NC STATE
UNIVERSITY

IMPLEMENTING INNOVATIVE STREET RETROFITS TO REDUCE STORMWATER RUNOFF VOLUMES AND POLLUTANTS IN BURNT MILL CREEK WATERSHED

EPA319 grant Sponsored by NC Division of Water Resources
FY09 DWQ Contract Number 3637;
Contract Period: 01/01/11- 06/31/13
www.ncsu.edu/WECO/burntmill

PIs: Christy Perrin, NC Cooperative Extension, Dept. ARE
Dr. Bill Hunt, Ryan Winston, Jonathan Page, Dept. BAE

Acknowledgements:

This project was funded under an EPA319 grant. Thank you to our sponsors, NCDWQ and USEPA .

Thank you to our grant partners and participants:

From the City of Wilmington:

David Mayes
Jennifer Butler
Harvey London, Carl Scott and the rest of the Stormwater Services crew
Jay Carter and the Street Maintenance crew
Todd Davis
Phil Prete
Don Bennett
Bill McDow
Danny Costin
Suraiya Rashid
Tara Murphy

Others:

Patrick Beggs
Hollis Briggs
Cape Fear River Watch
Martin Luther King, JR. Community Center
UNC-Wilmington Women’s Rugby Team
B + O design studio, pllc

Table of Contents

1. Executive Summary

The restoration of Burnt Mill Creek, an urban stream impaired by impacts from stormwater runoff, continued with this innovative effort to apply current stormwater management technologies to public street retrofits. The effort also increased knowledge and understanding about the main toxic impact to the watershed, polycyclic aromatic hydrocarbons (PAHs). The first recommendation in a recently published fact sheet on how to mitigate the impacts from PAHs is to intercept and manage stormwater runoff from parking lots and roads. Monitoring of the Port City Java bioretention cell showed that it provided significant reductions of PAHs from the parking lot, and additional research in the literature has shown evidence of bioretention successfully reducing PAH loads.

NCSU staff met with City of Wilmington staff from Stormwater Services, Transportation Planning, and Streets Maintenance to determine the types of retrofits that would work best in Wilmington, and determine the best locations for piloting retrofits. While the bioretention areas were originally proposed for existing grassed right-of-ways (called plazas), City staff preferred to remove pavement and place the BMPs in the roadway, thus reducing impervious surface and also increasing pedestrian and bicyclist safety. The results of this collaboration produced street retrofit designs for an intersection and a mid-block area. The street retrofits were envisioned to reduce stormwater runoff volumes and pollutants, and helped to reduce localized flooding while also meeting community goals for traffic calming and increased pedestrian safety.

The team brought these draft designs to the community for feedback via a public meeting, a presentation to a community group, door to door visits, and door hangers. While the mid-block retrofits were greeted with either enthusiasm or disinterest, very strong concerns were received by a landowner adjacent to the proposed intersection retrofit. Without this targeted outreach to solicit neighborhood feedback, this project could have exploded into a negative publicity event resulting in an extremely angry constituent. By identifying the concerns of this landowner who had significant political clout, the team was able to identify a better location for the project and proceed with an even more innovative retrofit than the original proposal.

Due to efficiencies with the budget and a significant construction contribution by the City of Wilmington, the grant resulted in the two proposed retrofit projects (a treatment train of permeable pavement, tree filter boxes, and bioretention on 12th and Dock Streets and a bioretention retrofit on Anne Street) as well as additional deliverables including two Silva Cell applications and an additional section of permeable pavement.

A bioretention cell (BRC) bumpout, four permeable pavement parking stalls installed in two separate sections and a tree filter device were monitored in a paired study. The retrofit site's runoff coefficient significantly decreased from 0.38 to 0.18, and was substantially less than other runoff coefficients reported for traditional residential development. Retrofit concentrations of TKN, TP, TSS, Cu, Pb and Zn significantly decreased from 38- 89%. Concentrations of NO2,3-N and TAN did not change. Mass loads of TKN, TAN, O-PO4-3, TP, TSS, Cu, Pb and Zn significantly decreased by 53- 91%. Most improvements in water quality were due to dramatic decreases of particulate and particulate-bound pollutant loads. This was attributed to first flush retention of runoff by the bioretention cell and permeable pavement that treated 52% of the impervious area and treatment by the tree filter unit that serviced an additional 42% of the impervious area. This study has shown that a limited number of LID stormwater control measures installed within a medium-density residential street right-of-way over sandy soils can mitigate some hydrologic and water quality impacts of existing development. Although PAH monitoring was originally planned for the study, it was suspended after review of the pre-retrofit data that showed all PAH analytes were below the practical quantification limits reported by the DWQ Chemistry Lab. This was likely due to a lack of consistent and typical PAH sources, such as coal tar sealants, in the contributing drainage area.

Based on results from these installations and monitoring, some lessons about retrofitting urban streets in Wilmington, NC were learned. Early and targeted community engagement is necessary for ensuring that residents' concerns and interests are incorporated into retrofit location and design; retrofits that do not reduce on-street parking are important in high density areas where off-street parking is scarce, permeable pavement and practices located in the plaza (area between curb and sidewalk) were accepted best by the community; monitoring revealed significant reductions in stormwater runoff volumes and pollutants, also revealed insignificant levels of PAHs in street runoff. Street retrofits are ideal for reducing volume and pollutants loads, especially in areas with underlying sandy soils. Reducing PAH levels in this watershed will require targeting parking lots in the future.

2. List of figures and abbreviations

Abbreviations:

Best management practices (BMPs)

Cape Fear River Watch (CFRW)

Clean Water Management Trust Fund (CWMTF)

Directly connected impervious area (DCIA)

Low impact development (LID)

North Carolina Division of Water Quality (NCDWQ)

North Carolina Ecosystem Enhancement Program (EEP)

NC State University (NCSU) Department of Agricultural and Resource Economics (ARE

NC State University (NCSU) Department of Biological and Agricultural Engineering (BAE)

Polycyclic aromatic hydrocarbons (PAHs)

Stormwater Control Measures (SCMs)

Watershed Education for Communities and Officials (WECO)

3. Introduction/Background

Burnt Mill Creek, in the lower Cape Fear River Basin, is listed as impaired for aquatic life and secondary recreation on the state's 303(d) list form impacts of urban stormwater runoff, including impacts from toxic pollutants. In 2002, the NC Ecosystem Enhancement Program (NCEEP) completed a watershed plan for the creek. NCDWQ's Assessment Report of the Burnt Mill Creek Watershed (2004) indentified toxic impacts from polycyclic aromatic hydrocarbons (PAHs) as the primary cause of biological impairment, with secondary and cumulative causes identified as sedimentation and nutrient enrichment. Stakeholders led by NC State University and City of Wilmington have been working together since then to implement watershed improvement projects such as those recommended in the NCDWQ Report:

- Feasible and cost-effective stormwater retrofit projects should be implemented throughout the watershed to mitigate the hydrologic effects of development.
- A strategy to address toxic inputs should be developed and implemented, including a variety of source reduction and stormwater treatment methods.

The team has installed several BMP retrofits so far with previous funding sources, including large stormwater wetlands in Mary Bridgers Park and Stonesthrow Townhomes, innovative parking lot bioretention at Port City Java, permeable pavement and bioretention at YMCA, bioretention and cisterns at schools, and 14 residential raingardens and 36 rainbarrels in the Bottom Neighborhood (an underserved, floodprone neighborhood in the watershed).

A recent CWMTF project allowed us to investigate potential urban sources of PAHs, including coal-tar based sealants, and to develop a draft fact sheet on how to mitigate the impacts from PAHs. The first recommendation is to intercept and manage stormwater runoff from parking lots and roads. Monitoring of the Port City Java bioretention showed that bioretention provided significant reductions of PAHs from the parking lot, and additional research literature shows evidence of bioretention successfully reducing PAH loads.

The same project allowed us to identify and design additional retrofits. While working on residential BMPs in the Bottom Neighborhood, our team noticed the wide expanse of streets that was contributing to high runoff volumes and localized flooding. NCSU approached the City of Wilmington with the idea of investigating a street retro-fit project to reduce runoff volumes and pollutants reaching Burnt Mill Creek, and to help alleviate local flooding problems in the Bottom Neighborhood. The response was enthusiastic. Over several months, NCSU staff met with City of Wilmington staff from Stormwater Services, Transportation Planning, and Streets Maintenance to determine the types of retrofits that would work best in Wilmington, and determine the best locations for piloting retrofits. While the bioretention areas were originally proposed for existing grassed right-of-ways (called plazas), City staff preferred to remove pavement and place the BMPs in the roadway, thus reducing impervious surface and also increasing pedestrian safety. The results of this collaboration produced street retrofit designs for an intersection and a mid-block area. The street retrofits were envisioned to reduce stormwater runoff volumes and pollutants, and help to reduce localized flooding while also meeting community goals for traffic calming and increased pedestrian safety. The EPA319 grant allowed the team to bring these draft designs to the community for feedback, install the projects, and monitor and adapt them as needed.

4. Purpose and Goals

The overall purpose of the project was to continue advancing the restoration of the impaired Burnt Mill Creek watershed through applying, testing, and adapting new street retrofit technologies within the watershed. Specific goals included:

- engage the community in finalizing innovative street retrofit designs;
- construct 2 identified street retrofits;
- develop a long-term outreach and maintenance plan for the retrofits;
- quantify runoff and pollutant removal capabilities of the street retrofit;
- develop a model for future street improvement projects that can meet multiple benefits of stormwater runoff reduction, flooding amelioration, pollution removal, and pedestrian safety in the Burnt Mill Creek watershed and City of Wilmington; and
- Educate watershed residents about how to reduce PAHs by distributing a new fact sheet, Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Waterways.

5. Deliverables

Finalized street retrofit engineered designs

Both draft retrofit designs were initially reviewed and discussed at meetings with the NCSU project team and City of Wilmington staff from Stormwater, Planning, Streets Maintenance, Transportation, and the Wilmington MPO (Metropolitan Planning organization). After agreement on draft designs was reached, the designs were brought to the community for review and feedback (see the next deliverable).

One homeowner at the proposed 10th & Anne Street intersection retrofit site expressed concerns about losing parking in front of her home, since she did not have a driveway. We met with this homeowner and her daughter to discuss the project and potential alternative designs. She was adamantly opposed to any project of any type adjacent to her property. She had experienced a situation many years ago when the electric company tried to take her property via eminent domain so they could locate a substation on the block- her family successfully blocked the effort and subsequently hers was the only house on the block that currently contains that substation. With this experience in her memory, she was unwilling to negotiate a solution, so the project team decided to try locating the project a block away at 9th and Anne St.

Two community workshops- one for collecting feedback on the draft designs, including plant preferences, and one for developing an outreach and maintenance program.

A community workshop to collect draft feedback was held in May 2011 at Williston Middle School. Turnout was very low, and only a few people gave feedback.

To better reach the community, we created fliers about the project, including the designs and planting schemes, and went door-to-door on the streets where projects were proposed to share information and ask individuals for feedback about the proposed retrofits. We spoke with 8 residents, and the owner of several rental units. We left fliers at homes where nobody answered the door, with contact information and request to call with any questions. A couple calls were received from homeowners who received fliers and wanted more information. General support was expressed by those we spoke to.

One homeowner at the intersection retrofit site expressed concerns about losing parking in front of her home, since she did not have a driveway.

The City of Wilmington committed to maintaining the retrofits since they were all on their property. The project team worked with Cape Fear River Watch to engage them in additional “aesthetic” maintenance, including litter removal. A maintenance education event and work-day was held in conjunction with “Burnt Mill Creek Week”, which was hosted by Cape Fear River Watch. CFRW staff, board members and volunteers attended an event at the Family YMCA to learn about maintaining bioretention, and to provide hands-on maintenance to a large bioretention cell installed with a previous grant. Talks between the City of Wilmington and CFRW continue regarding maintenance of public BMPs.

Meeting(s) with the Bottom Neighborhood Empowerment Association (BNEA), school administrators and teachers

The BNEA had become inactive by the time this project started. The former BNEA coordinator volunteered for a political precinct organization and was organizing precinct meetings instead. The precinct includes the Bottom Neighborhood, as well as an area north of Market Street that is within the Burnt Mill Creek watershed. The organizer invited us to present at a meeting in lieu of a BNEA meeting. We gave a presentation at a precinct meeting about the project, and collected feedback.

Gregory Elementary School staff were contacted by phone and email. Though interest was initially expressed in getting students involved with planting the bioretention originally proposed on the corner of Anne and 10th Streets (on the same intersection as the school), that particular project was relocated to a block further away from the school. The science teacher we had previously worked with also left the school by this time. Due to these developments, active involvement with the school on this project didn't seem necessary or feasible. To engage youth, we instead worked with the Martin Luther King Jr. Community Center's after school program. The relocated bioretention is adjacent to this Center.

Completed intersection retrofit that includes bioretention and native planting area (intersection of 9th and Ann Streets)

Because of the homeowner's unwillingness to work with us at 10th and Ann streets, the intersection retrofit was moved one block where neighbors were willing to work with us on the project. This meant that the entire design process, including stakeholder meetings, surveying, engineering design and review, had to be repeated. A bioretention cell was designed to capture one-half of a city block of runoff, and was located in the plaza area (between the sidewalk and the back-of-curb).   The site was excavated to a depth of 4 ft, and engineered soil media was trucked in for the bioretention cell. Concrete walls were installed along the three sides of the cell, to make it look similar to street-side bioretention cells in Portland, OR. The cell was mulched and planted with daylilies, liriope, and switch grass with the help of fourth grade students from the Martin Luther King Jr., Community Center.

Figure 1: Bioretention in plaza on Ann St.

Location: Latitude 34°13'56.04" North, Longitude 77°56'15.25" West

Size of treatment area: 0.043 ha (0.11 acres) of 100% impervious roadway

Size of bioretention cell: 20 ft by 9 ft (180 ft^2)

Pollutant removal: The bioretention cell was designed to capture 30% of the 1.5" design storm, due to space limitations in the existing plaza area. However, this design is extremely conservative, as it does not include infiltration during the storm event, which is probably occurring at >2 in/hr rate into the underlying sandy soils. Given that undersized bioretention cells perform better (per dollar spent on construction) for pollutant removal than their full-sized cousins (Luell et al. 2011), we expect this cell to reduce TSS by 70%, TN by 30%, and TP by 30%.

Completed mid-block street retrofit that includes bioretention, tree filter boxes, and permeable pavement parking stalls (proposed for Dock St and two perpendicular streets that drain to Dock St.- Jasmine St)


Figure 3: Permeable parking on 12th St.

Construction of the bioretention areas, permeable pavement parking stalls and Filterra (tree filter box) devices was completed in February 2012. The retrofit watershed size is 1.11 ha with 40% impervious coverage including 0.18 ha of street surface. Bioretention bumpouts designed to capture and treat street surface runoff from the first 3.81 cm of rainfall. The bumpouts will extend 1.8 m into the existing street for the added benefits of traffic calming and pedestrian safety. A 2.4 m x 1.2 m Filterra® tree filter device was installed on Dock Street at the southwest corner of the intersection with 12th Street to treat runoff from Jasmine Street and Dock Street that is down-slope of the bioretention bumpouts. Four permeable pavement parking stalls 7.01 m x 2.44 m were installed in two separate sections on 12th Street between Dock Street and Orange Street. The permeable pavement parking stalls are designed to capture and store street surface runoff from the first 3.81 cm of rainfall of the contributing drainage area along 12th Street.


Figure 2: Volunteers plant the Dock St. bioretention

Cape Fear River Watch recruited volunteers to plant the bioretention cells at a weekend event- 11 volunteers from CFRW and the UNC-Wilmington women's rugby team, along with NCSU staff, installed plants.

Location: Latitude 34°14'6.21" North, Longitude 77°56'3.23" West

Size of treatment area: 1.11 ha (2.74 acres) with 40% impervious coverage including 0.18 ha (.44 acres) of street surface

Size of bioretention cells: Two 207 ft^2 trapezoidal-shaped bioretention cells were installed. They were roughly 35 ft long by 6 ft wide, and reduced the street width by 12 ft, providing traffic calming benefits.

Size of permeable pavement: Two 24 ft x 8 ft (192 ft^2) permeable pavement applications were installed.

Size of Filterra® devices: one 6 ft x 8 ft and one 4 ft by 6 ft device were installed

Pollutant removal: See section of this document entitled: “Summary of Retrofit Monitoring Results”

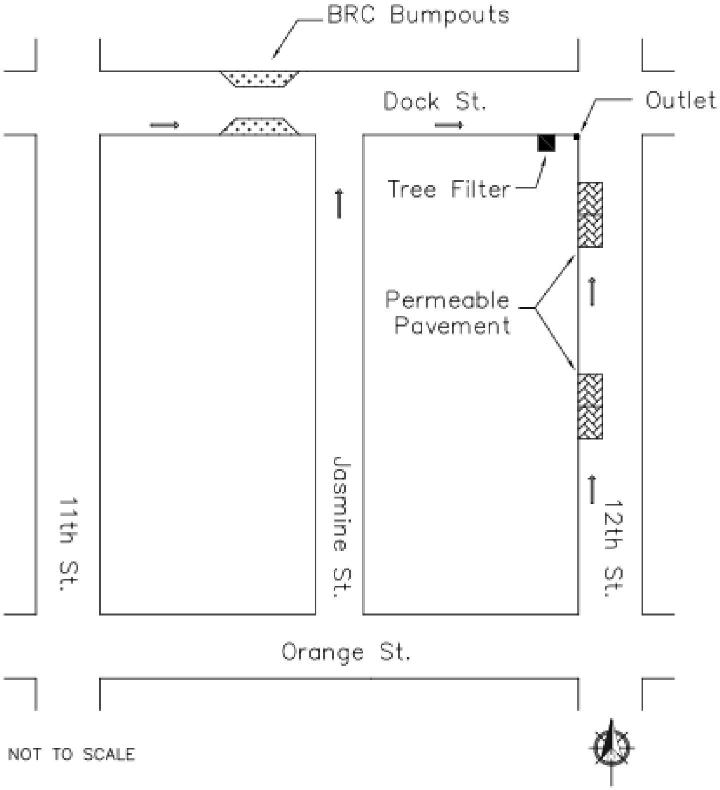
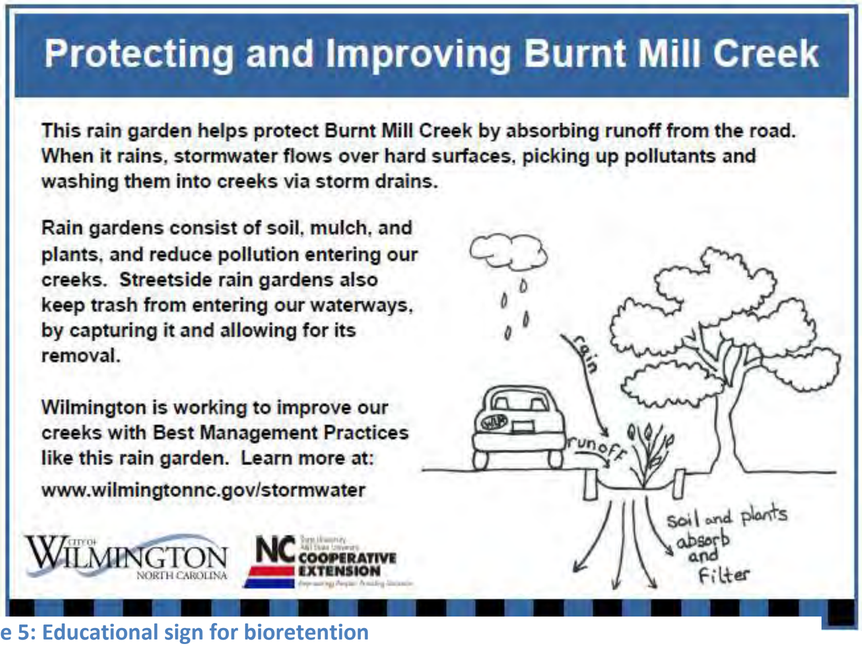


Figure 4: Layout of LID SCMs with arrows indicating direction of flow (not to scale).

Two educational signs installed adjacent to the retrofits for pedestrian viewing

Four signs (two to accompany the bioretention retrofits, two to accompany the permeable pavement retrofits) were designed and created, and provided to City of Wilmington for installation. The signs were designed using new guidelines from the City of Wilmington for educational street signs.



Protecting and Improving Burnt Mill Creek

This rain garden helps protect Burnt Mill Creek by absorbing runoff from the road. When it rains, stormwater flows over hard surfaces, picking up pollutants and washing them into creeks via storm drains.

Rain gardens consist of soil, mulch, and plants, and reduce pollution entering our creeks. Streetside rain gardens also keep trash from entering our waterways, by capturing it and allowing for its removal.

Wilmington is working to improve our creeks with Best Management Practices like this rain garden. Learn more at: www.wilmingtonnc.gov/stormwater

Figure 5: Educational sign for bioretention

PAH fact sheets printed and distributed in public and private locations

throughout the City of Wilmington

The draft PAH fact sheet was edited based on new information and discussions with the USGS scientist who discovered the link between PAHs and coal-tar based sealcoat (Dr. P.C. Van Metre). The fact sheet was peer reviewed, copy edited, and published by NC Cooperative Extension as part of the “Urban Waterways” fact sheet series. Several printed copies were provided to City of Wilmington for distribution. The electronic version was posted on the project website, and distributed via the Burnt Mill Creek listserve that is maintained by the NCSU project team.

Summary of retrofit monitoring results

Low Impact Development (LID) is a design approach that utilizes Stormwater Control Measures (SCMs) to maintain and restore the natural hydrologic regime of an urban watershed through infiltration, runoff treatment at the source, and minimization of impervious surfaces. This paired watershed study evaluated the impacts of LID SCMs on hydrology and water quality at a catchment-scale in a small urban drainage area (0.53 ha). In February 2012, a bioretention cell (BRC) bumpout, four permeable pavement parking stalls installed in two separate sections and a tree filter device were constructed to treat residential street runoff in Wilmington, North Carolina (Table 1, Figure 1). In the SCM-Retrofit catchment, 52% of the directly connected impervious area (DCIA) and 69% of the total drainage area was treated for potential mitigation of peak discharge and runoff volume. For water quality improvement, 94% of the DCIA and 91% of the total drainage area was retrofitted. Underlying soils in the study area were Baymeade Urban and Leon Urban sands. Analysis of Covariance (ANCOVA) was used to statistically quantify changes in the hydrologic and water quality parameters from pre- to post-retrofit conditions.

Figure 6: Table 1: Summary of LID SCM design parameters

Parameter	**BRC**[a]	**Filterra®**	**PP I**[b]	**PP II**[c]
Surface Area	19 m^2	3 m^2	34 m^2	34 m^2
Street Surface Area	160 m^2	539 m^2	265 m^2	226 m^2
Loading Ratio[d]	8.4:1	180:1	7.8:1	6.6:1
Street Surface Area Treated	13%	42%	21%	18%
Total Catchment Area Treated	12%	22%	30%	27%
As Built Design Rainfall Event[e]	33 mm	N/A	24 mm	27 mm
Underdrain	No	Yes	No	No

[a] Bioretention Cell on Dock Street
[b] North permeable pavement parking area on 12th Street
[c] South permeable pavement parking area on 12th Street
[d] Calculated as drainage area/SCM surface area
[e] Runoff from given rainfall depth that is stored in SCM before overflow occurs, assuming no infiltration to underlying soils

Figure 7: Aerial photo post-retrofit with approximate drainage area boundary

Post-retrofit, peak discharge significantly decreased 28% and lag times in the catchment remained unchanged, while mean runoff depth significantly decreased 52% (Table 2). When compared to the control catchment, runoff depths in the SCM-Retrofit catchment were significantly less for storms with low hourly storm intensities (<2.7 mm/hr), but significantly greater for storms with high intensities (>7.4 mm/hr). This was primarily due to clogging at the surface of the permeable pavement and runoff flow depths in the gutter that overwhelmed the flow diverters. In North Carolina, SCMs are typically required to capture and detain runoff associated with 25 mm (1 in) or 38 mm (1.5 in) of rainfall (NCDENR, 2009). Based on the cumulative 1.14 years of monitoring data from the control catchment, 25 mm of rainfall generated 4.3 mm of runoff and 38 mm of rainfall generated 6.7 mm of runoff. For 25 mm and 38 mm rainfall depths, the decreases in runoff depths from calibration to treatment monitoring were 35% and 28%, respectively. Runoff thresholds in the SCM-Retrofit and control catchments were 5.2 mm and 3.5 mm, respectively. The SCM-Retrofit runoff coefficient significantly decreased from 0.38 to 0.18, and is substantially less than other runoff coefficients reported for traditional residential development.

Figure 8:Table of Means and ANCOVA summary for hydrologic metrics

				ANCOVA		
Period	**Mean**	**Median**	**LSM**	**LSM**	**Slope**	**Intercept**
Peak Discharge (L/s)						
Calibration	15.0	8.8	7.8			
Treatment	12.4	5.5	5.7			
Change[a]	-17%	-38%	-28%	0.1000*	-	<0.0001*

Lag Time (hrs)						
Calibration	1.94	0.43	0.86			
Treatment	2.40	0.73	0.73			
Change[a]	78%	70%	-15%	0.1802^{NS}	0.0367*	0.3848^{NS}
Runoff Depth (mm)						
Calibration	8.1	2.2	2.5			
Treatment	3.6	1.1	1.2			
Change[a]	-55%	-50%	-52%	0.0002*	0.0001*	0.0259*
Runoff Coefficient						
Calibration	0.22	0.14	0.18			
Treatment	0.13	0.10	0.10			
Change[a]	-41%	-29%	-47%	0.0002*	-	0.0002*

*Significant

^{NS}Not Significant

[a] Negative sign "-" implies decrease

SCM-Retrofit concentrations of TKN, TP, TSS, Cu, Pb and Zn significantly decreased by 62%, 38%, 82%, 55%, 89% and 76%, respectively (Table 3). Concentrations of NO2,3-N and TAN did not change. Mass exports of TKN, TAN, O-PO4-3, TP, TSS, Cu, Pb and Zn significantly decreased by 78%, 61%, 55%, 73%, 91%, 53%, 88% and 77%, respectively. NO2,3-N load decreased by 46%, although this was not significant. Most improvements in water quality were due to dramatic decreases of particulate and particulate-bound pollutant loads. This was attributed to first flush retention of runoff by the BRC and permeable pavement that treated 52% of the DCIA and treatment by the tree filter unit that serviced 42% of the DCIA. This study has shown that a limited number of LID SCMs installed within a medium-density residential street right-of-way over sandy soils can mitigate some hydrologic and water quality impacts of existing development.

Figure 9: Summary of nutrient and sediment concentrations at the catchment outlets (mg/L)

Station	Duration (yr)	n[a]	TKN	TAN	$NO_{2,3}$-N	TSS	$O\text{-}PO_4^{-3}$	TP
Control	1.14	25						
Mean			1.92	0.20	0.25	53	0.23	0.44
Median			1.14	0.06	0.14	42	0.10	0.22
SCM-Calibration	0.47	9						
Mean			1.52	0.07	0.30	50	0.21	0.29
Median			1.35	0.04	0.26	54	0.11	0.21
SCM-Treatment	0.67	16						

Mean	0.66	0.04	0.18	11	0.12	0.21
Median	0.45	0.03	0.07	7	0.10	0.17
LSM Difference[b]	-62%*	0%[NS]	0%[NS]	-82%[T]*	-54%[S]*	-38%*
US Residential[1]	1.51	-	0.48	172	0.12	0.26
NC Residential[2]	1.48	0.34	0.49	42	-	0.40
LID Residential[3]	1.30	0.04	0.40	11	-	0.29
LID Commercial[4]	0.69	0.06	0.56	18	0.01	0.06

*Significant

[NS] Not Significant

[T] Paired t-test used for statistical comparison between control and SCM-Retrofit catchments with treatment data set

[S] Sign test used for statistical comparison between control and SCM-Retrofit catchments with treatment data set

[a] Number of events sampled

[b] Negative sign "-" implies reduction

[1] Claytor and Schueler, 1996

[2] Line et al., 2002

[3] Bedan and Clausen, 2009

[4] Line et al., 2012

Although PAH monitoring was originally planned for the study, it was suspended after review of the pre-retrofit data that showed all PAH analytes were below the practical quantification limits (PQL, which ranged from 10-50 ug/L depending the compound) reported by the DWQ Chemistry Lab. This was likely due to a lack of consistent and typical PAH sources in the contributing drainage area (recently applied seal coats, vehicular fluids on pavements or waste PVC manufacturing products).

