints and parameters, and the decision-making information to model at least portions (pilot areas) of the system prior to scaling up to cover the entire District.

3. Literature Review

This research covers a variety of technical areas, including green stormwater infrastructure (GSI), agent-based modeling (ABM), theories on decision-making dynamics, diffusion of innovation principles, and social network behavior. This section provides background on these topics as it pertains to this study.

Overview of Green Stormwater Infrastructure Practices (Adapted from Brown, 2014)

When presenting information on GSI, EPA states that this type of infrastructure, "uses vegetation, soils, and natural processes to manage water and create healthier urban environments" (U.S. EPA, 2014a). The universe of GSI practices varies between regulated entities, but there are common categories that have emerged. The following is a subset of GSI practices listed by U.S. EPA (2014) along with a brief definition of each:

- Downspout disconnection
- Rainwater
- Rain gardens (bioretention)
- Planter boxes
- Bioswales
- Permeable pavements
- Green roofs

Differing types of GSI practices are more suitable for specific situations and landscapes, reflect varying treatment levels, and provide unique benefits. For instance, green roofs are well-suited for high-density urban areas, such as on large industrial or office buildings (U.S. EPA, 2014a), can reduce total annual runoff from a building envelope by 60 to 70 percent (Kohler, 2006), and can reduce temperatures on building rooftops by between 40-60 degrees Fahrenheit (Gaffin, et al. 2005). These practices are generally categorized as being extensive or intensive in profile, with the former being considered "thin" and defined as having a substrate of 5-15 centimeters with the latter having a more robust profile of greater than 15 centimeters (Carter and Butler, 2009). In Germany, where green roof technology is widespread (Pederson, 2001) over 80 percent of green roofs are extensive (Harzmann, 2002). Due to the ubiquitous nature of extensive green roofs, that this will be the default considered when discussing green roofs.

The typical extensive green roof includes four components: a waterproof membrane, a drainage layer, a growing medium, and a vegetative covering layer (see Figures 2 and 3). A study by Li and Babckock (2014) illustrates how green roofs used widely in an area has, "the potential to mitigate flash flood risks, reduce stresses on downstream storm drainage structures, and return to a more natural, pre-development hydrological cycle." More specifically, this study illustrates that stormwater runoff volume can be reduced by 30 to 86 percent and reduce peak flow rate by 22 to 93 percent. Costs for green roofs typically range from $30 to $40 per square foot (U.S. EPA, 2009a).

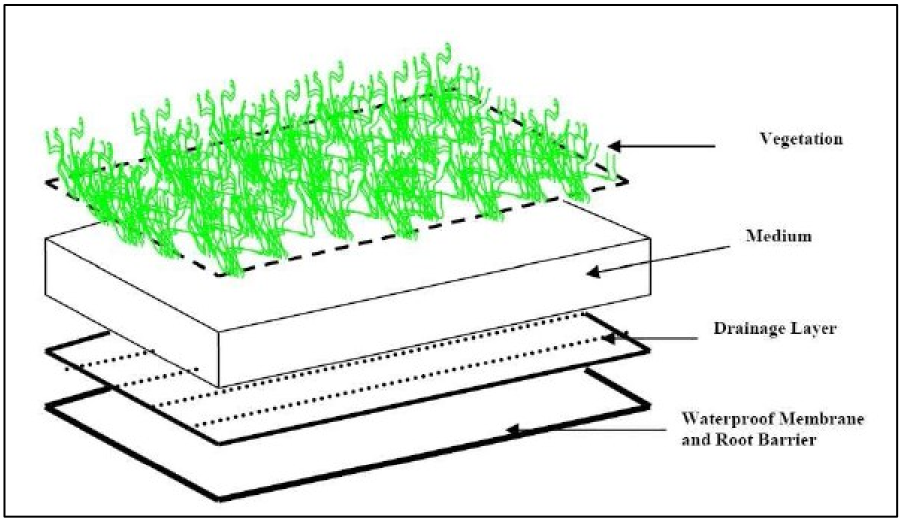


Figure 2 – Typical cross-section of an extensive green roof system (From Berghage et al, 2007)

Figure 3 – Typical green roof application (Source: Evan Bindenglass, CBS New York)

In urban areas, it is common practice to hydraulically tie rooftop and building drainage directly to receiving separate or combined collection sewer systems. These systems are commonly referred to as downspouts. Breaking this connection between building and site drainage from downstream receiving collection system infrastructure is referred to as "downspout disconnecting". The purpose of this practice is to eliminate direct connections between impervious areas, which allows for opportunities for on- or near-site retention through rainwater harvesting or infiltration practices. A common configuration is to divert rooftop or building drainage to a bioretention facility or a cistern. See Figure 4 for an illustrative example of a downspout disconnection.

Figure 4 – Typical downspout disconnection configuration (From LID Center, 2005)

Studies have shown that disconnecting downspouts can mitigate volumetric-driven dynamics for drainage systems. Salim et al. (2002) showed that a downspout disconnection program in Detroit, Michigan will reduce the directly connected impervious area by between 40 and 44 percent. Additionally, this study showed that approximately 2 billion gallons of combined sewer overflow (CSO) would be avoided annually due to downspout disconnections. The City of Portland, Oregon disconnected over 56,000 downpouts between 1993 and 2011 leading to a reduction of CSO volume of 1.3 billion gallons per year (City of Portland, 2011). Carmen et al. (2014) showed a runoff volume reduction between 59 and 99 percent by coupling downspout disconnections and directing to residential lawns in the Durham, North Carolina area.

Rainwater harvesting (RWH) is the capturing of runoff generated from impervious areas (most commonly rooftops) in a storage facility. The American Rainwater Catchment Systems Association (ARCSA) highlights that although rainwater harvesting systems have been used for thousands of years, there is a renewed interest in this practice. ARCSA notes this interest is due to the concern for access to high quality water, the rising cost of potable water distributed by a central resource, health concerns related to the treatment of potable water, and the cost efficiency associated with rainwater harvesting (ARCSA, 2012).

RWH systems can range from 40-gallon "rain barrels", used most commonly in residential applications, to 10,000-gallon cistern systems. The two most common types of RWH approaches when addressing stormwater management are shared and integrated systems (Reidy, 2010). A shared system holds a harvested amount of rainwater to be used for on-site purposes with a detention volume made available to address runoff generated by precipitation events. The detention volume is used as "buffer" volume for storm events and is drained through a controlled discharge. The harvested volume is used between storm events for on-site purposes. An integrated system combines the two volumes together (detention and harvested) with an automated system to discharge harvested rainwater as needed (Reidy, 2010).

Volume captured for a RWH varies depending upon purpose. For instance, if meeting a regulatory requirement for on-site retention, a system may be sized to meet this volume. Reidy (2010) points out that typical systems accommodate the volume generated from a 2-inch rain event, which can account for most retention standards (if they exist locally) along with a harvested volume. For instance, in Washington, D.C. the on-site retention requirement for new construction is to capture runoff from the 1.2-inch rain event. A system accommodating the 2-inch storm would meet this regulatory requirement with additional storage for non-potable uses. Harvested water associated with RWH systems are most commonly used for non-potable uses (irrigation, toilet flushing, etc.). These non-potable uses comprises approximately 30 percent of potable water uses for residential properties (Vickers, 2001) and up to 86 percent for office/business properties (Frye, 2009). The cost for a typical RHW ranges between \$2 and \$5 per gallon captured, which roughly translates to \$2 to \$5 per square foot of impervious treated (assuming 1.6 inches of runoff is captured per square foot of impervious area treated). Figure 5 illustrates urban and residential RWH applications.

Figure 5 – Typical Rainwater harvesting tank in an urban setting (left) (Source: www.sswm.info) and typical rain barrel application (right) (Source: www.rainbarrel.org)

Rain gardens/bioretention facilities capture runoff and provide enhanced water quality treatment while also providing aesthetic value to landscapes. These facilities can be adapted for suburban as well as urban settings, making bioretention facilities a common GSI practice (Hunt and Lord, 2006). Rain gardens generally comprised of small depressed areas capturing small areas of runoff (between 0.25 and 1 acre) that use a mixture of sand and organic filter media to treat pollutants that is aided by woody and herbaceous vegetation (U.S. EPA, 1999b).

These facilities provide relatively high treatment capacity for a variety of pollutants including heavy metals, nutrients, sediment, and oil/grease (Low Impact Development, 2007).

Additionally, these facilities can provide significant water quantity treatment through infiltration into surrounding soils (where in situ soils have infiltrative capacity) or underground detention (Low Impact Development, 2007). Costs associated with rain gardens typically range from $3 to $4 per square foot of impervious area treated (Coffman et al., 1999), which is an order of magnitude less than the typical per unit cost for green roofs. See Figure 6 for a typical urban bioretention application.

Figure 6 – Typical bioretention application (Source: Vermont Watershed Management Division, 2013)

Planter boxes, also known as stormwater or infiltration planters, are bioinfiltration-based structures with vertical walls normally located in transportation corridors or parking areas. Planter boxes can be depressed to readily capture and retain urban runoff generated on sidewalks and roadways, or they can at ground level to capture runoff from downspout disconnection efforts. These practices can exfiltrate directly to underlying soils or can be tied into drainage infrastructure. Due to their linear and compact design, planter boxes are ideal for dense urban areas (Philadelphia Water Department, 2014). The design and function of planter boxes mirrors bioretention facilities. The cost for planter boxes, ranging from $3/80 to $7.70 per square foot of impervious treated (Natlab, 2013), tends to be slightly higher than a rain gardens since they are often located in challenging areas with high amounts of existing infrastructure and other site constraints. See Figure 7 for a typical planter box application.

Figure 7 – Typical planter box (Source: Philadelphia Water Department, 2014)

Bioswales are channels lined with grass or vegetation with a relatively flat longitudinal slope (normally <2%) and flat side-slopes (normally < 1:3) (U.S. EPA, 1999c). While these practices provide runoff conveyance, they are configured to be less hydraulic efficient than traditional drainage swales in order to provide water quality treatment through filtering and infiltration. Check dams are used in some cases to enhance infiltrative capacity, and filtering media can be used under the bioswale for added pollutant removal efficacy (U.S. EPA, 1999c). Bioswales can be used in many settings, but are particularly well-suited for linear applications, such as roadway medians or shoulders and parking lots (U.S. EPA, 1999c). These practices can be used in suburban as well as urban applications, and are relatively inexpensive, as the cost to construct these practices range from $1 to $2 per square foot of impervious area treated (Natlab 2013, King and Hagan, 2011). Figure 8 shows an urban bioswale.

