



Research and Technical Performance

MONITORING OF A NEW GREEN ROOF FOR WATER QUALITY AND QUANTITY

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Abstract

This paper evaluates the performance of the 3,000 sq ft green roof installed in May of 2006 at the headquarters of the American Society of Landscape Architects (ASLA) on 636 Eye Street NW, Washington DC. This green roof is one of seven in the Anacostia River watershed of Washington D.C. that the Chesapeake Bay Foundation has partially funded with an incentive grant. Water quality and quantity were measured on this roof for 5 rain events in the fall of 2006 and the spring of 2007. Temperature, pH, total suspended solids, total dissolved solids, dissolved oxygen, chemical oxygen demand, and nutrients were measured on rain water and runoff collected from the green roof. Heavy metals were measured for two rain events to check for their presence. The ASLA green roof retained approximately 75% of the total rainfall volume that fell on it over the ten month period that data were collected. The COD, phosphate, total phosphorus, total suspended solids, and total dissolved solids all increased by significant amounts over the concentration originally present in rain water; however the concentrations were below the E.P.A.'s promulgated freshwater chronic concentration standards. Nitrogen concentrations measured in the ASLA green roof runoff were similar to the values measured in the rainwater indicating that, when combined with the measured volume reduction, a significant overall reduction of nitrogen in stormwater runoff from a green roof can be expected. Heavy metals can also be produced by green roofs however they too measured below the allowable limits and below street concentrations.

INTRODUCTION

This project was designed to address the needs of the Chesapeake Bay Foundation (CBF), the American Society of Landscape Architect's (ASLA), and the District of Columbia's Water and Sewer Authority by monitoring the performance of the ASLA green roof for water



runoff reduction and water quality improvement. Under the National Pollutant Discharge Elimination System (NPDES), Municipal Separate Storm Sewer System (MS4), the government is tasked to utilize best management practice (BMP) methods to substantially minimize pollution transport from stormwater runoff. Green roofs are being promoted as an optional BMP throughout the Washington D.C. Metropolitan area. The 3,000 sq ft ASLA green roof was installed in May of 2006 at its headquarters building on 636 Eye Street NW, Washington DC. It is one of seven green roof demonstration projects in the Anacostia River watershed that the Chesapeake Bay Foundation has partially funded with an incentive grant.¹ The greenroof was monitored water quality and quantity on this roof for 5 rain events in the fall of 2006 and the spring of 2007. The sampling and monitoring of the green roof was performed in accordance with the standard operations for collection and measurement promulgated by the USEPA.

In this study pH, temperature, total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), and nutrients (ammonia, nitrite, nitrate, phosphate, and total phosphorus) were measured on rain water collected on the roof and runoff collected from the downspout from the green roof. Heavy metals (e.g. Cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), arsenic (As)) were measured for two rain events to check for their presence. All of the samples were measured in triplicate to confirm the reproducibility of the results and the accuracy of both the equipment and the sampling methodology.

The two primary goals of this project were to determine the reduction in runoff and to determine the concentrations of contaminants of concern leaving this green roof.² Two flow meters were already installed on the roof of the ASLA building giving flow data for the water leaving the roof. ASLA collected the water in two clean collection jars. A quantitative measure of the total flow or rainfall load on the roof was calculated by the known area of the roof and the acquired depth of rainfall. Sampling followed the same protocols as in earlier studies performed by Dr. Glass, with the only adjustment necessary being the collection of rain water, which is quite a different input source from normal stormwater runoff from streets or parking lots.

MATERIALS AND METHODS

The field methodology of this project consisted simply of collection of rainwater directly into a glass sample vessel placed on the ASLA roof and collection of the effluent water flowing from the roof through a sample port in the ceiling under the roof. Once a sample was obtained

¹ A description and evaluation of the CBF Green Roof Demonstration Program for Washington DC was documented in a paper presented at the 2007 GRHC Conference in Minneapolis. See: *Lessons Learned from a Green Roof Grant Program in Washington DC*, Peter A. Johnson, Chesapeake Bay Foundation, in the Conference Proceedings.

http://www.greenroofs.org/index.php?option=com_content&task=view&id=636&Itemid=120

² The ASLA green roof is a unique design with a variety of plantings including sedums, other hardy perennials and grasses and specific growing media composition for each. Descriptive data on the roof design and operation can be found on the website: www.asla.org



by ASLA, Howard University was contacted and collected the sample from ASLA within the day. The sample was then prepared for storage or analyzed that same day. Table 1 lists the parameters evaluated in this project and the methods used to determine their values.