ADDITIONAL DELIVERABLES COMPLETED:

Silva Cells

Installation of two Silva Cell suspended pavement systems took place in June and July 2012. Silva Cells are a plastic composite grid structure with 92% void space that support loads up to AASHTO H-20 standards. The static and active loads above the Silva Cells are transferred to the sub-grade by the composite columns and beams. The uncompacted soil volume contained in the Silva Cells is ideally suited for tree root growth, but also creates a potentially novel subsurface Stormwater Control Measure (SCM). Water was routed to the Silva Cells through a new catch basin. Two 6" distribution pipes conveyed water to the top of the Silva Cells, where water filters down through 3 ft of soil media. Three 4" diameter underdrains were used to drain the soil profile, effectively providing a stormwater filter underneath the sidewalk. It is our hope that these systems could be used to treat stormwater in ultra-urban areas, where space is limited for traditional stormwater control measures.

The Silva Cell manufacturer provided funding to construct, implement and study the systems in the Burnt Mill Creek watershed. These retrofits occurred during the period that this grant was funded and were installed in the Burnt Mill Creek watershed, providing additional urban stormwater treatment. Two types of media were installed in the systems: the NC standard mix and more traditional tree planting mix. The hydrologic and water quality components of the two systems were evaluated and compared. These two systems are an addition to the required grant products.

1. Corner of Ann Street and 10th Street

Location: Latitude 34°13'58.27" North, Longitude 77°56'10.70" West

Size of treatment area: 0.0485 ha (0.12 acres) – 100% impervious roadway

Size of best management practice: 32 ft by 10 ft (320 ft^2)

Pollutant removal: Preliminary monitoring results show that TN was reduced from 0.65 mg/L at the inlet to 0.23 mg/L at the outlet. 69% and 86% reductions were observed for TP and TSS, respectively. Additionally, between 83-92% reductions of Cu, Pb, and Zn were observed.

2. Corner of Orange Street and 10th Street

Location: Latitude 34°13'58.27" North, Longitude 77°56'10.70" West

Size of treatment area: 0.057 ha (0.14 acres) – 100% impervious roadway

Size of best management practice: 32 ft by 10 ft (320 ft^2)

Pollutant removal: Preliminary monitoring results show that TN was reduced from 0.88 mg/L at the inlet to 0.20 mg/L at the outlet. 71% and 62% reductions were observed for TP and TSS, respectively. Additionally, between 47-84% reductions of Cu, Pb, and Zn were observed.

Figure 10: Orange Street and Ann Street retrofit sites with directly connected impervious areas (DCIA) in blue

Church Street Permeable pavement

As the EPA319 grant was coming to a close, the project PIs realized that a small amount of additional funds were remaining in the grant. During May and June of 2013, we worked with suppliers (who donated materials) and the City of Wilmington to fast track the design and installation of a side-street permeable pavement retrofit. The site was chosen by Dave Mayes (stormwater engineer with the City of Wilmington), and was located at the intersection of 19th street and Church street. The southwest corner of the intersection was a low spot that has historically flooded in all but the smallest rainfall events. To remedy the problem without installation of a new catch basin and expensive piping, full depth permeable pavement was installed to allow the stormwater to infiltrate into the underlying sandy soils. Permeable interlocking concrete pavers were used as the surface course, with 18” of gravel beneath it to provide both structural support and void space for water to promote infiltration. Based on visual observation during a few storm events, the retrofit has helped to reduce standing water at the intersection. This type of design may prove useful in other locations in both Wilmington and in other cities across NC.

Location: Latitude 34°13'51.73" North, Longitude 77°55'30.60" West

Catchment area: 0.069 ha (0.17 acres, 7396 ft^2)

Size of permeable pavement: 38 ft x 8 ft (308 ft^2)

Pollutant removal: This practice was not monitored. However, expected pollutant removal is 85% TSS, 30% TN, and 60% TP, which are the credits in the current DENR BMP manual chapter for permeable pavement. The subgrade of this permeable pavement application had 18 inches of rock, enough to store about 6 inches of water in the void space. Even with the large run-on ratio (24:1), we expect it to be able to store and infiltrate the 1.5 inch storm event (no underdrain in the system) due to the high infiltration rates of the sandy soils underlying the practice.

Technology Transfer

The project team provided presentations on the project at six national conferences and North Carolina conferences including:

- 2013 ASCE/T&DI Green Streets and Highways conference in Austin, TX
- 2013 NC American Public Works Association (APWA)conference in Wilmington, NC
- 2013 California Stormwater Quality Association (CASQA) conference in Lake Tahoe, CA
- 2012 ASCE Environmental & Water Resources Institute (EWRI) conference in Cincinnati, OH
- 2012 USDA Land Grant/Sea Grant National Water conference in Portland, OR
- 2012 Water Environment Federation Technical (WEFTEC) conference in New Orleans, LA
- 2012 ASCE Environmental & Water Resources Institute (EWRI) conference in Albuquerque, NM
- 2011 NC Water Resources Research Institute Conference,(WRRI) conference in Raleigh, NC

Two peer-reviewed journal articles have been produced from the research effort associated with implementation of the green street (see below). Additionally, a peer-reviewed journal article will be produced from the Silva Cell research, which is still ongoing through non-EPA 319 funding.

- Page, J.L., Winston, R.J., and Hunt, W.F. (2014). “Catchment-scale evaluation of water quality impacts of residential stormwater street retrofits.” *Journal of Environmental Engineering*. Submitted for review.
- Page, J.L., Winston, R.J., and Hunt, W.F. (2014). “Catchment-scale evaluation of hydrologic impacts of residential stormwater street retrofits.” *Journal of Hydrology*. Submitted for review.

6. Methodology and Execution

All engineering designs for this project were completed by either Ryan Winston, P.E. or Jonathan Page, E.I. William F. Hunt, P.E. signed and sealed all engineering plans after reviewing them thoroughly. The design review process included, in all cases, (1) meetings with stakeholders to obtain their opinions on the design, and (2) meetings with the City of Wilmington staff to get their feedback. Once this was received, revisions to their engineering plans were made. This feedback loop often meant that 2-3 revisions were made to a single set of engineering plans. All engineering plans can be found in the Appendices to this document.

NCSU engineers worked with City of Wilmington Streets and Stormwater Department staff to construct the retrofit projects. NCSU staff were on site during all phases of construction, providing feedback and guidance to the crews. This was an excellent working relationship, and we believe that this type of mutualistic relationship should be a model for future SCM implementation in the Burnt Mill Creek watershed. As described above, four major retrofit projects were completed: (1) a street retrofit on 12th and Dock Street, (2) two Silva Cell retrofits were installed at 10th and Ann and 10th and Orange streets, (3) a Portland-style bioretention cell was installed at the corner of 9th and Ann streets, and (4) a permeable pavement retrofit was installed at 19th and Church streets.

Stormwater monitoring was undertaken at both the street retrofit and Silva Cell retrofit projects (numbers 1 and 2 above). Monitoring setups varied slightly between the six monitoring points (one at LID catchment outlet, one at control catchment outlet, and one at the inlet and outlet of each Silva Cell system). The following describes the monitoring at the street retrofit project, which was funded by this EPA 319 grant:

The paired watershed study design was used to evaluate the hydrologic impacts of the LID SCM retrofits (Clausen and Spooner, 1993; Grabow et al., 1999). This approach requires two watersheds: control and treatment (LID) and two monitoring periods: calibration and treatment. During the calibration period, management practices in the catchments remained the same (no SCMs), the SCMs were installed in the LID catchment and treatment monitoring began post-construction (Table 4). The paired watershed approach is underpinned by a quantifiable and predictable (linear) relationship between the catchments. A relationship is developed during the calibration period, and is considered valid until the

SCM treatment is applied to the LID catchment, at which time a new relationship between the catchments is developed during the second period of monitoring (Clausen and Spooner, 1993).

Figure 11: Table of paired watershed study design

Period	Catchment	
	LID	Control
Calibration	No SCMs	No SCMs
Treatment	SCMs	No SCMs

Monitoring equipment was installed at the catchment outlets in May 2011. Manual and HOBO™ Tipping Bucket rain gauges were installed on a wooden post free of trees and overhead obstructions at the LID station (Table 5). An ISCO 6712™ portable sampler logged rainfall data from the tipping bucket. Hydrologic data were recorded by installing V-notch weirs and weir boxes inside the existing catch basins (Figure 2). Forty-five degree and 60° V-notch weirs were installed at the control and LID stations, respectively. The V-notch weirs and weir boxes were fitted with a 1 m (3.3 ft) long contracted rectangular weir to pass discharges from large storms. ISCO 730™ bubbler flow modules were used to monitor discharge and total runoff volume by measuring stage above the weir at two minute intervals.

Figure 12: Summary of monitoring equipment

Equipment	LID	Control
Location	Southwest corner of intersection of 12th and Dock St	Northwest corner of intersection of 8th and Orange St.
Structure	60° V-notch weir	45° V-notch weir
Flow Monitoring Device	ISCO 730™ Bubbler Module	ISCO 730™ Bubbler Module
Rain Gauges	Manual and HOBO™ Tipping Bucket	NA[a]

[a] Control station located 0.5 km from LID station

Figure 13: V-notch weir and weir box being installed inside existing catch basins for the street retrofit project

During each site visit hydrologic and rainfall data were downloaded with an ISCO Rapid Transfer Device™ (RTD) at both stations. The ISCO 730™ bubbler flow modules were calibrated by bringing the water level in the weir box up to the weir invert, and the bubbler tubing was purged with an air compressor to combat moisture intrusion. Bubbler module desiccant was replaced when it became saturated approximately every two weeks during summer and fall and every four weeks during winter and spring.

7. Outputs and results

See section 4 "Deliverables" for a complete and detailed explanation of all results, Deliverables are listed here also. Any changes in the expected results are listed here in parenthesis.

1. Finalized street retrofit engineered designs
2. Two community workshops- one for collecting feedback on the draft designs, including plant preferences, and one for developing an outreach and maintenance program.
3. Meeting(s) with the Bottom Neighborhood Empowerment Association, school administrators and teachers
4. Completed intersection retrofit at 9th and Ann Streets that includes bioretention and native planting area (originally proposed for the intersection of 10th and Ann Streets)
5. Completed mid-block street retrofit that includes bioretention, tree filter boxes, and permeable pavement parking stalls (proposed for Dock St and two perpendicular streets that drain to Dock St.- Jasmine St. and 12th St.)
6. Two educational signs installed adjacent to the retrofits for pedestrian viewing (four signs were produced- 2 for the bioretention retrofits, 2 for the permeable pavement retrofits).
7. PAH fact sheets printed and distributed in public and private locations throughout the City of Wilmington
8. Installation of permeable pavement retrofit at 19th and Church Streets (an additional deliverable)
9. Installation of two Silva Cell retrofits within the Burnt Mill Creek watershed (an additional deliverable)
10. Summary of retrofit monitoring results
11. Quarterly Progress Reports
12. Final Report

9. Outcomes and Conclusions

The methods described above allowed for the following outcomes to be reached:

- Tested different street retrofit methods, including bump-out bioretention, plaza bioretention, Silva cells, and permeable pavement.
- Resulted in 3.28 acres of amount of impervious surface treated.
- Built the capacity of City of Wilmington staff to construct street stormwater retrofits.
- Identified pollutants received by street retrofit BMPs and quantified pollutant removal from the practices
    - Retrofit runoff coefficient significantly decreased from 0.38 to 0.18, and is substantially less than other runoff coefficients reported for traditional residential development.
    - Retrofit concentrations of TKN, TP, TSS, Cu, Pb and Zn significantly decreased from 38-89%.
    - Concentrations of NO2,3-N and TAN did not change.
    - Mass loads of TKN, TAN, O-PO4-3, TP, TSS, Cu, Pb and Zn significantly decreased by 53-91%. Most improvements in water quality were due to dramatic decreases of particulate and particulate-bound pollutant loads.
- This study has shown that a limited number of LID stormwater control measures installed within a medium-density residential street right-of-way over sandy soils can mitigate some hydrologic and water quality impacts of existing development.
- Monitoring of 3 in-stream sites by UNC-Wilmington in 2012 (through a contract with the City of Wilmington) showed two algal blooms that exceeded state standards, low dissolved oxygen, and exceedances of fecal coliform at two sites.TSS levels were below levels considered by UNC-W to be of concern for the lower Coastal Plain. PAHs were not sampled. Improvements in in-stream water quality were not seen from previous sampling.

In conclusion,

- Retrofitting stormwater management practices in urban areas requires flexibility and time in order to address limited space, utility locations, residents' concerns about losing parking and community aesthetics.
- While the city had hoped to increase pedestrian safety by installing bumpouts, in reality it was difficult to retrofit these in residential communities where many residents do not have their own off-street parking. Loss of on-street parking becomes a significant issue to residents.
- Bioretention located in the "plaza", or area between curb and sidewalk, appears to be the most feasible location for stormwater street retrofits in downtown residential areas in the watershed. Locating retrofits here does not impact parking at all. "Bump-out" style bioretention may work best in areas that have more off-street parking, such as driveways and garages.
- If minimal landscape maintenance will occur in a street side bioretention cell, dense plantings of a few species of hearty grasses or other plants seems to provide a more attractive and easily maintained look than a garden-type planting with many different plant species.
- PAH levels in street runoff were very low, indicating that for targeting this particular pollutant, practices that treat parking lot runoff are more important than those that treat street runoff. However, street retrofits do benefit overall watershed restoration by reducing the stormwater volumes and pollutants that reach Burnt Mill Creek.

10. Budget

Figure 14: Actual and budgeted expenditures

	Federal request	Matching funds
Budgeted in contract	$224,889	$150,177
Actual expenditures	$224,433.43	$188,259.65
Difference	$455.57	($38,082.65)

11. References

NCDENR DWQ Planning Branch. 2004. Assessment Report: Biological Impairment in the Burnt Mill Creek Watershed. Collaborative Assessment of Watersheds and Streams (CAWS) project.110 pp.

NCDENR DWQ Basinwide Planning Unit. 2005. Cape Fear River Basinwide Water Quality Plan.

NCDENR NC Wetlands Restoration Program (current Ecosystem Enhancement Program). 2002. New Hanover County Local Watershed Planning Initiative: Causes and sources of Water Quality Degradation in Burnt Mill Creek, Lower Smith, and Prince George Creeks. Prepared by KCI Associates of NC for NCWRP.

Mallin, M.A., L.B. Cahoon, Posey, M.H., Johnson, V.L., Parsons, D.C., Alphin, T.D., Toothman, B.R., Ortwine, M.L., Merit, J.F. 2006. Environmental Quality of Wilmington and New Hanover County Watersheds 2012. CMS Report 13-01. Center for Marine Science, UNC-Wilmington.

Perrin, C., Winston, R., Beggs, P., Hunt, B. 2009. Planning for Reducing Stormwater Runoff and Toxicity in Burnt Mill Creek Watershed. Final Report for CWMTF Grant 2007-812. Online at www.ncsu.edu/WECO/burntmill

Perrin, C.A.; Wright, J.; Hunt, W.F.; Beggs, P.G.; Mallin, M.; Burchell, M. 2008. Restoring the Burnt Mill Creek Watershed through Stormwater Management and Community Development. Final EPA 319 Report to NC Division of Water Quality. Online at www.ncsu.edu/WECO/burntmill

Watershed Education for Communities and Officials and NC Wetlands Restoration Program. 2002 Watershed Plan Summary for the Hydrologic Unit Containing Burnt Mill, Upper and Lower Smith, Prince George.

12. Appendices

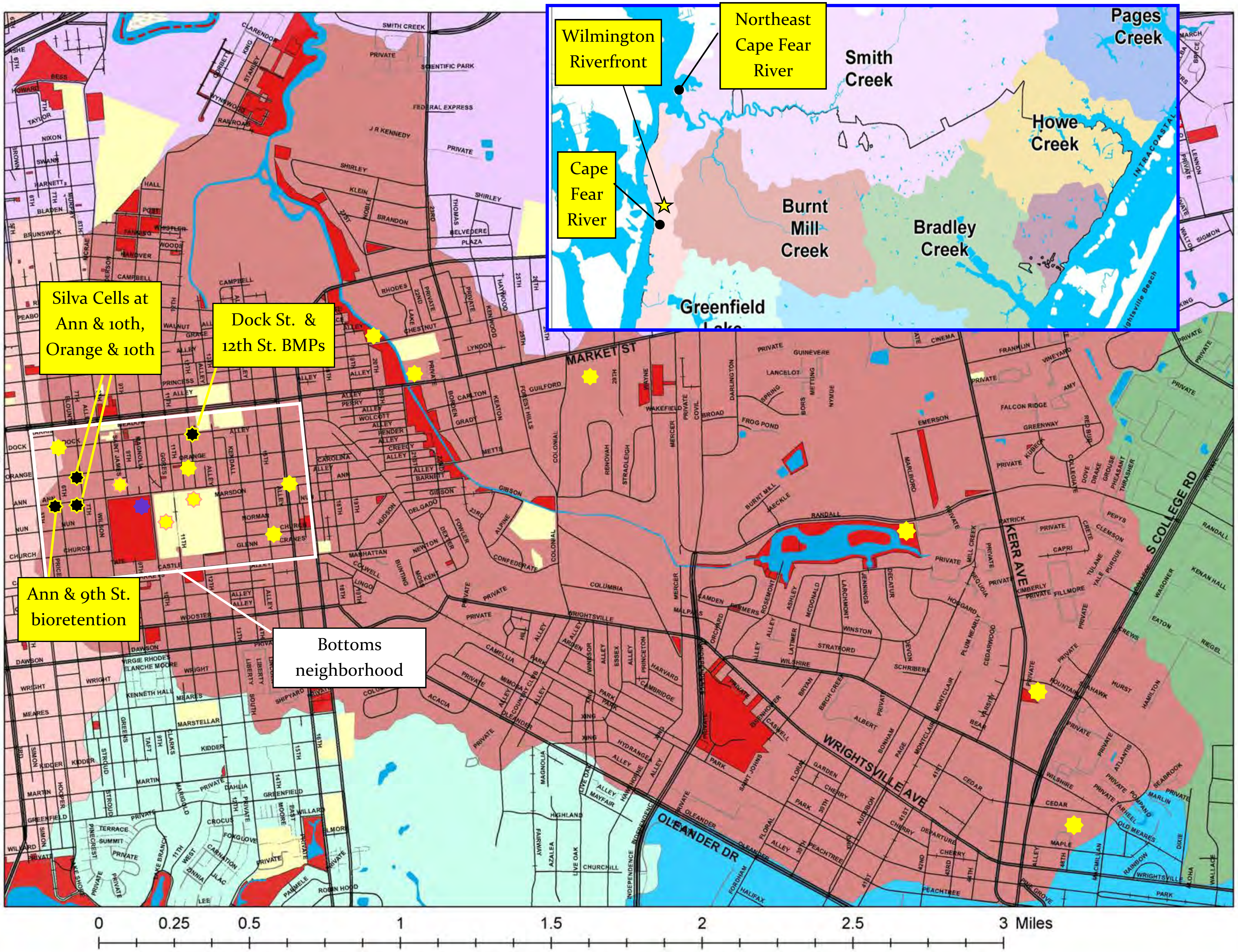
Map of watershed with BMPs located
Retrofit engineer plan sheets
Workshop and construction announcement fliers
Posters created for workshop

Bioretention fact sheet
Bioretention and permeable pavement signs
PAH Fact Sheet
Final Monitoring Report

Burnt Mill Creek Watershed

28 Acres of Creek
4,223 Acres of Land

- 🟥 Burnt Mill Creek
- 🟪 Smith Creek
- 🟩 Bradley Creek
- 🟦 Hewletts Creek
- 🟩 Greenfield Lake
- 🟥 Drains directly to Cape Fear
- — City Maintenance
- ═ State Maintenance
- ┄ Private Maintenance
- +—+ Not open or no maintenance
- — Outside City limits
- ▭ City Limits
- 🟦 Water
- ▨ Marsh
- 🟥 City Properties
- 🟨 County Properties
- ✸ ✸ Completed projects
- ✦ 12 raingardens & 36 rainbarrels in Bottoms



CITY OF WILMINGTON
STORMWATER SERVICES

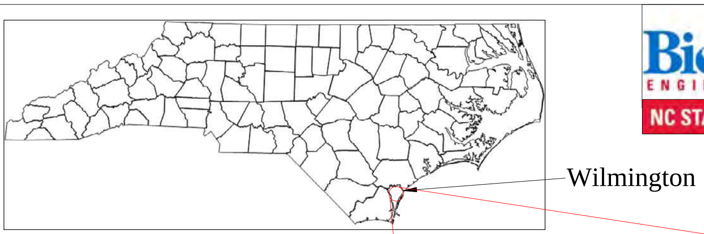
Public Services
Stormwater Services
209 Coleman Drive
PO Box 1810
Wilmington, NC 28402-1810
910 343-4777
910 341-0099 fax
wilmingtonnc.gov
Dial 711 TTY/Voice

Stormwater best management practices (BMPs)in Burnt Mill Creek

1.	Bottoms Neighborhood (Market to Castle / 5th to 17th)	12 residential rain gardens & 36 rain barrels
2.	Family and Neighborhood Institute	2 rain barrels
3.	Gregory Elementary School	raingarden, cistern
4.	Williston Middle School	raingarden, cistern
5.	Fannie Norwood Memorial Home	raingarden
6.	Anderson Tabernacle	raingarden
7.	Mary Bridgers Park	wetland
8.	Port City Java	raingarden
9.	Wilmington Family YMCA	raingarden, pervious pavement lot
10.	McCrary park	stormwater demonstration site
11.	Kerr Avenue	wetland
12.	Stones Throw Townehomes	wetland
13.	Dock & 12th Sts	bioretention, permeable pavement, tree filter box
14.	Ann & 9th Sts	bioretention
15.	Ann & 10th, Ann & Orange Sts	Sylva cells

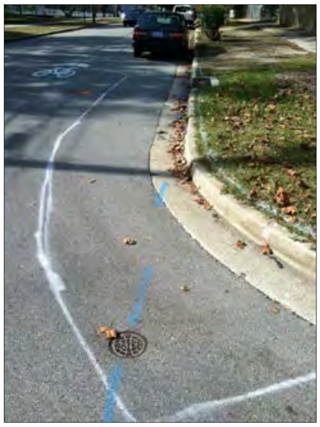
Wilmington Intersection Retrofit Design

Corner of Ann & 9th Streets
Wilmington, NC 28401



Prepared by:

Ryan J Winston, PE
NC State University
Campus Box 7625
Raleigh, NC 27695-7625
(919) 515-8595
ryan_winston@ncsu.edu



Sheet Index

- Sheet 1: Cover & Sheet Index
- Sheet 2: Existing Site Conditions
- Sheet 3: Proposed Stormwater BMP Retrofits
- Sheet 4: Details and Construction Sequence