Figure 8 – Typical urban bioswale (Source: American Forests, 2012)

Permeable pavements allow water to soak through paved areas, such as parking lots, roadway shoulders or basketball courts. Pavement types vary from porous asphalt to pervious concrete, which allow runoff to drain through the pavement, and include permeable pavers, which are blocks of solid pavement spaced apart to allow for infiltration to occur. Other pavements include open-matrix pavements constructed with plastic cells filled with crushed stone. A study by Brattebo and Booth (2003) investigated the durability as well as infiltrative capacity and pollutant removal efficacy of four types of permeable pavements (two open-matrix and two paver applications). The investigators found little sign of wear after six years of used in a parking facility. Additionally, almost no surface runoff was generated from these systems and the incidence of heavy metals was lower compared to a traditional pavement parking stall in the study area. Construction costs for permeable pavements range from $5 to $7 per square foot of impervious area treated (Natlab 2013, King and Hagan, 2011). Figure 9 shows porous asphalt and paver applications.

Figure 9 – Typical porous asphalt (left) and permeable paver (right) applications (Source: Philadelphia Water Department, 2012)

The connection between the technical topic of GSI to investment output requires an understanding of how decisions are made by individual property owners, how these individuals influence each other regarding the adoption of an innovative technology (GSI in this case), and what macro-level patterns of investment emerge under a variety of initial conditions reflecting differing policy scenarios, programmatic conditions, and economic assumptions. This section will address these dimensions of the research effort.

For this research, the behavior of interest centers around factors that affect the decision-making of individual private property owners when considering the adoption of GSI onsite. The assumption is that decisions would be made in the context of incentives provided, such as credit on a stormwater fee. Additionally, other financial advantages (e.g., energy savings gained, cost avoidances) and non-monetary benefits associated either with personal or social beliefs (e.g., aesthetic quality, environmental ethic, conformity with social norms), or ecosystem services (carbon sequestration, microclimate control, social well-being) are assumed to play into decision-making. Literature examining the decision-making of private property owners to adopt GSI onsite is limited. Considering the limited information in the literature driving decision-making to invest in GSI, another approach to estimate this dynamic is through a well-constructed survey of stakeholders to understand motivating factors associated with the adoption of GSI. Interview of subject matter experts (SMEs) may be considered to replace or a complement, a stakeholder survey. As pointed out by Manson (2002), "for social-ecological systems with significant human intervention, particularly valuable 'real' data are found through surveys, interviews, censuses, and broader scale remote sensing or geographic information sources (GISs)."

Overview of Theory of Planned Behavior (Adapted from Brown, 2014)

Several approaches have been devised to aid in the prediction of decision-making through survey methods. The most notable leader in this area is Ajzen, whose Theory of Planned Behavior (TPB) has become one of the most influential approaches to predict human social behavior (Rivis and Sheeran, 2003). The basis of TPB is that a quantifiable correlation exists between decision-making factors and the intention to take action based upon these factors. Specifically, TPB posits that one's personal beliefs (attitude, AT) regarding a potential action taken along with social pressure (social norms, SN) and perceived behavioral control (PBC), which refer to one's perception of the ease or difficulty of performing an action or behavior, taken together represent behavioral intention (BI), and that this relationship is summative (Armitage and Christian, 2003). An assumption of TPB is that the stronger the intention in a behavior, the more likely that action will be taken reflecting this intention (Ajzen, 1991). Attitude, social norms, and perceived behavioral control are broken down into two components: an outcome belief (OB) and an outcome evaluation (OE) with respective components multiplied together in the relationship. The mathematical expression for this relationship is shown in Equation 1. The weights in Equation 1 are determined through regression. This regression is based upon information received through a survey of given population of stakeholders. The survey targets the outcome belief and outcome evaluation related to all three factors (attitude, social norm, perceived behavioral control) as well as a prediction by the stakeholder on whether he will take action on a given subject. For instance, a survey may ask a group of stakeholders about the attitudes, social norms and perceived behavioral control related to recycling, and also inquire whether they predict that they actually will recycle in the near future.

Equation (1): $\boldsymbol{BI = W_1(AT) + W_2(SN) + W_3(PBC)}$

Where:

$$\boldsymbol{AT \propto \sum_{i}^{n}(b_i e_i) = Attitude}$$

$$\boldsymbol{SN \propto \sum_{i}^{n}(n_i m_i) = Social\ Norm}$$

$$PBC \propto \sum_{i}^{n}(c_i p_i) = Perceived\ Behavior\ Control$$

- W1, W2, W3 determined through regression with BI as criterion
- Factor is based upon:
  - The strength of belief in each case (b, n, c); and
  - The evaluation of belief in each case (e, m, p)

A significant component beyond the perceived behavioral control is the actual behavioral control to move from intention to action. For instance, an individual may have beliefs regarding personal attitude, social norms and perceived behavioral control that are aligned towards the intention to act on a specific behavior; however, limitations such as economics or other constraints may limit his ability to move from intention to action. Figure 10 illustrates the relationship between these aspects.

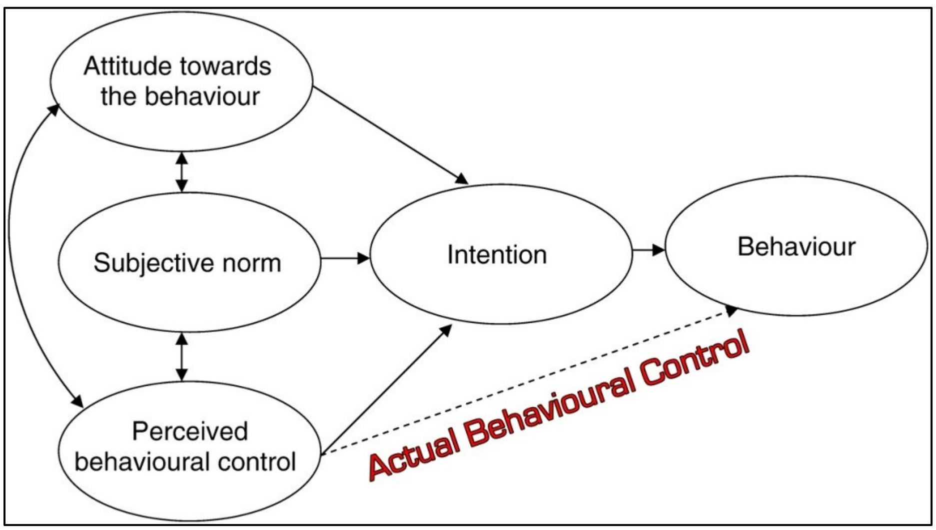


Figure 10 - Generalized Version of Theory of Planned Behavior (from Ajzen, 1991)

Assuming a statistically-significant number of the population takes the survey, the regression analysis may be performed providing relative weights of statistical significance for each decision-making component. These weights provide insights on the relative significance of decision-making aspects of the stakeholder population surveyed. A key statistical metric used to determine internal reliability in these efforts is Cronbach's Alpha Coefficient (CAC), which is simply the average correlation within a composite score category. The CAC value is compared against values considered to reflect reasonable reliability, such as a study by Cohen (1988) that estimated a CAC of 0.70 or above reflects scores in a study are reasonably reliable.

Diffusion of Innovation

Considering that GSI is not the "default" stormwater practice is most areas at this time, and also that this approach has so many co-benefits beyond enhanced treatment of stormwater runoff quality and volume, it should be considered an innovative practice. In fact, Federal legislation introduced in the 110^{th} and 111^{th} Congresses titled the "Green Infrastructure for Clean Water Act" was re-named the "Innovative Stormwater Infrastructure Act" in the 112^{th} Congress when it was introduced in November, 2013, to recognize the innovative nature of GSI. As with other innovative technologies and approaches, the expected growth for GSI implementation may follow an "S-curve". This type of growth has been observed in many fields, including public health, information technology, and education (Rogers, 2003).

In the environmental sector, S-curve growth has occurred in the municipal waste recycling sector (U.S. EPA, 2012b), and is currently occurring for photovoltaics and wind energy adoption (Schilling and Esmundo, 2009). In Figure 11, which illustrates the S-curve growth, we see that initial adoption rates will likely be slow and dominated by "innovators" until a "tipping point" is reached. At that point, growth increases exponentially through adoption by "early adopters" and "early majority" populations until the market matures or is saturated and the innovation becomes the "norm" or the default practice.

How this growth occurs, often referred to as "Diffusion of Innovation", has been the focus of significant study, most notably by Everett Rogers. His book, Diffusion of Innovation (2003), captures many of the major points of this topic. In this publication, Rogers states that, "the main idea of diffusion theory (is) that interpersonal communication with near peers about innovation drivers the diffusion process." This "word of mouth" dissemination of information is based upon social relationship and networks. Rogers' view is that, "an individual is more likely to adopt an innovation if more of the other individuals in his or her personal network have adopted previously." This social behavior is also described as the "small-world network" effect. This phenomena is based upon research showing that social networks composed primarily of local (geographically close) comprise a large majority (90 percent or more) of social interactions, and therefore, influence on decision-makers (Watt and Strogatz, 1998).

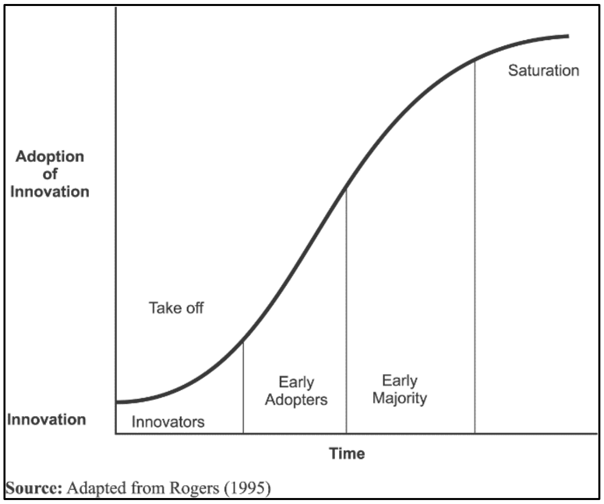


Figure 11 – S-curve Growth of Innovation Adoption (From: Rogers, 1995)

Figure 12 provides a graphical representation of network types with varying probabilities, *p*, of randomly establishing a connection. The far left network is completely non-random ($p = 0$), as information is only gained and share with/from local (adjacent) contacts. The far right network is completely random ($p = 1$) where information is randomly shared/gained with local/adjacent contacts and remote contacts. The middle network approximates a "small-world network", with a majority of information sharing/gaining is made with local/adjacent contacts while random information sharing/gaining is made with remote contact. This drive towards input from within a social network is largely driven by the supposition that observations regarding the adoption of an innovation by earlier adopters may reduce the uncertainty surrounding the efficacy and performance the innovation. This tendency to gage risk through peer input regarding innovation adoption outcome is referred to as a "threshold model" (Granovetter, 1978).