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Constituent Name	Analytical Method	Collection method	Containers	Volume Required *	Preservative	Maximum holding time
Cadmium	AAS- Furnace	Composite	Plastic, Glass	60 µL	Filter on site HNO ₃ to PH<2	6 mths
Chromium	AAS- Furnace	Composite	Plastic, Glass	60 µL	Filter on site HNO ₃ to PH<2	6 mths
Copper	AAS- Furnace	Composite	Plastic, Glass	60 µL	Filter on site HNO ₃ to PH<2	6 mths
Iron	AAS- Furnace	Composite	Plastic, Glass	60 µL	Filter on site HNO ₃ to PH<2	6 mths
Lead	AAS- Furnace	Composite	Plastic, Glass	60 µL	Filter on site HNO ₃ to PH<2	6 mths
Arsenic	AAS- Furnace	Composite	Plastic, Glass	60 µL	Filter on site HNO ₃ to PH<2	6 mths
Zinc	AAS- Furnace	Composite	Plastic, Glass	60 µL	Filter on site HNO ₃ to PH<2	6 mths
Mercury	Cold Vapor Technique	Composite	Plastic, Glass	300 mL	Filter on site HNO ₃ to PH<2	Glass: 38 days/ Plastic: 13 days
TS-Total Solids	Total Solids Dried at 103-105°C	Composite	Plastic, Glass	< 200 mg residue	Cool, 4°C	24 hrs
TDS- Total Dissolved Solids	Total Dissolved Solids Dried at 180°C	Composite	Plastic, Glass	< 200 mg residue	Cool, 4°C	24 hrs
TSS-Total Suspended Solids	Total Suspended Solids Dried at 103-105°C	Composite	Plastic, Glass	< 200 mg residue	Cool, 4°C	24 hrs
COD	Closed reflux, Colorimetric Method	Composite	Glass	≤ 500 mL	Filter on site H ₂ SO ₄ to PH<2	No holding (better)
Nitrogen Ammonia	Ammonia selective electrode	Composite	Plastic, Glass	150 mL	Cool, 4°C H ₂ SO ₄ to PH<2	24 hrs
Nitrogen-Nitrite	Ion Chromatography	Composite	Plastic, Glass	100 mL	Cool, 4°C	No holding (better)
Nitrogen-Nitrate	Ion Chromatography	Composite	Plastic, Glass	100 mL	Cool, 4°C H ₂ SO ₄ to PH<2	24 hrs
Soluble (dissolved) Phosphorus	Ion Chromatography	Composite	Plastic, Glass	100 mL	Filter on site Cool, 4°C	48 hrs
Total Phosphorus	Ion Chromatography	Composite	Plastic, Glass	100 mL	Filter on site Cool, 4°C	48 hrs
Temperature	Thermocouple	Measurement on site	Plastic, Glass	N/A	Determine on site	No holding
pH	pH-probe	Measurement on site	Plastic, Glass	N/A	Cool, 4°C Determine on site	6 hrs

Table 1: Parameters Measured and the Technique Utilized for Measurement

This study was not meant to be exhaustive or to completely answer the question of the effectiveness of green roof technology. Therefore, the scope of this study is intended to provide only an initial assessment of the performance of the green roof at ASLA. The sampling program

was completed in the spring of 2007. This document summarizes the results including the data collected and an initial analysis of the performance of the green roof facility.