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

COVER/CONTACTS/SHEET INDEX

Designed By: RJW
Reviewed By: WFH

Date:
MARCH 12, 2013

Scale:
NOT TO SCALE

Wilmington Street Retrofits
Corner of Ann St. and 9th St.
Wilmington, NC 28401

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

Designed By: RJW
Reviewed By: WFH

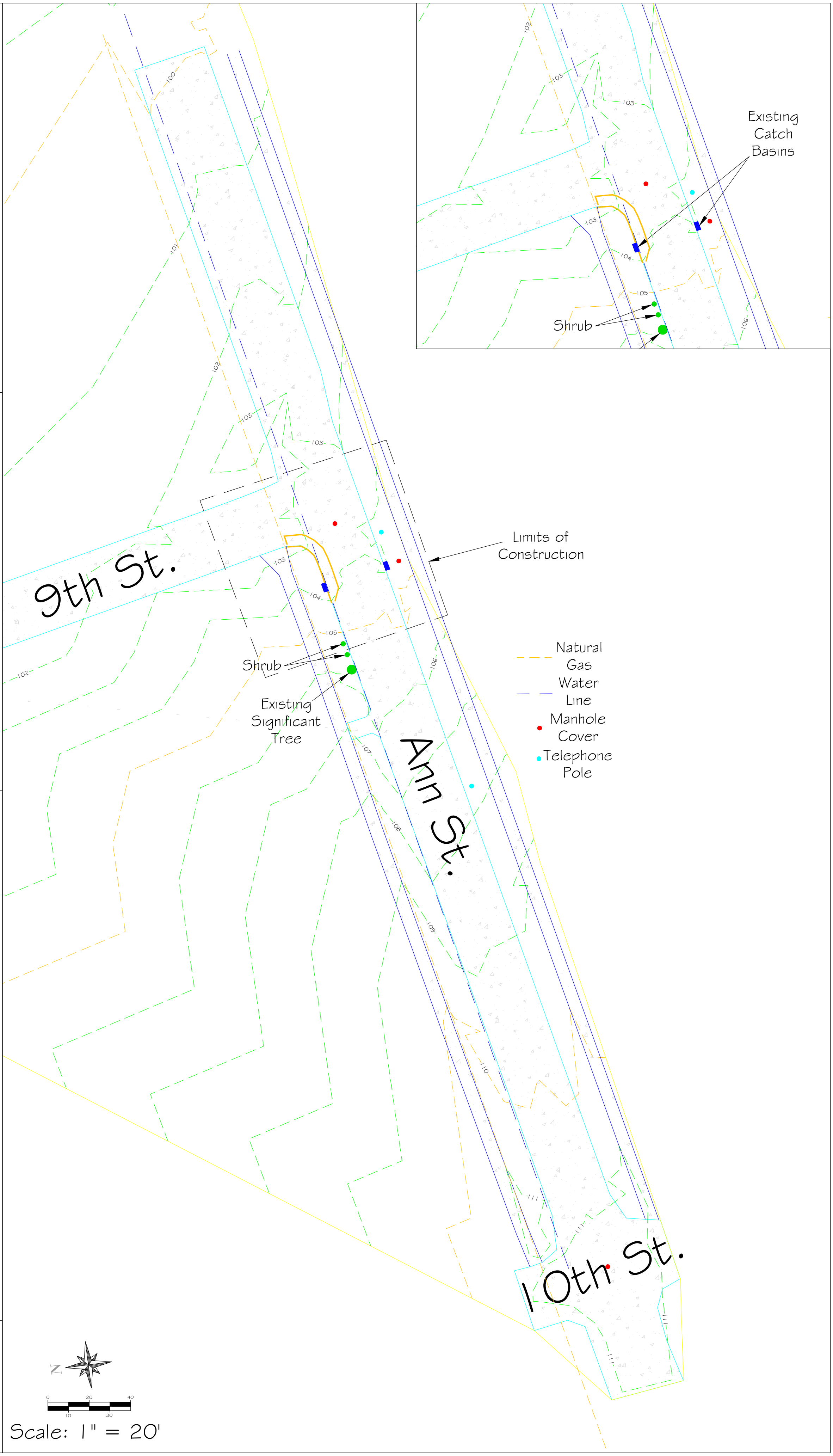
EXISTING SITE

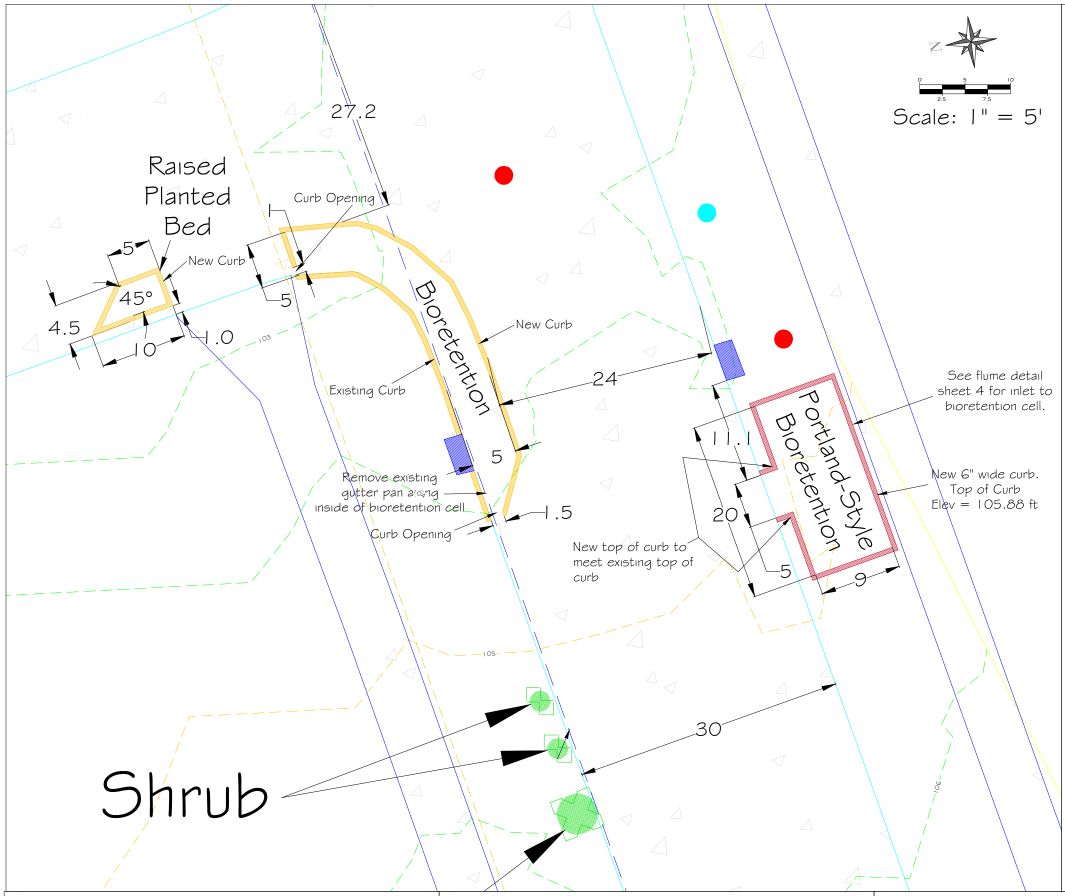
Date:
MARCH 12, 2013

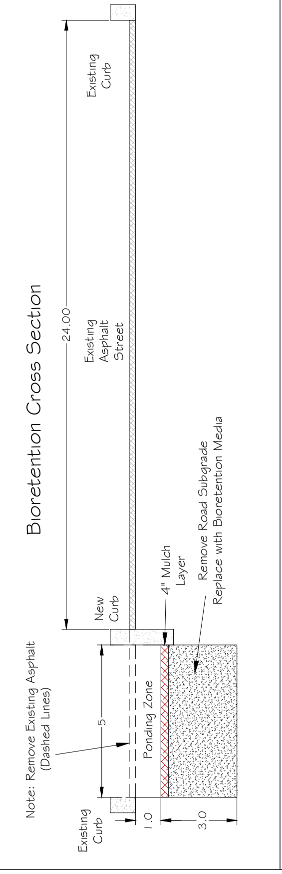
Scale:
1" = 20 ft

Wilmington Street Retrofits
Corner of Ann St. and 9th St.
Wilmington, NC 28401

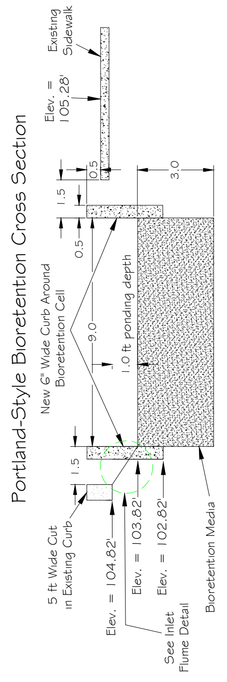
Page Number
2 of 4







Bioretention Cross Section



Portland-Style Bioretention Cross Section

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

PROPOSED SITE

Designed By: RJW
Reviewed By: WFH

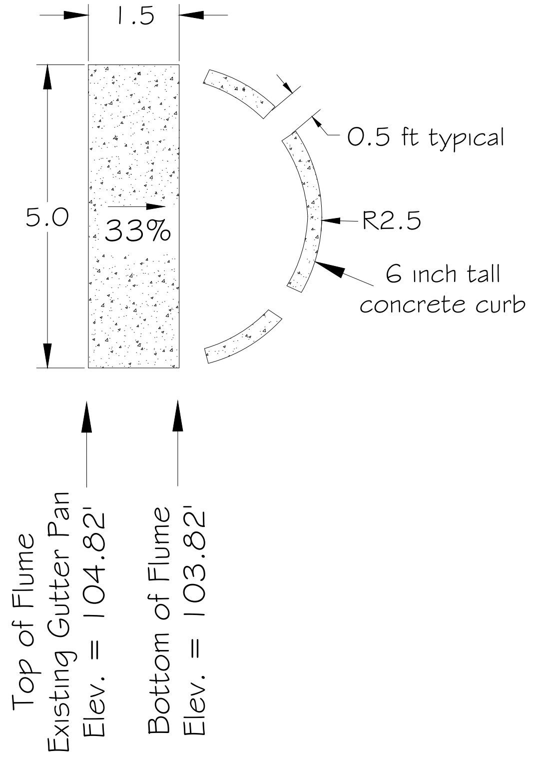
Date:
MARCH 12, 2013

Scale:
As Noted

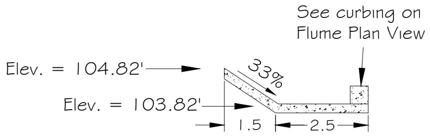
Wilmington Street Retrofits
Corner of Ann St. and 9th St.
Wilmington, NC 28401

Page Number
3 of 4

Flume Plan View



Flume Cross Section



Flume min. 3"
thick 3000 psi
concrete

Construction Sequence & Notes: Bioretention Cell

1. Ensure that traffic control is in place to direct traffic safely around the construction zone. Follow all City of Wilmington regulations for traffic control devices.
2. Place sediment control devices over drop inlet at the corner of Ann Street and 9th Street to prevent sediment-laden water from entering the storm drain network.
3. Be aware of existing utility locations. Utilities are shown on sheets 2 and 3.
4. Saw cut and remove asphalt over the entire surface area of the bioretention cell and raised planted bed (outlined in orange on sheet 3).
5. Saw cut and remove gutter existing gutter pan inside the bounds of the bioretention cell.
6. Excavate beneath area where new curb will be installed to a depth of 10 inches.
7. Where curbs will be installed, place 4" of ABC stone on top of soil. Install forms for curbs, and pour curb using 3000 psi concrete. Once concrete has set up, remove forms.
8. Excavate remainder of bioretention cell to a depth of 4 ft.
9. Install 3 ft of bioretention media over entire bioretention cell. Bioretention media to be 85-88% sand, 3-5% organic matter, and 10-12% fines (silt and clay). Ponding depth should be 1 ft.
10. Install 3" of mulch over bioretention media. Plant bioretention cell with appropriate plants, as approved by the engineer.
11. Install topsoil in the raised planted bed to bring the grade up to the curb. Plant with appropriate plants, as approved by the engineer.
12. Install rip-rap (class B minimum) or 6" diameter stone at inlet to bioretention cell to dissipate energy of stormwater.
13. Remove traffic control and sediment control devices from the site. Clean the site and ensure that any damaged plants are replaced.

Construction Sequence & Notes: Portland-Style Bioretention Cell

1. Ensure that traffic control is in place to direct traffic safely around the construction zone. Follow all City of Wilmington regulations for traffic control devices.
2. Place sediment control devices over drop inlet at the corner of Ann Street and 9th Street to prevent sediment-laden water from entering the storm drain network.
3. Excavate 21 ft by 10 ft hole to a depth of 102.5 ft.
4. Where curbs will be installed, place 4 inches of ABC stone base on soil.
5. Install curb forms around the perimeter of the hole. Pour curb to elevations shown on sheet 3 using 3000 psi concrete. The TOC elevation should be 105.88.
6. Place ABC stone under area where flume will be installed. Bring stone up to 103.2 ft elevation.
7. Grade 5 ft wide by 1.5 ft long flume from existing curb down to the ABC stone. See details on sheet 4. Install 3 inches of ABC stone on flume.
8. Install concrete (3 inch thick minimum) on flume. Splash pad should be 2.5 ft radius. Allow concrete to set up.
9. Install flow barriers (6 inch high curbs) out of concrete as shown on the plan view detail on sheet 4. Holes to allow flow into the bioretention cell should be 6 inches wide.
10. Excavate remainder of bioretention cell to a depth of 4 ft, or an elevation of 100.82 ft.
11. Install 3 ft of bioretention media over entire bioretention cell. Bioretention media to be 85-88% sand, 3-5% organic matter, and 10-12% fines (silt and clay). Ponding depth should be 1 ft.
12. Install 3" of mulch over bioretention media. Plant bioretention cell with appropriate plants, as approved by the engineer.
13. Cut curb (at location noted on sheet 2) to be flush with gutter. Curb cut should be 5 ft wide.
14. Remove traffic control and sediment control devices from the site. Clean the site and ensure that any damaged plants are replaced.

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

DETAILS

Designed By: RJW
Reviewed By: WFH

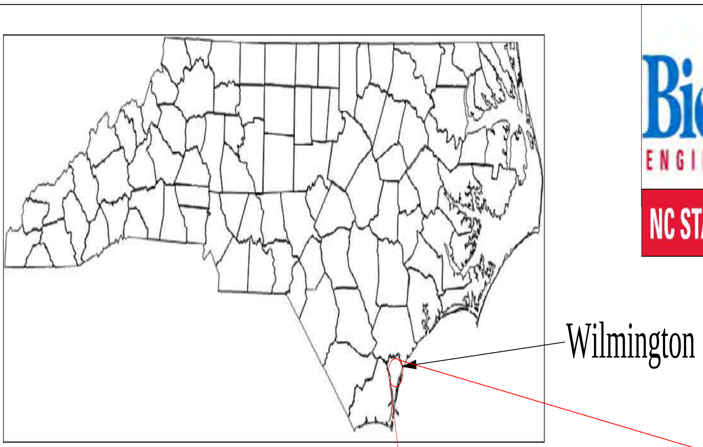
Date:
MARCH 12, 2013

Scale:
Not to Scale

Wilmington Street Retrofits
Corner of Ann St. and 9th St.
Wilmington, NC 28401

Wilmington
Street
Retrofit Design

Dock St., Jasmine St.,
and 12th St.
Wilmington, NC 28401



Prepared by:

Ryan J Winston, EI
NC State University
Campus Box 7625
Raleigh, NC 27695-7625
(919) 515-8595
ryan_winston@ncsu.edu

Sheet Index

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

COVER/CONTACTS/SHEET INDEX

Designed By: RJW
Reviewed By: WFH JLP

Date:
JANUARY 9, 2012

Scale:
NOT TO SCALE

Wilmington Street Retrofits
Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

EXISTING SITE CONDITIONS

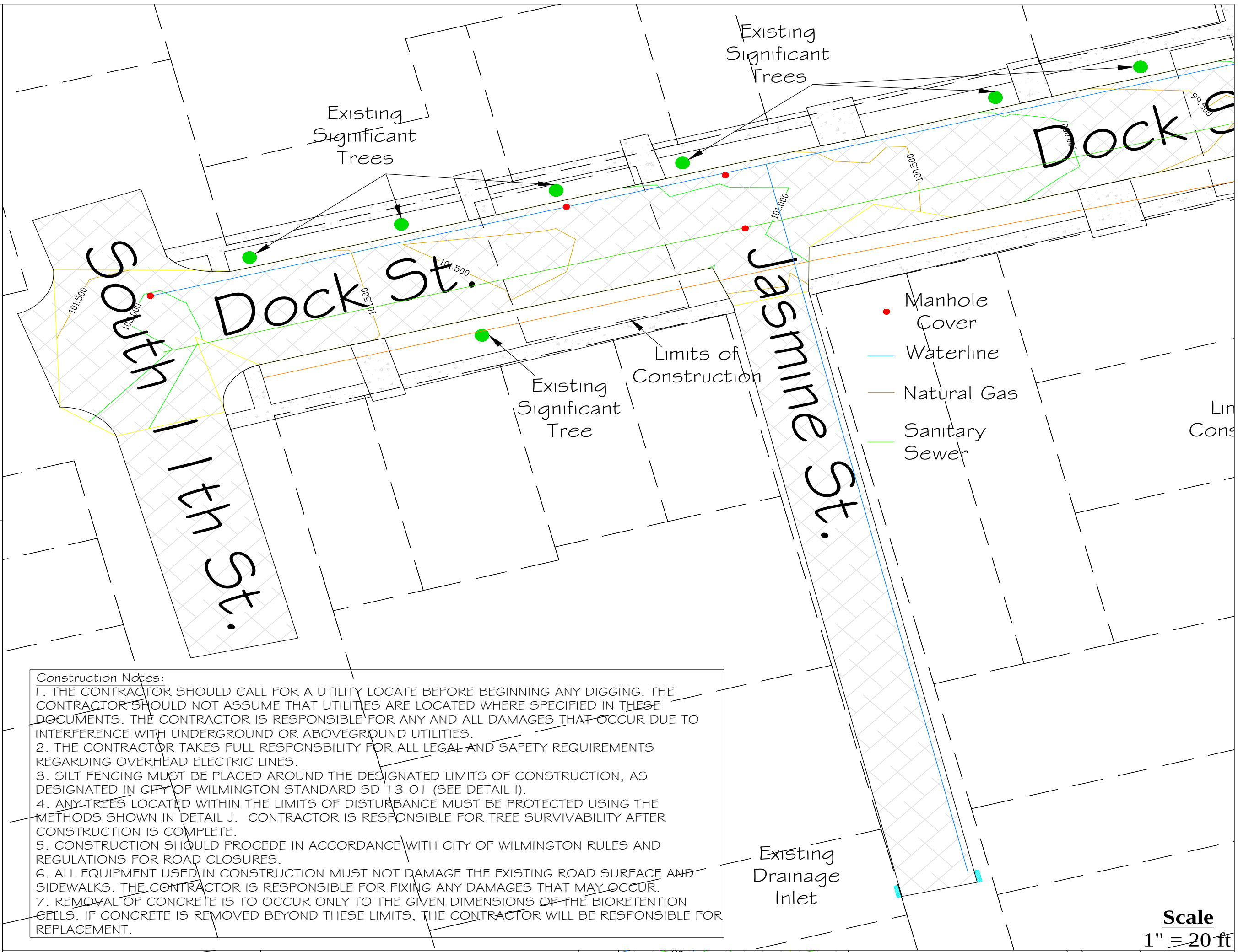
Designed By: RJW
Reviewed By: WFH JLP

Date:
JANUARY 9, 2012

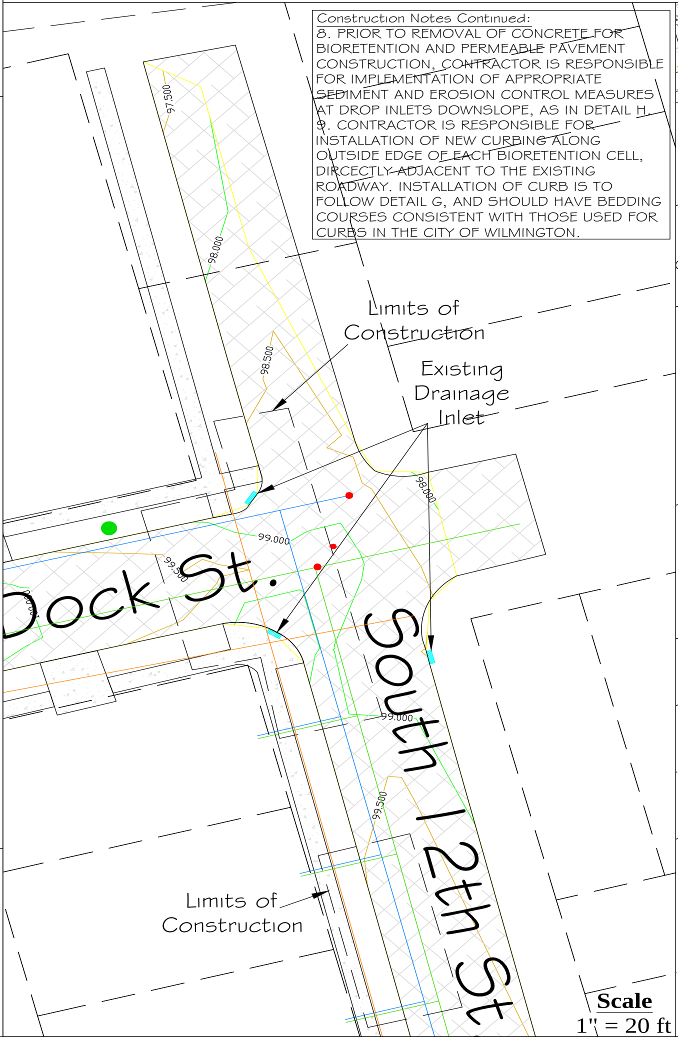
Scale:
As Noted

Wilmington Street Retrofits
Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

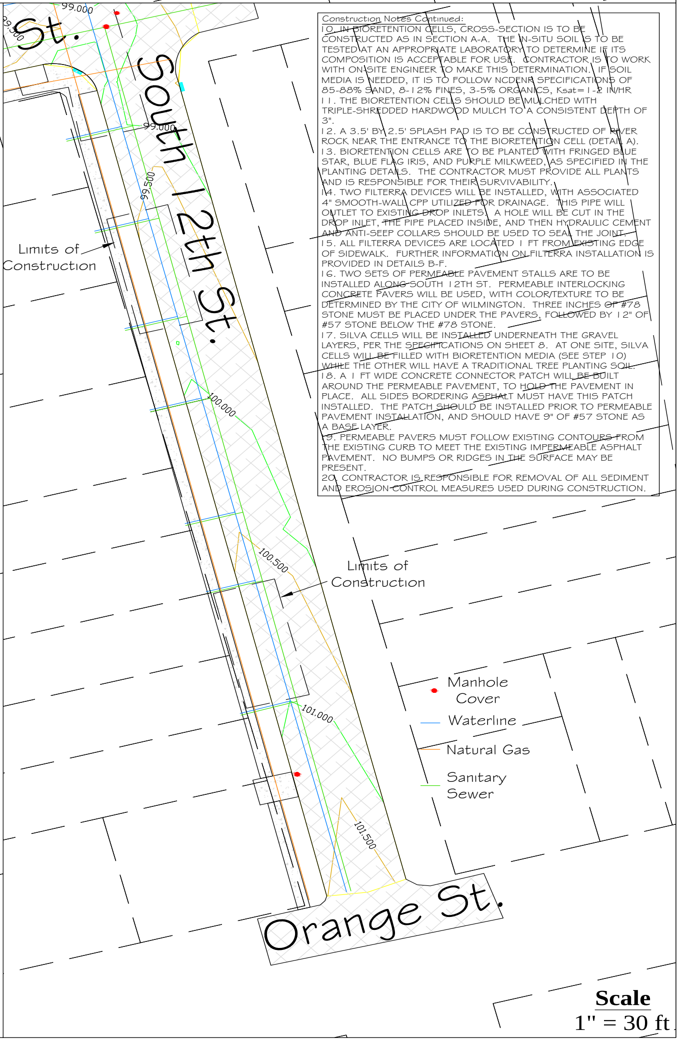
Page Number
2 of 8



Construction Notes:
1. THE CONTRACTOR SHOULD CALL FOR A UTILITY LOCATE BEFORE BEGINNING ANY DIGGING. THE CONTRACTOR SHOULD NOT ASSUME THAT UTILITIES ARE LOCATED WHERE SPECIFIED IN THESE DOCUMENTS. THE CONTRACTOR IS RESPONSIBLE FOR ANY AND ALL DAMAGES THAT OCCUR DUE TO INTERFERENCE WITH UNDERGROUND OR ABOVEGROUND UTILITIES.
2. THE CONTRACTOR TAKES FULL RESPONSBILITY FOR ALL LEGAL AND SAFETY REQUIREMENTS REGARDING OVERHEAD ELECTRIC LINES.
3. SILT FENCING MUST BE PLACED AROUND THE DESIGNATED LIMITS OF CONSTRUCTION, AS DESIGNATED IN CITY OF WILMINGTON STANDARD SD 13-01 (SEE DETAIL I).
4. ANY TREES LOCATED WITHIN THE LIMITS OF DISTURBANCE MUST BE PROTECTED USING THE METHODS SHOWN IN DETAIL J. CONTRACTOR IS RESPONSIBLE FOR TREE SURVIVABILITY AFTER CONSTRUCTION IS COMPLETE.
5. CONSTRUCTION SHOULD PROCEDE IN ACCORDANCE WITH CITY OF WILMINGTON RULES AND REGULATIONS FOR ROAD CLOSURES.
6. ALL EQUIPMENT USED IN CONSTRUCTION MUST NOT DAMAGE THE EXISTING ROAD SURFACE AND SIDEWALKS. THE CONTRACTOR IS RESPONSIBLE FOR FIXING ANY DAMAGES THAT MAY OCCUR.
7. REMOVAL OF CONCRETE IS TO OCCUR ONLY TO THE GIVEN DIMENSIONS OF THE BIORETENTION CELLS. IF CONCRETE IS REMOVED BEYOND THESE LIMITS, THE CONTRACTOR WILL BE RESPONSIBLE FOR REPLACEMENT.



Construction Notes Continued:
8. PRIOR TO REMOVAL OF CONCRETE FOR BIORETENTION AND PERMEABLE PAVEMENT CONSTRUCTION, CONTRACTOR IS RESPONSIBLE FOR IMPLEMENTATION OF APPROPRIATE SEDIMENT AND EROSION CONTROL MEASURES AT DROP INLETS DOWNSLOPE, AS IN DETAIL H.
9. CONTRACTOR IS RESPONSIBLE FOR INSTALLATION OF NEW CURBING ALONG OUTSIDE EDGE OF EACH BIORETENTION CELL, DIRECTLY ADJACENT TO THE EXISTING ROADWAY. INSTALLATION OF CURB IS TO FOLLOW DETAIL G, AND SHOULD HAVE BEDDING COURSES CONSISTENT WITH THOSE USED FOR CURBS IN THE CITY OF WILMINGTON.



Construction Notes Continued:
10. IN BIORETENTION CELLS, CROSS-SECTION IS TO BE CONSTRUCTED AS IN SECTION A-A. THE IN-SITU SOIL IS TO BE TESTED AT AN APPROPRIATE LABORATORY TO DETERMINE IF ITS COMPOSITION IS ACCEPTABLE FOR USE. CONTRACTOR IS TO WORK WITH ON-SITE ENGINEER TO MAKE THIS DETERMINATION. IF SOIL MEDIA IS NEEDED, IT IS TO FOLLOW NCDENR SPECIFICATIONS OF 85-88% SAND, 8-12% FINES, 3-5% ORGANICS, Ksat=1-2 IN/HR
11. THE BIORETENTION CELLS SHOULD BE MULCHED WITH TRIPLE-SHREDDED HARDWOOD MULCH TO A CONSISTENT DEPTH OF 3".
12. A 3.5' BY 2.5' SPLASH PAD IS TO BE CONSTRUCTED OF RIVER ROCK NEAR THE ENTRANCE TO THE BIORETENTION CELL (DETAIL A).
13. BIORETENTION CELLS ARE TO BE PLANTED WITH FRINGED BLUE STAR, BLUE FLAG IRIS, AND PURPLE MILKWEED, AS SPECIFIED IN THE PLANTING DETAILS. THE CONTRACTOR MUST PROVIDE ALL PLANTS AND IS RESPONSIBLE FOR THEIR SURVIVABILITY.
14. TWO FILTERRA DEVICES WILL BE INSTALLED, WITH ASSOCIATED 4" SMOOTH-WALL CPP UTILIZED FOR DRAINAGE. THIS PIPE WILL OUTLET TO EXISTING DROP INLETS. A HOLE WILL BE CUT IN THE DROP INLET, THE PIPE PLACED INSIDE, AND THEN HYDRAULIC CEMENT AND ANTI-SEEP COLLARS SHOULD BE USED TO SEAL THE JOINT.
15. ALL FILTERRA DEVICES ARE LOCATED 1 FT FROM EXISTING EDGE OF SIDEWALK. FURTHER INFORMATION ON FILTERRA INSTALLATION IS PROVIDED IN DETAILS B-F.
16. TWO SETS OF PERMEABLE PAVEMENT STALLS ARE TO BE INSTALLED ALONG SOUTH 12TH ST. PERMEABLE INTERLOCKING CONCRETE PAVERS WILL BE USED, WITH COLOR/TEXTURE TO BE DETERMINED BY THE CITY OF WILMINGTON. THREE INCHES OF #78 STONE MUST BE PLACED UNDER THE PAVERS, FOLLOWED BY 12" OF #57 STONE BELOW THE #78 STONE.
17. SILVA CELLS WILL BE INSTALLED UNDERNEATH THE GRAVEL LAYERS, PER THE SPECIFICATIONS ON SHEET 8. AT ONE SITE, SILVA CELLS WILL BE FILLED WITH BIORETENTION MEDIA (SEE STEP 10) WHILE THE OTHER WILL HAVE A TRADITIONAL TREE PLANTING SOIL.
18. A 1 FT WIDE CONCRETE CONNECTOR PATCH WILL BE BUILT AROUND THE PERMEABLE PAVEMENT, TO HOLD THE PAVEMENT IN PLACE. ALL SIDES BORDERING ASPHALT MUST HAVE THIS PATCH INSTALLED. THE PATCH SHOULD BE INSTALLED PRIOR TO PERMEABLE PAVEMENT INSTALLATION, AND SHOULD HAVE 9" OF #57 STONE AS A BASE LAYER.
19. PERMEABLE PAVERS MUST FOLLOW EXISTING CONTOURS FROM THE EXISTING CURB TO MEET THE EXISTING IMPERMEABLE ASPHALT PAVEMENT. NO BUMPS OR RIDGES IN THE SURFACE MAY BE PRESENT.
20. CONTRACTOR IS RESPONSIBLE FOR REMOVAL OF ALL SEDIMENT AND EROSION CONTROL MEASURES USED DURING CONSTRUCTION.