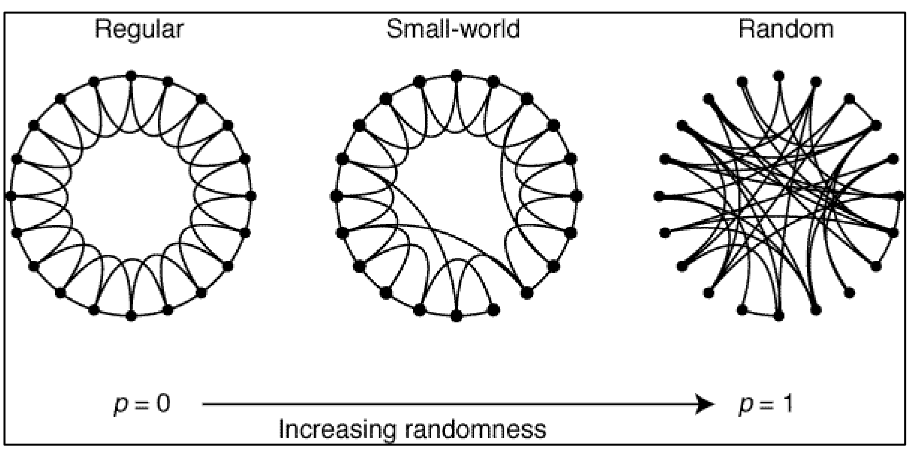


Figure 12 – Regular, Random, and Small-World Networks (From: Watt and Strogatz, 1998)

Role of Change Agent in Innovation Diffusion

In some instances, market forces or a promotional/sales campaign help to spur the adoption of innovative technologies, especially in the commercial sector; however, innovation diffusion in other systems benefits from change agents. The role of a change agent is to "facilitate the flow of innovations from a change agency to an audience of clients" (Rodgers, 2003). While those playing the role of change agent may range from public health workers to teachers to salespeople, there are some commonalities in background for change agents. Rodgers (2003) points out that "change agents usually possess a high degree of expertise regarding the innovations that are being diffused." Rodgers goes on to identify seven sequential roles change agents often play:

1. Develop a need for change
2. Establish an information exchange relationship
3. Diagnose problems
4. Create an intent to change in the client
5. Translate an intent into action
6. Stabilize adoption and prevent discontinuance
7. Achieve a terminal relationship

One of the most successful and most admired and copied example of a successful change agent (and one that is particularly applicable to the current research) is the agricultural extension model (Rogers, 2003). This program is funded at all levels of government with 40 percent from Federal and state and the remaining 20 percent from local/county sources. The program consists of three main components: (1) state agricultural research stations led by professors and researchers at land-grant universities, (2) county extension agents who work directly with farmers, and (3) state extension specialists who link the researchers with the county agents (Rodgers, 2003). The continued success of this program, started in 1911, has been attributed to its ability to adapt to changing priorities and environments over time, a focus on "pro-utilization" research efforts, and strong and continued engagement with farmers to identify needs and obtain feedback on program efforts and priorities (Rodgers, 2003).

Relative Agreement Algorithm

A method of capturing the dynamics of diffusion of innovation is the "Relative Agreement" (RA) algorithm, developed by Deffuant et al. (2002a). This approach models the influence of opinion between agents randomly selected in a model timestep. They illustrate this approach in a conceptualized manner: agent *i* with opinion x_i and uncertainty u_i influences agent *j* with opinion x_j and uncertainty u_j. Agreement is determined and opinion of agent *j* is adjusted accordingly. Figure 13 and the equations below illustrate this relationship.

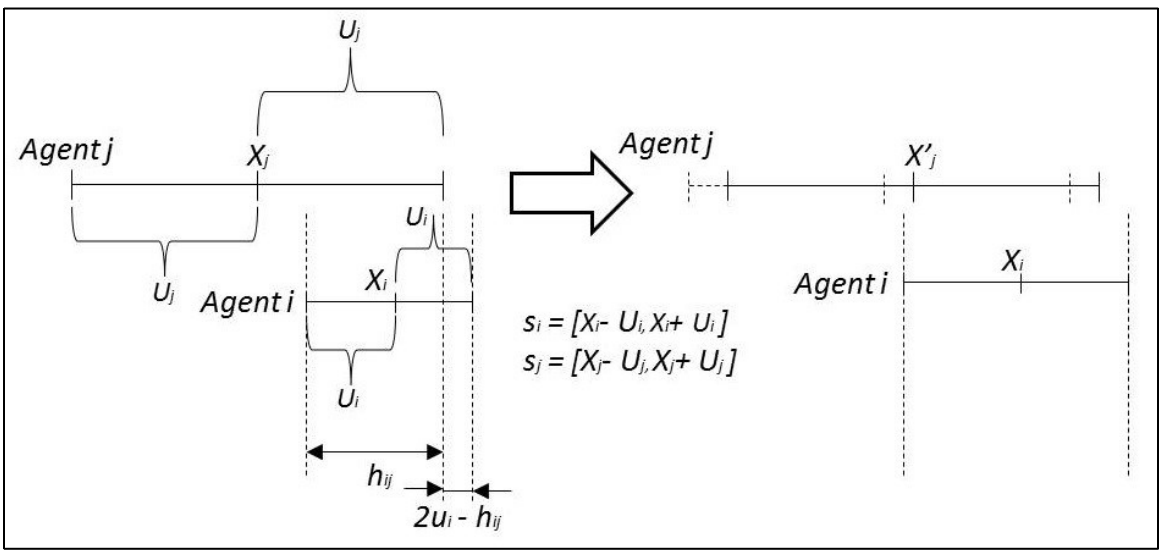


Figure 13 – Relative Agreement Algorithm (From: Deffuant et al., 2002a)

Consider opinion segments $s_i = [x_i - U_i, x_i + U_i]$ and $s_j = [x_j - U_j, x_j + U_j]$. Note that the total width of s_i equals 2 U_i (with s_j having the same relationship with 2 U_j). Agreement between agent *i* and *j* (which is not symmetric) is defined as the overlap of s_i and s_j minus the non-overlapping part. The overlapping width is referred to as h_{ij}. The non-overlapping width for this case is the total opinion segments attributed for agent *i* (2 U_i,) minus the overlapping width (h_{ij}). The bulleted list below provides the mathematical expression of the RA algorithm.

Overlapping width is: $\boldsymbol{h_{ij} = \min(x_i + u_i,\ x_j + u_j) - \max(x_i - u_i,\ x_j - u_j)}$

Non-overlapping width is: $\boldsymbol{2u_i - h_{ij}}$

The agreement is the overlap minus the non-overlap: $\boldsymbol{h_{ij} - (2u_i - h_{ij}) = 2(h_{ij} - u_i)}$

The relative agreement (RA) is the agreement divided by the length of the segment $s_{i,}$ (recalling that $s_{i,}$ equals $\boldsymbol{2u_i}$):

$$\boldsymbol{RA = \frac{2(h_{ij} - u_i)}{2u_i} = \frac{h_{ij}}{u_i} - 1}$$

Assuming overlap is greater than the uncertainty of the influencing agent, the opinion of Agent j is updated by the amount of relative agreement where μ is a constant parameter that controls the speed of the dynamics. Note that if $h_{ij} \leq u_j$, there is no influence of i on j.

Equation (2): $\boldsymbol{x_j = x_j + \mu\left(\frac{h_{ij}}{u_i} - 1\right)(x_i - x_j)}$

Similarly, the uncertainty of Agent j is updated as well:

Equation (3): $\boldsymbol{u_j = u_j + \mu\left(\frac{h_{ij}}{u_i} - 1\right)(u_i - u_j)}$

In this approach, both opinions and uncertainties are affected during interactions. Note that the influence of opinions is asymmetric and weighted by uncertainty such that agents with low uncertainty (confident opinions) have more influence than agents with high uncertainty (less confidence in opinions). It should be further noted that agent pairing is random (following the small-world network context), and the influence is mono-directional during each iteration. Subsequent randomly selected agent pairings will occur in a similar manner during each model timestep for all eligible agents in the model. To illustrate, agent A could be randomly paired with agent B during an initial timestep with agent A influencing agent B (influenced condition of B will be denoted as "agent B*"). In the second timestep, agent B* could be randomly paired with (and therefore influencing) agent C, leading to an influenced condition of agent C (agent C*). In the third timestep, agent C* could be randomly paired with and influent agent A leading to an influenced agent A (agent A*). This pairing dynamic reflects social situations where opinions are shared and individuals influenced. Replicating this paired dynamic also allows for diffusion of information (a.k.a., "word of mouth") in the model, which reflects the temporal and spatial spreading of opinions in the real world setting.

Deffuant (2002b) illustrates the RA method in a study focusing on conversion of traditional farms to organic farms in the Allier "region" (a sub-regional area within the Auvergne region) in France. The backdrop of this study is based upon incentives in the form of subsidies from the government for farmers to adopt organic practices over a course of five years. The modeling includes two types of deciders (farmers and institutional outreach agents) and is broken into two main sub-models: "decision propagation" and the "decision process". The former focused upon a two-stage information dissemination process: first, from institution to particular farmers (through extension agents), and then from farmer-to-farmer "word of mouth" (social network). The decision process dynamic goes beyond a binary (yes/no) for adoption, but also includes an "intermediate period of reflection and hesitation". This period reflects the a priori interest "state" (i.e., "attitude" in TPB context) of a farmer to convert (not interested, uncertain, interested) based upon economic and social criteria, an adjusted interest state based upon information from outreach agents and/or other farmers, and a recognition of the uncertainty in opinions and attitudes.

Results of the study are that information transmission is challenging in terms of conversion and that sustained interactions are needed in order to make thorough evaluations of interests and criteria. Additionally, Deffuant found that social information dissemination played a larger role in sustained dialogue rather than changing minds regarding conversion. Also, he found farmers may be open to the concept of organic conversion, but this openness rarely led to action to convert. These results were consistent with the actual limited conversion seen in the community, which reflects the skeptical (or negative) view of organic conversion among the farming community in Allier.

Another application of the RA method that also utilized the TPB is a study by Robinson et al. (2013) focusing on the adoption of solar photovoltaic (PV) systems in the Austin, Texas, area. This study focused on the diffusion of PV technologies based upon consumer decision-making factors for the goal of forecasting spatially-resolved PV adoption. ABM was used to model the system (see following section) with TPB employed to operationalize agent decision making dynamics.