Results and Discussion

The objectives of BMP's for stormwater management include peak flow attenuation, volume reduction, and water quality improvement. Decentralized controls use unit processes of the hydrologic cycle, such as infiltration and evapotranspiration, to meet these objectives. The ASLA green roof meets these same objectives, however the results of this study show that the largest impact of a green roof is in peak attenuation and volume reduction. As is shown in Figure 1, for the majority of the precipitation events (50 of 65, 77%), there was no runoff from the green roof. Also, during the period of this monitoring, the total volume of runoff leaving the roof was reduced by 74% (9,725 of 37,237 gallons), thus resulting in a significant reduction in the volume of water entering the combined sewer system from the roof over the ASLA building. Although no definitive peak attenuation is presented here, anecdotal evidence showed a significant delay between rainfall and water leaving the roof as runoff through the piping system.

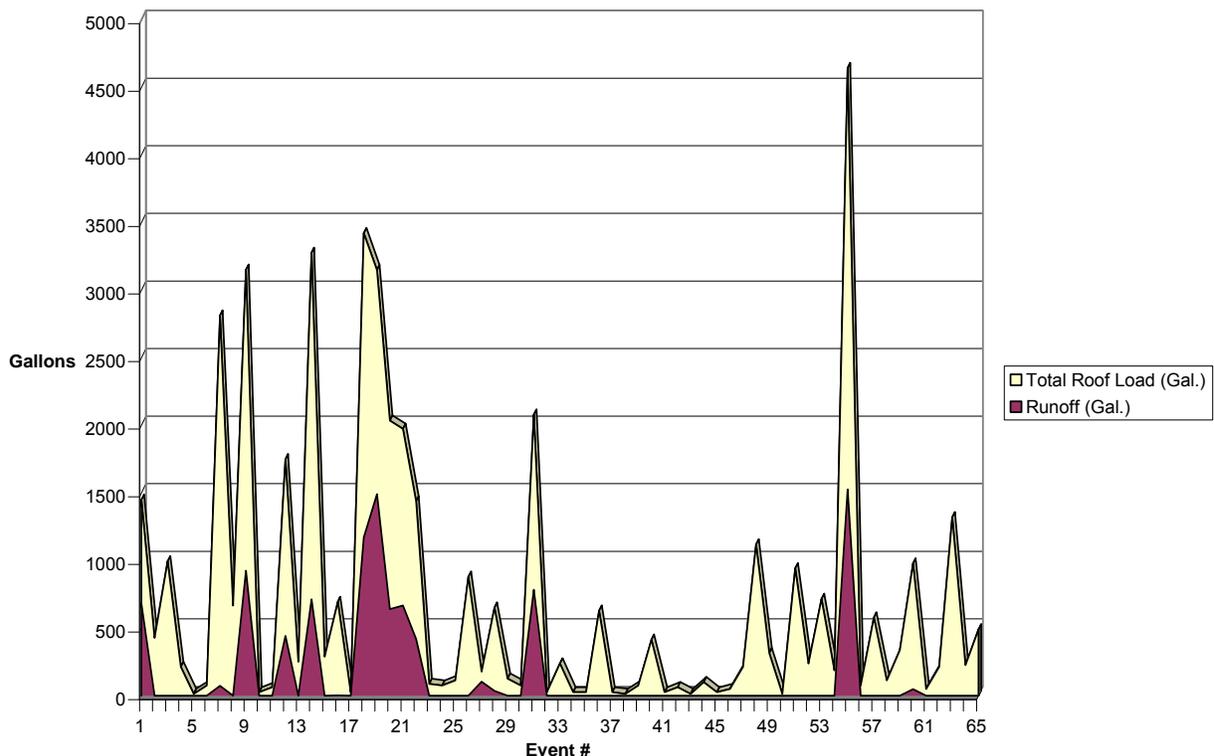


Figure 1: Rainfall Load versus Roof Runoff

Figure 1 clearly depicts the difference between the volume of rainfall that falls on the area of the green roof and the amount of runoff that is produced. This difference between the peaks represents the vast amount of rainfall that never reaches the CSO. From event 31 through event 55 no rainfall reached the effluent down pipe leading from the roof. While this demonstrates the benefits of the green roof, it also prevents the collection of many runoff samples since only significant rain events produce runoff. The water quality data for the rain water and the 26% of the water that made its way through the green roof is presented both in tabular form and in individual graphs in the following pages. Table 2 shows that the rain water pH and the temperature increased while passing through the green roof. Also, the COD, phosphate, total phosphorus, total suspended solids, and total dissolved solids all increased by significant amounts over the concentration originally present in rain water. While these data indicate, at first glance, that the green roof is producing some pollutants considered harmful to natural water