NWQEP NOTES

The NCSU Water Quality Group Newsletter

Number 109 May 2003 ISSN 1062-9149

NC STATE UNIVERSITY

NC STATE UNIVERSITY
A&T STATE UNIVERSITY
COOPERATIVE EXTENSION
Helping People Put Knowledge to Work

IN THIS ISSUE

NWQEP NOTES is issued quarterly. Subscriptions are free. *NWQEP NOTES* is also available on the World Wide Web at http://www5.bae.ncsu.edu/programs/extension/wqg/issues/Default.htm. To request that your name be added to the mailing list, use the enclosed publication order form or send an email message to wq_puborder@ncsu.edu.

PROJECT SPOTLIGHT

Bioretention Use and Research in North Carolina and other Mid-Atlantic States

Bill Hunt, PE, Extension Specialist
Dept. of Biological & Agricultural Engineering
N.C. State University

Introduction

Stormwater runoff is a primary factor in the degradation of many streams and other water bodies. The adverse impacts of this and other sources of pollution include shellfish closures, fish kills, and reduction of aesthetics, which consequently hurts the fishing and recreational industries. Stormwater runoff contains a variety of pollutants found at elevated levels including nitrogen, phosphorus, and many metals (Barrett *et al*., 1998, and Wu *et al*., 1998). All impermeable surfaces including rooftops and parking lots contribute to the pollution loads found in stormwater runoff.

In coastal areas of the eastern United States, nitrogen is a particular concern. Nitrogen, and to a lesser degree phosphorus, imbalances in coastal North Carolina are blamed for spawning fish kills in NC estuaries (Gray, 2000). Similar impacts were noted in the Chesapeake Bay. Chesapeake officials have declared a nitrogen reduction goal of 50% in the next eight years. State and federal regulations, such as the National Pollutant Discharge Elimination System (NPDES) Phase II force new developments to mitigate the effects of pollutants in stormwater by requiring the installation of stormwater treatment practices, called Best Management Practices (BMPs). Examples of stormwater BMPs include stormwater wetlands, sand filters, wet ponds, and most recently, bioretention areas.

Stormwater practices, particularly those installed in areas frequented by pedestrian traffic, not only need to be effective pollutant removers, but they must also maintain some aesthetic appeal. BMPs that can be integrated into the design of parking lots and neighborhoods are particularly important. The use of bioretention, essentially a vegetated sand filter planted with shrubs and trees (see Figure 1), is poised to grow because it appears to improve water quality and can be designed to be aesthetically pleasing, making it potentially ideal for residential and commercial settings. Bioretention can be used to treat commercial site runoff, particularly from parking lots and rooftops, because the cells can be sited within parking lot medians. Many communities require 10-15% of the area of large commercial development sites be set aside for medians and other open space (Avery, 2001; Paletta, 2001).

The focus of this article is on pollutant removal capabilities of bioretention designs. Davis et al. (2001) have shown that bioretention did not substantially reduce levels of nitrate-nitrogen, especially compared to the performance standards some states will require BMPs to meet. For example, NC requires all new stormwater practices to have nitrate removal rates approaching 30%. Davis's laboratory study reported nitrate-nitrogen removal rates of only 16%, however, levels of phosphorus and several metals were significantly reduced. In comparison, recent studies performed by the author and presented below suggest that bioretention is capable of significantly reducing nitrate-nitrogen and total nitrogen levels 60 to 90%.

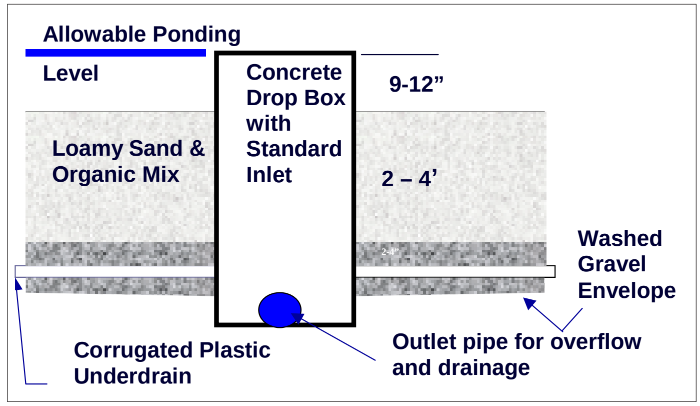

Figure 1. Schematic of bioretention unit. Infill soil depth varies based on cover vegetation. Underdrains typically required with tight soils.

EDITOR'S NOTE

Bioretention units, otherwise known as rain gardens, are becoming an increasingly popular best management practice for communities interested in alternative ways to manage their stormwater. Designed to not only detain and treat the first inch of runoff but to be aesthetically pleasing as well, bioretention is suitable for both residential and commercial settings.

As a relatively new practice, numerous questions remain as to the effectiveness of bioretention to reduce nonpoint source pollutant loads and stormwater quantities. Included in this uncertainty is the relationship of design features to performance. In an effort to lessen the knowledge gap and promote development of design standards for bioretention, studies were conducted in Maryland, Pennsylvania and North Carolina to evaluate bioretention's effectiveness at reducing nutrients and metals in stormwater runoff. Also looked at were effects of specific design considerations including infill soil depth, drainage configuration, and maturity of cover vegetation. This issue of *NWQEP NOTES* reports on the results of these studies and discusses future research needs and opportunities for bioretention.

As always, please feel free to contact me regarding your ideas, suggestions, and possible contributions to this newsletter.

Laura Lombardo
Editor, *NWQEP NOTES*
Water Quality Extension Associate
NCSU Water Quality Group
Campus Box 7637, NCSU
Raleigh, NC 27695-7637
Tel: 919-515-3723, Fax: 919-515-7448
Email: notes_editor@ncsu.edu

Bioretention: Development, Design, and Function

Bioretention is a relative newcomer to the world of stormwater treatment; however, its use has grown significantly for reasons discussed below. Initial design standards for the practice were relatively sparse, but have since begun to be based on standard engineering methods.

Bioretention Use

Bioretention was first introduced in Prince George's County, Maryland (Coffman *et al*., 1993a). The device was installed to treat parking lot runoff at a shopping center and has been monitored since by Davis *et al*. (2000). Initial reasons for bioretention utilization were both water quality-based and aesthetic. Coffman *et al*. (1993a) discussed the several mechanisms through which bioretention removes pollutants and reduces stormwater runoff intensity, including sedimentation, transpiration, evaporation, infiltration, bio-decay, nutrient cycling, and bio-uptake. Because bioretention also met important landscape issues such as aesthetic enhancement, shade, windbreak, and noise reduction, it appeared that its use would grow substantially.