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

PROPOSED STORMWATER BMP RETROFITS

Designed By: RJW
Reviewed By: WFH JLP

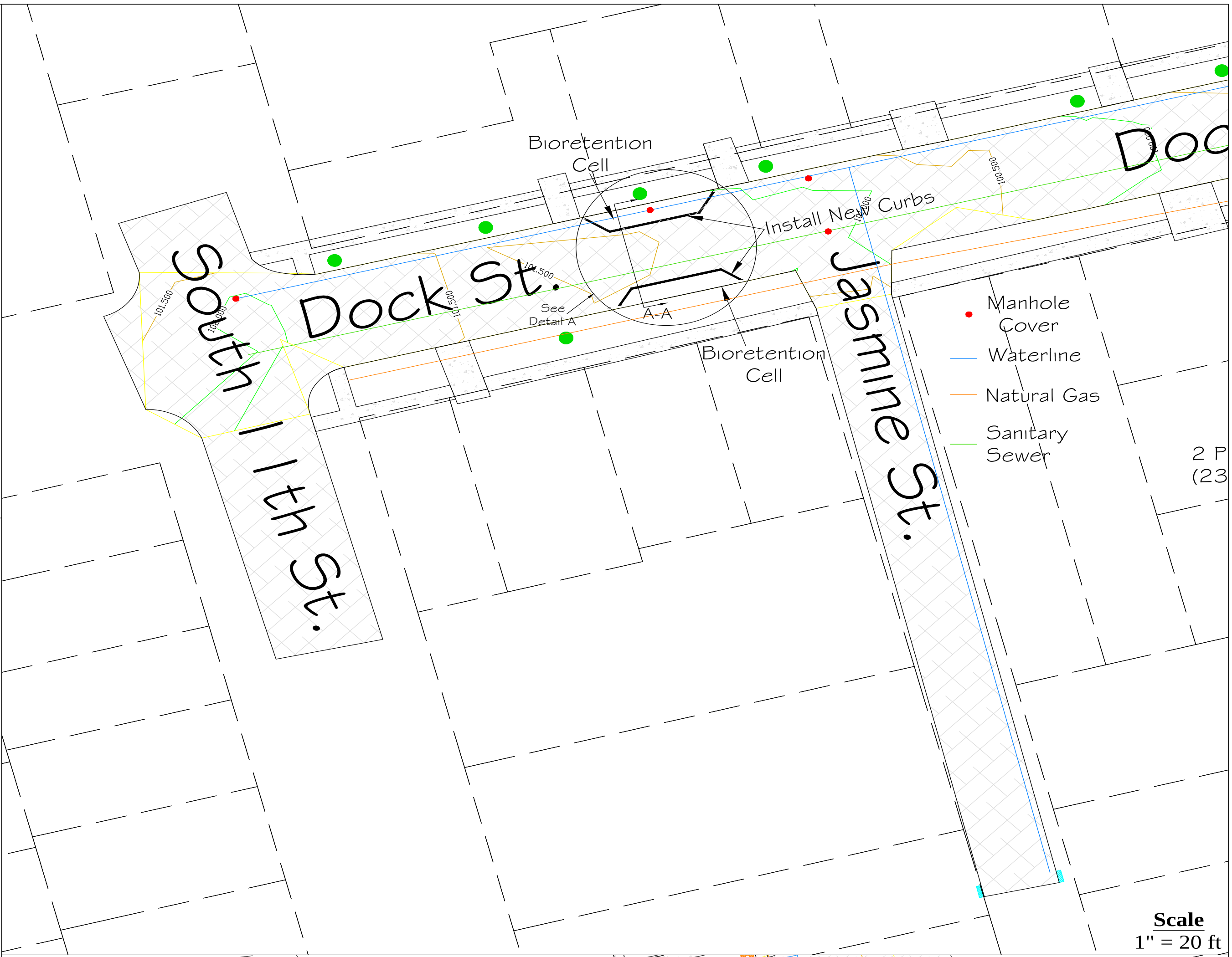
Date:
JANUARY 9, 2012

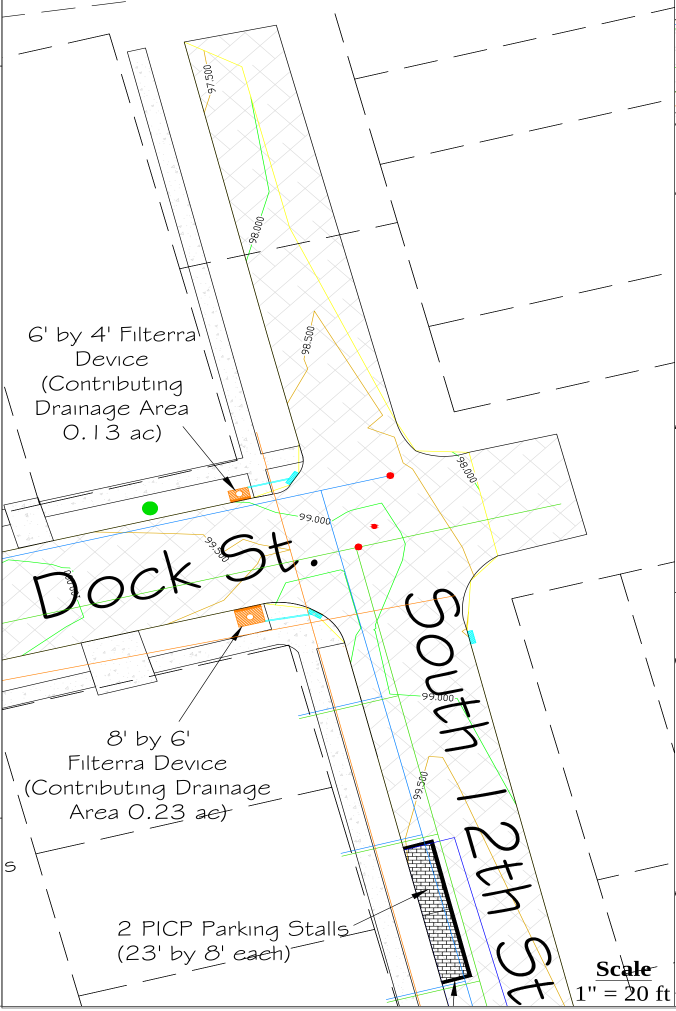
Scale:
As Noted

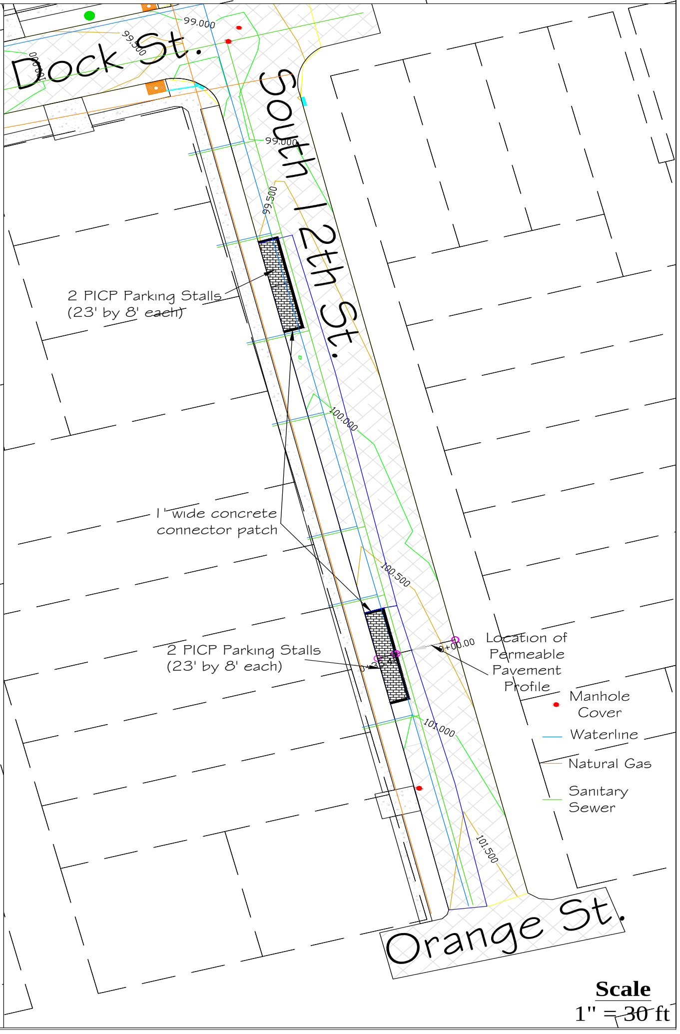
Wilmington Street Retrofits

Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

Page Number
3 of 8







North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

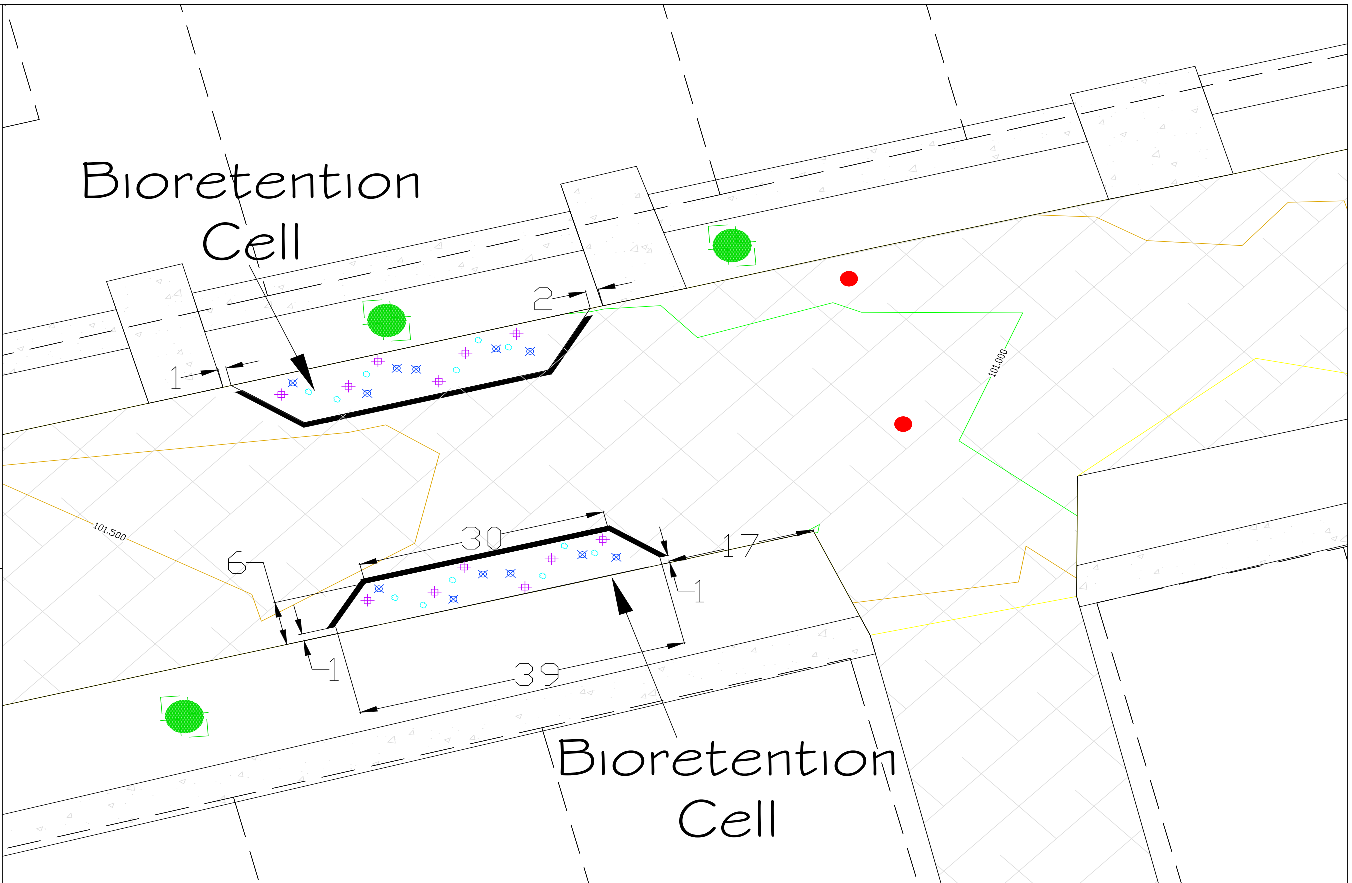
PLANTING PLAN & BUMP-OUT DETAILS

Designed By: RJW
Reviewed By: WFH JLP

Date:
JANUARY 9, 2012

Scale:
As Noted

Wilmington Street Retrofits
Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

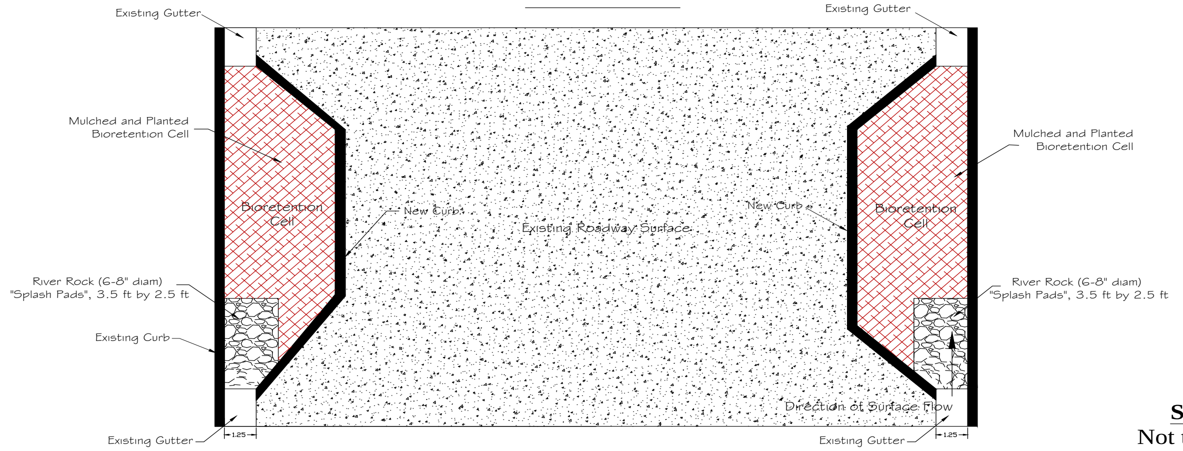


Legend	Scientific Name	Size	Number
Fringed Blue Star	Amsonia ciliata	3"-4" pot	12
Purple Milkweed	Asclepias cordifolia	3"-4" pot	12
Blue Flag Iris	Iris virginica shrevei	1 gal, 8"-12"	12

Scale
1" = 8 ft

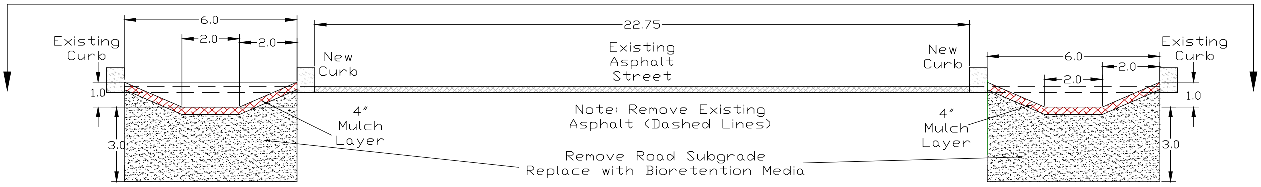
Detail A

Plan View

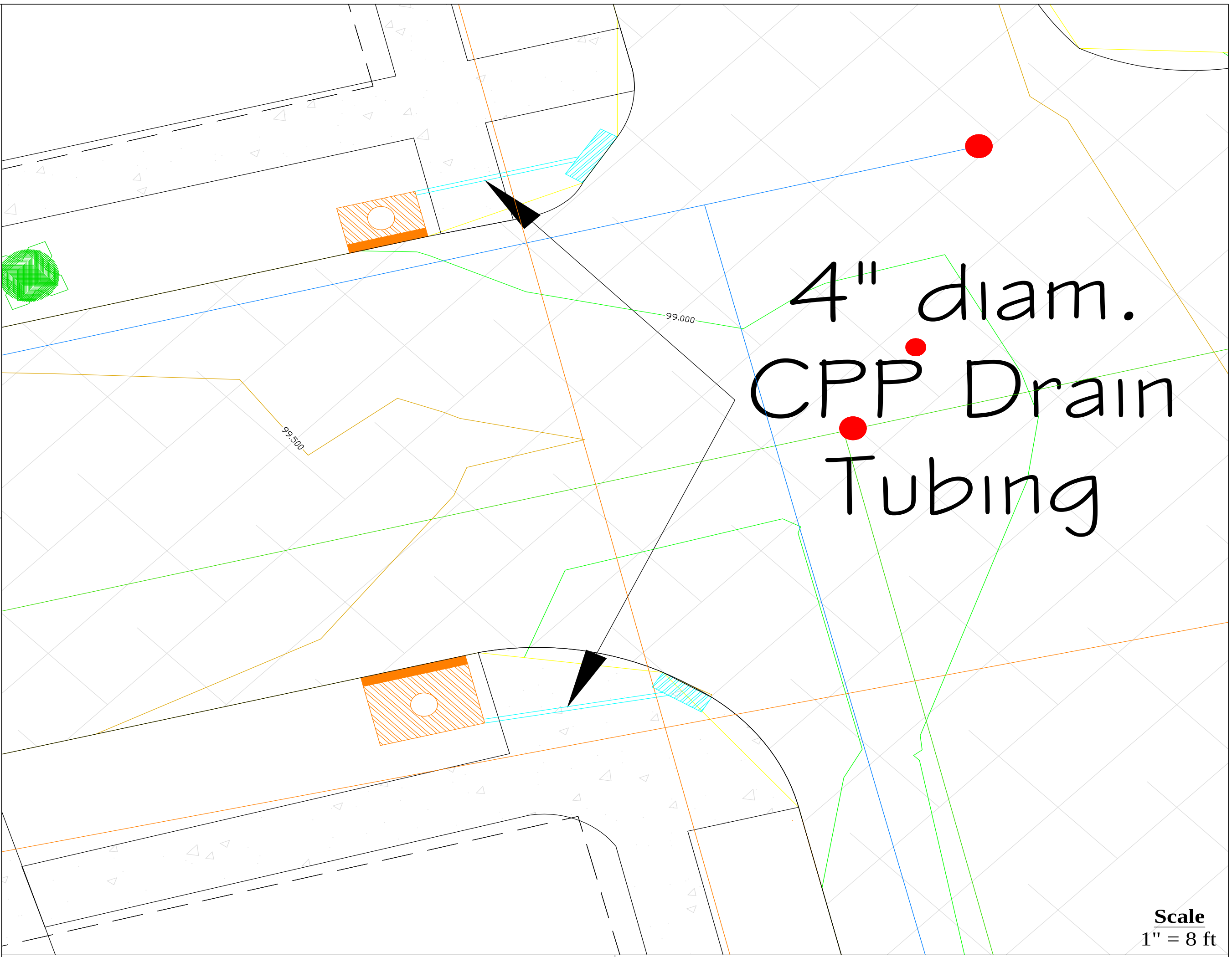


Scale
Not to Scale

Section A-A

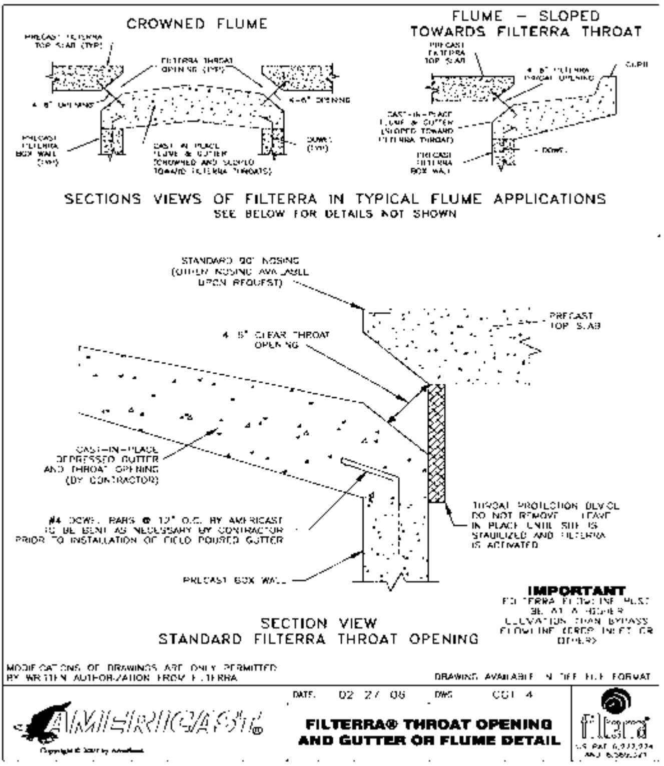


Scale
Not to Scale



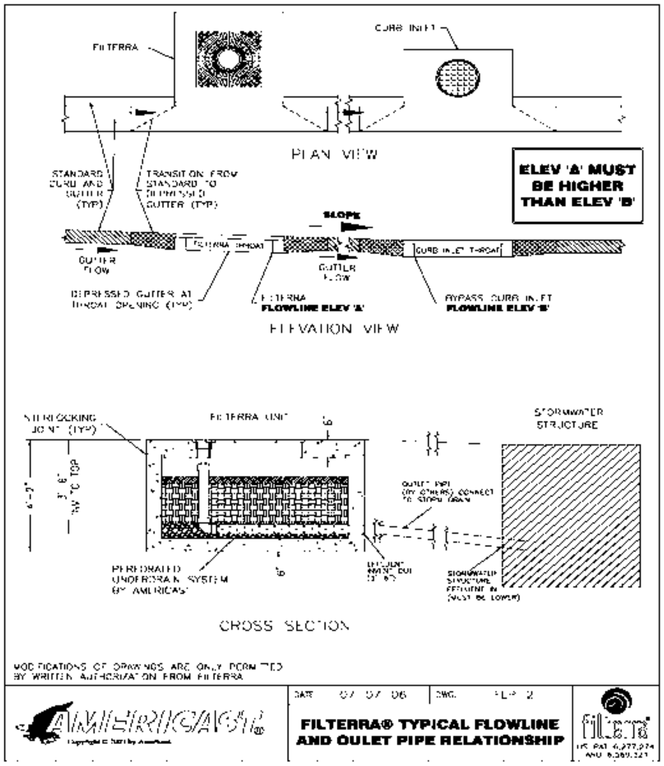
Scale
1" = 8 ft

Detail B



Scale
Not to Scale

Detail C



Scale
Not to Scale

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

FILTERRA PLANS AND DETAILS

Designed By: RJW
Reviewed By: WFH JLP

Date:
JANUARY 9, 2012

Scale:
As Noted

Wilmington Street Retrofits
Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

Page Number
5 of 8

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

FILTERRA DETAILS AND NOTES

Designed By: RJW
Reviewed By: WFH JLP

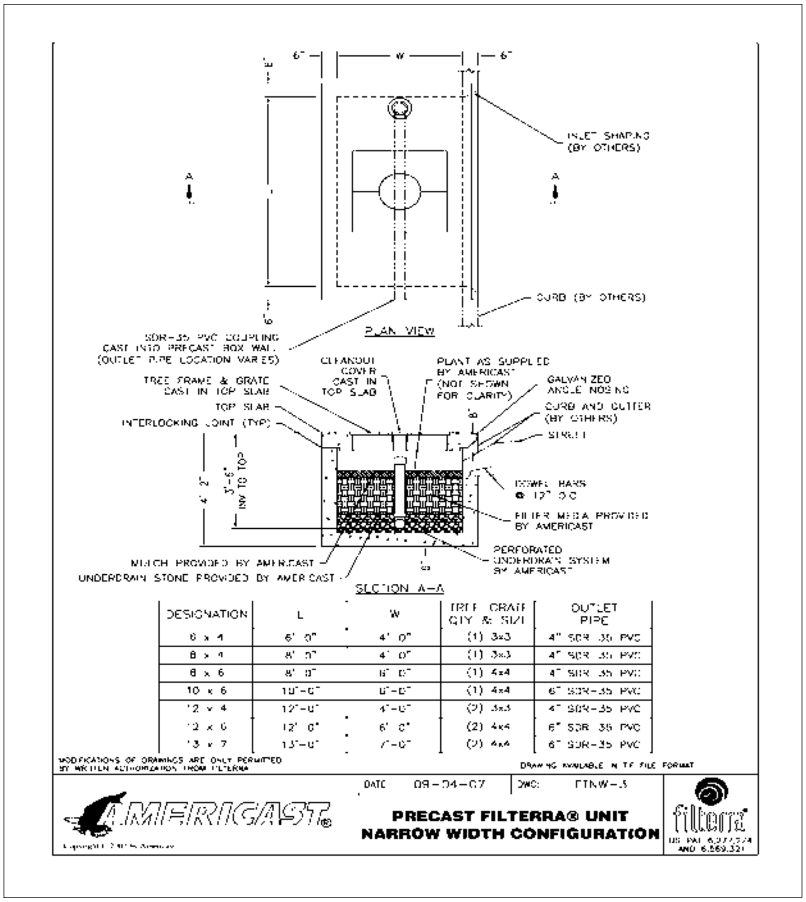
Date:
JANUARY 9, 2012

Scale:
Not to Scale

Wilmington Street Retrofits
Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

Page Number
6 of 8

Detail D



DESIGNATION	L	W	TREE GRATE QTY & SIZE	OUTLET PIPE
6 x 4	6'-0"	4'-0"	(1) 3x3	4" SDR-35 PVC
8 x 4	8'-0"	4'-0"	(1) 3x3	4" SDR-35 PVC
8 x 6	8'-0"	6'-0"	(1) 4x4	4" SDR-35 PVC
10 x 6	10'-0"	6'-0"	(1) 4x4	6" SDR-35 PVC
12 x 4	12'-0"	4'-0"	(2) 3x3	4" SDR-35 PVC
12 x 6	12'-0"	6'-0"	(2) 4x4	6" SDR-35 PVC
13 x 7	13'-0"	7'-0"	(2) 4x4	6" SDR-35 PVC

Detail E

filterra

Filterra Standard Plan Notes

Construction & Installation

A. Each unit shall be constructed at the locations and elevations according to the sizes shown on the approved drawings. Any modifications to the elevation or location shall be at the direction of and approved by the Engineer.

B. If the Filterra® is stored before installation, the top slab must be placed on the box using the 2x4 wood provided, to prevent any contamination from the site. All internal fittings supplied (if any), must be left in place as per the delivery.

C. The unit shall be placed on a compacted sub-grade with a minimum 6-inch gravel base matching the final grade of the curb line in the area of the unit. The unit to be placed such that the unit and top slab match the grade of the curb in the area of the unit. Compact undisturbed sub-grade materials to 95% of maximum density at +1- 2% of optimum moisture. Unsuitable material below sub-grade shall be replaced to the site engineer's approval.

D. Outlet connections shall be aligned and sealed to meet the approved drawings with modifications necessary to meet site conditions and local regulations.

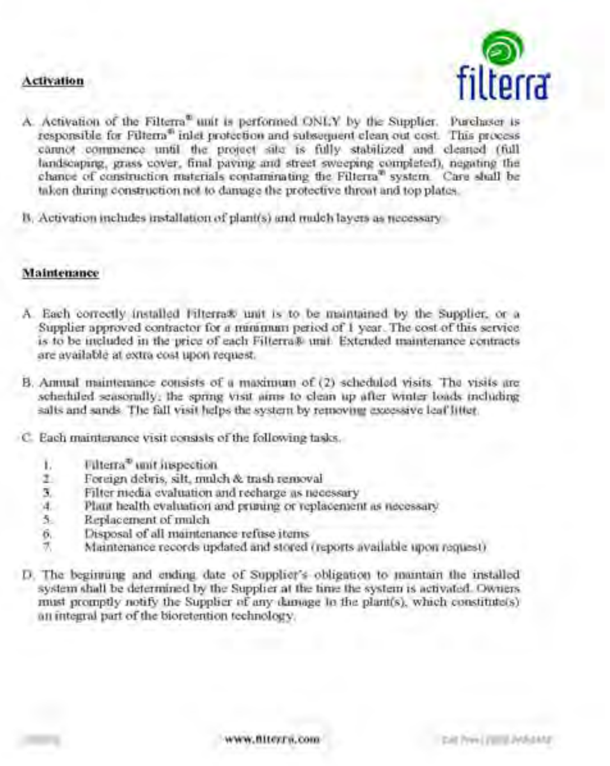
E. Once the unit is set, the internal wooden forms and protective mesh cover must be left intact. Remove only the temporary wooden shipping blocks between the box and top slab. The top lid should be sealed onto the box section before backfilling, using a non-shrink grout, butyl rubber or similar waterproof seal. The boards on top of the lid and boards sealed in the unit's throat must **NOT** be removed. The Supplier (Americast or its authorized dealer) will remove these sections at the time of activation. Backfilling should be performed in a careful manner, bringing the appropriate fill material up in 6" lifts on all sides. Precast sections shall be set in a manner that will result in a watertight joint. In all instances, installation of Filterra® unit shall conform to ASTM specification C891 "Standard Practice for Installation of Underground Precast Utility Structures", unless directed otherwise in contract documents.