bodies, two considerations must be made. First, if one were to evaluate the characteristics of runoff from a normal roof, although some of these pollutants may not be present, other byproducts of the weathering of roofing materials would be. There was some thought given initially to comparing the green roof to a normal roof, however, that was beyond the scope of this project. The second consideration is that most of the parameters measured were within the allowed freshwater chronic concentration values promulgated by the E.P.A., and none of the concentrations were above the acute level. When comparing this data to a recent study that Dr. Glass completed evaluating stormwater runoff and the performance of a bioretention cell, (see tables 2 and 3) the effluent COD was lower from the green roof (49.5 mg/L vs. 66 mg/L).

	pH	Temp	D.O.	COD*	NO ₃ ⁻	NO ₂ ⁻	PO ₄ ⁻³	TP	TSS	TDS
C _{rain} (mg/L)	7.0	23.0	8.9	9.1	1.3	0	0	3.4	0.6	0.8
C _{ef} (mg/L)	7.6	23.7	8.7	49.5	1.2	0	0.6	8.3	18.6	18.2
Removal %				-444	12		-1700	-145	-1971	-2294
Freshwater (mg/L)	6.5-9.0			20	10	1	1	1	250	500

Table 2: Summary of Non-metal Parameters ASLA Green roof

	pH	Temp	D.O.	COD*	NO3	NO2	PO3	TP	TSS*	TDS
C _{in} (mg/L)	8.1	19	5.9	112	0.19	0.4	0	0.5	71	52
C _{ef} (mg/L)	7.7	18.3	5.8	66	0.16	0.3	0	0.2	24	14
Removal %				41	17	21	-2	51	66	74
MCL (mg/L)	6.5-8.5			20	10	1	1	1	20	500

Table 3: Summary of Non-metal Parameters, Benning Road Bridge, Bioretention

Two samples were taken to measure heavy metals in the green roof runoff and the results are shown in Table 4. These indicate the production of copper, lead, and arsenic as the rain water passes through the green roof. This may be caused by the geotextiles or other roofing material that supports the soil and plant matrix on the roof. Only lead was produced at a higher concentration than that found to be acceptable for freshwater chronic effects.

	Cu	Cd	Zn	Cr	Pb*	Hg	As
C _{in} (µg/L)	18	0	174	0	0.7	0	0.4
C _{ef} (µg/L)	157	0	105	0	120	0	6
Removal %	-776		35		-16667		-1333
Freshwater Chronic Effects (µg/L)	1000	5	500	100	15	2	50
Detection limit (µg/L)	5.6	0.8	8	1.6	20	240	20

Table 4: Summary of Heavy Metal Concentrations



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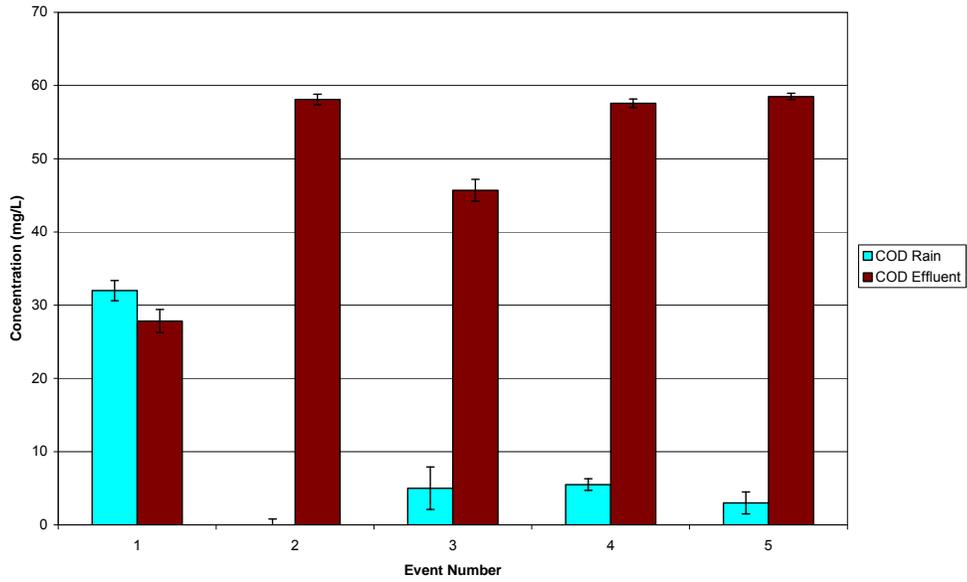