Since 1998, several North Carolina communities, particularly Cary, Chapel Hill, Greensboro, and Wilson have had 5 to 10 bioretention devices designed and installed. The second most commonly planned stormwater practice in Greensboro (North Carolina's third largest city with a population over 200,000) is bioretention (Bryant, 2001).

Bioretention use in North Carolina is triggered not only by current and upcoming water quality standards, which force all runoff from sites as small as 0.4 disturbed hectare (1.0 acre) to be treated, but also by community landscape ordinances. Very few stormwater practices can be neatly sited on small, 0.4 to 2.0 ha (1 to 5 acre), watersheds. The most common are infiltration trenches and sand filters. When comparing the costs of sand filters to those of bioretention, the impending use of bioretention becomes apparent (Hunt, 2002). On a per-acre treated basis, Hunt found that bioretention construction costs ranged between 5% and 20% of the cost of sand filters. Only in areas where land costs are very high ($200,000 per hectare or $500,000 per acre) would total sand filter costs compare to that of bioretention. Developers are finding that bioretention areas can potentially serve double duty: (1) potentially meeting water quality standards, and (2) fulfilling landscape requirements that many communities impose.

Bioretention Design

Bioretention design standards were initially sparse. Coffman *et al*. (1993a and 1993b) mentioned that bioretention areas should occupy at least 5% of the drainage area of impermeable land draining to it. Additionally, a minimum width of 4.5 m (15 ft) and length of 12.2 m (40 ft) were specified to provide an adequate microclimate for vegetation. Fill soil requirements were simply a maximum volume of clay around 15-25% of the total soil volume and an adequate amount of organic matter. State-issued BMP manuals, such as North Carolina's (1997) and Pennsylvania's (1998), quickly seized upon these relatively scant design guidelines. The *Pennsylvania Handbook of Best Management Practices for Developing Areas* (1998) specifically states that there are *no* bioretention design requirements for regulatory compliance. More recently, a North Carolina Cooperative Extension design manual (Hunt and White, 2001) now provides additional design guidance as detailed in Table 1.

While design recommendations are more detailed now than they were five years ago, there is still a substantial gap in knowledge with regards to several critical questions facing a bioretention designer, such as the following:

Table 1. Summary of bioretention design guidance from Hunt and White (2001).

Design Parameter	Design Guidance
Capture Volume	Runoff volume from 25 mm (1.00 in) rainfall, based on SCS Curve Number. From impermeable surfaces, 25 mm (1.00 in) is expected to produce about 20 mm (0.80 in).
Surface Area	Divide the Capture Volume by average depth of bioretention (suggested 230 mm or 9 in).
Fill Soil	Sandy Loam or Loamy Sand. Hydraulic conductivity of soil to range between 0.007 to 0.014 mm/sec (1-2 in/hour). Max clay content of 15% of volume.
Depth of Soil	Dependent upon cover vegetation – 0.46 m to 0.61 m (1.5-2.0 feet) for grassed bioretention areas. 1.2 m (4.0 feet) optimum for bioretention constructed of shrubs and trees.
Underdrain sizing	Based on gravity flow through drains using the Manning equation. Factor of safety is 10. A minimum of two pipes required for redundancy.

1. What is the required depth of fill soil for pollutant removal?
2. What material is best suited for mulch (e.g., hardwood or pine straw)?
3. What soils are best suited for backfill (e.g., very sandy or sandy/clay loam mix)?
4. How much organic matter is required in fill soil for pollutant removal?
5. Is the current aerobic drainage configuration most appropriate?
6. Do bioretention areas act as a sink for water, reducing the amount of water leaving a developed site?
7. Is bioretention performance enhanced in the summer similar to other BMPs that rely in part on vegetation and microbial action, such as level spreaders)?

Recent studies at the University of Maryland provide answers to questions #1 and 3. Field studies in North Carolina and a laboratory study at Penn State University attempt to answer questions #1, 5, 6, and 7. Additionally, the North Carolina studies comprise the first long term study of bioretention cells and will be used to estimate annual loading reductions of total nitrogen, phosphorus, and various metals. The studies are discussed below.

Review of University of Maryland Research

Dr. Allen Davis of the University of Maryland's Department of Civil Engineering has published a pair of studies principally describing metals removal by bioretention devices. The first (Davis *et al*., 2001) used synthetic runoff with pollutant loadings determined from literature, applied to bioretention prototype boxes in a laboratory. Davis's bioretention units were found to remove over 90% of Zn, Cu, and Pb that was applied. TP removals ranged from 71 to 81%; Total Kjeldahl Nitrogen (TKN) and NH_4^+ removal percentages ranged from 68 to 75%, and 60 to 79%, respectively. Bioretention performance with NO_3^-, however, was poor. Nitrate-nitrogen effluent levels ranged from a substantial increase of 205% to a moderate decrease of 24%.

In the second study, Davis *et al*. (2003) applied synthetic runoff to portions of bioretention cells that were at the time five and two years old, respectively. From the experiments, Dr. Davis and his colleagues found metal removal rates (Cu, Pb, and Zn) exceeded 95% at the more mature of the two sites studied, the Greenbelt mall parking lot. Removal rates were lower at the second study site, Largo, with mean removal rates of 43%, 70%, and 64% for Cu, Pb, and Zn, respectively. The differences are attributed to two factors: (1) A larger fraction of fines in soils at the Greenbelt site than the Largo site, which contained a higher amount of course soils (construction sand). Fines have a higher level of pollutant adsorption and hence, removal due to a greater surface area; and (2) Perhaps the more mature a site is (Greenbelt) with a denser vegetative root zone, the better the pollutant removal efficiencies, as more grass roots could have aided in metal attenuation. (Davis *et al*, 2003).

Another noteworthy finding from Davis's studies is the importance of soil depth. Laboratory studies and the Greenbelt field study all show high metals removal (greater than 90%) within the first 20 cm (8") of soil depth. This suggests that if the bioretention area is being designed for metals removal, a deep soil depth, such as four feet, may not be needed, particularly if a soil with a limited, but existing, fraction of fines is used.