The TPB provides a snapshot of the decision-making properties of a stakeholder population. The RA algorithm can be used to allow these properties to change over time to reflect the influence of opinion-sharing. This is the approach taken by Robinson et al., who used an initial attitude (AT) value and allowed AT to become "socially-informed attitudes" through the RA algorithm. Due to a lack of information on the opinions (AT) of PV adoption or the confidence in opinions within the stakeholder population an assumption was made that the distribution of opinions followed a normal distribution for both parameters with values for AT ranging between -1 (highly unfavorable) to 1 (highly favorable) and for uncertainty ranging between 0 (complete confidence) and 2 (no confidence). Once an agent adopts PV, the value for AT is assigned to 1 and for uncertainty to 0.001 (the author assumes the value could not be 0 due to the asymptotic construct of the normal distribution).

Since this study focuses on residential areas and innovation adoption, an assumption of small-world network was used. The actual control (the compatibility of a household to use PV technology, in this instance) was randomly assumed using a standard statistical distribution. The "intention threshold" (otherwise known as "opinion") was given an assumed value while the financial capability of household to afford the upfront capital required for PV adoption was determined through analysis of the market value of the house (based upon an analysis of historical data between home value and PV adoption for households in the Austin area). Other factors (i.e., payback threshold) were determined through assumed standard statistical distributions (i.e., normal, etc.). Figure 14 illustrates the agent decision process.

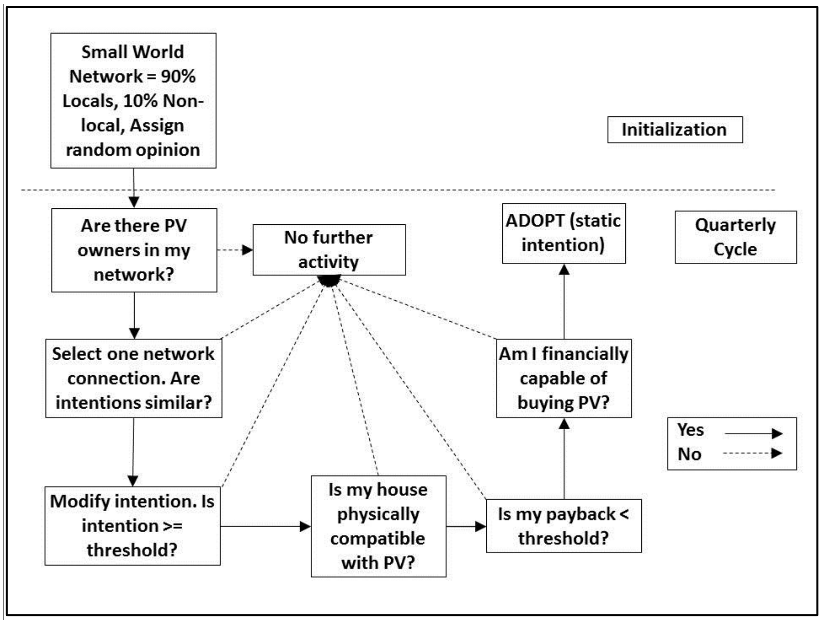


Figure 14 – PV Adoption Agent Decision Process (From: Robinson et al., 2013)

Agent-Based Modeling (Adapted from Brown, 2014)

Considering that decision-making in the context of GSI adoption in this study focuses on private property owners, a modeling approach that can capture the dynamics of a large heterogeneous population of decision makers should be considered. One approach that is well-designed for this type of application is agent based modeling (ABM), which has unique advantages for simulating a "bottom-up" system, such as private investment of GSI at the property or site level. This type of modeling approach is in contrast to a deterministic analytical (equation-based) method of analysis, which may be well-suited to physical systems that follow consistent and predictable patterns of behavior. The basis for ABM is that some systems, such as based in socio-economic dynamics, are non-deterministic by nature; therefore, deterministic modeling approaches may not capture the behavior of the system as well as a non-deterministic approach, such as ABM.

ABMs are modeling frameworks that are comprised of an "agents" or decision-makers who interact with their environment and other agents when taking action in a system. Agents in this context may be individuals, groups, firms, or companies who are identified and given decision-making properties that affect how various types of agents interact. Two of the previously described studies (Deffuant (2002b) and Robinson et al. (2013)) were based upon the use of ABMs as a central means to simulate systems. Helbing and Balietti (2011) state that ABM is a "method that (is) suited for the computer simulation of socio-economic systems," and that, "the behaviors and interactions of the agents may be formalized by equations, but more generally they may be specified through (decision) rules, such as if-then kind of rules or logical operations...this makes the modeling approach much more flexible."

The goal of ABM is to provide rules of behavior for agents and their environment that are employed at the local level and investigate the patterns and outcomes that emerge at the macro level under varying initial conditions. An advantage of this approach is the ability to capture the dynamics of decision-making by irrational and un- or less-informed deciders. Differences between *homo economicus* (perfectly knowledgeable/informed and rational deciders using optimization for decision) and *homo pyschologicus* (imperfect deciders who follow satisficing rather than optimization in decision-making) was investigated by Jager and Janssen (2002) to illustrate the value of ABM in this context. Additionally, the ability to treat decision-makers not as a monolithic group, but a heterogeneous population of individuals with varying levels of motivations (greed, altruism, ethics, etc.) and risk aversion is another advantage of ABM when investigating socio-economic systems. As stated by Janssen (2002), "too many tacit assumptions must be made about the way markets work, how much information is made available to decision makers and their ability to process it…this is where multi-agent modeling (aka ABM) has much to offer."

Structure of an Agent-Based Model

Hebling and Balietti (2011) provide a suitable process for the development of an agent-based model. These steps include:

- Provide context for the evidential or stylized properties for the system being simulated;
- Understand and articulate the purpose of the effort;
- Identify agents and environment as well as rules governing interactivity;
- Formulate a hypothesis based upon underlying socio-economic mechanisms;
- Use assumption in the modeling not directly tied to those that are of the subject of the simulation effort; and
- Focus on validation and verification of the model.

Regarding these steps in the context of this research, there is a lack of empirical evidence regarding the dynamics of investment behavior for stormwater infrastructure at the parcel or site level. This fact requires the use of analogues in similar sectors, such as the Robinson, et al. (2013) study of the diffusion of solar photovoltaics (PVs). The purpose of the simulating investment in GSI at the parcel level is to develop a useful, replicable, and tranferable methodology for analysis of incentive-based programs for GSI as well as investigating policy alternatives and resulting impacts on GSI investment.

Bradbury (2002) points out that, "economics and ecosystems, as complex adaptive systems, are inherently unpredictable as a whole," therefore the focus of modeling efforts should be on exploration of the dynamics of the system itself while also warning that, "exploration is not a *proxy* for prediction, it is *instead* of prediction." Considering these insights, the purpose of the model developed in the current research will focus on better understanding the behavior of the system of interest.

While the focus of this research is on model/methodology development, the general working hypothesis for the modeling behavior is that when economic conditions are favorable (return on investment is considered reasonable, etc.), information on the benefits of GSI is readily available, and a significant portion of a population is open to the benefits of GSI investment, there will be a growth of GSI investment. Conversely, if these conditions are not met, it is expected that investment in GSI will be diminished.

4. Methodology

An effort to collect and review available data and information pertinent to the study was performed and presented in this section along with an overview of the anticipated generalized pilot model development.

Data Collection and Synthesis

- Spatial data and other relevant information was gathered from the subject municipality selected for study (Washington, D.C.). This data includes:
    - Geographic Information System (GIS) spatial data (in ArcGIS format)
    - Private property database
    - Interviews/surveys of subject matter experts (SMEs) and other relevant stakeholders (religious/educational institution, commercial, industrial property owners or managers)
    - Technical and regulatory material related to stormwater management and GSI in the District
    - Beyond the collection of information is a presentation of the context in which the information will be manipulated and utilitzed to support the generalized pilot model.

GIS Data and Property Database

There is a significant amount of GIS information available to the public. The following data sets have been captured for this study:

- Impervious cover
- Land use
- Locations of "green" projects (which includes some GSI practices)
- Parcel data
- Census blocks and tracts
- Locations of religious instructions
- Commercial properties
- Ward boundaries
- Demographics by Ward
- City boundary
- Combined sewer shed boundary
- Watershed and subwatershed boundaries
- Building footprints
- Zoning information
- Soil coverages and types

Beyond this information, property database information related to places of worship have been gathered and compiled. Currently, work is being led by a University of the District of Columbia engineering to amend this database in order to locate the most significant religious institutions in terms of impact from stormwater fees (and therefore, most interested in reducing through on-site GSI implementation). Table 1 lists a data set reflecting this work. This table provides information on Catholic institutions within the District to illustrate the potential impact that religious institutions can play in generating credits. For example, this subset of religious institutions are associated with over 30 acres of impervious cover when including both surface parking lots building footprint. This amount of impervious cover could potentially generate $5 million dollars-worth of stormwater retention credits (SRCs) if all impervious cover were retrofitted to capture 1.7 inches of runoff assuming the current DDOE in-lieu fee price of $3.57/SRC. Since religious institutions, which are tax-exempt, are required to pay the rising stormwater fees in the District, the SRCs generates could reduce this financial burden and even perhaps provide an avenue to generating excess revenue.

Additional work will be done to develop a more comprehensive list of candidate sites who will be targeted to take the Non-technical survey (described later) in order to understand the role that this group can play in driving supply (and potentially demand) for SRCs in the market.

Decision-making Information

Various factors affect the decision-making associated with the adoption of stormwater infrastructure on privately-held property ranging from personal beliefs, social norms, perceived control, cost of adoption, and of course, personal economics. Ideally, the dynamics behind these factors would be taken from technical literature; however, the availability of this information is limited. Most decision-making analysis for stormwater infrastructure in the literature is from the viewpoint of the stormwater manager who makes decisions based upon parameters such as cost-effectiveness and maximum pollutant load reduction. While this approach to stormwater investment decision-making is relevant, there is an inherent assumption that adoption of infrastructure will occur in an ideal fashion based upon the results of these analyses. In reality, the adoption of infrastructure, especially on private property, will likely not occur in an ideal fashion based upon the optimal pollutant load reduction or a similar planning-level viewpoint, but rather based upon factors significant to the private property owner.