F. Curb and gutter construction (where present) shall ensure that the flow-line of the Filterra® units is at a greater elevation than the flow-line of the bypass structure or relief (drop inlet, curb cut or similar). Failure to comply with this guideline may cause failure and/or damage to the Filterra® environmental device.

G. Each Filterra® unit must receive adequate irrigation to ensure survival of the living system during periods of drier weather. This may be achieved through gutter flow or through the tree grate.

www.filterra.com

Detail F



filterra

Activation

A. Activation of the Filterra® unit is performed ONLY by the Supplier. Purchaser is responsible for Filterra® inlet protection and subsequent clean out cost. This process cannot commence until the project site is fully stabilized and cleaned (full landscaping, grass cover, final paving and street sweeping completed), negating the chance of construction materials contaminating the Filterra® system. Care shall be taken during construction not to damage the protective throat and top plates.

B. Activation includes installation of plant(s) and mulch layers as necessary.

Maintenance

A. Each correctly installed Filterra® unit is to be maintained by the Supplier, or a Supplier approved contractor for a minimum period of 1 year. The cost of this service is to be included in the price of each Filterra® unit. Extended maintenance contracts are available at extra cost upon request.

B. Annual maintenance consists of a maximum of (2) scheduled visits. The visits are scheduled seasonally; the spring visit aims to clean up after winter loads including salts and sands. The fall visit helps the system by removing excessive leaf litter.

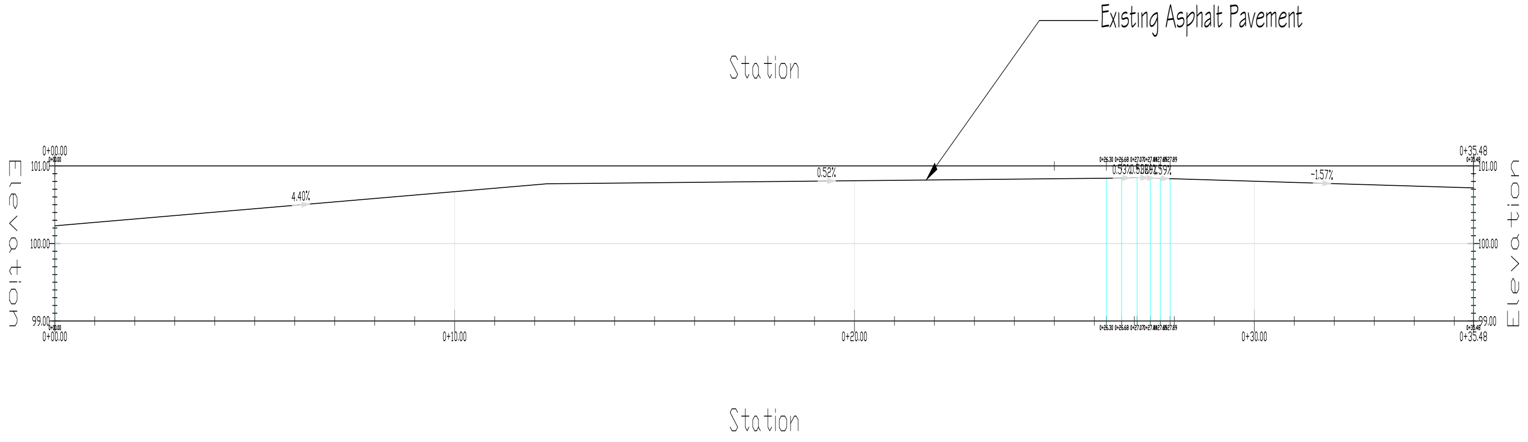
C. Each maintenance visit consists of the following tasks.

1. Filterra® unit inspection
2. Foreign debris, silt, mulch & trash removal
3. Filter media evaluation and recharge as necessary
4. Plant health evaluation and pruning or replacement as necessary
5. Replacement of mulch
6. Disposal of all maintenance refuse items
7. Maintenance records updated and stored (reports available upon request)

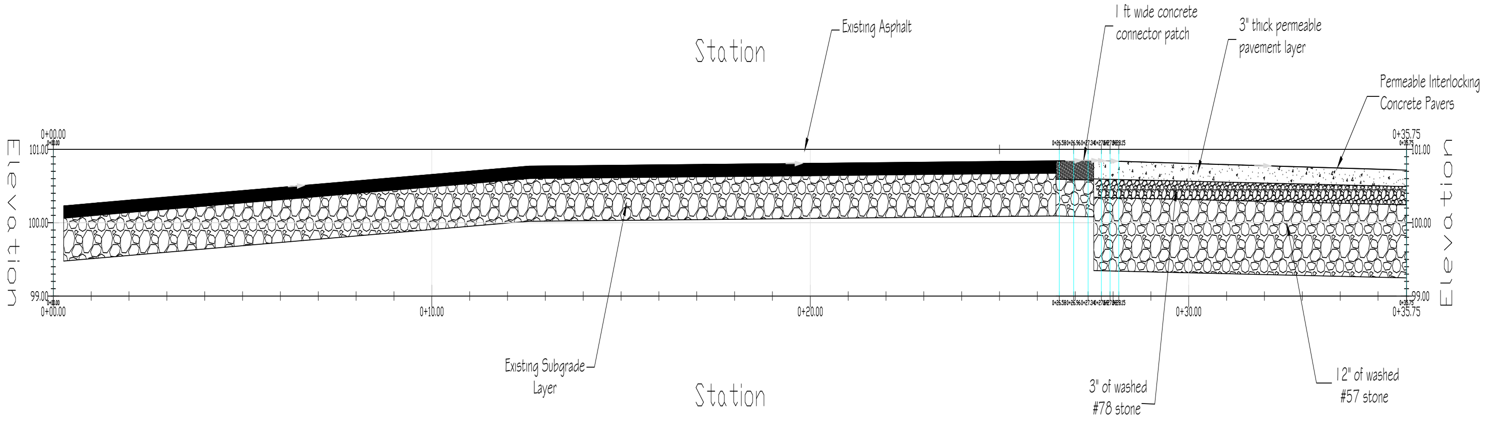
D. The beginning and ending date of Supplier's obligation to maintain the installed system shall be determined by the Supplier at the time the system is activated. Owners must promptly notify the Supplier of any damage to the plant(s), which constitute(s) an integral part of the bioretention technology.

www.filterra.com

Existing Pavement Profile



Proposed Pavement Profile



North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

PERMEABLE PAVEMENT DETAILS

Designed By: RJW
Reviewed By: WFH JLP

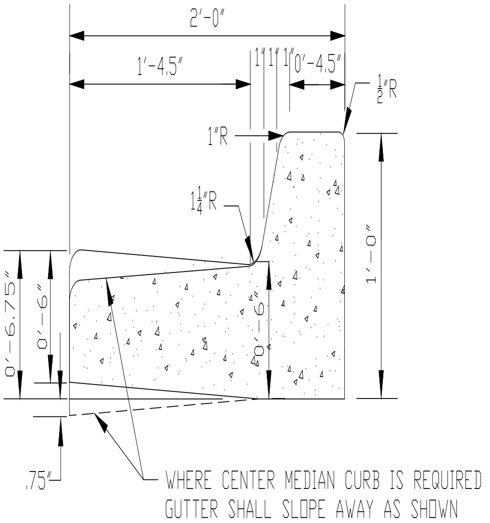
Date:
JANUARY 9, 2012

Scale:
Not Standard

Wilmington Street Retrofits
Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

Page Number
7 of 8

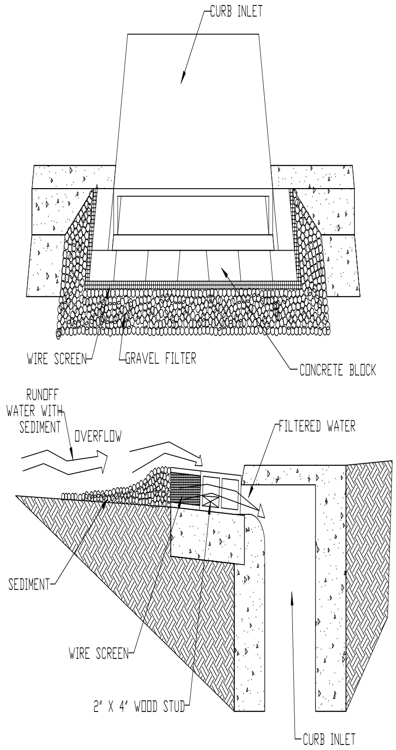
Detail G



STANDARD CURB SECTION TYPE "A"

SD 7-01

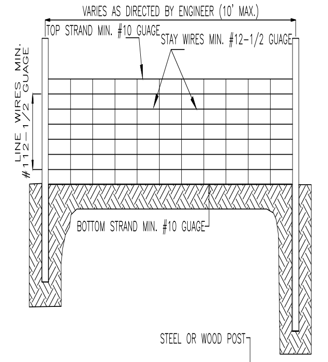
Detail H

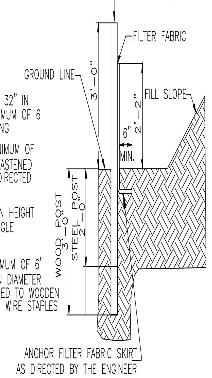


CURB INLET PROTECTION

SD 13-02

Detail I





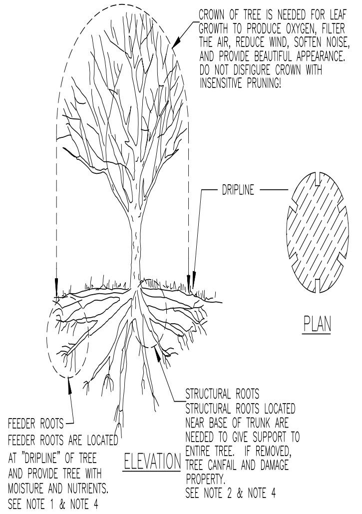
NOTES:

1. WIRE SHALL BE A MINIMUM OF 32" IN WIDTH AND SHALL HAVE A MINIMUM OF 6 LINE WIRES W/12" STAY SPACING
2. FILTER FABRIC SHALL BE A MINIMUM OF 36" IN WIDTH AND SHALL BE FASTENED ADEQUATELY TO THE WIRE AS DIRECTED BY THE ENGINEER
3. STEEL POSS SHALL BE 5' 0" IN HEIGHT AND BE OF SELF FASTENER ANGLE STEEL TYPE
4. WOOD POSTS SHALL BE A MINIMUM OF 6' IN HEIGHT AND 3" OR MORE IN DIAMETER WIRE FABRIC SHALL BE FASTENED TO WOODEN POST WITH NOT LESS THAN #9 WIRE STAPLES 1-1/2" LONG

GUIDELINES FOR TEMPORARY SILT FENCE DETAIL

SD 13-01

Detail J



TREE PROTECTION DURING CONSTRUCTION

1. DO NOT COMPACT SOIL BENEATH TREES. NO VEHICLE SHALL BE ALLOWED TO PARK UNDER TREES. NO HEAVY MATERIALS SHALL BE STORED BENEATH TREES. RESULTS OF COMPACTION CAUSE WATER AND AIR NOT TO REACH THE ROOTS AND THE TREE WILL DIE. THESE "FEEDING ROOTS" OCCUR WELL AWAY FROM THE BASE OF THE TREE TO THE EDGE OF THE OVERHEAD BRANCH CANOPY. DAMAGING THE BARK WITH LAWNMOWERS, CONSTRUCTION EQUIPMENT, OR ANYTHING ELSE IS PROHIBITED. APROTECTIVE BARRIER SHOULD PREVENT DAMAGE FROM OCCURING DURING CONSTRUCTION.
2. NO CUTTING OF LARGE STRUCTURAL ROOTS LOCATED NEAR THE BASE OF THE TRUNK. THESE ARE ESSENTIAL IN SUPPORTING THE TREE AND HOLDING IT UPRIGHT IN HIGH WINDS. REMOVAL OF THESE ROOTS ALONG ONE SIDE IS OFTEN DONE BECAUSE OF A WALK, PAVING OR BUILDING WHICH IS BEING CONSTRUCTED.
3. AVOID CUT AND FILL WITHIN DIAMETER OF TREE CROWN DURING EXCAVATION.

METHOD OF TREE PROTECTION DURING CONSTRUCTION

SD 15-09

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

CITY OF WILMINGTON DETAILS

Designed By: RJW
Reviewed By: WFH JLP

Date:
JANUARY 9, 2012

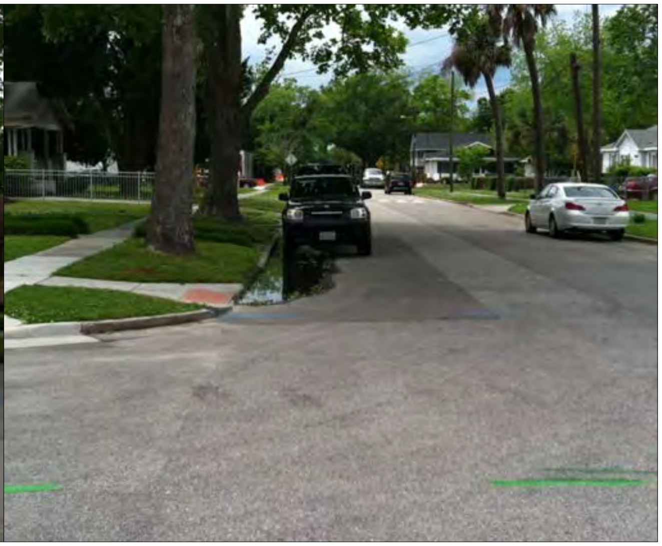
Scale:
Not Standard

Wilmington Street Retrofits
Dock St., Jasmine St., and 12th St.
Wilmington, NC 28401

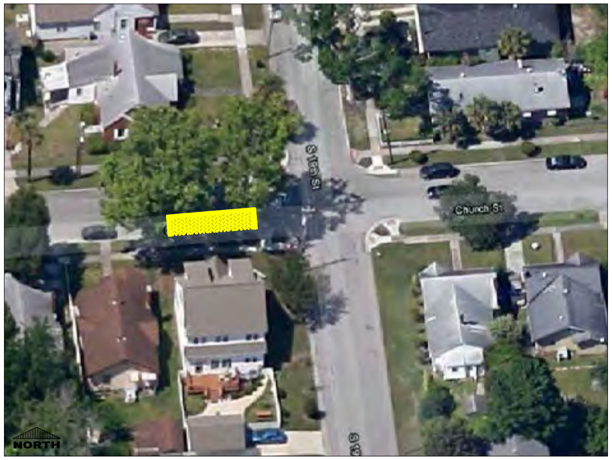
Page Number
8 of 8

Wilmington
Permeable Pavement Retrofit
Church Street and 19th Street
Wilmington, NC 28401

19th Street Looking South



Church Street Looking West



Location of Proposed
Permeable Pavement Retrofit

Sheet Index

Sheet 1: Cover & Sheet Index
Sheet 2: Existing Conditions
Sheet 3: Proposed Retrofit
Sheet 4: Details

Prepared by:
Jonathan L Page, EI
NC State University
Campus Box 7625
Raleigh, NC 27695
(919) 515-8595
jlpage3@ncsu.edu

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

TITLE PAGE

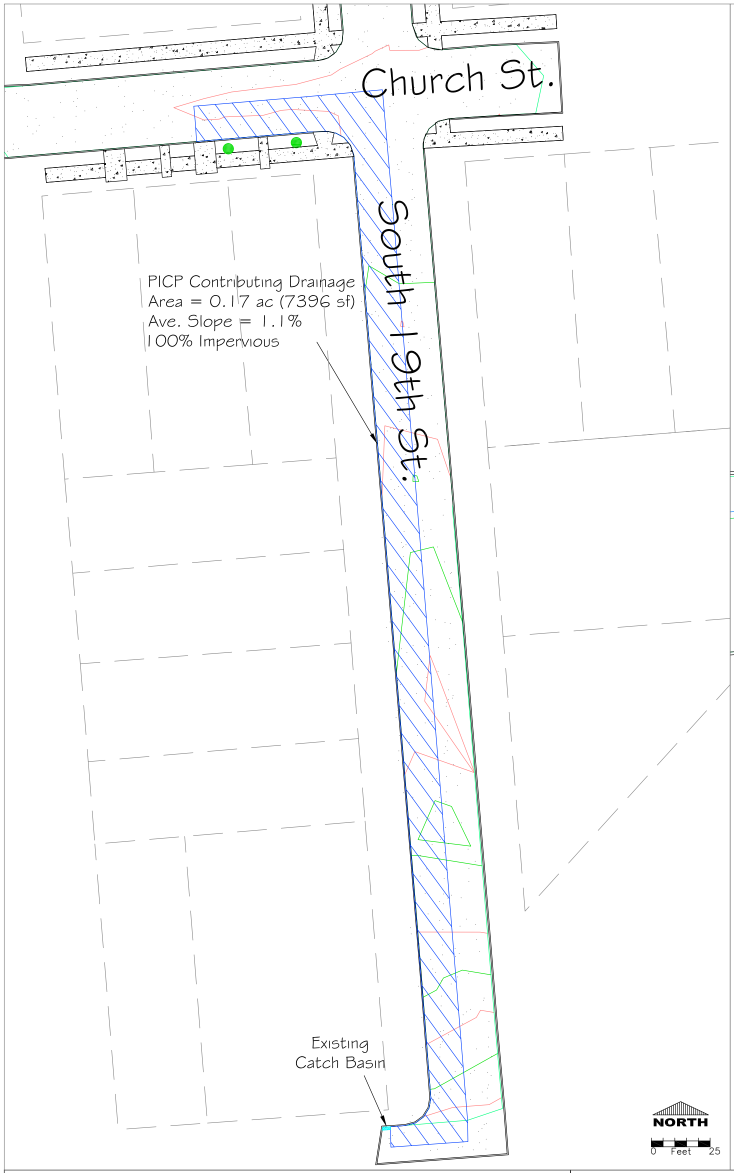
Designed By: JLP
Reviewed By: RJW

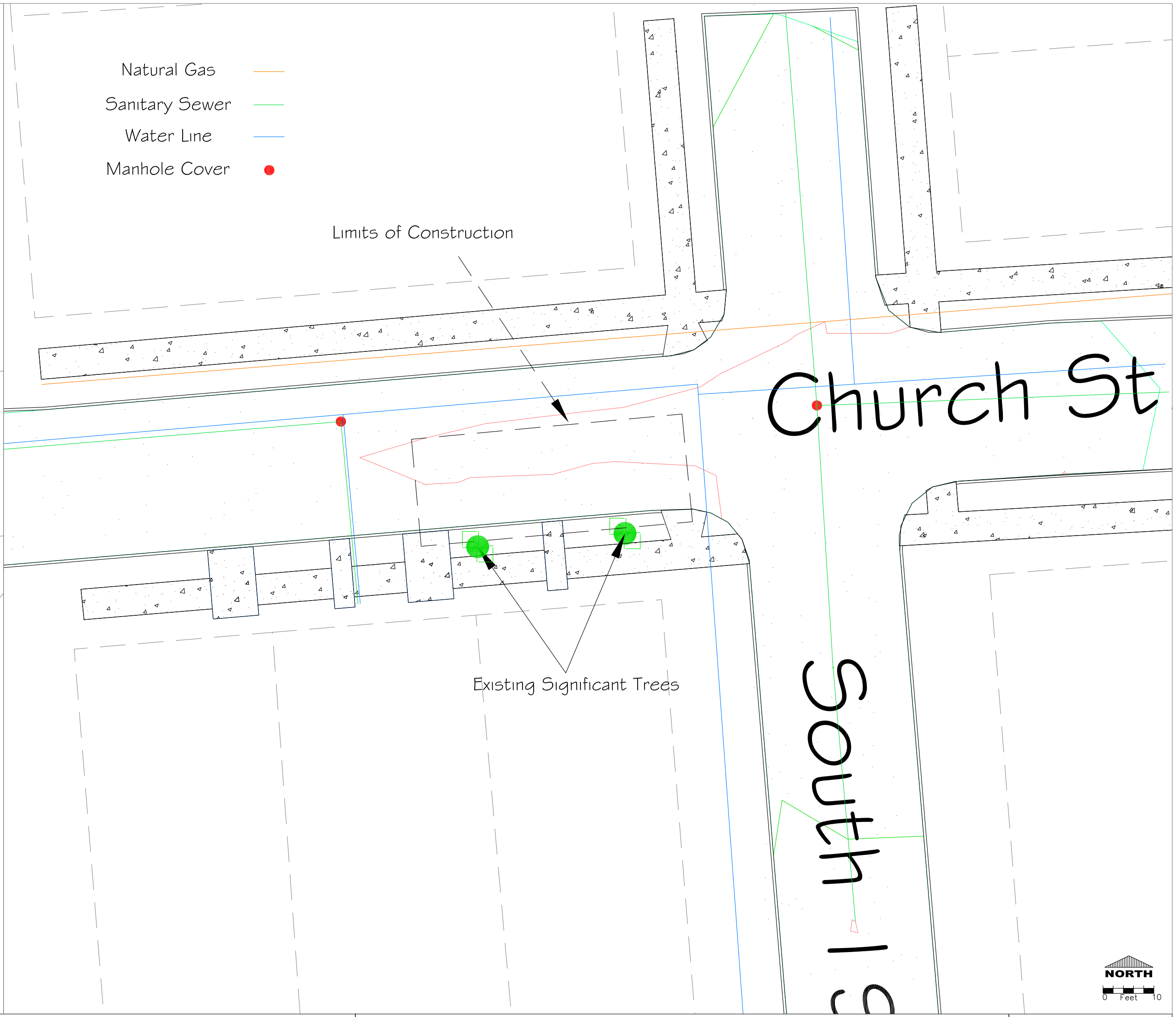
Date:
MAY 24, 2013

Scale:
AS NOTED

Wilmington Permeable Pavement Retrofit
Church St and 19th St
Wilmington, NC 28401

Page:
1 of 4





North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

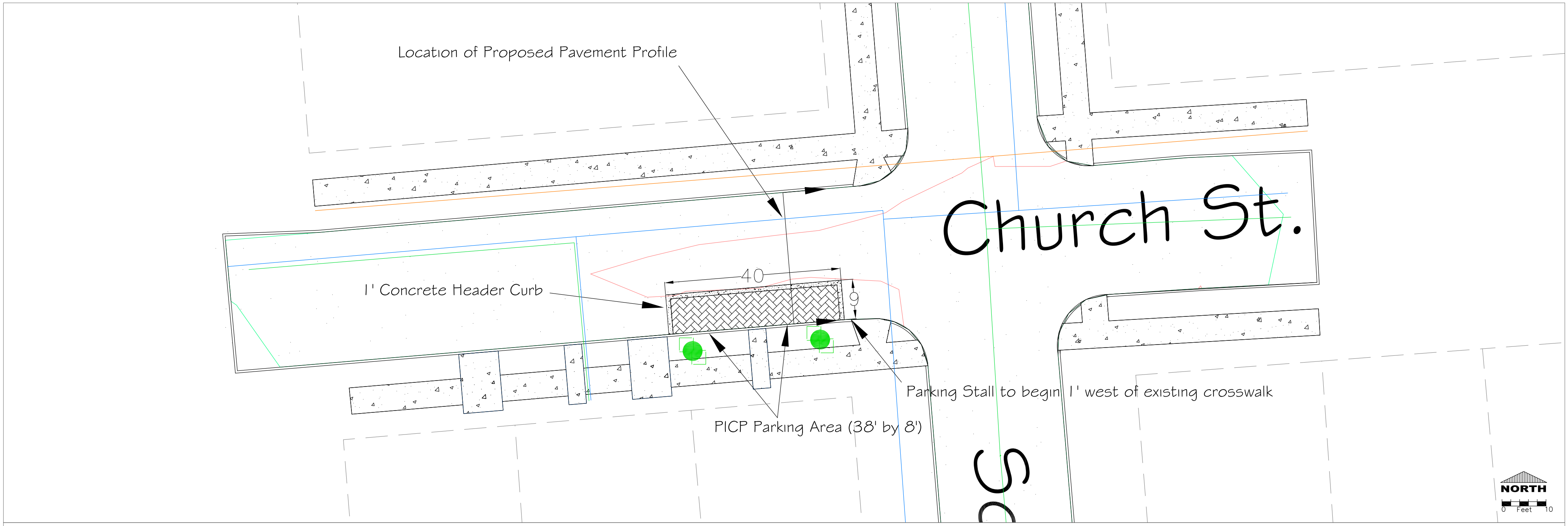
EXISTING CONDITIONS

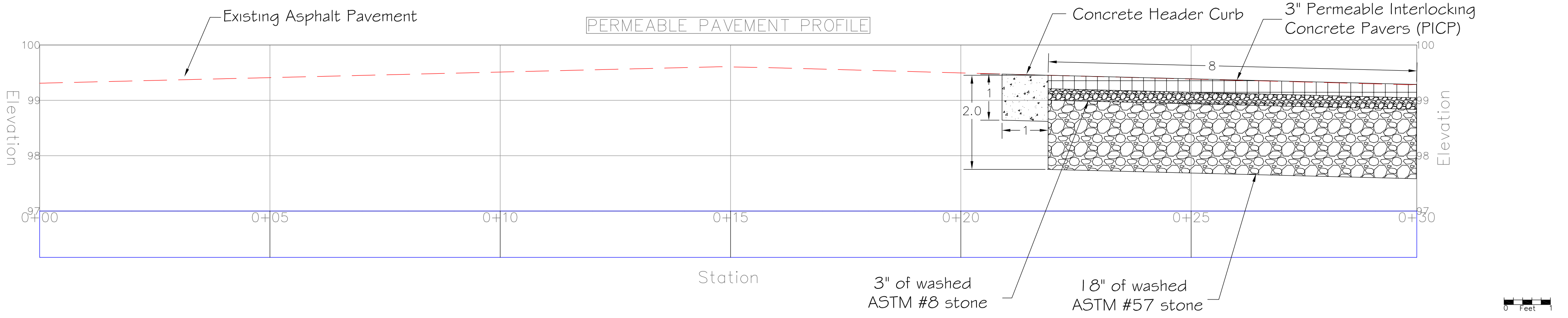
Designed By: JLP
Reviewed By: RJW

Date:
MAY 24, 2013

Scale:
AS NOTED

Wilmington Permeable Pavement Retrofit
Church St and 19th St
Wilmington, NC 28401





North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

PROPOSED PERMEABLE PAVEMENT

Designed By: JLP
Reviewed By: RJW

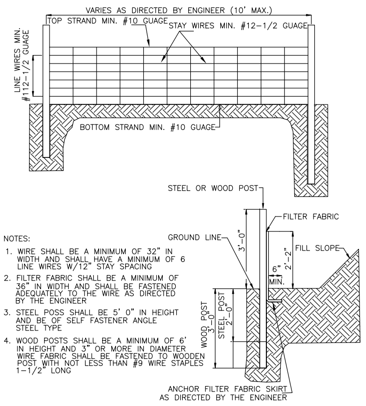
Date:
MAY 24, 2013

Scale:
AS NOTED

Wilmington Permeable Pavement Retrofit
Church St and 19th St
Wilmington, NC 28401

Page:
3 of 4

DETAIL A

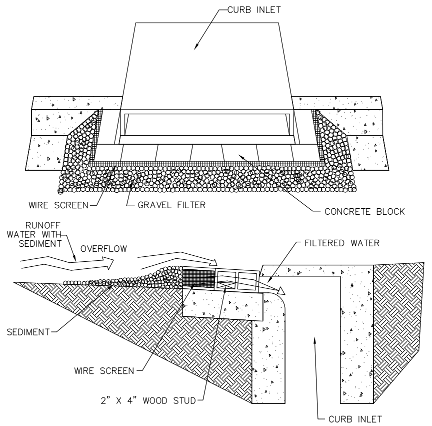


NOTES:

1. WIRE SHALL BE A MINIMUM OF 32" IN WIDTH AND SHALL HAVE A MINIMUM OF 6 LINE WIRES W/12" STAY SPACING
2. FILTER FABRIC SHALL BE A MINIMUM OF 36" IN WIDTH AND SHALL BE FASTENED ADEQUATELY TO THE WIRE AS DIRECTED BY THE ENGINEER
3. STEEL POSS SHALL BE 5' 0" IN HEIGHT AND BE OF SELF FASTENER ANGLE STEEL TYPE
4. WOOD POSTS SHALL BE A MINIMUM OF 6' IN HEIGHT AND 3" OR MORE IN DIAMETER WIRE FABRIC SHALL BE FASTENED TO WOODEN POST WITH NOT LESS THAN #9 WIRE STAPLES 1-1/2" LONG

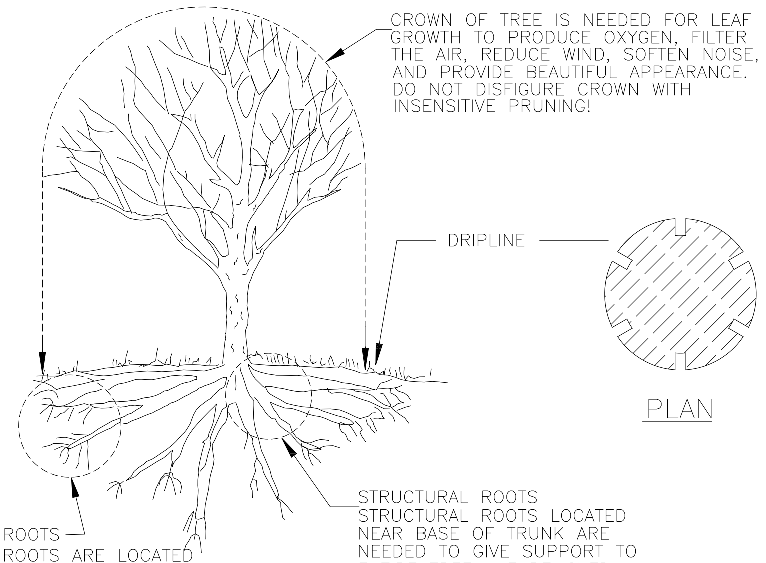
GUIDELINES FOR TEMPORARY SILT FENCE DETAIL
SD 13-01

DETAIL B



CURB INLET PROTECTION
SD 13-02

DETAIL C



CROWN OF TREE IS NEEDED FOR LEAF GROWTH TO PRODUCE OXYGEN, FILTER THE AIR, REDUCE WIND, SOFTEN NOISE, AND PROVIDE BEAUTIFUL APPEARANCE. DO NOT DISFIGURE CROWN WITH INSENSITIVE PRUNING!