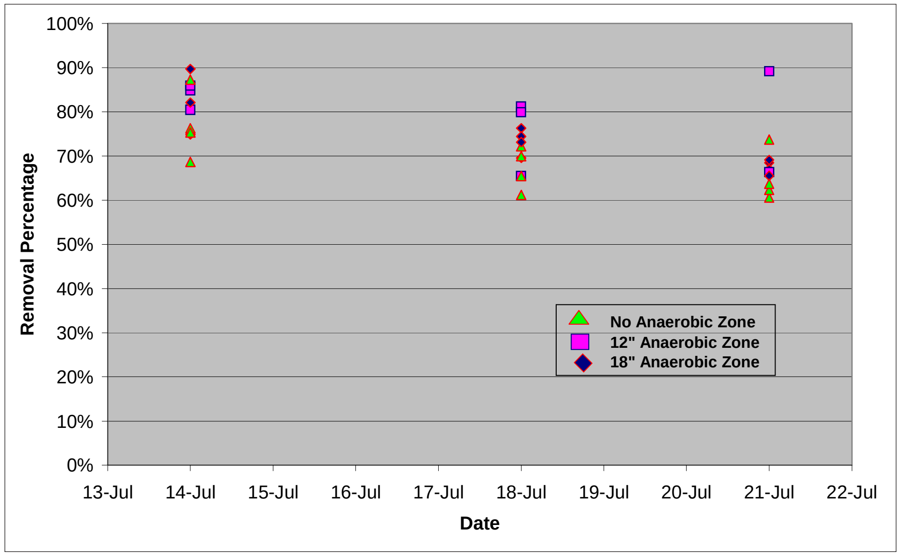

Figure 3. TN removal efficiencies from PSU lab study–anaerobic layer thickness

Review of Research Conducted at Pennsylvania State University

A team of researchers led by Dr. Albert R. Jarrett and W.F. Hunt conducted a series of column studies to determine the importance of establishing an aerobic layer for TN removal. Dr. Davis (2000) noted in the University of Maryland studies that in cases where there was positive NO_3-N removal, there were apparent zones of saturation, which may have aided in the conversion of nitrate to nitrogen gas. Jarrett and Hunt decided to force anaerobic zones by designing a saturated layer into the bioretention cells (Hunt *et al*., 2002). Figure 2 shows four cylinders used for testing. The following parameters were tested using the columns: (1) the impact of having a saturated zone; (2) the importance of saturated zone thickness; (3) the impact of rainfall frequency; and (4) the importance of soil temperature. The soil used to fill the columns was the A Horizon of a Cecil soil (sandy loam to sandy clay loam), imported from North Carolina. The percent of fines in the soil was relatively high, approximately 25%. Hydraulic conductivity tests were run on four of the columns after they were constructed, and each had a conductivity ranging from 0.003 to 0.010 mm/s (0.5 in/hr to 1.5 in/hr), which is at the lower end of design standards. A synthetic runoff based upon that used by Davis *et al*. (2001) was applied to the columns. The concentrations of the effluent were compared to those of the influent. The results for each experiment were very positive toward the removal of TN and NO_3. Independent of drainage configuration (aerobic or anaerobic), anaerobic zone depth, temperature, or rainfall frequency, nearly every bioretention microcosm reduced TN outflow levels at least 55% of their influent levels. The reduction of NO_3 levels was even more pronounced, as the concentration of NO_3 was reduced by at least 90% during every experiment.

Figure 2. Columns tested at Penn State included the ability to create an anaerobic zone using flexible tubing. Each was filled with four feet of Cecil Sandy Loam.

Figure 3 shows results from an experiment in July 2002 where varying anaerobic zone soil depths (0, 12, and 18") were tested. As shown, TN removal rates all exceeded 60%. While the removal efficiencies for columns without an anaerobic zone may appear slightly lower, there is no statistical significance. Conclusions from this experimentation are similar to those reached by Davis *et al*. (2003), except with a different pollutant. A fill soil with a higher amount of fines appears to remove TN and NO_3 at a high rate, regardless of a designed anaerobic zone. Jarrett and Hunt concluded that pocket anaerobic zones developed independent of the design, but were perhaps dependent on fill soil.

Review of Field Research in North Carolina

Four bioretention areas at two sites have been monitored in North Carolina since the summer of 2002. At each site, several questions are being investigated including the importance of soil depth, change of drainage configuration, and the seasonal performance of bioretention with respect to the removal of nitrogen, phosphorus, zinc, lead, and copper. Bioretention's potential role as a sink for water, reducing runoff volume, is also being evaluated. The studies are presented below, followed by preliminary results.

Greensboro Battleground Crossing Shopping Center

Battleground Crossing Shopping Center in Greensboro was constructed in 2000 and 2001. The county soil survey indicates that the soil on site is a Madison clay loam, relatively tight, with a very low permeability (0.2 to 0.6 in/hr) and a hydraulic conductivity less than 0.42 mm/s (0.06 in/hr) below the A soil horizon. The soil typically has a perched water table near the surface (0.15-0.46 m or 6-18 inches). This bioretention design included underdrains due to the soil's low conductivity. The watershed's use is commercial with nearly all site visits coming from leisure-commercial traffic (Figure 4). The shopping center is immediately upstream from Horsepen Creek, which eventually drains into the Cape Fear River, an important water supply for Fayetteville and Wilmington, NC. Two bioretention areas were constructed at the site. Both are 1.2m (4 feet) deep soil layers. One cell was retrofitted to create an anaerobic layer as seen in Figure 5. An upturn in the drainage pipe forces the bottom two feet of the bioretention cell to be saturated. The second cell is conventionally drained. The watersheds of the bioretention areas are nearly 0.5 acres each and the watershed size to bioretention surface area ratio are nearly the same (5%). An organic sandy soil was backfilled over the underdrains. The soil's hydraulic conductivity was tested two years after construction and was found to be around 0.11 mm/s (15 in/hr), which is higher than standard design guidelines.

Figure 4. Bio-retention Cell #1 completed and outfitted for monitoring at Battleground Crossing Shopping Center in Greensboro, NC.