The Theory of Planned Behavior (TPB) will be used to capture these factors in a quantifiable manner by developing a survey following the approach laid out by Ajzen (1991). The population for this survey will target relevant stakeholders in Washington, D.C. The population used will be calibrated to the relevance of the location and the incentive-based program utilized locally. Specifically, the SRC trading program in Washington, D.C., is theoretically open to anyone; therefore, some residential private property owners may be included in a survey for this area as well as non-residential (commercial, institutional, industrial). A survey based upon TPB is included in Appendix B, which targets the supply side of the market – those non-technical property owners who may be interested in reducing their stormwater fee as well as generate income based upon the premise of generating stormwater retention credits (SRCs) on the open

This information will be used to develop the "attitude" (AT) (otherwise known as "opinion") and "perceived behavioral control" (PBC) (also thought of as "barriers to action") parameters with the understanding that the "social norm" (SN) component will market or in a bi-lateral transaction. The survey results can be used to determine non-monetary drivers for property owners who may consider installing GSI on their property. be accounted for through the Relative Agreement (RA) algorithm. A statistical analysis will be performed to determine the reliability of the results by determining the Cronbach Alpha Coefficient, as described in the previous section, and a regression analysis will be performed to discern the relative importance of decision-making aspects (AT and PBC). This analysis will also determine which decision-making aspects are considered to be statistically-significant, and therefore, factors to include in developing agent decision-making behavior.

NAME OF RELIGIOUS INSTITUTION	BUILDING FOOTPRINT (sq ft)	PARKING LOT SIZE (sq ft)	TOTAL IMPERVIOUS COVER (sq ft)	WARD	WATERSHED
Basilica of the National Shrine of the Immaculate Conception	78,461	0	78,461	5	Anacostia
Cathedral of St. Matthew the Apostle	25,493	3,519	29,012	2	Rock Creek
Catholic Information Center	63,080	0	63,080	2	Rock Creek
Church of the Annunciation	27,934	31,546	59,480	3	Potomac
Church of the Assumption	15,338	4,271	19,608	8	Potomac
Church of the Incarnation	14,464	32,342	46,806	7	Anacostia
Church of the Nativity of Our Lord Jesus	30,089	39,422	69,511	4	Rock Creek
Epiphany Church	5,100	0	5,100	2	Rock Creek
Franciscan Monastery	68,566	35,633	104,199	5	Anacostia
Holy Comforter St. Cyprian Church	15,641	1,599	17,239	6	Anacostia
Holy Name Parish	8,637	11,300	19,937	6	Anacostia
Holy Redeemer Parish	15,214	16,326	31,540	6	Anacostia
Holy Rosary Parish	14,440	3,931	18,371	2	Anacostia
Immaculate Conception Parish	14,812	0	14,812	6	Potomac
Mission St. Blaise (OLV PARISH)	9,154	23,766	32,920	3	Potomac
Monastery of the Holy Cross	2,787	0	2,787	5	Anacostia
Missionaries of the Holy Apostles	4,002	1,781	5,783	5	Anacostia
Our Lady of Lebanon Maronite Church	8,490	13,079	21,569	4	Rock Creek
Our Lady Queen of Peace Parish	20,334	22,028	42,363	7	Anacostia
Our Lady Queen of the Americas Parish	29,288	16,116	45,404	2	Rock Creek
Shrine of the Most Blessed Sacrament	42,833	19,060	61,893	3	Rock Creek
Shrine of the Sacred Heart	19,344	2,793	22,136	1	Rock Creek
St. Ann Parish	15,423	12,204	27,627	3	Potomac
St.Anthony of Padua Parish	22,069	3,680	25,749	5	Anacostia
St. Augustine Catholic Church	30,256	43,858	74,114	1	Rock Creek
St. Benedict The Moor Church	30,349	35,266	65,615	7	Anacostia
St. Frances de Sales Parish	0	21,535	21,535	5	Anacostia
St. Frances Xavier Parish	17,188	6,597	23,785	7	Anacostia
St. Gabriel Parish	25,587	13,452	39,038	4	Rock Creek
St. Joseph's Church on Capitol Hill	13,149	15,593	28,742	6	Anacostia
St. Luke Parish	27,197	22,322	49,518	7	Anacostia
St. Martin of Tours Parish	13,068	1,193	14,261	5	Anacostia
St. Mary Mother of God Parish	9,802	6,426	16,228	2	Anacostia
St. Patrick Parish	27,401	0	27,401	2	Potomac
St. Peter Parish	14,653	3,129	17,783	6	Anacostia
St. Stephen Martyr Parish	42,717	0	42,717	2	Potomac
St. Teresa de Avila Parish	6,422	0	6,422	8	Anacostia
St. Thomas The Apostle Parish	11,285	1,094	12,379	3	Rock Creek
St. Vincent De Paul Parish	8,416	5,698	14,114	6	Anacostia
Ukrainian Catholic Natl. Shrine of the Holy Family	10,466	32,287	42,753	5	Anacostia
Totals	**858,948**	**502,845**	**1,361,793**		

Additional information, such as risk adverseness and ability to invest, will be included in survey efforts. Consideration will be made to interview relevant subject matter experts (SMEs) in lieu of, or to augment, the survey effort. If SMEs are used, significant effort will be made to identify those experts who will provide the more credible information associated with the research goals. A recent study led by the Federal City Council focused on interviews of SME's in the land development community, which will also be utilized to determine rules for developers (see following section for details).

5. Generalized Pilot Model Development

The components of an agent-based model will be explored, including the identification of agents, investigation of modeling environment, modeling framework, development of agent and environment interaction and behavioral rules, and description of policy alternatives as well as programmatic and financial assumptions. Figure 16 provides an overview of modeling elements and parameters. Initial modeling efforts will use an existing concept model to develop a generalized model. This initial modeling effort will use synthetic behavioral assumption with a goal of determining an appropriate model architecture that will be used for applied versions of the model. Also, this generalized model will provide further proof of concept for the approach laid out in this document.

Identification of Agents

A concept agent-based model has been developed to aid in the development of an initial modeling framework (Brown and Ferreira, 2013). This model focused on the dynamics of project aggregation associated with GSI adoption based upon synthetic behavioral data. There was only one agent population in this conceptual model (investors); however, the ABM for the current research will likely expand this agent population to include:

- Private property owners (focus on non-residential initially)
- Land developers
- Public outreach agents
- Outside investors
- Aggregators / service providers

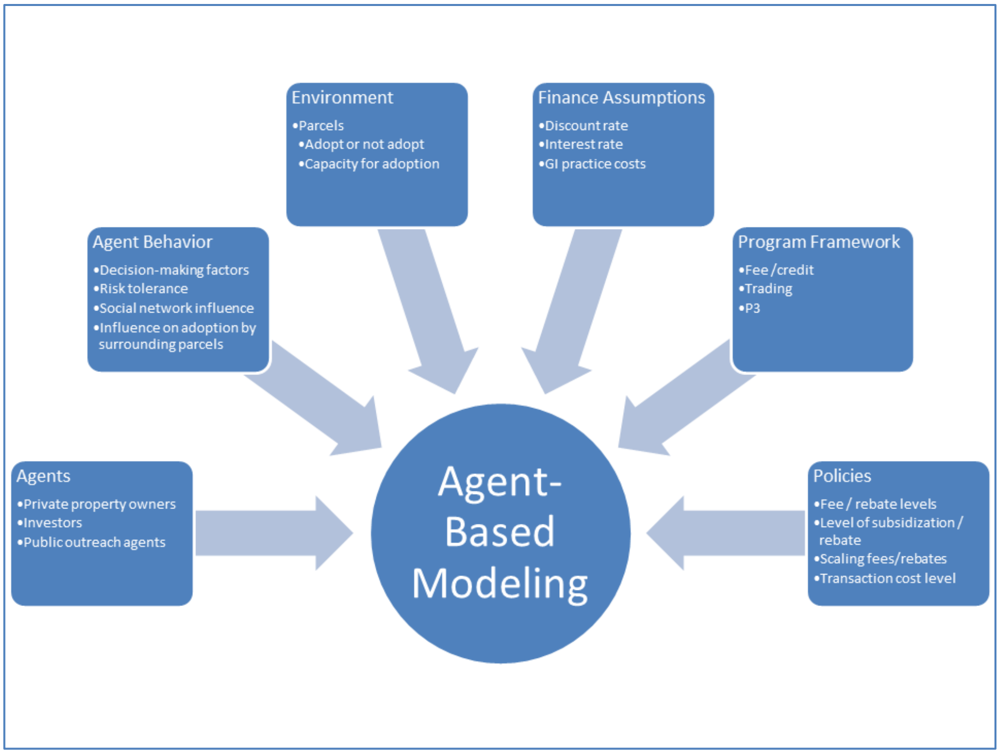


Figure 16 – Overview of agent-based modeling elements and parameters

The existing conceptual model (Brown and Ferreira, 2013) used synthetically-derived spatial information (parcels), assumed all parcels were privately-held (and therefore were all available for potential investment). The generalized model will use agents to identify privately-held properties explicitly. This is to help to account for spatial dynamics that may impact diffusion of innovation/adoption rates. The conceptual model used either random or normally distributed populations of initial investors. The generalized pilot model will use similar standard statistical distributions for initial conditions associated with number and location of private property owners, investors and public outreach agents.

Land developers may play the role of SRC consumer and/or generator depending upon a variety of factors, such as regulatory aggressiveness, SRC cost and market stability. There are a variety of land development firms in the District ranging from multi-billion dollar firms to small specialized groups. Similarly, some land developers focus on specific types of land development projects (e.g. residential vs. commercial). The modeling will respect these differences, especially as these factors may influence the ability of a developer to self-finance as well as develop an internal banking program that would allow for the use of excess SRCs on one project to be used on another project that has more cost or physical challenges in meeting stormwater regulations.

Investors in this context could include both self-investors (property owners who decide to invest in their own GSI implementation) as well as outside investors (non-property owner entities who may provide upfront capital for GSI implementation based upon a financial arrangement for a single site). Outside investors could represent financial institutions, investment companies, “social” investors, or non-profit organizations who may wish to catalyze the market through sharing investment cost and risk (through subsidization, for example) in order to encourage and accelerate stormwater infrastructure adoption. The aggressiveness of each of these investors will be reflected in the interest rate on investments, return-on-investment, and limits on payback period.