Figure 2: Chemical Oxygen Demand

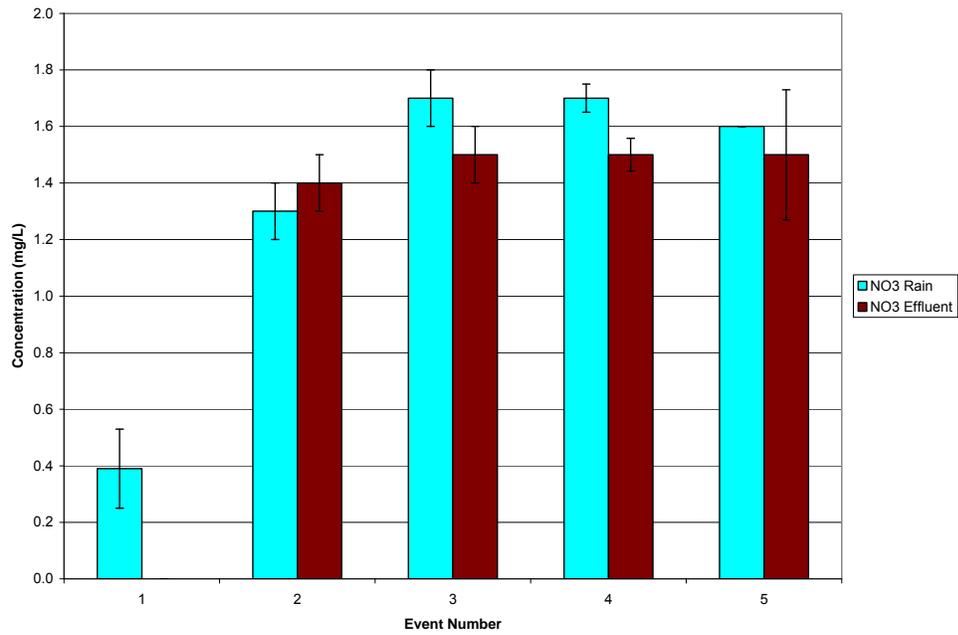


Figure 3: Nitrate



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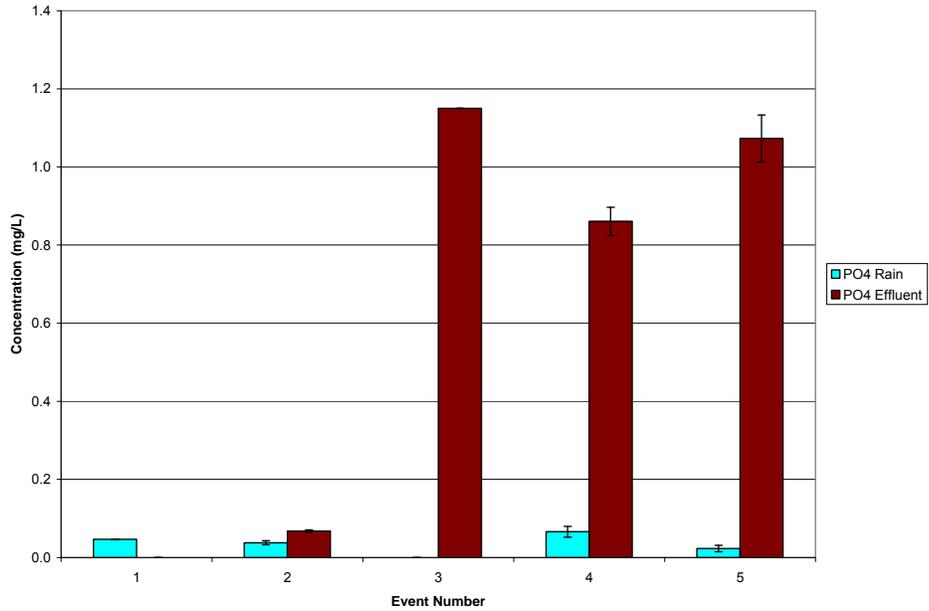