Chapel Hill University Mall

The University Mall in Chapel Hill has been open since the early 1970's. The county soil survey shows that the soil on site is relatively tight: clay, clay loam, and silty clay (White Store-urban complex). The soil has a very low permeability with a hydraulic conductivity less than 0.42 mm/s (0.06 in/hr) below the A soil horizon. The soil typically has a perched water table near the surface (0.15-0.46 m or 6-18 inches). Two separate bioretention areas were constructed at the mall during the summer and fall of 2001. As with the Greensboro site, the

Figure 5. Underdrain with upturned elbow to induce anaerobic conditions in bioretention cell.

bioretention designed here included underdrains due to the soil's low conductivity. The location of one cell's underdrain tied into the overflow inlet structure is shown in Figure 6. The watershed's use is primarily commercial with nearly all site visits coming from leisure-commercial traffic. The shopping center drains to Little Creek, which eventually drains into Jordan Lake, an important water supply for the Raleigh-Durham metropolitan area. The watershed of the bioretention areas varies from 0.09 ha to 0.23 ha (0.2 acres to 0.5 acres) each, but the watershed to surface area ratio of each BMP is somewhat consistent (5% to 8%). The design parameter tested at the Chapel Hill site is soil depth, as nominal depths of 0.6 and 1.2 m (2 and 4 feet) were tested. No anaerobic conditions were designed into the system. The bioretention cells each had imported sandy soil that was placed over the underdrains. The hydraulic conductivity of fill soil cores was calculated 18 months after the sites were constructed using the constant head permeability test and were found to range from 0.009 to 0.021 mm/s (1.3 to 3.1 in/hr). This permeability is in the target range for design purposes. The fill soil was sandy to sandy loam. Figure 7 shows cell #1 eight months after it was constructed.

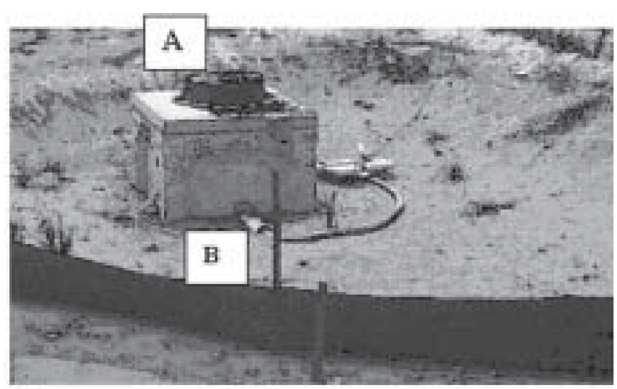

Figure 6. Sediment basin at Chapel Hill, NC site, 2001, before conversion to bio-retention. Manhole cover (A) will serve as overflow, and site where skimmer is connected (B) will be location of underdrain pipes.

Figure 7. Bio-retention cell #1 eight months after construction during a hydraulic test.

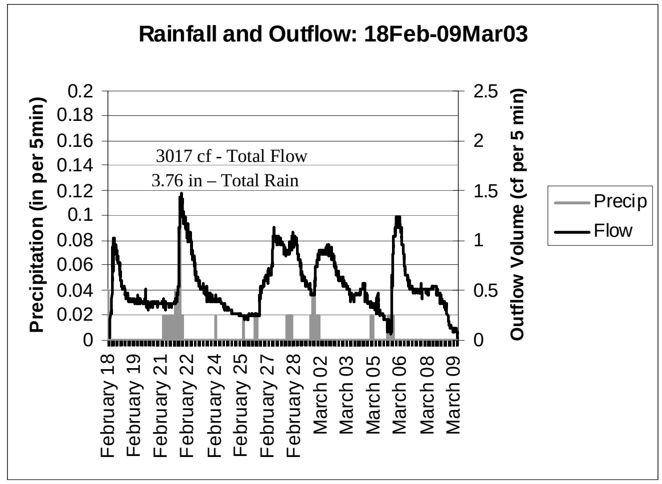

Figure 9. Rainfall and Outflow 18 Feb – 09 Mar 03

Initial Field Results

Seasonal Effect: Bioretention's impact on outflow is substantially different in the summer/fall and winter. The modified hyetograph and hydrographs shown in Figures 8 and 9 illustrate the difference. At the Greensboro site, during each 21-day period, approximately the same amount of rain fell on the watershed (4.16" in September 2002 and 3.76" in February-March 2003). In late summer/early fall (Figure 8), outflow occurred only 4 times for maximum periods of 1.5 days. In the winter, when evapotranspiration rates are very low, outflow persisted the entire 21-day period. The resulting mass removal efficiencies were substantially different, as the nutrient and metal masses directly entering the storm drainage network from the bioretention outflow in September 2002 were much lower than that of February-March 2003. Consequently, the mass removal efficiencies of September 2002 are much higher than those of February-March 2003. This is highlighted in Table 2.

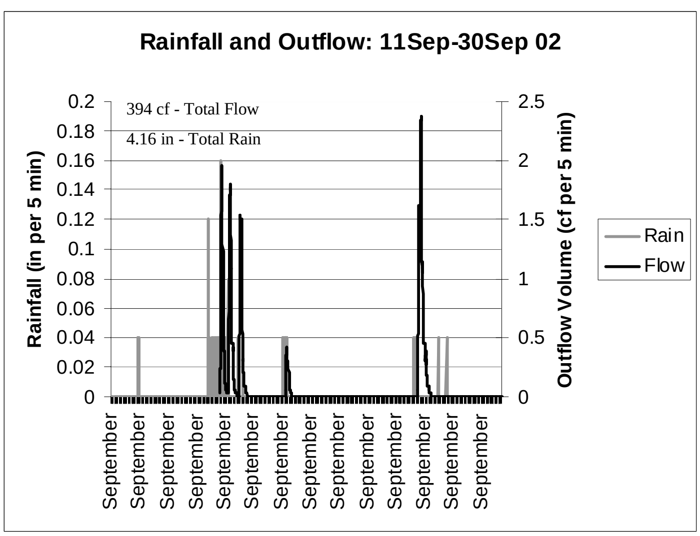

Figure 8. Rainfall and Outflow 11Sept – 30 Sept 02

Table 2 shows the mass removal efficiencies for several storms from Greensboro. It illustrates the outstanding mass removals for Zn, Cu, and TN during the summer and fall. TP removal rates are variable. In the winter, removal efficiencies are much lower, as only Cu removal efficiencies remain high. A strong seasonal effect is obviously present. All removal efficiencies shown are for a four feet deep conventionally drained bioretention device (Greensboro Cell #2).