Beyond investors are "aggregators" who would search of multiple parcels to overcome transaction cost barriers and optimize investment through economies of scale. It should be noted that there is a limit to aggregation that is consistent with the principle of optimal profit-making that coincides with the circumstance where marginal cost roughly equates to marginal revenue. There is no available information in the literature on this topic as it relates to GSI; however, the Philadelphia Water Department's (PWD) Greened Acre Retrofit Program (GARP), which is a cost-threshold subsidy program for GSI retrofit projects, relies on the concept of project aggregation to enhance cost-effectiveness. In the GARP program, an aggregator is rewarded a payment from PWD for a set of aggregated projects totaling to ten impervious acres or more if the total cost for the aggregated projects is $90,000 per impervious acres or less. In lieu of other information, this study will assume marginal costs dominate marginal revenues at ten impervious acres. Aggregators will either self-finance or seek investment through other parties similar to the "outside investor" types listed in the previous paragraph. Aggregators may include Energy Service Company (ESCO)-like entities who structure deals similar to outside investors (provide upfront capital with expected paybacks over a long time horizon (20-30 years); however, they also provide technical and contractual expertise likely needed for stormwater infrastructure investment. Unlike outside investors, it is unlikely that the non-profit or public sectors will have the technical knowledge required to be effective aggregators, so it is assumed that only private actors will represent this agent class.

Public outreach agents are often used in stormwater programs to increase awareness of a certain topic or to educate the public on specific program initiatives. The use of outreach officials (and the level of usage) can help to facilitate further the diffusion of innovative technologies, such as green stormwater infrastructure. The amount of enhanced adoption associated through public outreach will be based upon the dynamics of the agricultural extension service as presented by Rogers (2003).

Agent Behavioral Rules

Decisions by private-property owners may also be influenced by a number of factors, including:

- Social networks
  - Influenced by neighbors, demographics, level of homophilly
- Environmental/site conditions
  - Level of difficulty to implement GSI (therefore cost)
- Awareness of the SRC program
  - Influenced by public outreach campaigns and investment by DDOE in public outreach agents
- Opinions regarding environmental (especially stormwater-related) issues
  - Based upon demographic information (income/wealth, Ward, age, rent vs. own, etc.)
- Risk behavior
  - Based upon survey information as well as demographics

- Innovativeness
    - Influenced by demographics (age, wealth)

Rules governing agent decision-making will be based upon the results of the infrastructure investment decision-making analysis. Flexibility will be built into the model to allow for varying weights for decision-making aspects through user-input. Because risk tolerance/avoidance behavior is inherent in decision-making dynamics, the amount of risk exhibited by both private property owner and investor agents will be integrated into decision-making rules. Rules for risk tolerance will be taken from results of survey and interview efforts. These results will be compared to the risk aversion utility function used by Hoffman et al. (2002) by described by Parks (1995) as well as other risk aversion relationships found in the literature.

As previously mentioned, a recent study led by the Federal City Council focused on interviews of SME's in the land development community. This information will be utilized to determine rules for developers who will have five options when they face decisions about addressing stormwater management requirements for projects build in the District:

1. Meet full on-site retention requirements within the building or site envelope
2. Meet minimum on-site retention requirements and address remaining volume through internal land development portfolio
3. Meet minimum on-site retention requirements and address remaining volume through bi-lateral agreement with SRC generator
4. Meet minimum on-site retention requirements and address remaining volume through purchase of SRCs from the DDOE exchange (open market)
5. Meet minimum on-site retention requirements and address remaining volume through purchase of in-lieu SRCs

As previously presented, land developers will be motivated by a variety of factors, which will drive developers to take actions 1-5 as listed above.

Regarding the effect of social networks, the amount of adoption that has occurred on parcels within a defined radius is likely to have some influence on investment adoption at a given location. The amount of this influence will gleaned from survey and interview results and compared with similar dynamics in the literature (Deffuant (2002b)). While there is little research done on the effects of non-monetary neighborhood-type influences for GSI, there is literature in the Clean Energy (CE) sector that illustrates the influence of neighbor-hood effects on opinions and uncertainties associated with adoption of new and emerging technologies. Graziano and Gillingham (2014) conclude that a number of factors influence photovoltaic (PV) adoption for residential areas, which includes homophilly, cost of electricity, a "solarize" program by local government, and the spatial neighboring effects. Specifically, they have found for a Connecticut community, the number of PV adoptions that take place within a 0.5-mile radius within the previous six months has a significant impact on PV adoption. Due to the similarities between GSI and CE infrastructure (decentralized, site/parcel-level, driven by cost avoidance, seen as a "green" emerging technology), it is reasonable to conclude that there are likely to be similar adoption dynamics.

Other factors influencing decision-making based upon social networks will be based upon an assumption of "small-world" networks, where a majority of information impacting decision making comes from agents located near the decision maker. The exact dynamics of influence will be based upon the Relative Agreement algorithm, as previously described. This algorithm will capture the influence of "opinion" on private property owner agents, with "opinion" being defined through the strength of attitude (AT) influence as indicated by the results from the infrastructure investment decision-making analysis. Consideration will be made to generate a heterogeneous population of opinion-strengths survey efforts or subject matter expert (SME) interviews. These results will be compared with similar dynamics described in the literature (Jager and Janssen, 2002).

Property Owner Decision-making Process

The decision-making process for private property owners will make to adopt stormwater infrastructure onsite or remain untreated will occur at a fixed time-step, which will likely be quarterly or annually. Figure 17 provides a potential decision-making path for property owners. Walking through this process, the first question is whether GSI exists on the site. If yes, there may be a maintenance cost implication to consider. If no, the property owner will go through a series of steps regarding their opinion (defined as the attitude component of TPB) compared with a user-defined opinion "threshold". The influence of a public outreach program is integrated into the "opinion vs. threshold" process.

Once the decision is made to move forward based upon opinion, the next phase is to ascertain if the site is compatible with GSI investment, and if so, what type(s) of GSI practices are allowed, which will dictate the costs to the property owner. The property owner will then perform a financial analysis to determine if capital and operations and maintenance costs can be afforded by the property owner. The ability to invest in GSI onsite will be determined from survey and/or interview results. If these results do not provide this information, a number of options are available. A probability for ability to invest may be based upon a standard statistical distribution. Another option could include the use of an analogue found in the literature (Robinson et al., 2013). Lastly, ability to invest in GSI may be estimated through statistical correlations found in the data from a particular urban area between the patterns of adoption of innovative practices and a proxy for wealth (property value, income, annual property taxes). If there are no financial barriers and opinion is favorable, then adoption of GSI can occur. If financial barriers exist, funding provided by an outside investor and/or through an incentive-based policy may help to remove/reduce financial barriers. This is determined by comparing the potential return-on-investment (ROI) for the property owner (and investor if an investor is included in the analysis) with the risk thresholds of all parties involved in the transaction (property owner and potential investor). If the ROI is acceptable for all parties, then adoption can occur.

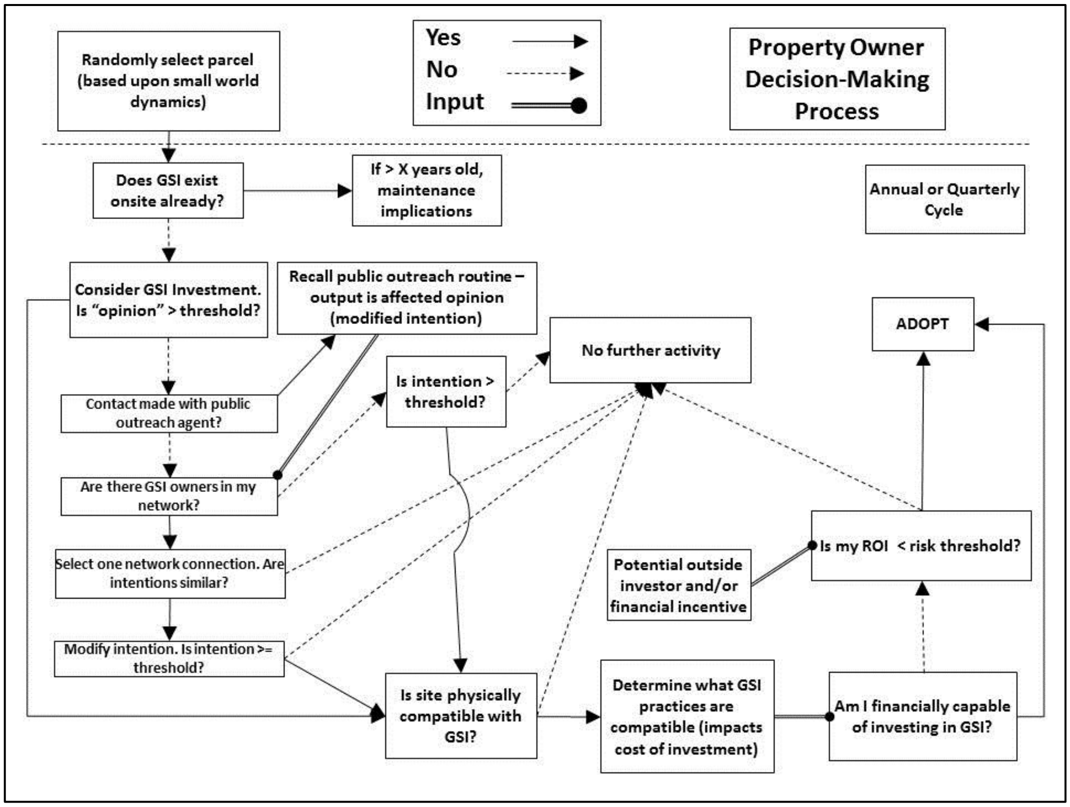


Figure 17 – Overview of Potential Decision-Making Process

Environmental Modeling Parameters

The environment in the generalized model will be parcels (cells in the model) which will be assumed to be untreated (i.e., "not green") at the beginning of the model set-up. The parcel data used in the generalized model will be based upon D.C. information, but will limited to rasterized format due to limitations within Netlogo. To the extent possible, the data used will reflect realistic composition and distribution of parcels based upon land use. For instance, the composition and distribution of land use types (commercial, industrial, residential, public, etc.) will reflect the typical urban setting within a range of scales, such as neighborhood, census block or Ward in order to provide a more realistic modeling environment.

The parcel data properties assumed in this model will include parameters associated with the GIS information listed in the previous section. This includes information that would most likely impact the type of GSI practices allowed on the parcel and the level of capacity for GSI investment as well as demographic data that will impact decision-making dynamics as well as social network influences. Parameters associated with the ease of GSI implementation as well as costing information related to GSI implementation include land use, soil type, and Ward (to capture opportunity cost of practice footprint). Specifically, land use will be used to define which GSI practices are allowed on that parcel. For instance, for a high-rise apartment building with no attached parking facility would be limited to green roofs and cisterns for GSI practices. To contrast, a religious institution with a large parking lot may have many more options, such as rain gardens/bioretention, bioswales, permeable pavements and other landscapecentric GSI options. Soil type and site constraints (determined through random assignment in the model) play into the capacity for landscape-based GSI practices. For instance, a parcel may have ample open space for landscape-based GSI practices, but if underlying soils are poorly-draining or other infrastructure or similar site constraints exist on the site, the capacity for this parcel to integrate retrofits on-site is limited. In the conceptual model, the soil properties and site constraints were lumped and expressed as a parameter referred to as "favorability for retrofit". For the generalized pilot model, the composition and distribution of soil types for parcels will be based upon information consistent with soil coverages in urban areas and applied through a statistical distribution or distributed from a typical urban area. Site constraints may be assumed as a percentage of total parcels based upon a standard statistical distribution or a distribution from a typical urban area.