Figure 4: Orthophosphate

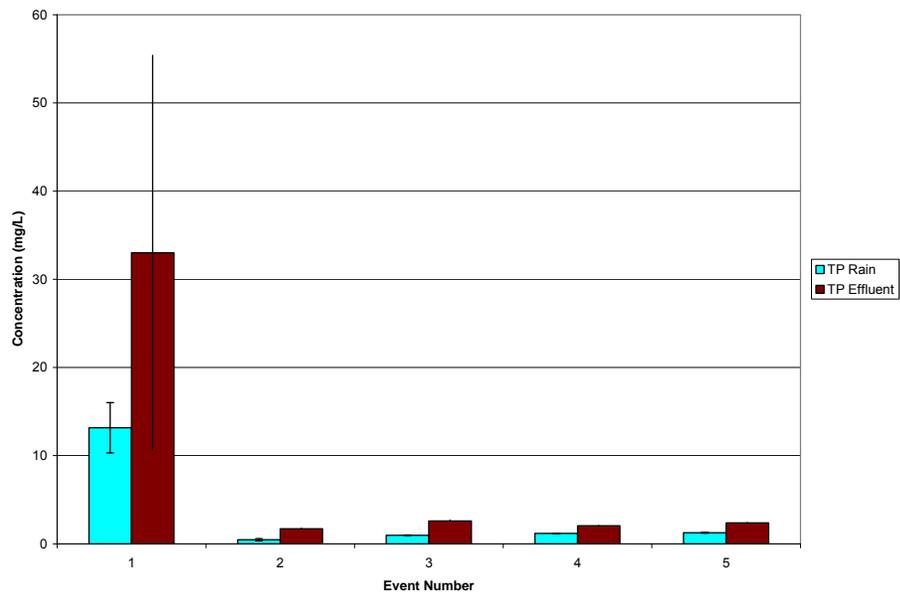


Figure 5: Total Phosphorus

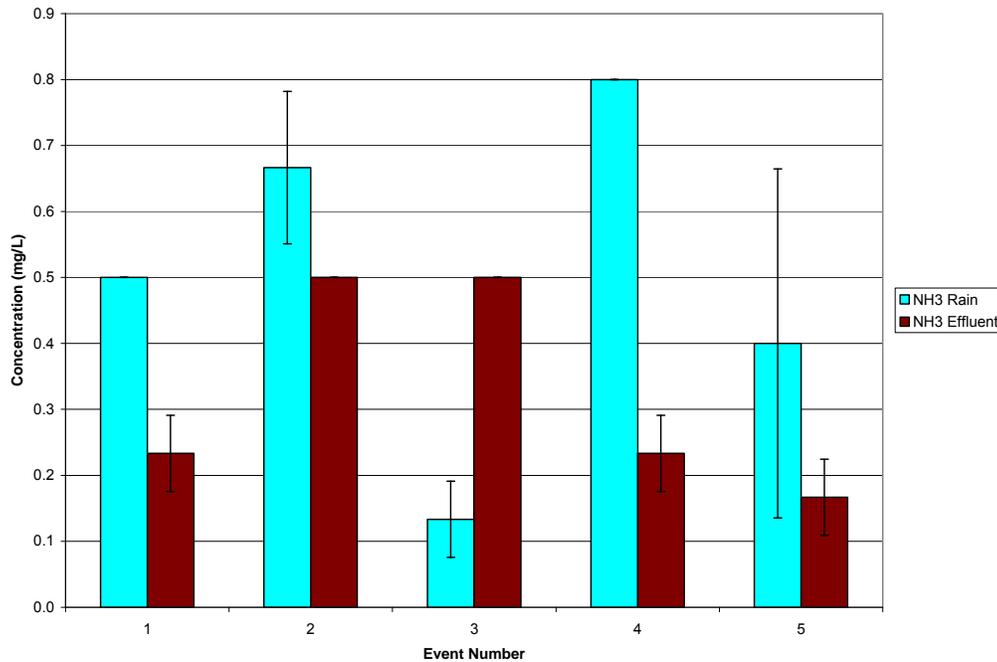


Figure 11: Ammonia

Conclusions

As previously noted, this sampling and monitoring project was designed to provide initial indications of the performance of a typical green roof operating in Washington DC with a focus on water quality measurements because very few previous studies produced such data. The data collected must be examined with care given the limited scope of monitoring and the low number of samples. However, the following general observations are instructive and can be used as a starting point for a more comprehensive evaluation of green roof technology and how its application in the Washington D.C. metropolitan area could reduce city-wide pollution problems from stormwater runoff.

1. Green roofs are highly effective at stormwater volume reduction. To produce runoff from green roofs, storms generally have to be larger than 1 inch in a 24-hour period, and often must come in quick succession. The ASLA green roof retained approximately three quarters of the total rainfall volume that fell on it over the ten month period that data were collected for this monitoring effort.
2. Production of certain nutrients (esp. phosphorus) can be expected from a young green roof; however the concentrations of nutrients should generally fall below the E.P.A.'s promulgated freshwater chronic concentration standards and concentrations currently found in runoff from local streets and possibly normal roofs. Nitrogen



concentrations measured in the ASLA green roof runoff were similar to the values measured in the rainwater indicating that, when combined with the measured volume reduction, a significant overall reduction of nitrogen in stormwater runoff from a green roof can be expected.

3. Heavy metals can also be produced by green roofs however they too should largely fall below the allowable limits and below street concentrations.