Table 2. Mass pollutant removal efficiencies for a Conventionally Drained bioretention cell in Greensboro. The cell has soil that is nominally four feet deep.

Date	Rainfall (in)	Removal Efficiencies (%)			
		TN	TP	Zn	Cu
24Jun02	1.36	88.9	50.6	NS	NS
17Sep02	2.16	57.9	-535	99.5	99.5
27Sep02	2.12	73.9	12.2	99.9	100
17Oct02	2.76	63.3	-87.8	99.5	99.9
15Feb03	0.66	-235	-1000+	30.1	97.0
01Mar03	3.54	-636	-242	98.7	100

Effectiveness of Anaerobic Zone: A comparison of anaerobic and conventional drainage designs in the field at the Greensboro site was made by examining concentration data. Two bioretention cells, each with nominally four feet of soil, were tested. As seen in Table 3, pollutant concentrations are generally lower in the anaerobic design (G1) than in the conventional (G2) drainage configuration. This does not necessarily indicate total mass removal, however, as flow was not measured at the outfall from G1. Of interest, the anaerobic design has neither clearly higher nor lower TN removal levels, the purpose for which it was designed. Because each device shares the same watershed, it is assumed that the inflow concentrations were the same for each device.

Continued on p. 9

NCSU Water Quality Group Publications List and Order Form (May 2003)

Publication Number	Reports & Journal Articles	Price($)	Quantity	Total($)
WQ-128	2002 NC Stream Restoration Conference (Conference Agenda and Proceedings) (2002) (73p)	10.00	_______	_______
WQ-127*	Hydraulic Geometry Relationships for Urban Streams Throughout the Piedmont of North Carolina (2002) (11p)...	Free	_______	
WQ-126*	Pollutant Export from Various Land Uses in the Upper Neuse River Basin (2002) (9p)...	Free	_______	
WQ-125	Efficiencies of Temporary Sediment Traps on Two North Carolina Construction Sites (2001) (9p)...	Free	_______	
WQ-124	Section 319 Nonpoint Source National Monitoring Program: Successes and Recommendations (2000) (32p)... *(on the World Wide Web at http://www.ncsu.edu/waterquality/section319/index.html)*	Free	_______	
WQ-123	Nonpoint-Source Pollutant Load Reductions Associated with Livestock Exclusion (2000) (9p)	Free	_______	
WQ-120	Comparing Sampling Schemes for Monitoring Pollutant Export From a Dairy Pasture (1998)	Free	_______	
WQ-119	Performance Evaluation of Innovative and Alternative On-Site Wastewater Treatment Systems in Craven County, NC (1998) (12 p)	Free	_______	
WQ-109**	Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Forestry (EPA/841-B-97-009) (1997)	Free	_______	
WQ-108**	Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Agriculture (EPA/841-B-97-010) (1997)	Free	_______	
WQ-107	WATERSHEDSS GRASS-AGNPS Model Tool (Transactions of the ASAE) (1997) (5p)	Free	_______	
WQ-103	WATERSHEDSS: A Decision Support System for Watershed-Scale Nonpoint Source Water Quality Problems (Journal of the American Water Resources Association) (1997) (14p)	Free	_______	
WQ-105	Linear Regression for Nonpoint Source Pollution Analyses (EPA-841-B-97-007) (1997) (8p)	Free	_______	
WQ-104	Water Quality of First Flush Runoff from 20 Industrial Sites (Water Environment Research) (1997) (6p)	Free	_______	
WQ-100	Water Quality of Stormwater Runoff from Ten Industrial Sites (Water Resources Bulletin) (1996) (10p)	Free	_______	
WQ-96	Goal-Oriented Agricultural Water Quality Legislation (Water Resources Bulletin) (1996) (14p)	Free	_______	
WQ-92	The Rural Clean Water Program: A Voluntary, Experimental Nonpoint Source Pollution Control Program and its Relevance to Developing Countries (1995) (18p)	Free	_______	
WQ-76	Elements of a Model Program for Nonpoint Source Pollution Control (Seminar Publication: Proc. National Rural Clean Water Program Symposium) (EPA/625/R-92/006) (1992) (14p)	Free	_______	
WQ-83	Effective Monitoring Strategies for Demonstrating Water Quality Changes from Nonpoint Source Controls on a Watershed Scale (Wat. Sci. Tech.) (1993) (6p)	Free	_______	
WQ-04	Conceptual Framework for Assessing Agricultural NPS Projects (1981) (60p)	4.00	_______	_______
WQ-05	Guidelines for Evaluation of Agricultural NPS Water Quality Projects (1982) (59p)	5.00	_______	_______
WQ-21	Setting Priorities: The Key to Nonpoint Source Control (EPA 841-B-87-110) (1987) (50p)	Free	_______	
WQ-22	Interfacing Nonpoint Source Programs with the Conservation Reserve Program: Guidance for Water Quality Managers (EPA/506/2-88/001) (1988) (24p)	4.00	_______	_______
WQ-60	Selecting Priority Nonpoint Source Projects: You Better Shop Around (EPA/506/2-89/003) (1989) (39p)	5.00	_______	_______
WQ-24	Selecting Critical Areas for NPS Pollution Control (J. Soil & Water Conservation) (1985) (4p)	Free	_______	
WQ-25	Practical Guidelines for Selecting Critical Areas for Controlling Nonpoint Source Pesticide Contamination of Aquatic Systems (USEPA) (1985) (5p)	Free	_______	
WQ-26	Appropriate Designs for Documenting Water Quality Improvements from Agricultural NPS Control Programs (USEPA) (1985) (5p)	Free	_______	
WQ-27	Increasing Sensitivity of NPS Control Monitoring Programs (Water Res. Assoc. Proc.) (1987) (15p)	Free	_______	
WQ-30	Pollution From Nonpoint Sources: Where We Are and Where We Should Go (J. Env. Science & Technology) (1987) (6p)	Free	_______	
WQ-32	Determining Statistically Significant Changes in Water Pollutant Concentrations (J. Lake & Reservoir Mgmt.) (1987) (7p)	Free	_______	

* new addition to publication list
** Also available by calling EPA's National Service Center for environmental publications at 1-800-490-9198