Another significant factor that is associated with the model environment is the costs associated with GSI practices. Data associated with the cost of GSI practices is highly variable (King and Hagan, 2011). Considering this, flexibility will be made to allow the user to define costs for capital and annual operations and maintenance for all GSI practices. For the generalized pilot model, information from local sources, such as DDOE who has a rich data set for GSI costs, will be used along with general information from the literature on costing in developing the generalized pilot model. This will provide a model dynamics based upon realistic costs.

Working Overview of Generalized Modeling Architecture

<u>Model Platform: Netlogo 5.1.0 or higher</u>

- Cells are referred to as "patches"
- Agents are referred to as "turtles"

<u>Model Set-up Module:</u>

- Environmental Initiation:
    - Create patches that represent land use
        - Land use distribution is based upon GIS-analysis of land use distribution by ward
    - Assign parcel size by applying an assumed distribution (log-normal) of parcel size by land use
    - Estimate property value of parcel based upon land use and size of parcel and adjust for ward or neighborhood
    - Estimate federally adjusted gross income (FAGI) based upon census data per neighborhood and ward with an assumed normal distribution used
    - Estimate impervious cover by land use type (normal distribution applied here as well, most likely)
    - Determine annual (or quarterly) stormwater fee based upon impervious area on parcel (which will be estimated by land use type), and is determined through "Equivalent Residential Units" (ERUs) – this is the amount of impervious cover on the typical single-family residential home (1,000 square feet for DC).
- Agent Initiation:

- Agents used in this model include ***investors*** (which could be self-investors or outside investors), "***change agents***", and ***public outreach agents***
    - Number of initial agents will be defined by the user
    - The investor agent class will spend his time roaming the landscape looking for good deals to develop
    - The change agent class will likely be significant force in opinion influencing dynamics as well as awareness
    - The public outreach agents will provide further catalyzing influences on opinions and awareness

<u>Decision-making Process Module</u>:

- Five-step process - Awareness/Knowledge, Opinion/Attitude, Decision, Implementation, Continue Implementation
    - *Awareness/Knowledge - Heard of It or Not?*
        - Based upon level of innovation (earlier adoption with innovators, etc.) and contact with "Change Agents" and/or Public Outreach Agents
    - *Opinion/Attitude - For or Against*
        - Form an opinion (attitude) based upon TPB and innovation type
    - *Decision - Green or Not*
        - Based upon attitude in alignment with site conditions and economic viability
        - There could be a situation where a favorable opinion is formed, yet the property owner is awaiting economic conditions to become more favorable – such as an outside investor providing aggregation to drive down costs, and therefore increase profit (or cost avoidance) potential
    - *Implementation*
        - Cost/time varies based upon level of bureaucracy
    - *Continue to Implement*
        - Are costs/benefits still favorable?
- Mathematical relationships to express decision-making for steps above are in progress, but the following is a listing of potential options:
        - Montalto (2013): $P = \boldsymbol{F} * \boldsymbol{E} * \boldsymbol{W} * \boldsymbol{K}$
    - P = F*E*W*K
        - P is probability of GSI adoption by a property owner
        - E is the economic incentive factor
        - W is the willingness to consider GSI adoption
        - K is knowledge factor (awareness)
    - Robinson et al (2014): $sia = \frac{\mathbf{1}}{\mathbf{3}}(\boldsymbol{w1}\ (\boldsymbol{F}) + \boldsymbol{w2}\ (\boldsymbol{E}) + \boldsymbol{S})$
        - Sia = opinion
        - F = Finance component
        - E = Economic component
        - S = Social benefit belief
        - W1, W2 are weighting factors

- Kelly (2002) use of utility and risk aversion functions in farming/fallow practicing based upon relative wealth and volatility of commodity price in market:
  - $p_{t-1}^{e} = \boldsymbol{p_t} + \boldsymbol{\varepsilon_t}$
    - Where $\boldsymbol{p_t}$ **is price last observed price of a commodity and** $\boldsymbol{\varepsilon_t}$ **is an error term for price distribution with** $\boldsymbol{\mu}$ **being the average volatility assuming a normal distribution. Note that a** $\boldsymbol{\mu}$ **of 0 is average conditions, less than 0 is a bearish view and greater than 0 is a bullish view of the market.**
  - $\boldsymbol{U_{farm}} = (\boldsymbol{1} - \boldsymbol{w})\left[\frac{(\boldsymbol{farm} * \boldsymbol{p_{farm}^{e}})(\boldsymbol{1} - \boldsymbol{t_{farm}^{e}})}{\boldsymbol{1} + \boldsymbol{slope}} - \boldsymbol{Cost_{farm}}\right] - (\boldsymbol{\alpha} * \boldsymbol{farm^2} * \boldsymbol{\sigma_{farm}^2}) - (\boldsymbol{\beta_{farm}} * \boldsymbol{Age_{farm}} * \boldsymbol{farm})$
    - **Where:**
      - **w represents the current normalized wealth of the farm**
      - $\boldsymbol{farm} * \boldsymbol{p_{farm}^{e}}$ **term represents expected profit produced by the proportion of a parcel allocated to farming**
      - $\boldsymbol{1} - \boldsymbol{t_{farm}^{e}}$ **is the tax implications associated with profits**
      - $\boldsymbol{1} + \boldsymbol{slope}$ **represents impact of slope on farming productivity (lower is better)**
      - $\boldsymbol{Cost_{farm}}$ **is the cost for farming operations**
      - $\boldsymbol{\alpha} * \boldsymbol{farm^2} * \boldsymbol{\sigma_{farm}^2}$ **is the risk aversion of farmer based upon farming profits and tax impacts**
      - $\boldsymbol{\beta_{farm}} * \boldsymbol{Age_{farm}} * \boldsymbol{farm}$ **is the loss of productivity from harvesting from same plot of land**
- Deffuant (2002) focus on information diffusion and opinion transference socially on organic farming practices based upon the following decision process assumptions:
  - The interest state of farmers,$\boldsymbol{\tau}$**, is not interest, uncertain, and interested.**
  - **Farmers discuss potential benefits for conversion to organic farming based upon openness and certain of opinions, as defined by the parameter μ.**
  - Information can be analyzed if uncertain or interested, which is defined by parameter **Ω**.
  - Input from a technician on economic benefits of conversion.
  - The assumption is the information is sent to farmers via press and outreach efforts as well as technical support. Additionally, it is assumed farmers discuss conversion within their own social networks.

- Social Dynamics Process
  - Relative Agreement algorithm will simulate "word of mouth" dynamics
    - Initial opinions will be developed through demographics such as age, Ward, property value, and Federally Adjusted Gross Income (FAGI)
      - Generally, the literature points to younger and more affluent populations tend to be early adopters, so it is assumed this population will initially be more favorable while other populations are likely to not be as favorable

    - Initial level of uncertainty will be assigned as the inverse of opinion – those with highly favorable or unfavorable opinions will have low uncertainty with the converse relationship occurring for those with less polarized opinions per Robinson et al. (2013)
    - Opinion influence on other agents is as discussed in a previous section: $\boldsymbol{x_j = x_j + \mu\left(\frac{h_{ij}}{u_i} - 1\right)(x_i - x_j)}$
    - Uncertainty influence is governed by a similar relationship: $\boldsymbol{u_j = u_j + \mu\left(\frac{h_{ij}}{u_i} - 1\right)(u_i - u_j)}$
    - Note that $\boldsymbol{\mu}$ controls the rate at which dynamics occur. Varying levels of this constant parameter will be used based upon literature input.
    - Public Outreach Agents will catalyze spread of awareness/information
  - "Change Agents" are individuals who are "highly influential", and therefore, spread more information than the average property owner – but these are NOT Public Outreach Agents

<u>Economic Module:</u>

- Cost Process:
  - Generate SW fees for each parcel
    - Based upon "Equivalent Residential Units" (ERUs), which is the currency for stormwater fee generation). In DC, this is 1,000 sq ft of impervious cover for both the DDOE and DC Water fee programs.
      - http://green.dc.gov/node/608812
      - http://green.dc.gov/riversmartrewards
      - http://green.dc.gov/service/changes-districts-stormwater-fee
      - Stormwater fee is based upon the DDOE Stormwater Fee and the DC Water Impervious Area Charge. The DDOE fee is based upon the following:
        - $2.67 per ERU per month per 1,000 square feet of impervious cover for all properties that are not single family residential.
        - Single family residential charge $2.67 per ERU and use the following scale:
          - 100-600 ft^2 impervious cover = 0.6 ERU
          - 700- 2,000 ft^2 impervious cover = 1.0 ERU
          - 2,100 – 3,000 impervious cover = 2.4 ERU
          - 3,100 = 7,000 impervious cover = 3.8 ERU
          - 7,100 – 11,000 impervious cover = 8.6 ERU
          - 11,000 and up impervious cover = 13.5 ERU
      - The DC Water program is called the Clean Rivers Impervious Area Charge (IAC) is based upon:
        - For single family residential, the scale is the same as DDOE's, but the charge is $16.75 per ERU

        - For non-single family residential, it is simply $16.75 times ERUs on site.
    - The total charge is then DDOE plus DC Water = $2.67 + $16.75 = $19.42/ERU
    - There is a credit program – DC Water's Clean Rivers IAC Incentive Program is a 4% reduction on the IAC charge ($0.67 per ERU) and DDOE's "RiverSmart Rewards" program offers 55% off their portion of the charge ($1.47 per ERU) for a total of $2.14 per ERU.
    - Estimate gallons of retention require to "green"
    - Determine cost for greening based upon land use type and retention volume
    - Determine cost/gallon and compare to in-lieu fee ($3.50/gallon) to determine if it is below the "ceiling" placed by DDOE
    - Need to further define other costs, such as:
        - O&M (depends up on GSI practice type and age, expressed in terms of % of construction costs, normally, and on an annual basis (that would increase with age?))
        - Risk (if an outside investor takes on the risks of the project, there should be a cost assumed as part of this – need to determine/estimate this)
        - Transaction (includes legal, administrative, design, siting, documentation, permitting, etc.) – can be significant – between 20-40% of total project cost by many estimations
        - Monitoring (if any is required – we may want to relate this cost inversely to Risk Cost and/or relate directly to O&M costs – or include this in O&M?)
        - Opportunity (this represents the cost of taking a piece of land "out of production" for some other purpose for the sake of using for GSI practice – the obvious example is parking spaces in a strip mall, etc.)
- Incentive Process:
    - Compare cost to adopt with reduction in SW Fee
    - Additional incentives could be payments made by outside investors to further off-set SW fee
    - Could be tied to trading market (DC SRC program) driven by both development rate and/or regulatory target
        - Economic benefit would be deal cut with investor on profit split based upon credit selling potential to off-set/reduce stormwater fee as well as generation of ongoing revenue stream
        -
    - Could be a limited pool of subsidies for cost efficient projects (i.e, GARP) driven by both development rate and/or regulatory target
    -
- Project Aggregation:
    - Premise is that the more projects completed together in a "package" and by a single, third-party, outside investor, the lower the marginal costs – however, economic theory states that at some point, marginal costs start to increase due to complexities with scaled-up business practice.