FEEDER ROOTS
FEEDER ROOTS ARE LOCATED AT "DRIPLINE" OF TREE AND PROVIDE TREE WITH MOISTURE AND NUTRIENTS.
SEE NOTE 1 & NOTE 4

STRUCTURAL ROOTS
STRUCTURAL ROOTS LOCATED NEAR BASE OF TRUNK ARE NEEDED TO GIVE SUPPORT TO ENTIRE TREE. IF REMOVED, TREE CANFAIL AND DAMAGE PROPERTY.
SEE NOTE 2 & NOTE 4

TREE PROTECTION DURING CONSTRUCTION

1. DO NOT COMPACT SOIL BENEATH TREES. NO VEHICLE SHALL BE ALLOWED TO PARK UNDER TREES. NO HEAVY MATERIALS SHALL BE STORED BENEATH TREES. RESULTS OF COMPACTION CAUSE WATER AND AIR NOT TO REACH THE ROOTS AND THE TREE WILL DIE. THESE "FEEDING ROOTS" OCCUR WELL AWAY FROM THE BASE OF THE TREE TO THE EDGE OF THE OVERHEAD BRANCH CANOPY. DAMAGING THE BARK WITH LAWNMOWERS, CONSTRUCTION EQUIPMENT, OR ANYTHING ELSE IS PROHIBITED. APROTECTIVE BARRIER SHOULD PREVENT DAMAGE FROM OCCURING DURING CONSTRUCTION.
2. NO CUTTING OF LARGE STRUCTURAL ROOTS LOCATED NEAR THE BASE OF THE TRUNK. THESE ARE ESSENTIAL IN SUPPORTING THE TREE AND HOLDING IT UPRIGHT IN HIGH WINDS. REMOVAL OF THESE ROOTS ALONG ONE SIDE IS OFTEN DONE BECAUSE OF A WALK, PAVING OR BUILDING WHICH IS BEING CONSTRUCTED.
3. AVOID CUT AND FILL WITHIN DIAMETER OF TREE CROWN DURING EXCAVATION.

METHOD OF TREE PROTECTION DURING CONSTRUCTION
SD 15-09

North Carolina State University
Biological and Agricultural Engineering
NCSU Box 7625 | Raleigh, N.C. 27695

DETAILS

Designed By: JLP
Reviewed By: RJW

Date:
MAY 24, 2013

NOT TO SCALE

Wilmington Permeable Pavement Retrofit
Church St and 19th St
Wilmington, NC 28401

SAFER, GREENER STREETS:
IMPROVING
10TH, ANN & DOCK STREETS

STREETSIDE RAIN GARDENS ARE PLANNED FOR YOUR NEIGHBORHOOD!
TELL US WHAT YOU THINK! GET INVOLVED!

Thursday, May 5

6:30– 8:00 p.m.

Williston Middle School

10th Street (in the Media Center)

Learn how raingardens
- increase pedestrian safety
- Increase cyclist safety
- reduce pollution
- reduce street flooding

Provide feedback on plants for the gardens

Enjoy dessert, snacks and fellowship

Project locations:
- Corner of 10th & Ann Street
- Dock Street, between 12th & Jasmine
- 12th Street, just north of Dock St.

Sponsored by:
- North Carolina State University
- City of Wilmington
- Cape Fear River Watch
- Williston Middle & Gregory Elementary
- B+O Design
- US Environmental Protection Agency (EPA)
- NC Division of Water Quality
- NC Cooperative Extension

JOIN US ON THURSDAY, MAY 5 TO HELP MAKE YOUR STREETS SAFER, HEALTHIER, AND MORE BEAUTIFUL!

STREET IMPROVEMENT PROJECTS:
SAFER, GREENER STREETS

CITY OF WILMINGTON
STORMWATER SERVICES

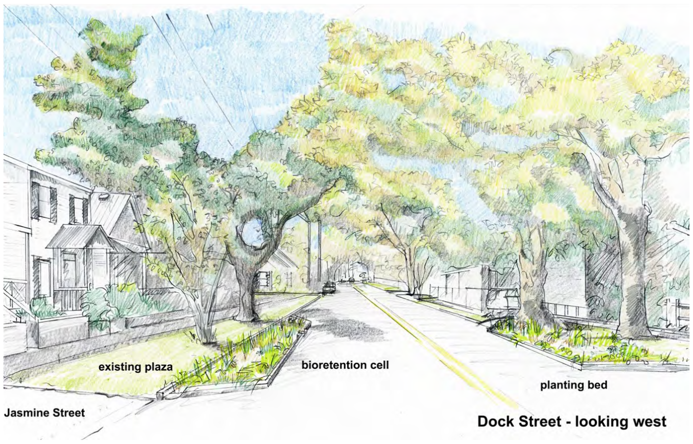
STREETSIDE RAIN GARDENS AND PERVIOUS PAVEMENT ARE PLANNED FOR THE NEIGHBORHOOD

The City of Wilmington and NC State University have a grant to create streetside raingardens and other practices to:

- increase pedestrian safety
- reduce polluted runoff
- reduce street flooding

Raingardens (also called bioretention) temporarily hold and filter stormwater runoff (the rainwater that flows off streets, driveways, and roofs) to remove pollutants and reduce flooding. Streetside raingardens will bump out from curbs mid-block on Dock Street. The bump outs will also help reduce speeding.

Other pollution-reducing practices will be installed on S. 12th Street, reducing the stormwater that reaches Dock Street after storms. NC State is monitoring pollution in stormwater running off the streets before and after the project is constructed. Boxes are visible where the monitoring equipment is installed.



Dock Street - looking west

Construction is planned for February 2012 and is expected to last 4-6 weeks. Please contact us to learn about opportunities to help plant and maintain the gardens, or if you have any questions about this project.

Sponsored by:

- NC Cooperative Extension
- City of Wilmington
- Cape Fear River Watch
- B+O Design
- US Environmental Protection Agency (EPA)
- NC Division of Water Quality, NCDENR
- NC Clean Water Management Trust Fund
- North Carolina State University

Christy Perrin, NC State University:	christy_perrin@ncsu.edu	919-515-4542
Dave Mayes, City of Wilmington:	dave.mayes@wilmingtonnc.gov	919-343-4777

GREEN STREET PROJECT - LOCATION MAP

Construction will begin in early February and is expected to last 4 to 6 weeks.
Periodic lane or road closures will occur on Dock and 12th Streets.

CITY OF WILMINGTON
STORMWATER SERVICES

PROJECT NOTICE

Intersections of:
10th & Ann Street
10th & Orange Street

This notice is to inform you that construction is scheduled to occur approximately mid-June to mid-July to install stormwater management measures at the intersections of 10th & Ann Street and 10th & Orange Street.

These measures include Silva Tree Cells, which are essentially underground temporary water storage devices, that allow stormwater to be absorbed and filtered naturally by soil and tree roots. Added benefits include reduced flooding in the area and neighborhood beautification by tree planting.

This project is a grant collaboration between the City and NC State to improve the water quality in Burnt Mill Creek. Future stormwater installations in this neighborhood will include biorention areas. All of these measures will benefit Burnt Mill Creek (BMC), which is one of the most polluted creeks in Wilmington. BMC ultimately drains into the Cape Fear River.

Please observe posted construction signage and crews working in the area. The city appreciates your patience and regrets any inconvenience while improvements are being made.

For more info, please contact Stormwater Services at 910.343.4777

CITY OF WILMINGTON
STORMWATER SERVICES

PROJECT NOTICE

Intersections of:
10th & Ann Street
10th & Orange Street

This notice is to inform you that construction is scheduled to occur approximately mid-June to mid-July to install stormwater management measures at the intersections of 10th & Ann Street and 10th & Orange Street.

These measures include Silva Tree Cells, which are essentially underground temporary water storage devices, that allow stormwater to be absorbed and filtered naturally by soil and tree roots. Added benefits include reduced flooding in the area and neighborhood beautification by tree planting.

This project is a grant collaboration between the City and NC State to improve the water quality in Burnt Mill Creek. Future stormwater installations in this neighborhood will include biorention areas. All of these measures will benefit Burnt Mill Creek (BMC), which is one of the most polluted creeks in Wilmington. BMC ultimately drains into the Cape Fear River.

Please observe posted construction signage and crews working in the area. The city appreciates your patience and regrets any inconvenience while improvements are being made.

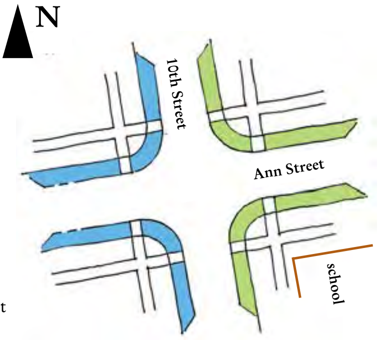
For more info, please contact Stormwater Services at 910.343.4777

Wilmington Intersection Retrofits

May 5, 2011 Community Workshop

Planting Options

This intersection features two types of planting areas - bioretention cells and simple planting beds. Bioretention cells (aka “rain gardens”) are designed to temporarily hold and filter stormwater runoff in order to remove pollutants. They can support plants that are adapted to brief inundation and some drought. The planting beds are included to balance the appearance of the intersection, and can support plants that are considered ‘low-maintenance.’ Plants larger than 3’ in height are not permitted in close proximity to intersections for safety reasons. We have selected native plants for all areas. Native plants are “species that occur naturally in an area, having not been introduced by human action. Over time, they have evolved with the physical and biological factors specific to their region, such as climate, soil, rainfall, and interactions with other plants, animals, and insects that live in the area. Thus, they are uniquely adapted to the local conditions and the area’s wildlife, including important pollinators and migratory birds.” - NC Native Plant Society.



bioretention A

mostly perennials, some grass-like species
- fewer plants visible during winter months
- more colorful during warm months


source: prairiemoon.com

asclepias purpurascens
purple milkweed
spring


source: tva.gov

amsonia tabernaemontana
bluestar
spring


source: rook.org

iris virginica
blue flag
spring


source: wildflower.org

coreopsis lanceolata
lanceleaf tickseed
spring/summer


source: b+o

lobelia cardinalis
cardinalflower
spring/summer


source: nrcs.gov

phlox carolina
carolina phlox
spring


source: ncsu.edu

baptisia x ‘purple smoke’
false indigo
spring/summer


source: ncsu.edu

schizachyrium scoparium
little bluestem
all year


source: we-du.com

solidago rugosa
goldenrod
fall

Ann Street

planting bed 1

mostly perennials, some grass-like species
- fewer plants visible during winter months
- more colorful during warm months


source: mellowmarshfarm.com

asclepias tuberosa
butterflyweed
spring/summer


source: sunlightgardens.com

oenothera tetragona
sundrops
spring/summer/fall


source: ces.ncsu.edu

verbena canadensis
verbena
spring/summer/fall


source: b+o

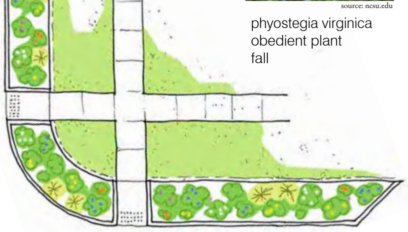
conoclinium coelestinum
blue mistflower
summer/fall


source: ncsu.edu

phyostegia virginica
obedient plant
fall


source:b+o

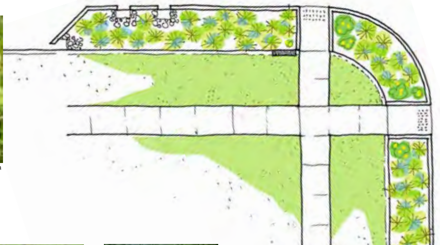
muhlenbergia capillaris
muhly grass
all year



0' 4' 8'
approximate scale


source: mellowmarshfarm

carex intumescens
greater bladder sedge
all year




source: usda.gov

juncus effusus
common rush
all year


source: mobot.org

rudbeckia fulgida
orange coneflower
summer/fall


source: ncsu.edu

schizachyrium scoparium
little bluestem
all year

bioretention B

mostly grass-like species, some perennials
- more visible during winter months
- less colorful during warm months

10th Street


source: mobot.org

rudbeckia fulgida
orange coneflower
summer/fall


source: ncsu.edu

schizachyrium scoparium
little bluestem
all year


source: b+o

muhlenbergia capillaris
muhly grass
all year


source: clemson.edu

panicum virgatum
‘shenandoah’
panicgrass
all year

planting bed 2

mostly grass-like species, some perennials
- more visible during winter months
- less colorful during warm months

What do you think?

A for both bioretention areas	B for both bioretention areas	**A + B**
1 for both planting beds	2 for both planting beds	**1 + 2**
none of the above - equal mix of perennials + grasses		**thank you for your time!**

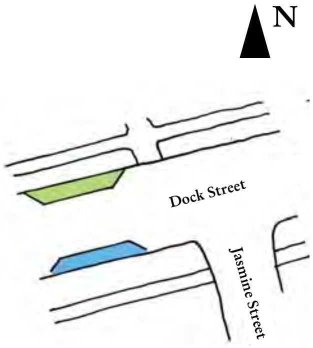
Planting Ideas for these WECO / NCSU BAE / City of Wilmington projects provided by:

B+O: design studio, PLLC
landscape architecture / architecture
205 Princess Street
Wilmington, NC 28401
www.b-and-o.net

Wilmington Street Retrofits

May 5, 2011 Community Workshop

Planting Options



The Dock Street retrofit features two types of planting areas - a bioretention cell and a simple planting bed. Bioretention cells (aka "rain gardens") are designed to temporarily hold and filter stormwater runoff in order to remove pollutants. They can support plants that are adapted to brief inundation and drought extremes. The planting bed is included to balance the appearance of the street, and can support plants that are considered 'low-maintenance.' This area is partially-shaded, so plant choices include some shade-tolerant species. We have selected native plants for all areas. Native plants are "species that occur naturally in an area, having not been introduced by human action. Over time, they have evolved with the physical and biological factors specific to their region, such as climate, soil, rainfall, and interactions with other plants, animals, and insects that live in the area. Thus, they are uniquely adapted to the local conditions and the area's wildlife, including important pollinators and migratory birds." - NC Native Plant Society.

planting bed 1

perennials + low shrubs

- fewer plants visible during winter months

- more colorful during warm months


source: ncsu.edu

aquilegia canadensis
red columbine
early spring


source: tva.gov

heuchera americana
alumroot
almost all year

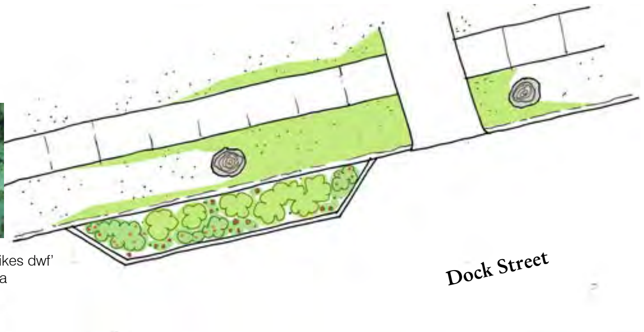

source: ncnps.org/tharville

spigelia marilandica
indian pink
spring/summer

3' shrub


source: b+o

hydrangea quercifolia'sikes dwf'
dwarf oakleaf hydrangea
spring/summer/fall




source: wildflower.org/wasowski

polystichum acrostichoides
christmas fern
all year


source: diversityoflife.org

osmunda cinnamomea
cinnamon fern
spring/summer/fall


source: vanderbilt.edu

chasmanthium latifolium
wood oats
all year

bioretention A

ferns + grasses only

- visible during winter months

- less colorful during warm months

---

planting bed 2

mostly ferns, some perennials

- more visible during winter months

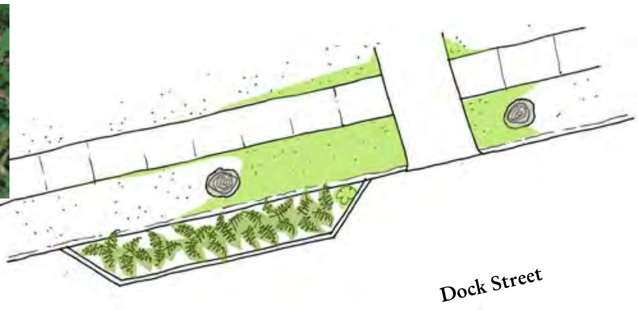
- less colorful during warm months


source: wildflower.org/wasowski

polystichum acrostichoides
christmas fern
all year


source: ncnps.org/tharville

eurybia divaricata
white wood aster
fall




source: vanderbilt.edu

chasmanthium latifolium
wood oats
all year


source: b+o

muhlenbergia capillaris
muhly grass
all year

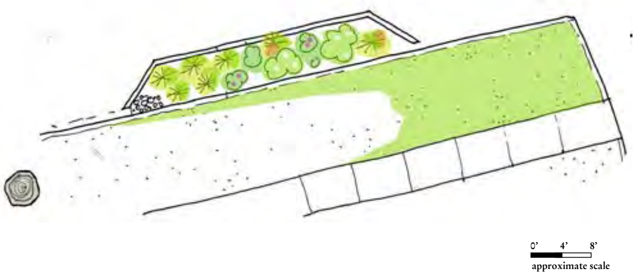

source: nrcs.gov

phlox carolina
carolina phlox
spring


source: nps.gov

4' shrub

itea virginica
virginia sweetspire
spring/summer/fall



bioretention B

mostly grass-like species, some perennials

- less visible during winter months

- more colorful during warm months

What do you think?

A for the bioretention area	B for the bioretention area
1 for the planting bed	2 for the planting bed
none of the above - equal mix of perennials + grasses	**thank you for your time!**

Planting Ideas for these WECO / NCSU BAE / City of Wilmington projects provided by:

DESIGN STUDIO B+O pllc

B+O: design studio, PLLC
landscape architecture / architecture
205 Princess Street
Wilmington, NC 28401
www.b-and-o.net

SAFER, GREENER STREETS:

IMPROVING 10TH, ANN & DOCK STREETS

STREETSIDE RAIN GARDENS ARE PLANNED IN YOUR NEIGHBORHOOD

The City of Wilmington and NC State University have a grant to create streetside raingardens and other practices to:

- increase pedestrian safety
- reduce pollution
- reduce street flooding

Raingardens (also called bioretention) temporarily hold and filter stormwater runoff (the rain water that flows off streets, driveways, and roofs) to remove pollutants and reduce flooding. Streetside raingardens will bump out from curbs at the intersection of Ann and 10th Streets, and mid-block on Dock Street. The bump outs will reduce traffic speed.

Ann Street - looking east

Other pollution-reducing practices will be installed on S. 12th Street, reducing the stormwater that reaches Dock Street after storms. NC State is monitoring pollution in water running off the streets before and after the project is constructed. Boxes are visible where the monitoring equipment is installed.

Construction is planned for Fall 2011. Please contact us to learn about opportunities to help plant and maintain the gardens, or if you have any questions.

Dock Street - looking west

Sponsored by:

- North Carolina State University
- City of Wilmington
- Family & Neighborhood Resource Center
- Cape Fear River Watch
- Williston Middle & Gregory Elementary
- B+O Design
- US Environmental Protection Agency (EPA)
- NC Department of Environmental and Natural Resources, Division of Water Quality
- NC Clean Water Management Trust Fund

Christy Perrin, NC State University: Christy_perrin@ncsu.edu 919-515-4542
Jennifer Butler, City of Wilmington: jennifer.butler@wilmingtonnc.gov 910–341-5895

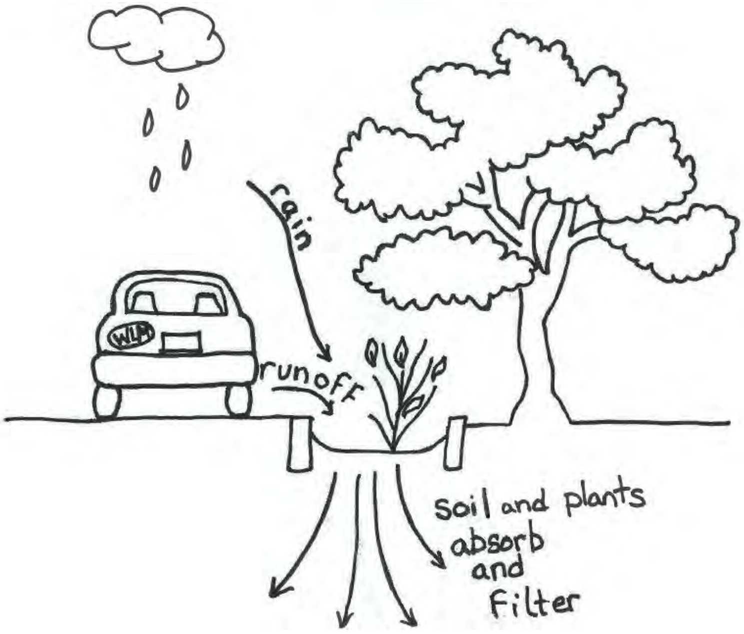
Protecting and Improving Burnt Mill Creek

This rain garden helps protect Burnt Mill Creek by absorbing runoff from the road. When it rains, stormwater flows over hard surfaces, picking up pollutants and washing them into creeks via storm drains.

Rain gardens consist of soil, mulch, and plants, and reduce pollution entering our creeks. Streetside rain gardens also keep trash from entering our waterways, by capturing it and allowing for its removal.

Wilmington is working to improve our creeks with Best Management Practices like this rain garden. Learn more at:

www.wilmingtonnc.gov/stormwater

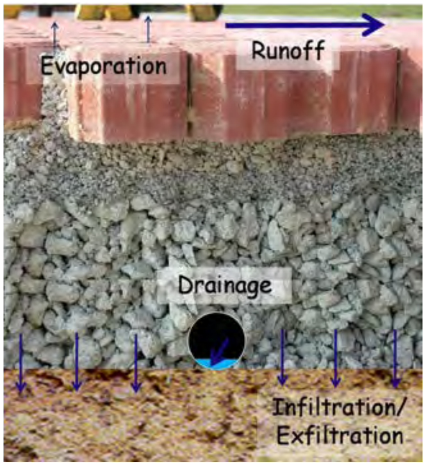


CITY OF WILMINGTON
NORTH CAROLINA

NC State University
A&T State University
COOPERATIVE EXTENSION
Empowering People · Providing Solutions

Protecting and Improving Burnt Mill Creek

Permeable parking bays have been installed along this street. Permeable (also known as pervious) materials allow stormwater to soak into the ground, rather than running off into local waterways, and are used for driveways, pathways and parking lots.



Stormwater soaks in between the pavers, through a stone layer, and then into the ground. A small amount may evaporate or run off the surface.

Permeable materials include permeable interlocking pavers such as you see here, permeable asphalt, permeable concrete, and plastic grid pavers. Permeable materials require regular street sweeping to keep from clogging.

Benefits of using permeable materials include:

- **Recharges groundwater**
- **Cost-effective and easy to maintain**
- **Absorbs less heat than typical concrete or pavement**
- **Reduces and cleans stormwater runoff**

Wilmington is working to improve our creeks with Best Management Practices like this permeable parking stall.

Learn more at:

www.wilmingtonnc.gov/stormwater

CITY OF WILMINGTON
NORTH CAROLINA

NC State University A&T State University COOPERATIVE EXTENSION
Empowering People · Providing Solutions

URBAN Waterways

Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Waters

Purpose of this document

Recent studies by the US Geological Survey (USGS) and several universities indicate that PAHs are an important emerging contaminant in urban waterways, including the rapidly growing metro areas of North Carolina. This document offers an overview of recent studies of potential sources for PAHs in urban waterways and provides information on management strategies for reducing the risks of PAH impacts on aquatic ecosystems.

What are PAHs?

PAHs, or Polycyclic Aromatic Hydrocarbons, consist of hundreds of separate chemicals that occur together as mixtures. PAHs are naturally occurring and are concentrated by the burning of fossil fuels and the incomplete burning of carbon-containing materials (such as wood, tobacco, and coal). PAHs are a wide and varied group of compounds whose sources include tire particles, leaking motor oil, vehicle exhaust, crumbling asphalt, atmospheric deposition, coal gasification, and parking lot sealants, as well as sources inside the home (such as tobacco smoke, wood fire smoke, grilling or charring meat). PAHs are also commonly found in particulate matter of air pollution. PAHs tend to adhere to surfaces, attaching readily to sediment particles and leading to elevated concentrations in sediments. PAHs have complex chemical structures (see figure 1), so they do not break down easily and are persistent in the environment.

Why should we be concerned about PAHs?