Publication Number	Reports & Journal Articles (continued)	Price($)	Quantity	Total($)
WQ-33	Water and Sediment Sampler for Plot and Field Studies (J. Environmental Quality) (1987) (6p)	Free	_______	
WQ-34	Extension's Role in Soil and Water Conservation (J. Soil & Water Conservation) (1988) (4p)	Free	_______	
WQ-35	Agricultural Nonpoint Source Control: Experiences from the Rural Clean Water Program (J. Lake & Reservoir Management) (1988) (6p)	Free	_______	
WQ-36	Determining the Statistical Sensitivity of the Water Quality Monitoring Program in the Taylor Creek Nubbin Slough, Florida, Project (J. Lake & Reservoir Management) (1988) (12p)	Free	_______	
WQ-65	Determining and Increasing the Statistical Sensitivity of Nonpoint Source Control Grab Sample Monitoring Programs (Colorado Water Resources Research Institute) (1990) (17p)	Free	_______	
WQ-70	North Carolina's Sediment Control Program (Public Works) (1991) (3p)	Free	_______	
WQ-06	Best Management Practices for Ag. Nonpoint Source Pollution Cntrl: I. Animal Waste (1982) (67p)	8.00	_______	_______
WQ-07	Best Management Practices for Ag. Nonpoint Source Pollution Cntrl: II. Commercial Fertilizer (1982) (55p).	6.00	_______	_______
WQ-08	Best Management Practices for Agric. Nonpoint Source Pollution Cntrl: III. Sediment (1982) (47p)	5.00	_______	_______
WQ-09	Best Management Practices for Agric. Nonpoint Source Pollution Cntrl: IV. Pesticide (1984) (87p)	8.00	_______	_______
WQ-98	Farm*A*Syst Fact Sheets (7 fact sheets) (1997) (*on the World Wide Web at http://h2osparc.wq.ncsu.edu/info/farmassit/index.html*)	Free	_______	
WQ-99	Home*A*Syst Fact Sheets (5 fact sheets) (1997) (*on the World Wide Web at http://h2osparc.wq.ncsu.edu/info/farmassit/homeindx.html*)			
WQ-89	Rural Clean Water Program Technology Transfer Fact Sheets (10 fact sheets) (1995) (*on the World Wide Web at http://h2osparc.wq.ncsu.edu/info/concepts.html*)	Free	_______	
WQ-91	Watershed Management: Planning and Managing a Successful Project to Control Nonpoint Source Pollution (contains a list of resources specific to North Carolina) (1995) (8p) (*on the World Wide Web at http://www.bae.ncsu.edu/bae/programs/extension/publicat/wqwm/ag522.html*)	Free	_______	
WQ-86	Paired Watershed Study Design (EPA 841-F-93-009) (1993)	Free	_______	
WQ-48	Pesticide Fact Sheets (10 fact sheets) (1988)	4.00	_______	_______
	Literature Reviews and Bibliographies			
WQ-121	Nonpoint Sources (Review of 1998 Literature) (Water Environment Research) (1999) (16p)	Free		
WQ-118	Nonpoint Sources (Review of 1997 Literature) (Water Environment Research) (1998) (17p)	Free	_______	
WQ-106	Nonpoint Sources (Review of 1996 Literature) (Water Environment Research) (1997) (17p)	Free	_______	
TOTAL =	Total Amount of Purchase			$__________

IMPORTANT NOTES ABOUT ORDERING PUBLICATIONS:

Prices include postage within the U.S. Prices for publications to be sent outside the U.S. may be higher. Please call or write for this information. All prices are subject to change without notice. The price list is updated with each issue of *NWQEP NOTES*. Requests are filled while supplies last. Only one copy of each free publication is available. FEIN #56-6000-756

To order: Fill out order form and enclose with payment. ____ Check here if requesting we bill your institution
Please make checks payable to **NCSU Water Quality Group** ____ Check here if enclosing payment

Please note: Only institutions can be billed. Individuals must enclose payment with order form.

Send order to: Publications Coordinator, NCSU Water Quality Group, Campus Box 7637, North Carolina State University, Raleigh, NC 27695-7637 Fax: 919-515-7448, email: wq_puborder@ncsu.edu. An electronic order form is also available on the World Wide Web at: http://www.bae.ncsu.edu/bae/programs/extension/wqg/issues/pub_order.html.

Ordered by: Name:____
Institution:____
Street Address:____
City, State, Zipcode: ____
Telephone:____

________ Please place my name on the mailing list for *NWQEP NOTES*, the quarterly newsletter on nonpoint source pollution published by the NCSU Water Quality Group (with support from the U.S. Environmental Protection Agency) (subscriptions are free).

- NCSU Water Quality Group home page: http://www.bae.ncsu.edu/bae/programs/extension/wqg
- U.S. Environmental Protection Agency's Office of Water publications list: http://www.epa.gov/OW/info
- WATERSHEDSS — Water, Soil, Hydro-Environmental Decision Support System, Internet-based management tool: http://h2osparc.wq.ncsu.edu
- Understanding the Role of Agricultural Landscape Feature Function and Position in Achieving Environmental Endpoints: Final Project Report (to the U.S. Environmental Protection Agency) (1996) (118p) (*abstract and instructions for downloading the report available on the World Wide Web at: ftp://ftp.epa.gov/epa_ceam/wwwhtml/software.htm*

Table 3. Comparison of pollutant concentrations from Anaerobic (G1) and Conventional (G2) drainage systems in Greensboro, NC.

Date	Outflow Concentrations (mg/L)					
	G1–TN	G2–TN	G1–Zn	G2–Zn	G1–Cu	G2–Cu
15Sep02	9.25	4.85	0.019	0.019	0.0037	0.0073
16Oct02	6.25	4.65	<0.02	<0.02	<0.01	0.027
29Dec02	3.45	4.95	<0.01	<0.01	0.023	0.031
24Feb03	1.95	3.00	<0.01	0.033	0.014	0.034

Soil Depth: Concentration results from the field study in Chapel Hill were used to compare the effectiveness of soil depths. Two conventionally drained cells, one with a nominal soil depth of two feet deep, the other with a nominal soil depth of four feet deep, have been monitored since July 2002. Due to some short circuiting of the 2 foot cell, it has been difficult to obtain results from all storms. The results displayed in Table 4 do not provide an indication that the deeper soil depth reduces concentrations of pollutants in the outflows. While this data is still preliminary, the measures are consistent with data gathered by Davis *et al*. (2003).