    - Need to gain an understanding of relationship between maintenance costs per acre or per project in a given area
    - Philadelphia assumes 10 acres for an optimal marginal cost threshold (as expressed by Philadelphia GARP) – this could be one assumption

<u>Other Assumptions/Relationships:</u>

- Innovation Behavior:
    - Estimate level of innovation
        - Educational status
        - Property values / income-wealth
    - Innovators and Early Adopters have a higher frequency of contact with "Change Agents" in a given unit of time (per year) compared with others
        - Per Rogers (Diffusion of Innovations, p. 382) based upon a study of Brazilian farmers, here is one distribution of change agents contacts per year
            - Innovators (20)
            - Early Adopters (15)
            - Early Majority (12)
            - Late Majority (5)
            - Laggards (2)
        - Take away: Innovators have an order of magnitude more contact with change agents than laggards, and 4 times as much as later majority, 30% more than early adopters, and 75% more than early majority.
- Economic viability:
    - Associated with property value
- Land use type determines impervious cover
    - Impervious cover drives the volume of runoff generated
- Land use determines the types of GI appropriate

<u>Ongoing/Future Research Efforts/Needs:</u>

- Need to estimate realistic discount rate
- Need to estimate realistic interest rate
- Need to estimate realistic inflation rate
- Need to estimate realistic/reasonable ROI for both typical (profit maximizing) investors and for "social investors" who may allow for low or no ROI if GSI investments can be increased
- Need info related to GSI practice costs for both construction, design, O&M and monitoring
    - Have much of this data, but may need to consider additional sources

Data Collection (Survey Effort)

One way to measure the motivations for potential engagement in the DDOE SRC market is through survey efforts. The survey questions listed below were developed through an effort with the Federal City Council who has been studying the nuances and drivers of the SRC market. The intended audience for this survey are non-technical land owners or property owners to capture the general opinion of potential players in the supply-side of the market. The questions listed below represents an initial draft of question

Questions for Non-Technical Group

(Non-Monetary Factors)

The health of the Anacostia and Potomac Rivers as well as Chesapeake Bay is important to my organization/institution.

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

Installing stormwater/green infrastructure practices on my property will improve the health of the Anacostia and Potomac Rivers as well as Chesapeake Bay.

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

Our neighbors and/or other similar organizations/institutions would support/approve if my organization/institution installed stormwater/green infrastructure on my property.

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

My organization/institution cares deeply of the opinion of our neighbors and/or other similar organizations/institutions.

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

My organization/institution could easily design/install-construct/maintain stormwater/green infrastructure on our property in order to generate and maintain the validity of SRCs.

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

The following obstacle is preventing my organization/institution from implementing stormwater/green infrastructure on our property:

Money/capital

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

The following obstacle is preventing my organization/institution from implementing stormwater/green infrastructure on our property:

Design skills/licensing

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

The following obstacle is preventing my organization/institution from implementing stormwater/green infrastructure on our property:

Construction skills and/or equipment

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

The following obstacle is preventing my organization/institution from implementing stormwater/green infrastructure on our property:

Maintenance skills and/or equipment

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

It is likely that my organization will install/construct stormwater/green infrastructure on our property in the near future for the sole purpose of generating SRCs.

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

Would you describe your organization/institution as a risk-averse?

Strong Disagree | Disagree | Somewhat Disagree | Neutral | Somewhat Agree | Agree |Strongly Agree

[1]--------[2]------------[3]----------[4]-----------[5]----------[6]--------[7]

6. Conclusion

This draft report provides an overview of work performed to-date on the topic of investigating the feasibility of using an agent-based modeling (ABM) platform to simulate the D.C. Stormwater Retention Credit (SRC) trading program. Further, ongoing and future efforts on this research will be presented in this section.

Feasibility of Modeling DC SRC Program

Based upon the data available and the literature assembled, it is clear that it is feasible to develop an ABM framework to model a generalized pilot scale of the D.C. SRC market. Agents in this model have been identified and the modeling environment has been described as well. This model will use available GIS as well as census and property databases along with information gained from subject matter experts (SMEs) from the Federal City Council study alone or, if resources allow, in conjunction with a survey to develop behavioral rules for identified agents that guide how agents make decisions on investing in green stormwater infrastructure (GSI) on their property over a period of time. These rules will also provide a basis on how various agents influence each other's behavior as well as how agents are influenced by their environment.

There are many unknowns regarding the future of the SRC market, which calls for a tool that can simulate a variety of scenarios in frameworks and assumptions on behavior as well as financial conditions. An ABM platform lends itself to this type of flexibility. Developing this type of model for the SRC market can help policy-makers as well as potential investors better understand how this market may behave under certain conditions. Beyond this, an ABM could be pivotal in providing support for property owners as they consider various options on if and how to invest in GSI on their property.

Future Efforts

The focus of this study up to this point has been on identifying and collecting data, reviewing peer-reviewed literature and developing a procedure to determine if an ABM approach to modeling the SRC market was feasible. Remaining work includes the development of a generalized pilot model to confirm that this type of approach is feasible, as predicted.

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Appendix

1. Student Support

Category	Number of Students Supported
Undergraduate	1 (University of the DC)
Master	
Ph.D.	1 (George Mason University)
Post Doc.	
Total	2

2.. List of publications (APA format)

- Peer reviewed journal article
- Conference proceeding

2015 National Capital Region Water Resources Symposium: Urban Water Management and Resilience in Uncertain Time, April 10, 2015, Washington DC

Title: To Green or Not to Green: Modeling Incentive-Based Programs for Green Infrastructure Investment on Private Properties

Seth Brown, PE, Stormwater Program and Policy Director, Water Environment Federation; Pradeep Behera, Professor and Chairman, Department of Civil Engineering, University of the District of Columbia; Celso Ferreira, Assistant Professor, Department of Civil, Environmental and Infrastructure Engineering, George Mason University; and Mark Houck, Professor , Department of Civil, Environmental and Infrastructure Engineering, George Mason University.

2014 American Water Resources Association Annual Conference, November 4, 2014, Tysons Corner, VA

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2015 Ohio Stormwater Conference, May 7, 2015, Sandusky, OH

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- Poster presentation (attach poster): Title, Author, and title of the symposium or conference

Information Transfer Program Introduction

The institute has no funded project for information transfer activities , but the Institute has been working closely with other water organization in the region and land grant units in the hosting institution to meet its mission. In collaboration with other Water Institutes in the Mid-Atlantic Region, the Institute co-hosted the regional water conference titled "The Future of Mid-Atlantic Water Infrastructure: Challenges and Solutions" in Shepherdstown, West Virginia, Sept. 24th & 25th, 2014. The purpose of these two-day conference is to bring together experts from governmental agencies, academia, the private sector, and non-profits to present and discuss challenges and opportunities for aging water infrastructure management and resilience in the regional and national scope. The agenda of the conference and presentations can be found in the following link: http://www.midatlanticwc.com/event-info/conference-agenda/

In collaboration with the American Water Resources Association in the National Capitol Region (AWRA-NCR), the Institute organized the 3nd Annual National Capitol Region Water Symposium on April 10, 2015, at the University of DC, titled Urban Water Management and Resilience in Uncertain Times. This one day symposium sought to bring together experts from governmental agencies, academia, the private sector, and non-profits to present and discuss challenges and opportunities for water management and resilience in the region, as well as national and international scope. In close collaboration with other land-grant centers in CAUSES, such as the Center for Sustainable Development, the Center for Urban Agriculture and gardening education, the Institute continued in conducting outreach activities by organizing training workshop, distributing newsletters, media releases and factsheets. The agenda of the symposium can be found in the following link:
http://www.awrancrs.org/images/Symposiums/2015AWRA_NCRWaterSymposiumProgram.pdf

In collaboration with the land grant units of the hosting institution, CAUSES, UDC, the Institute has provided laboratory services, trainings and outreach activities in advancing sustainability concepts in the District. The Institute conducts free soil quality and water quality testing service to the District to advance the urban food hub concept in order to address food and water security challenges in the District of Columbia and beyond. (<http://www.thesolutionsjournal.com/node/237308>). The institute is also working closely with the center for sustainable development in advancing the green infrastructure and creating green jobs by integrating urban agriculture and urban stormwater management by creating partnership with private and public institutions.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	5	0	0	0	5
Masters	3	0	0	0	3
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	9	0	0	0	9

Notable Awards and Achievements

The Institute is the process of getting Accreditation in Water Quality Testing through the National Environmental Laboratory Accreditation Program, NELAP. This is a big deal for the University of the District of Columbia in Particular, and the District of Columbia Department of Environment in General. We just completed the site audit and now responding to the audit.

Publications from Prior Years

1. 2009DC100B ("Modeling Model Uncertainty for Storm Water Quantity and Quality Analysis ") - Articles in Refereed Scientific Journals - Bejleri, Valbona. and Deksissa, T. (2014). A Bayesian Technique for Estimating the Uncertainty Associated with Parameters of Effluent Flow Rate of the Hydraulic Model. International Journal of Social Health Information Management, 7(15), 16-23.
2. 2011DC123B ("GIS-based Ecosystem Service Analysis of Urban Green Infrastructure as a Tool for Attaining Water and Air Quality Objectives in the District of Columbia") - Articles in Refereed Scientific Journals - Deksissa, Tolessa. (2014). GIS-Based Ecosystem Service Analysis of Green Infrastructure, International Journal of Innovative Research in Science, Engineering and Technology, 3(12), 17778- 17784