Some PAHs are known to be toxic to aquatic animals and humans. Generally, higher molecular weight PAHs tend to be more stable, persist in the environment longer, are less water soluble, and are more toxic. Exposure to UV light can increase toxicity of PAH compounds and increase toxicity to some aquatic species. (Garrett 2004)

Scientific studies have documented detrimental impacts from PAHs on aquatic organisms. Examples include:

- In Austin, Texas biological studies revealed a loss of species and decreased number of organisms in streams with PAHs present (Van Metre 2005)

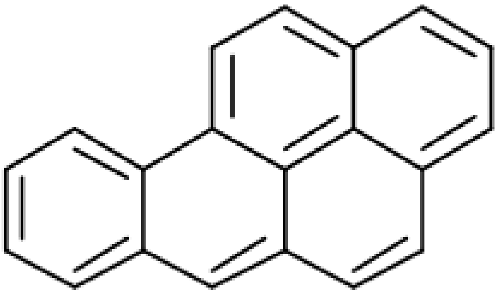


Figure 1. The chemical structure of Benzo[a]-pyrene, a carcinogenic PAH.

NC State University
A&T State University
COOPERATIVE EXTENSION
Empowering People • Providing Solutions

- In Puget Sound, Washington's Ambient Monitoring Program (WA DFW) found PAHs were associated with:
  - Liver lesions and tumors in fish,
  - Liver problems leading to reproductive impairment,
  - Malformations in fish embryos and embryonic cardiac dysfunction,
  - Reduction in aquatic plants (eelgrass) that provide fish habitat.
- Benzo(a)pyrene was lethal to newt larvae at low levels (50 parts per billion) (Fernandez and Lharidon 1994)
- A 2006 study showed developmental delays and deformities in amphibians with exposure to coal tar pavement sealants (which contain PAHs), with larger levels of sealant causing greater developmental problems and death. (Bryer 2006)
- Brown bullhead catfish and English sole have been documented as among the more sensitive bottom-dwelling fish to the carcinogenic effects of PAHs (Garrett 2004).
- Crustaceans and fish metabolize PAH compounds more efficiently than do bivalve species such as mussels, clams, and oysters, which readily accumulate PAHs (Garrett 2004).
- Interactions between aquatic organisms and PAHs in sediment are complex, depending on many factors including—but not limited to—sensitivity of species, stage of development, bioavailability of PAHs, and exposure to sunlight (Garrett 2004).

The most significant effect of PAH toxicity to humans is cancer. Increased incidences of lung, skin, and bladder cancers are associated with occupational exposure to PAHs (USDHHS 2009). Other non-cancer effects are not well understood, though they may include adverse effects on reproduction, development, and immunity. PAHs generally have a low degree of acute toxicity to humans, meaning harmful effects through a single or short-term exposure are minimal. Mammals absorb PAHs through inhalation, contact with skin, and ingestion (EPA Ecological Toxicity). Recent research by USGS raises concerns about exposure of children through inhalation and ingestion of house dust contaminated by PAHs that have abraded from nearby parking lots sealed with coal tar sealant (Mahler 2010).The International Agency for Research on Cancer (IARC) classifies two PAHs as probable human carcinogens and three as possible human carcinogens. The US EPA classifies seven PAHs as probable human carcinogens, while the state of California classifies 25 PAHs as carcinogenic PAHs (cPAHs). The IARC and EPA both classify benzo(a)pyrene and benz(a)anthracene as probable human carcinogens. Benzo(a)pyrene is often used as an environmental indicator for PAHs.

PAHs in streams and lakes are thought to rarely pose a human health risk via drinking water because of their tendency to attach to particles rather than dissolve in water. USEPA has a maximum contaminant level (MCL) for PAH in drinking water of 0.2 ppb of drinking water. Human health risks from consuming fish are thought to be low because PAHs do not readily bioaccumulate within vertebrates. Bivalve mollusks readily accumulate PAHs in their tissues, however. (Garrett 2004). The U.S. Food and Drug Administration (FDA) has not established standards governing the PAH content of foodstuffs (USDHHS 2009), with the exception of issuing levels of concerns for PAHs in fish and shellfish following the Deepwater Horizon oil spill. The European Union has set a maximum allowable level of benzo(a)pyrene for bivalve mollusks on the market (EU Commission 2006).

How do PAHs get into streams, lakes, estuaries, and the ocean?

PAHs enter water bodies through atmospheric deposition and direct releases of substances through petroleum spills and use, municipal wastewater treatment plants, industrial


Figure 2. Bivalves, including oysters, readily accumulate PAHs in their tissues.

discharges, stormwater runoff, landfill leachate, and surface runoff. Many studies have been conducted recently regarding runoff sources of PAHs. Rainfall runs off parking lot and road surfaces, transporting PAHs that originate from tire particles, leaking motor oil, vehicle exhaust, crumbling asphalt, atmospheric deposition, coal gasification, and parking lot sealants. PAHs attach readily to sediment particles, leading to high concentrations in bottom sediments of water bodies. A literature review on tire wear particles in the environment indicates that the high aromatic (HA) oils generally used in tires contain PAHs. Zinc, PAHs, and a suite of other organic compounds (including phthalates, benzothiazole derivatives, phenolic derivatives, and fatty acids) found in tires are noted to likely cause toxicity in aquatic organisms. Because of this toxicity, the European Union has banned sales of tires that contain HA oils. This is estimated to reduce future PAH emissions from tires by 98 percent. (Wik & Goran 2009) It is unclear whether tire manufacturers will continue to sell tires containing HA oils in the United States.


United States Geological Survey

Figure 3. Sealant is applied to a parking lot.

Coal tar-based sealants

Research from the USGS in the City of Austin, Texas (Van Metre et al 2005), nine other cities (Van Metre et al 2009)), and from the University of New Hampshire (Mahler et al 2012) indicates that coal tar-based sealants (also called sealcoats) on parking lots likely contribute significant amounts of PAHs to waterways via stormwater runoff. These sealants (CTS) are made of coal tar, a product created during the coking of coal. This type of sealant and another sealant made from asphalt are used to prevent damage to asphalt surfaces. Friction from automobile tires causes the sealcoat to flake off. These flakes are then scrubbed from the surface during a rain event and into storm-drain networks, and then flow into lakes and streams. In the Austin study, parking lots with coal tar sealcoat yielded an average PAH concentration of 3,500 mg/kg on particles in runoff, 65 times more than from unsealed lots in simulated rain events. The average concentration of PAHs in particles washed off asphalt-based sealants was 620 mg/kg, about 10 times higher than the average concentration from the unsealed parking lots. The other sources of PAHs previously mentioned, besides sealants, can account for the PAH concentrations found washing off the unsealed parking lots (Van Metre 2005). A recent UNH study compared runoff from lots they sealed with both types of sealants to an unsealed lot. They found both types of sealcoat led to a rapid increase in PAH concentrations in the initial runoff—up to 5,000 parts per billion (ppb), compared to 10 ppb released from the unsealed lot. Concentrations decreased after several rainstorms. The PAH concentrations in the sediments immediately downstream of the coal tar sealed lot increased by nearly two orders of magnitude within the first year (14). The Pavement Coating Technology Council maintains that improper curing of the test plots at UNH contributed to the high concentrations of PAHs found in runoff (LeHuray 2009). The results of analyzing sources of PAHs in sediment cores from 40 lakes across the U.S. has led some USGS researchers to conclude that coal tar sealcoat likely is the primary cause of upward trends in PAHs in response to urban sprawl in much of the United States. (Van Metre 2010)

Attributing sources of PAHs to land uses

Determining the sources of PAHs in streams is a complex process and is usually done by evaluating the ratios of individual compounds found in stream sediment. USGS is currently conducting research in North Carolina to examine PAH concentrations in bridge deck runoff. Research on metals and PAHs in Santa Monica, California, found that both commercial and industrial land uses and roads provided higher concentrations of both metals and PAHs than single-family residential land uses (Lau & Strenstrom 2005). A study of the relative importance of individual source areas in contributing to contaminants in an urban watershed in Marquette, Michigan, found parking lots to be a major contributor (~64 percent) of PAH compounds (Steuer et al 1997). The USGS study of bridge decks may be the first North Carolina study evaluating land-use contributions to PAH concentrations in waterways. Future research in N.C. could seek to attribute sources of PAHs to land uses, including commercial and industrial land uses, roads, and parking lots. Estimating PAHs from various land uses could be calculated using methods used in the Marquette, Michigan, study.

At what concentration do PAHs affect in-stream aquatic organisms?

The sediment quality guideline, known as the Probable Effect Concentration (PEC), represents the concentration of a contaminant in bed sediment expected to adversely affect bottom-dwelling organisms. The PEC for PAHs is 22.8 mg/kg.


Figure 4. Burnt Mill Creek is an urban stream in NC that is impaired by PAHs.

How do PAHs affect streams in North Carolina?

The North Carolina Division of Water Quality (NCDWQ) does not monitor the presence of PAHs in streams. Laboratory analysis for PAHs is much more expensive than for commonly measured pollutants like nutrients and bacteria, and North Carolina has no official standard for PAHs. Special studies do sometimes include PAH analysis, such as:

- The USGS National Water Quality Assessment found a strong correlation between PAHs and urban intensity across the country, including 30 watersheds of the Raleigh-Durham metro area. The highest concentrations of PAHs in sediments at the bottom of water bodies were found in watersheds with increasing development and motor vehicle traffic. These results echo studies from around the world (Garrett 2004).
- Levels of PAHs have been indicated by NCDWQ as the lead impairment of Burnt Mill Creek, an urban stream in Wilmington, N.C. A subsequent UNC-Wilmington/NC State University research project found high levels of PAHs throughout the creek at six sites for four yearly sampling events. Zinc levels, which can be used as indicators of tire-wear particles, were

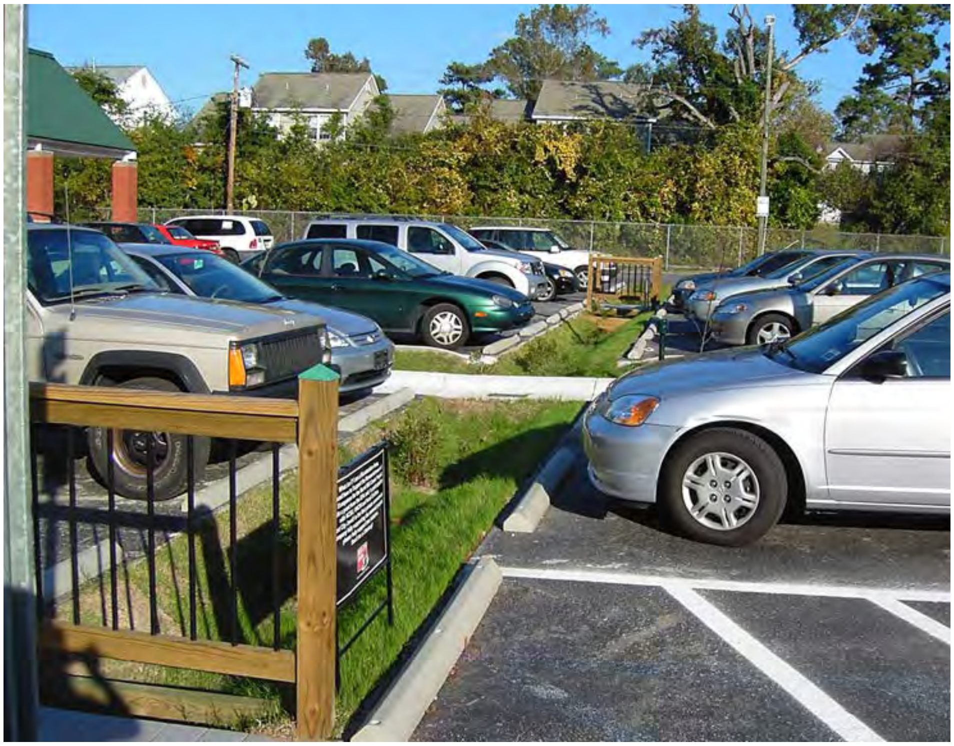


Figure 5. This bioretention cell reduced PAHs in runoff flowing through it.

> low at these same sampling sites, indicating that tire-wear particles from parking lots may be ruled out as major contributors to this watershed's PAH toxicity problems. (Perrin et al 2008)

Reducing risk of PAH contamination from stormwater runoff

Use asphalt sealants or latex modified asphalt sealants if sealing an asphalt surface is necessary. Asphalt or latex modified asphalt sealants contain PAH concentrations of about 5 percent, whereas coal tar based-sealants contain between 20 to 35 percent PAHs. Homeowners should read and follow directions closely for applying and curing the sealant, or consider hiring a trained professional. Industry professionals note that coal tar-based sealants perform better than asphalt sealants at protecting parking lots from petroleum and UV degradation and wear, and they are focusing research and development on creating higher-performing asphalt sealants (WECO 2009).

A number of national home-improvement and hardware stores have discontinued coal tar-based sealants (Hogue 2007), so homeowners who purchase sealant at these stores are using asphalt or latex modified asphalt sealants. That said, coal tar-based sealants are still readily available for purchase online and through wholesale and commercial suppliers, and they are produced and used in North Carolina (WECO 2009).

Intercept and manage stormwater runoff from all parking lots and roads. PAH compounds can be removed from aquatic systems or transformed to new compounds by volatilization (of low molecular weight PAHs), photo oxidation, and biodegradation (Garrett 2004). Installing bioretention cells (also called rain gardens) to treat parking lot runoff reduces PAHs in stormwater, likely through biodegradation. An NC State study in Wilmington, N.C., found a reduction in the concentration of PAHs from parking lot runoff after treatment by a vegetated bioretention cell (Wright et al 2009). A University of Maryland study indicates that a shallow bioretention cell design is adequate for removing PAHs, with mitigation focused on the top surface layer near the inlet where sediment accumulation occurs. PAHs were found to be degraded through indirect plant processing of microbial-soil-root interactions with the rhizosphere (the area of soil 1 mm from the plant root). (Diblasi, et al 2009). Since PAHs are often sediment-bound, stormwater practices that reduce sediment (such as bioretention, stormwater wetlands, wet ponds, swales, and filter strips) may be important for reducing PAH concentrations. Some proprietary stormwater management devices, such as inlet filtration devices, are marketed as reducing organic toxins, including PAHs. Regular maintenance of these and all stormwater management devices is integral for continued pollutant removal (see AG-588-7 for further discussion on maintenance). Proper disposal of contaminated sediment is a concern. Recommendations for disposing of sediments from BMP maintenance are included in the NCDENR Stormwater Best Management Practice Manual.

Figure 6. A parking lot with interlocking pavers in Swansboro, N.C.

Create parking lots with surfaces other than asphalt, such as concrete or permeable pavement. The upfront costs for installing concrete are higher than those for installing asphalt parking lots. Long-term maintenance is likely lower, however, since concrete parking lots do not require sealants and have a longer lifespan. The lighter surface of concrete also provides a benefit of reducing the urban heat island effect by absorbing less solar energy than darker surfaces (EPA 2008). Pervious pavement, including interlocking pavers and permeable concrete, are alternatives to concrete and asphalt that reduce stormwater runoff and pollution (see AG-588-14). Although pervious pavement is the most expensive of the paving options when considering only construction cost, regulatory credit from NCDENR for reducing imperviousness and attenuating peak runoff with appropriate design can offset the cost. This may allow permeable pavement to replace or reduce the size of other stormwater practices.

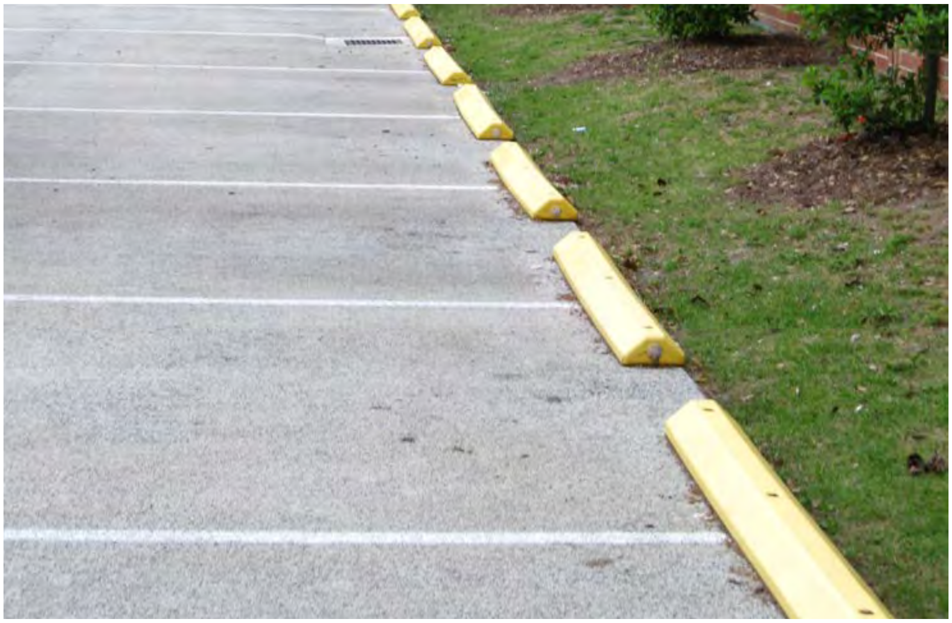


Figure 7. A permeable pavement lot in Wilmington, N.C.

Summary

PAHS have been identified by USGS as an important emerging contaminant in the waterways of growing metropolitan areas of the United States, including those of North Carolina. Negative impacts from PAHs in waters have been well documented in fish, amphibians, bivalves, and benthic macro-invertebrates. Human-health impacts from drinking water and short-term contact with contaminated waters are thought to be minimal, though consumption of contaminated bivalves is a concern. There are many potential sources of PAHs to urban waters, though a growing body of research has highlighted the use of coal tar based parking lot sealant as a major contributor. Strategies for reducing the risks of PAHs to aquatic ecosystems include eliminating the use of coal tar-based sealants on parking lots, intercepting and managing runoff from parking lots and roads, and creating parking lots with materials that don't require sealing such as concrete or permeable pavement.

Acknowledgments

Funding for this fact sheet was provided by the NC Clean Water Management Trust Fund and the US Environmental Protection Agency, CWA Section 319.

Early versions of the fact sheet were reviewed by Sharon Fitzgerald, U.S. Geological Service, and David Mayes and Jennifer Butler, City of Wilmington Stormwater Services Division.

Peer review of this fact sheet was conducted by Bill Hunt, P.E., Ph.D., associate professor, and Mike Burchell, P.E., Ph.D., assistant professor, Department of Biological and Agricultural Engineering, North Carolina State University; and Mitch Renkow, Ph.D., professor, Department of Agricultural and Resource Economics, North Carolina State University.

References

Ahrens, M.; C.Depree; Olsen. G. “Environmental forensics: cracking the case of the contaminated streams”. 2007. Water & Atmosphere 15(1). Online at www.niwa.co.nz.

Bryant, W.L., S.L. Goodbred, T.L. Leiker, L. Inouye, B.T. Johnson. 2007. “Use of Chemical Analysis and Assays of Semipermeable Membrane Devices Extracts to Assess the Responses of Bioavailable Organic Pollutants in Streams to Urbanization in Six Metropolitan Areas of the United States.” U.S. Department of the Interior, U.S. Geological Survey. Scientific Investigations Report 2007-5113.

Bryer, P.J., J.N. Elliot, J.N., E.J. Willingham. 2006. “The effects of coal tar-based pavement sealer on amphibian development and metamorphosis.” Ecotoxicology, 15. New York: Springer Science+Business Media.

European Union. Commission Regulation No. 1881/2006 of 19 December 2006. (2006). “Setting maximum levels for certain contaminants in foodstuffs.”

DiBlasi, C.J., H. Li, A.P. Davis, U. Ghosh. 2009. “Removal and Fate of Polycyclic Aromatic Hydrocarbon Pollutants in an Urban Stormwater Bioretention Facility.” Environmental Science & Technology, 43(2) Washington, D.C.: American Chemical Society Publications.

Environmental Protection Agency. Region 5 Superfund. Ecological Toxicity Information. Online at: http://www.epa.gov/R5Super/ecology/html/toxprofiles.htm#pahs

Fernandez, M. , J. Lharidon. 1994. “Effects of light on the cytotoxicity and Genotoxicity of Benzo(a) pyrene and an oil refinery effluent in the newt.” Environmental and Molecular Mutagenesis. Volume 24 Issue 2. Wiley-Blackwell.

Garrett, C.L. 2004. Priority substances of interest in the Georgia Basin: profiles and background information on current toxics issues: Report of the Canadian Toxics Work Group. GBAP Publication no. EC/GB/04/79. Online at: georgia.basin@ec.gc.ca

Hogue, C. 2007. “Dustup Over Pavement Coatings.” Chemical & Engineering News. Volume 85, Number 7. pp. 61-66. Washington, D.C.: American Chemistry Society Publications.

Lau, S-L. , M.K.Stenstrom, 2005. “Metals and PAHs adsorbed to street particles." Water Research. Volume 39, Issue 17, October, 4083-4092. London: IWA Publishing.

LeHuray, Anne P. 2009. Pavement Coatings Technology Council. Letter to author. October 20, 2009.

MacDonald, D.D., C.G. Ingersoll, T.A. Berger. 2000. "Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems." Archives of Environmental Contamination and Toxicology. 39:20-31. New York: Springer Science+Business Media.

Mahler, B.J., P.C.Van Meter, J.T. Wilson, M. Musgrove, T.L. Burbank, T.E. Ennis, T.J. Bashara. "Coal tar-based parking lot sealcoat: An unrecognized source of PAH to settled house dust." Environmental Science and Technology. 2010. 44, Pp 894-900. Washington, D.C.: American Chemistry Society Publications.

Mahler, B.J.; P.C. Van Metre, T.J. Bashara, D.A. Johns. 2005. "Parking lot sealcoat- An unrecognized source of urban PAHs". Environmental Science and Technology, V. 39, p. 5560-5565. Washington, D.C.: American Chemistry Society Publications.

North Carolina Department of Environmental and Natural Resources. 2007. Stormwater Best Management Practices Manual. Raleigh, NC: Division of Water Quality. http://portal.ncdenr.org/web/wq/ws/su/bmp-manual

North Carolina Department of Environmental and Natural Resources. 2004. "Assessment Report: Biological Impairment in the Burnt Mill Creek Watershed". Division of Water Quality, Collaborative Assessment of Watersheds and Streams (CAWS) Project.

WECO Focus group. Parking Lots and Water: A focus group for professionals in the business of building and/or sealing parking lots. August 17, 2009. Wilmington, NC. Sponsored by NC State University Cooperative Extension and City of Wilmington.

Perrin, C.A.; Wright, J.; W.F. Hunt, P.G. Beggs, M. Mallin, M. Burchell. 2008. Restoring the Burnt Mill Creek Watershed through Stormwater Management and Community Development. Final EPA 319 Report to NC Division of Water Quality. Online www.ncsu.edu/WECO/burntmill

Richardson DC. 2006. "Parking lot sealants: on the trail of urban PAHs." Stormwater, The Journal for Surface Water Quality Professionals, 7 (4). Santa Barbara, CA: Forester Media Inc.

SeaGrant New Hampshire. Pavement Sealcoat a Source of Toxins in Stormwater Runoff. Online at: http://www.seagrant.unh.edu/news-sealcoat.htm

Steuer, J.,W. Selbig, N. Hornewer, J. Prey. 1997 . "Sources of Contamination in an Urban Basin in Marquette, Michigan, and an Analysis of Concentrations, Loads, and Data Quality". U.S. Geological Survey Water Resources Investigations Report 97-4242; U.S. Geological Survey: Denver, CO,.

U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry (ATSDR). July 1,2009. Toxicity of Polycyclic Aromatic Hydrocarbons (PAHs). Case Studies in Environmental Medicine. Online at http://www.atsdr.cdc.gov/csem/pah/pah_where-found.html

U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry (ATSDR) ToxFAQ for Polycyclic Aromatic Hydrocarbons (PAHs). Online at: http://www.atsdr.cdc.gov/tfacts69.html

Food and Drug Agency. Protocol for Interpretation and Use of Sensory Testing and Analytical Chemistry Results for Re-Opening Oil-Impacted Areas Closed to Seafood Harvesting Due to The Deepwater Horizon Oil Spill. June 2010, Updated November 2010.

Van Metre, P.C., B.J. Mahler. 2010. "Contribution of PAHs from coal–tar pavement sealcoat and other sources to 40 U.S. lakes". Science of the Total Environment 409 (2010) 334–344. Elsevier publications.

Van Metre, P.C, B.J. Mahler, J.T. Wilson. 2009. "PAHs Underfoot: Contaminated Dust from Coal tar Sealcoated Pavement is Widespread in the United States." Environmental Science and Technology 43 (1), pp 20–25. Washington, D.C.: American Chemistry Society Publications.

Van Metre, P.C, B.J. Mahler, M. Scoggins, P.A. Hamilton. 2005. Parking lot sealcoat- A major source of PAHs in urban and suburban environments: U.S. Geological Survey Fact Sheet 2005-3147, 6 pp.

Washington Department of Fish and Wildlife, Puget Sound Ambient Monitoring Program. Online at http://www.wdfw.wa.gov/fish/psamp/

Wik, A.,G. Dave. January 2009. "Occurrence and effects of tire wear particles in the environment – A critical review and an initial risk assessment." Environmental Pollution, Volume 157, Issue 1. Pages 1-11. Elsevier publications.

Wright, J.D.; Hunt,W.F.;Burchell, M.R.; Perrin, C.A.;McCoy, E.R. Implementation and performance of stormwater best management practice retrofits in Wilmington, NC. Proceedings of World Environmental and Water Resources Congress 2009: Great Rivers 2009;342():5293-530. Kansas City, MO.

Environmental Protection Agency. 2008. Reducing Heath Islands: Compendium of Strategies Cool Pavements. Available at: www.epa.gov/heatisld/mitigation/pavements.htm

Prepared by

Christy Perrin, Extension Associate,
Program Manager of Watershed Education for Communities and Officials
Department of Agricultural and Resource Economics
North Carolina State University

Published by
NORTH CAROLINA COOPERATIVE EXTENSION SERVICE

COLLEGE OF
AGRICULTURE & LIFE SCIENCES
ACADEMICS ▴ RESEARCH ▴ EXTENSION

Distributed in furtherance of the acts of Congress of May 8 and June 30, 1914. North Carolina State University and North Carolina A&T State University commit themselves to positive action to secure equal opportunity regardless of race, color, creed, national origin, religion, sex, age, or disability. In addition, the two Universities welcome all persons without regard to sexual orientation. North Carolina State University, North Carolina A&T State University, U.S. Department of Agriculture, and local governments cooperating.

10/12—VB/BW 13-CALS-3429 AG-588-25

NC STATE UNIVERSITY

Final Monitoring Report: Street Retrofits in Wilmington, NC

Jonathan Page, Ryan Winston, and William Hunt
Department of Biological and Agricultural Engineering
North Carolina State University

CHAPTER 1: CATCHMENT-SCALE EVALUATION OF THE HYDROLOGIC IMPACTS OF RESIDENTIAL STORMWATER STREET RETROFITS IN WILMINGTON, NORTH CAROLINA

2.1 Abstract

Low Impact Development (LID) is a design approach that utilizes Stormwater Control Measures (SCMs) to maintain and restore the natural hydrologic regime of an urban watershed through infiltration, runoff treatment at the source, and minimization of impervious surfaces. This paired watershed study evaluated the impacts of LID SCMs on hydrology at a catchment-scale. In February 2012, a pair of bioretention cell (BRC) bumpouts, two permeable pavement parking stalls and a tree filter device were installed to treat residential street runoff in Wilmington, North Carolina. In the LID catchment, 52% of the directly connected impervious area (DCIA) and 69% of the total catchment was treated for hydrologic improvement. Underlying soils in the study area were Baymeade Urban and Leon Urban sands. Peak discharge decreased by 28% post-retrofit and lag times in the catchment remained unchanged, while runoff depth significantly decreased by 52%. When compared to the control catchment, runoff depths in the LID catchment were significantly less for storms with low hourly storm intensities (<2.7 mm/hr), but significantly greater for storms with high intensities (>7.4 mm/hr). Runoff thresholds in the LID and control catchments were 5.2 mm and 3.5 mm, respectively. The LID runoff coefficient significantly decreased by 47% from 0.22 to 0.13, and is substantially less than other runoff coefficients reported for traditional residential development. This study has shown that a limited

number of LID SCMs installed within a medium density residential street right-of-way over sandy soils can mitigate some hydrologic impacts of existing development.