Table 4. Pollutant concentrations from bioretention areas that have soil depths that are nominally 2 feet (C2) and 4 feet (C1) deep. Both bioretention cells are in Chapel Hill and utilize conventional drainage.

Date	Outflow Pollutant Concentrations (mg/L)					
	C1–TN	C2–TN	C1–Zn	C2–Zn	C1-TP	C2-TP
29Aug02	0.05 (NH_4)	0.02 (NH_4)	0.028	0.226	0.44	0.2
26Dec02	1.72	0.64	0.13 (OP)	0.09 (OP)	0.13	0.09
22Mar03	0.83	0.65	0.01	0.059	0.05	0.06

Conclusions and Recommendations

There are four main conclusions that can be drawn from the studied sites. These conclusions impact design guidance and can be used to revise state standards for bioretention removal efficiencies.

(1) Bioretention areas remove most pollutants, particularly metals, at a very high rate. Studies by Davis *et al.* (2003) show very high pollutant removal levels for metals, with rates in excess of 90%. Laboratory studies at Penn State illustrate TN removal rates over 60%. Field studies from North Carolina support much of these findings.

(2) Bioretention areas appear to reduce the amount of runoff, particularly in the summer months, when evapotranspiration is high. The effect is much less pronounced in the winter. Assuming much of the runoff is laterally exfiltrating the bioretention cell, entering the in-situ soil, and travelling to surface water bodies as shallow groundwater, the importance of urban buffer zones for additional treatment cannot be stressed enough.

(3) There is no apparent difference in the concentration of pollutants leaving bioretention fill soils that are only two feet thick compared to fill soils that are four feet thick. Davis *et al*. (2003) and findings from North Carolina presented herein indicate that a deep soil may not be required to maintain high pollutant removal rates. These studies, however, do not compare the amount of flow leaving bioretention areas comprised of varying soil depths. If more flow were to pass through the shallower soil depth, the shallow soil depth's performance would be reduced.

(4) Anaerobic zones appear to develop regardless of the drainage configuration of the bioretention cell. This was observed in Maryland, Pennsylvania, and at the field studies in North Carolina. There does not appear to be grounds to recommend a change in drainage configuration in order to increase TN removal rates, at this current time.

Future Research Opportunities

There are still many questions left to be answered regarding bio-retention function and design. Research will continue not only at N.C. State and the University of Maryland, but also other mid-Atlantic schools, such as Clemson University and the University of Virginia. In North Carolina, the two field sites described will continue to be monitored through summer of 2003. A third set of bioretention cells in Wilson, NC, are just beginning to be monitored by NCSU faculty, with data being collected from 6 cells until the Fall of 2004. These cells will test the importance of an anaerobic layer in shallow (2 feet deep) soils. Additional studies are being carried out in Cary, NC, and will be initiated this fall in Louisburg, NC, where the importance of ground cover (shrubs/mulch v. grass) will be monitored. As the research results continue to accrue, bioretention design standards are sure to be adjusted.

For More Information

Bill Hunt, PE
Extension Specialist
Department of Biological & Agricultural Engineering
N.C. State University
Box 7625
Raleigh, NC 27695-7625
919-515-6751
bill_hunt@ncsu.edu

References

Avery, Donna. 2001. Personal communication. Ms. Avery is the Chief Planner in the Stormwater Services Department in Wilson, NC.

Barrett, M. E., L. B. Irish, J. F. Malina, and R. J. Charbeneau. 1998. Characterization of highway runoff in Austin, Texas, area. *Journal of Environmental Engineering* 124(2): 131-137.

Bryant, Scott. 2001. Personal communication. Mr. Bryant is director of Greensboro, NC's Stormwater Services department.

Coffman, L., R. Green, M. Clar, and S. Bitter. 1993a. Development of bioretention practices for stormwater management. In *Proc. Water Management in the 90's: A Time for Innovation*. 126-129. Reston, VA: American Society of Civil Engineers.

Coffman, L., R. Green, M. Clar, and S. Bitter. 1993b. Design considerations associated with bioretention practices. In *Proc. Water Management in the 90's: A Time for Innovation*. 130-133. Reston, VA: American Society of Civil Engineers.

Davis, A.P., M. Shokouhian, H. Sharma, C. Miniami, and D. Winogradoff. 2000. Bioretention as an urban storm water best management practice. Unpublished.

Davis, A. P., M. Shokouhian, H. Sharma, and C. Minami. 2001. Laboratory study of biological retention for urban stormwater management. Water Environment Research 73(1): 5-14.

Davis, A.P., M. Shokouhian, H. Sharma, C. Minami, and D. Winogradoff. 2003. Water Quality Improvement through Bioretention: Lead, Copper, and Zinc Removal. Water Environment Research 75(1): 73-82.

Hunt, W.F. 2002. Stormwater BMP Cost – Effectiveness Relationships for North Carolina. In *Proc. Watershed 2002 Specialty Conference*. Alexandria, VA: Water Environment Federation.

Hunt, W.F. and N.M. White. 2001. *Designing Rain Gardens/ Bioretention Areas*. N.C. Cooperative Extension Service Bulletin. Urban Waterfronts Series. AG-588-3. Raleigh, NC: North Carolina State University.

Hunt, W.F., A.R. Jarrett, J.T. Smith. 2002. Optimizing Bioretention Design for Denitrification. Presented at 2002 International Meeting of the American Society of Agricultural Engineers. Chicago, Ill.

N.C. DENR. 1997. *Stormwater Best Management Practice Design Manual*. Raleigh, NC: North Carolina Department of Environment and Natural Resources – Division of Water Quality.

Paletta, Rochelle. 2001. Personal communication. Ms. Paletta is a Zoning Officer in State College, PA.

Pennsylvania Association of Conservation Districts. 1998. *Pennsylvania Handbook of Best Management Practices for Developing Areas*. Harrisburg, PA: Pennsylvania Department of Environmental Protection.

Wu, J. S., C. J. Allan, W. L. Saunders, and J. B. Evett. 1998. Characterization and pollutant loading estimation for highway runoff. *Journal of Environmental Engineering* 124(7): 584-592.