This report should be viewed as providing useful initial data for beginning to evaluate green roof performance in the Washington D.C. metropolitan area. The ASLA green roof seems to perform well with water retention and evapotranspiration and reducing the nitrogen load in runoff. In time, as the green roof continues to mature, there will probably be lower concentrations of phosphorus in the water that does pass through the roof.

The results obtained here are also consistent with other recent research on green roof performance. For example, the Center for Green Roof Research at Penn State University collected and analyzed samples from test plots during 2005-06 and reported a significant reduction in the observed nutrient loading rate for nitrate.³ Similar results were also obtained from research by Dr. Bill Hunt and others at the Water Resources Research Institute, N. C. State University.⁴ Studies conducted by Dr. Manfred Kohler and Dr. Marco Schmidt at the Technical University of Berlin add longer-term data on green roof water quality performance.⁵ Their work reported in 2004 show that green roofs retain and bind contaminants from air dust or rain but nutrients can leach out of the substrate as well. However, the leaching of nutrients can be reduced over time as shown by experiments over four years. These studies indicate that, with the appropriate choice of substrate, mature green roofs can be designed to reduce total pollutant discharges.

In Conclusion, Green roofs have significant potential for reducing certain most harmful stormwater carried pollutants in major metropolitan areas such as Washington DC. However, more comprehensive and extensive monitoring studies are needed to evaluate specific performance measures of specific designs and develop accurate predictive tools.

³ See *Green Roof Runoff Water Quality*, by Robert Berghage, et al, Penn State, in 2007 GRHC Conference Proceedings, Minneapolis. And <http://hortweb.cas.psu.edu/research/greenroofcenter/>

⁴ Greenroof Research of Stormwater Runoff Quantity and Quality in North Carolina, Amy Moran, Research Assistant, Bill Hunt, Assistant Professor, Greg Jennings, Professor, N.C. State University, The NCSU Water Quality Group Newsletter, August 2004.

⁵ Study of Extensive Green Roofs in Berlin, Germany, [Part III – Retention of Contaminants] by Manfred Kohler and Marco Schmidt, Technical University of Berlin, 2003