■

Information

Release of New Guide for Stakeholder Involvement

EPA announces the publication and release of a new guide entitled "Getting in Step: Engaging and Involving Stakeholders in Your Watershed." The guide, which is the second in the *Getting in Step* series, features information on how to generate interest and participation in watershed assessment, planning, and management. A web-based version of the new guide (along with the previous *Guide to Effective Outreach in Your Watershed*) is posted on the EPA's server at: **http://www.epa.gov/owow/watershed/outreach/documents/**

New Research from the Center For Watershed Protection: Impacts of Impervious Cover on Aquatic Systems

The Center's newest report is a comprehensive examination of more than 225 multi-disciplinary research studies documenting the impact of urbanization and the associated impervious cover on aquatic systems. This report is the Center's most extensive exploration of imperviousness to date, and reviews the available scientific data on the myriad ways urbanization influences hydrologic, physical, water quality, and biological indicators of aquatic health.

The report is available electronically at the Center For Watershed Protection website: **http://www.cwp.org.** Price: $25.

Natural Approaches to Stormwater Management, Low Impact Development in Puget Sound

A book offering innovative techniques for builders and developers, local planners, engineers and others to better protect Puget Sound from the harmful effects of development is now available. The Puget Sound Action Team (Action Team) recently compiled examples of more than 30 projects, programs and ordinances using an innovative approach to develop land and manage stormwater. The innovative approaches, known as low impact developments, are highlighted in *Natural Approaches to Stormwater Management, Low Impact Development in Puget Sound*.

The book emphasizes a natural approach versus conventional development that involves clearing, grading and paving sites. In traditional development, engineers typically design and build stormwater facilities such as retention ponds to hold stormwater and remove pollutants. The low impact development designs use the natural features of a piece of property and special management practices to manage stormwater in residential neighborhoods, retail centers and more.

Low impact development projects include rain gardens which involve layering different types of gravel, soil and mulch; natural drainage systems that use native plants; sidewalks, patios and driveways with permeable pavements and other projects that filter oil, grease, dirt and other contaminants from stormwater runoff.

The document is available at: **http://www.psat.wa.gov/Publications/LID_studies/LID_approaches.htm** For more information, visit **http://www.psat.wa.gov/.**

■

Meetings

Call For Papers

WATERSHED 2004: July 11-14, 2004, Dearborn, MI. Abstracts are invited on the following topics: Program Development; Assessment and Modeling; Restoration and Protection; and Regional Topics. For more information, visit web site: http://www.wef.org/pdffiles/Watershed04Call.pdf. **Abstracts due August 1, 2003**.

Meeting Announcements — 2003

June

Society of Wetland Scientists 24th Annual Meeting: Wetland Stewardship: Changing Landscapes and Interdisciplinary Challenges: June 8-13, 2003, New Orleans, LA. Contact the Program Committee Co-chairs Doug Meffert (dmeffert@tulane.edu) or Robert Twilley (ceet@louisiana.edu). Web site: http://www.sws.org/neworleans/.

Environmental Statistics Short Course: June 16-18, 2003. Colorado State University, Fort Collins, CO. For information contact Jim Loftis, loftis@engr.colostate.edu.

The Fourth National Workshop on Constructed Wetlands/BMPs for Nutrient Reduction and Coastal Water Protection: June 23-25, 2003, Wilmington, NC. Contact Dr. Frank Humenik, Waste Management Programs, College of Agriculture and Life Sciences, Campus Box 7927, North Carolina State University, Raleigh, NC 27695-7927. Tel: 919-515-6767; Fax: 919-513-1023; Email: frank_humenik@ncsu.edu.

Riparian Ecosystems & Buffers: Multi-Scale Structure, Function & Management: June 28-30, 2004, Olympic Valley, CA. Web site: http://www.awra.org/meetings/Olympic2004/summer2004.doc

AWRA's 2003 International Congress: Watershed Management for Water Supply Systems: June 29-July 2, 2003, New York City, NY. Contact Peter E. Black, International Congress Organizing Chair, SUNY ESF, 1 Forestry Dr., Syracuse, NY 13210. Tel: 315-470-6571; Fax: 315-470-6956; Email: pebchair@esf.edu; web site: www.awra.org.

July

National Forum on Water Quality Trading: July 22-23, 2003, Chicago, IL. Web site: http://www.wef.org/conferences/cosponsevents/; Email: Wynn.Lynda@epamail.epa.gov

Soil and Water Conservation Society 2003 Annual Conference: July 26-30, 2003, Spokane, WA. Web site: http://www.swcs.org.

September

11th National Nonpoint Source Monitoring Workshop:
Monitoring and Modeling the Urban Environment
September 8-11, 2003, Dearborn, Michigan.
http://ctic.purdue.edu/NPSWorkshop.html

The 11th year of this workshop will once again bring together land managers and water quality specialists to share information on the effectiveness of best management practices in improving water quality, effective monitoring techniques, and statistical analysis of watershed data. The workshop will focus on the successes of Section 319 National Monitoring Program projects as well as other innovative monitoring projects from throughout the U.S. The agenda will include three days of workshop sessions/presentations and a one-day field trip to visit nonpoint source project sites relating to the workshop.

October

Wetlands 2003 Landscape Scale Wetland Assessment and Management: October 20-24, 2003, Nashua, NH. Association of State Wetland Managers web site: http://aswm.org/calendar/2003am/.

Getting It Done: The Role of TMDL Implementation In Watershed Restoration Conference: October 29-30, 2003, Stevenson, WA. Web site: http://www.swwrc.wsu.edu/conference2003/index.html; Email: watercenter@wsu.edu.

November

AWRA 2003 Annual Water Resources Conference: November 3-6, 2003, San Diego, CA. Web site: http://www.awra.org/meetings/California2003/index.html

■

Production of NWQEP NOTES is funded through U.S. Environmental Protection Agency (EPA) Grant No. X825012. Project Officer: Tom Davenport, Office of Wetlands, Oceans, and Watersheds, EPA. 77 W. Jackson St., Chicago, IL 60604. Website: http://www.epa.gov/OWOW/NPS

NCSU Water Quality Group
Department of Biological and Agricultural Engineering
North Carolina Cooperative Extension Service
Campus Box 7637
North Carolina State University
Raleigh, NC 27695-7637

NC STATE UNIVERSITY

NCSU Water Quality Group
Campus Box 7637
North Carolina State University
Raleigh, NC 27695-7637
Telephone: (919) 515-3723
Fax: (919) 515-7448
Web Site: http://www.ncsu.edu/waterquality/

Personnel