2.2 Introduction

Impervious land cover associated with urbanization has led to increases in stormwater runoff volumes and pollutants entering surface waters (Jennings and Jarnagin, 2002; Line and White, 2007). Ten percent impervious cover in a watershed can negatively impact nearby streams, rivers, lakes and estuaries, and a strong correlation has been shown between the fraction of impervious cover in a watershed and the degree to which the receiving water body is impaired (Schueler, 1992; Schueler, 1994; Novotny, 2003). The National Water Quality Inventory estimates 44% of stream km, 64% of lake ha and 30% of estuary km^2 are impaired, with urban runoff listed as a primary cause of impairment (US EPA, 2009).

Street surfaces are sources of stormwater runoff volume and pollutants as well as pathways for the transport of runoff from adjoining land areas (Bannerman et al., 1993). Most municipal streets and roadways are directly connected to conventional storm sewer networks with curb and gutter drainage systems. The subsurface channelization of runoff in urban watersheds has been shown to increase peak discharges and reduce lag times (Leopold, 1968; Booth et al., 2002). Directly connected impervious area (DCIA) rapidly conveys runoff to the watershed outlet and is the primary contributor of storm flow during small rainfall events (<25.4 mm) (Walsh, 2000; Walsh et al., 2004; Flint and Davis, 2007). Walsh et al. (2004) suggest DCIA is a more appropriate predictor of stormwater impacts to surface waters than total impervious area (TIA) of a watershed, and DCIA is particularly important in watersheds with sandy soils (Lee and Heaney, 2001).

Low Impact Development (LID) is an integrated design approach intended to mimic pre-development hydrology by discretely locating impervious surfaces and utilizing stormwater control measures (SCMs) to capture and treat runoff at the source (Prince Georges County, 1999; Coffman, 2000; Davis et al., 2006; Dietz, 2007). For the most part, studies of LID practices, such as bioretention cells (BRCs) and permeable pavements, have focused on individual systems or side-by-side comparisons to refine design and regulatory standards (Brattebo and Booth, 2003; Hunt et al., 2006; Brown and Hunt, 2011; Wardynski et al., 2013). BRCs have been shown to maintain or restore pre-development hydrology by providing depressional storage and infiltration, which enhances ground water recharge and natural base flow to streams (Davis et al., 2009; DeBusk et al., 2011). Permeable pavements are well suited to mitigate the hydrologic impacts of urbanization through substantial reductions in peak discharge and runoff volume. (Collins et al., 2008; Ball and Rankin, 2010; Fassman and Blackbourn, 2010). Compared to conventional asphalt pavements, permeable pavements have been shown to generate 72% less runoff when installed over sandy loam soils (Gilbert and Clausen, 2006). When constructed over sandy soils, BRCs and permeable pavements may eliminate nearly all runoff volume (Bean et al., 2007b; Brown and Hunt, 2011).

Limited peer-reviewed literature is available on the hydrologic impacts of LID SCMs at a watershed or catchment-scale (Hood et al., 2007; Bedan and Clausen, 2009; Line et al., 2012). At a residential LID site in Waterford, Conn., BRCs, grassed swales and permeable pavements effectively mitigated the hydrologic effects of development (Hood et al., 2007; Bedan and Clausen, 2009). Runoff volumes and flowrates were 2.5 and 3 time less than an adjacent traditional residential development, respectively. The authors concluded this to be a direct result of distributing LID SCMs throughout the watershed designed to capture and treat runoff associated with the first 25.4 mm (1 in) of rainfall. In North Carolina, Line et al. (2012) reported a commercial LID watershed with undersized BRC, permeable pavement and stormwater wetland installations provided greater runoff volume reduction than a commercial watershed with a conventional wet detention pond. Line et al. (2012) noted the LID SCMs were not sized and constructed according to current regulatory standards in North Carolina, and suggested that the runoff reductions may have been even greater with properly sized and constructed LID SCMs.

Streets and roadways make up approximately 25% of the urban landscape and represent the majority of the impervious cover owned and maintained by municipalities (UACDC, 2010). Traditionally, roadways have been designed to provide maximum traffic flow and adequate drainage to prevent flooding in the driving lane with little regard for control and treatment of runoff. Limited, but usable, space exists within the right-of-way to install SCMs, which includes the roadway, sidewalk and adjoining plaza area. It is becoming increasingly important to quantify the impacts of SCMs on existing residential development runoff quantity as municipalities comply with total maximum daily load (TMDL) requirements or address goals for other watershed management plans. This study examined the impacts of LID SCM retrofits installed within the medium density residential street right-of-way on hydrology at a catchment-scale.

2.3 Materials and Methods

Site Description

The project site is located in Wilmington, North Carolina. Wilmington (population 110,000) is located in the southern coastal plain between the Cape Fear River and the Atlantic Ocean. Normal mean temperatures in summer and winter range from 23.9° – 27.2° C and 7.7° –

12.7° C, respectively (NC State Climate Office, 2012). The study site is part of the Burnt Mill Creek watershed of the Cape Fear River Basin. The Burnt Mill Creek watershed is on North Carolina's 303(d) list, with toxicity and sedimentation cited as the primary causes of impairment (NCDENR, 2004). Two residential street catchments, a control and retrofit (LID), were selected for use in a paired watershed study (Figure 2-1). The control and LID drainage areas are 0.35 ha (0.86 ac) and 0.53 ha (1.31 ac), respectively. The straight-line distance between the catchments is 0.5 km (0.3 mi).

Both catchments are considered to be medium-density residential with street surfaces, sidewalks, driveways, rooftops and open space; they are serviced by conventional curb and gutter drainage systems. Control and LID housing densities are 25.7 home/ha (10.5 homes/ac) and 28.3 homes/ha (11.5 homes/ac), respectively. Impervious cover is the same in each catchment at 60%. However, the directly connected impervious area (DCIA) (street surface) in the LID catchment is 24%, which is substantially greater than 16% observed in the control catchment (Table 2-1). The catchment outlets are existing stormwater catch basins. The control outlet is located at the northwest corner of the intersection of 8th Street and Orange Street, and the LID outlet is located at the southwest corner of 12th Street and Dock Street.

New Hanover County Orthophoto

Figure 2-1: Control and LID retrofit drainage areas in Wilmington, NC

Table 2-1: Summary of catchment areas and imperviousness

Parameter	**Catchment**	
	LID	**Control**
Drainage Area (m^2) (%)	5,300	3,480
Impervious Fraction	3,180 (60%)	2,088 (60%)
Street Surface (DCIA)	1,278 (24%)	557 (16%)
Rooftop	1,378 (26%)	1218 (35%)
Sidewalk	530 (10%)	313 (9%)
Open Space	2,120 (40%)	1,392 (40%)
Slope	0.5%	0.7%
Soil Series	Baymeade Urban	Leon Urban
USDA Soil Class	Sand	Sand
Outlet Location	N 34.235293 W 77.934061	N 34.233696 W 77.939200
Receiving Water Body	Burnt Mill Creek	
River Basin	Cape Fear	

The New Hanover County soil survey indicates underlying soils in the control and LID catchments are Baymeade Urban and Leon Urban, respectively. Particle size distribution analysis

(PSA) using the hydrometer method (Gee and Bauder, 1986) showed the USDA texture classification for the underlying soils is sand (Gee and Or, 2002). Infiltration rates in sandy urban soils range from 50 mm/hr (2 in/hr) to 460 mm/hr (18 in/hr) and are greatly impacted by compaction (Pitt et al., 2008). Maximum longitudinal slopes in the control and LID catchments are similar at 0.7% and 0.5%, respectively.

LID SCM Retrofits

LID SCMs constructed in February 2012 included a BRC bumpout, four permeable pavement parking spaces installed in two separate sections and one tree filter box installed along Dock Street and 12th Street (Figure 2-2, 2-4, 2-5). Post-retrofit, TIA decreased from 60% to 58% and DCIA decreased from 24% to 12%. BRC bumpouts were constructed just west of the intersection of Jasmine Street and Dock Street to treat runoff from Dock Street. The BRCs extend 1.8 m (6 ft) into the existing roadway to create 3.5 m (11.5 ft) driving lanes (east and west bound) for the added benefit of traffic calming and pedestrian safety. Four permeable pavement parking stalls 7 m x 2.4 m (23 ft x 8 ft) each were installed in two separate sections on 12th Street between Dock Street and Orange Street to treat runoff from 12th Street. Permeable pavement loading ratios (drainage area/SCM surface area) of 7.8 and 6.6 are atypical, and the impacts of loading ratios this large have not been reported in the literature. Flow diverters (16 mm tall) were installed along the curb and gutter at 3.6 m intervals to force runoff into the parking areas (Figure 2-3). The BRC and permeable pavement combined to treat 52% of the street surface and 69% of the total catchment area for potential runoff quantity reductions (Table 2-2).

Figure 2-2: Clockwise from top: BRC bumpouts along Dock Street, tree filter device at intersection of 12th Street and Dock Street, and permeable pavement parking stalls on 12th Street

A Filterra® tree filter device was installed on Dock Street at the southwest corner of the intersection with 12th Street to treat runoff from Jasmine Street and Dock Street that is down-slope of the bioretention bumpouts. The tree filter treats any overflow from the BRC bumpouts. The devices function as rapid flow-through filters such that ponding at the surface does not occur. Lenth et al. (2010) measured infiltration rates of ten Filterra® devices with varying maintenance periods (recent – 2 years) and found infiltration rates from 2200 mm/hr (86 in/hr) to 5200 mm/hr (205 in/hr) with up to 110 mm (4.5 in) of sediment accumulation at the surface. Volume reduction is negligible because the concrete lining does not allow exfiltration to occur.

Table 2-2: Summary of LID SCM design parameters

Parameter	**BRC**[a]	**Filterra®**	**PP I**[b]	**PP II**[c]
Surface Area	19 m^2	3 m^2	34 m^2	34 m^2
Street Surface Area	160 m^2	539 m^2	265 m^2	226 m^2
Loading Ratio[d]	8.4:1	180:1	7.8:1	6.6:1
Street Surface Area Treated	13%	42%	21%	18%
Total Catchment Area Treated	12%	22%	30%	27%
As Built Design Rainfall Event[e]	33 mm	N/A	24 mm	27 mm
Underdrain	No	Yes	No	No

[a] Bioretention Cell on Dock Street
[b] North permeable pavement parking area on 12th Street
[c] South permeable pavement parking area on 12th Street
[d] Calculated as drainage area/SCM surface area
[e] Runoff from given rainfall depth that is stored in SCM before overflow occurs, assuming no infiltration to underlying soils

Figure 2-3: Flow diverters installed on permeable pavement parking stalls along curb and gutter of 12th Street

Figure 2-4: Ariel photo post-retrofit with approximate watershed boundary

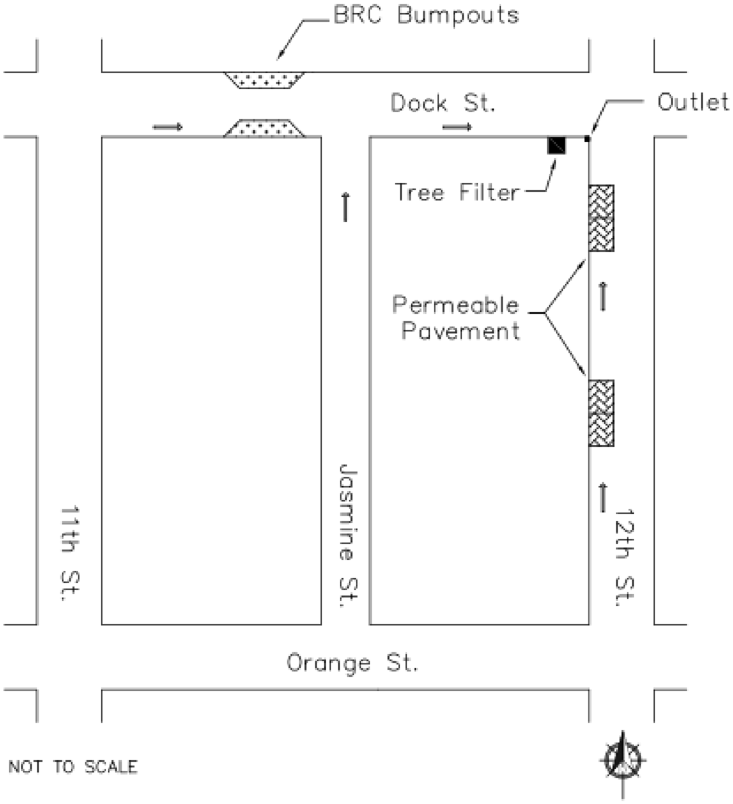


Figure 2-5: Layout of LID SCMs with arrows indicating direction of flow (not to scale)

Monitoring Design

The paired watershed study design was used to evaluate the hydrologic impacts of the LID SCM retrofits (Clausen and Spooner, 1993; Grabow et al., 1999). This approach requires two watersheds: control and treatment (LID) and two monitoring periods: calibration and treatment. During the calibration period, management practices in the catchments remained the same (no SCMs), the SCMs were installed in the LID catchment and treatment monitoring began post-construction (Table 2-3). The paired watershed approach is underpinned by a quantifiable and predictable (linear) relationship between the catchments. A relationship is developed during the calibration period, and is considered valid until the SCM treatment is applied to the LID catchment, at which time a new relationship between the catchments is developed during the second period of monitoring (Clausen and Spooner, 1993).

Table 2-3: Paired watershed study design

Period	Catchment	
	LID	Control
Calibration	No SCMs	No SCMs
Treatment	SCMs	No SCMs

Monitoring equipment was installed at the catchment outlets in May 2011. Manual and HOBO™ Tipping Bucket rain gauges were installed on a wooden post free of trees and overhead obstructions at the LID station (Table 2-4). An ISCO 6712™ portable sampler logged rainfall data from the tipping bucket. Hydrologic data were recorded by installing V-notch weirs and weir boxes inside the existing catch basins (Figure 2-6). Forty-five degree and 60° V-notch weirs were installed at the control and LID stations, respectively. The V-notch weirs and weir boxes were fitted with a 1 m (3.3 ft) long contracted rectangular weir to pass discharges from large storms. ISCO 730™ bubbler flow modules were used to monitor discharge and total runoff volume by measuring stage above the weir at two minute intervals.

Table 2-4: Summary of monitoring equipment

Equipment	LID	Control
Location	Southwest corner of intersection of 12th and Dock St	Northwest corner of intersection of 8th and Orange St.
Structure	60° V-notch weir	45° V-notch weir
Flow Monitoring Device	ISCO 730™ Bubbler Module	ISCO 730™ Bubbler Module
Rain Gauges	Manual and HOBO™ Tipping Bucket	NA[a]

[a] Control station located 0.5 km from LID station

Figure 2-6: V-notch weir and weir box being installed inside existing catch basins

During each site visit hydrologic and rainfall data were downloaded with an ISCO Rapid Transfer Device™ (RTD) at both stations. The ISCO 730™ bubbler flow modules were calibrated by bringing the water level in the weir box up to the weir invert, and the bubbler tubing was purged with an air compressor to combat moisture intrusion. Bubbler module desiccant was replaced when it became saturated approximately every two weeks during summer and fall and every four weeks during winter and spring.

Monitoring Challenges

The primary monitoring challenge was keeping the weirs and weir boxes clear of debris. Leaf litter, woody material, trash and coarse sediment that accumulated on the street surface (Figure 2-3) were frequently deposited in the base of the weir box during a storm (Figure 2-7). This was more common at the control station during fall and winter sampling seasons. Debris was removed from the weirs and weir boxes, during each site visit. In October 2011 the City of Wilmington was required to make existing crosswalks ADA compliant, including the western crosswalk at the intersection of 8th Street and Orange Street, which was 1 m (3 ft) upslope of the control station. This required the control station to be removed in November 2011, ending calibration monitoring. The ADA crosswalk was installed incorrectly in December 2011 allowing runoff to bypass the catch basin where the control station had been installed. In May 2012 the ADA crosswalk was corrected and runoff from the control catchment was directed into the original catch basin enabling treatment monitoring to begin.

Figure 2-7: Debris clogging control weir (left) and removing organic material from control weir box (right)

Data Processing

Hydrologic data were reviewed using FLOWLINK Version 5.0 software (ISCO, 2005) and compared to field notes. Rainfall intensities and total depths were adjusted by a scaling factor developed from the discrepancy (deficit) recorded by the tipping bucket vis-à-vis manual rain gauges. Four and five storms were removed from the calibration and treatment data sets, respectively, when paired data points were not collected due to power failure, equipment malfunction or weir obstructions.

Statistical Analysis

SAS Version 9.3™ was used for all statistical analyses (SAS Institute, 2010). Data sets from the calibration and treatment periods were log transformed and tested separately using analysis of variance (ANOVA) for a significant linear relationship with metrics from the LID and control catchments as covariates (control = x, LID = y). The residuals of regression were inspected graphically for normality and constant variance. Skew coefficients and the Shapiro-Wilk goodness-of-fit test were also used to assess normality of the residuals. Analysis of covariance (ANCOVA) was utilized to detect significant impacts on the slopes and intercepts of peak discharge, lag time, runoff depth and runoff coefficient regressions. All statistical tests were conducted using α=0.05. Significant differences in slopes or intercepts of the calibration and treatment regressions lines indicated the hydrologic impact of the LID SCM treatment was significant. If a significant difference in slopes was not detected, the slope term was removed from the full ANCOVA model and the reduced ANCOVA model was used for analysis. Least squared means (LSM) analysis was used to quantify significant changes in the hydrologic parameters from calibration to treatment monitoring. Percent reductions were calculated using Equation 3-1.

$$Change(\%) = [1 - \frac{10^{\bar{Y}_T}}{10^{\bar{Y}_C}}] \times 100 \qquad \text{Equation 2-1}$$

Where,

$\bar{Y}_T$ = LID LSMean during treatment monitoring

$\bar{Y}_C$ = LID LSMean during calibration monitoring

To compare means from the second monitoring period by storm size and intensity, differences in paired data points from the LID and control catchments were checked for normality using the Shapiro-Wilk goodness-of-fit test. If the differences were not normally distributed, the raw data sets were log transformed and tested again. Differences that were approximately normal were tested for a significant difference with a Student's t-test. In instances where the paired differences remained non-normally distributed, the Wilcoxon signed rank test was used for data with a single outlier and the sign test was used when two or more outliers were present.

2.4 Results and Discussion

Precipitation

Normal annual rainfall at Wilmington International Airport is 1,448 mm (57 in) (NC State Climate Office, 2012). The calibration and treatment monitoring periods occurred from 10 May 2011 to 31 October 2011 and 8 June 2012 to 13 February 2013, respectively. Total rainfall recorded during the calibration and treatment periods was 436 mm (17.2 in) and 811 mm (31.9 in), respectively. Storms less than 2.5 mm (0.1 in) were not included in the data set. A six-hour antecedent dry period was used to separate discrete rainfall events.

Similar rainfall characteristics were observed in both monitoring periods. Mean storm depth during the calibration period was 21.3 mm (0.84 in) compared to 19.3 mm (0.76 in) recorded during treatment monitoring. The difference in mean rainfall depth was primarily caused by 143 mm (5.6 in) of rainfall from Hurricane Irene that occurred on August 26, 2011. Rainfall depth and hourly intensity from the 50th and 75th percentile storms were used to partition rainfall data and make comparisons between means of the hydrologic metrics (Tables 2-5 and 2-6). Bean (2005) reported rainfall depth percentiles for Wilmington, NC, and peak hourly storm intensities were determined by cumulative probability analysis from 10-year weather records (1999 – 2008) at Wilmington International Airport (ILM).

Table 2-5: Precipitation summary for calibration and treatment periods (all units in mm)

Period	n[a]	Range	50th Percentile		75th Percentile		Mean	Median	Total
			<12.7	>12.7	<30	>30			
Calibration	17	3.3 - 143	10 (59%)	7 (41%)	14 (82%)	3 (18%)	21.3	10.7	436
Treatment	34	3.3 - 72	19 (56%)	15 (44%)	28 (82%)	7 (18%)	19.3	9.9	811

[a] Number of events >2.5 mm

Table 2-6: Peak hourly intensity summary for calibration and treatment periods (all units in mm/hr)

Period	n[a]	Range	50th Percentile		75th Percentile		Mean	Median
			<2.7	>2.7	<7.4	>7.4		
Calibration	17	0.8 - 13.7	8 (47%)	9 (53%)	15 (88%)	2 (12%)	3.3	3.3

Treatment	34	1.0 - 15.7	17 (50%)	17 (50%)	30 (88%)	4 (12%)	3.3	2.7

[a] Number of events >2.5 mm

Pre-retrofit, data collection was limited due to crosswalk construction in the control catchment (see *Monitoring Challenges)*. Ideally, the calibration and treatment monitoring periods would have lasted for one year or more each, as outlined by Clausen and Spooner (1993). The watersheds in this study were small urban drainage areas located 0.5 km apart with similar land use, imperviousness, topography, soil and nearly identical climate and weather patterns. The only difference between the catchments during this study was the SCM treatment. It was determined that data collected during the shortened calibration period established predictable relationships between the catchments sufficient to utilize ANCOVA to make valid statistical comparisons.

Peak Discharge

Mean peak discharge in the LID catchment decreased from 15.0 L/s to 12.4 L/s post-retrofit. The LID SCMs had a significant impact on flowrates evidenced by the difference in intercepts of the calibration and treatment regression lines in the reduced ANCOVA model (Table 2-7) (Figure 2-8). Peak discharge in the LID catchment decreased 28% during post-retrofit monitoring by LSM comparison. This decrease is not significant at the $\alpha=0.05$ level, however it is significant at the $\alpha=0.10$ level ($p=0.1000$).

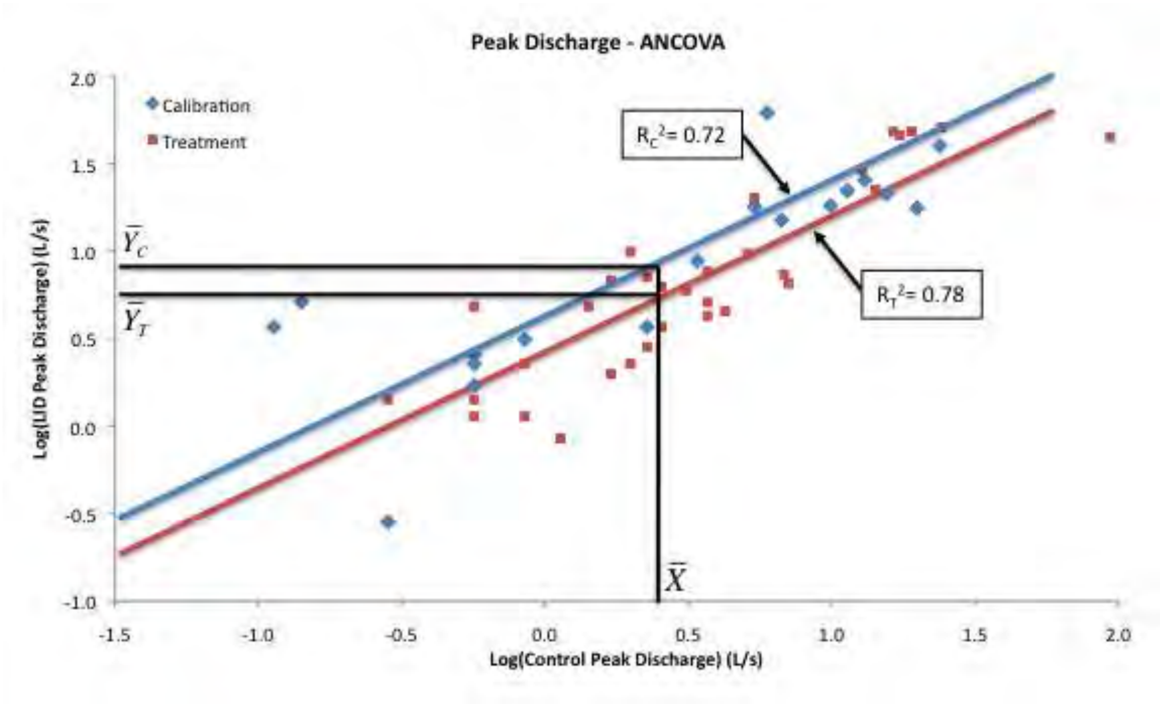


Figure 2-8: Reduced ANCOVA model for peak discharge

Bedan and Clausen (2009) reported peak discharge reduction of 26% from a residential LID watershed in Connecticut. BRCs and permeable pavements have frequently been shown to the capture runoff from small storms entirely, thus eliminating peak discharge (Brattebo and Booth, 2003; Bean et al., 2007a; Davis, 2008; Hunt et al., 2008; Li et al., 2009; Jones and Hunt, 2009; Wardynski et al., 2012). Li et al. (2009) found that the hydrologic benefits of BRCs are substantial for smaller storms, but deteriorate rapidly for storms with greater rainfall depths and intensities. In a statistical comparison of treatment monitoring flowrates, there were no significant differences between the LID and control drainage areas using hourly rainfall intensities as a basis. The decrease in peak discharge may have been greater if hydrologic treatment had been applied to the entire DCIA, rather than just 52% in the LID catchment.

Table 2-7: Means and ANCOVA summary for hydrologic metrics

Period	Mean	Median	LSM	ANCOVA		
				LSM	Slope	Intercept

Peak Discharge (L/s)						
Calibration	15.0	8.8	7.8	0.1000	-	<0.0001*
Treatment	12.4	5.5	5.7			
Change[a]	-17%	-38%	-28%			
Lag Time (hrs)						
Calibration	1.94	0.43	0.86	0.1802[NS]	0.0367*	0.3848[NS]
Treatment	0.43	0.73	0.73			
Change[a]	-78%	70%	-15%			
Runoff Depth (mm)						
Calibration	8.1	2.2	2.5	0.0002*	0.0001*	0.0259*
Treatment	3.6	1.1	1.2			
Change[a]	-55%	-50%	-52%			
Runoff Coefficient						
Calibration	0.22	0.14	0.18	0.0002*	-	0.0002*
Treatment	0.13	0.10	0.10			
Change[a]	-41%	-29%	-47%			

*Significant

[NS]Not Significant

[a]Negative sign "-" implies reduction

Lag Time

Lag is defined as the time rainfall begins to the time peak discharge occurs. The full ANCOVA model does indicate a significant difference in slopes of the regression lines, however this did not translate to a significant change in lag times in the LID catchment (Table 2-7) (Figure 2-9). Median lag time in the LID catchment increased from 0.43 hrs to 0.73 hrs post-construction. Mean lag times during calibration monitoring were influenced by the long duration and lag time of Hurricane Irene. Leopold (1991) suggests lag time is a useful theoretical variable to consider in watershed hydrology because it assimilates multiple components of runoff generation. Lag times are influenced by several watershed and climatic factors including soil type, topography, land use, rainfall, intensity and time of peak intensity. Hood et al. (2007) found that LID SCMs incorporated into the original site design with designated open space and a cluster housing arrangement significantly increased lag times at the watershed outlet.

Underdrains were not installed with the BRC and permeable pavement because underlying soils were sandy, meaning all runoff that entered the systems was retained rather than being released at a later time. While the SCMs did decrease the magnitude of peak discharge, the time at which it occurred remained unchanged.

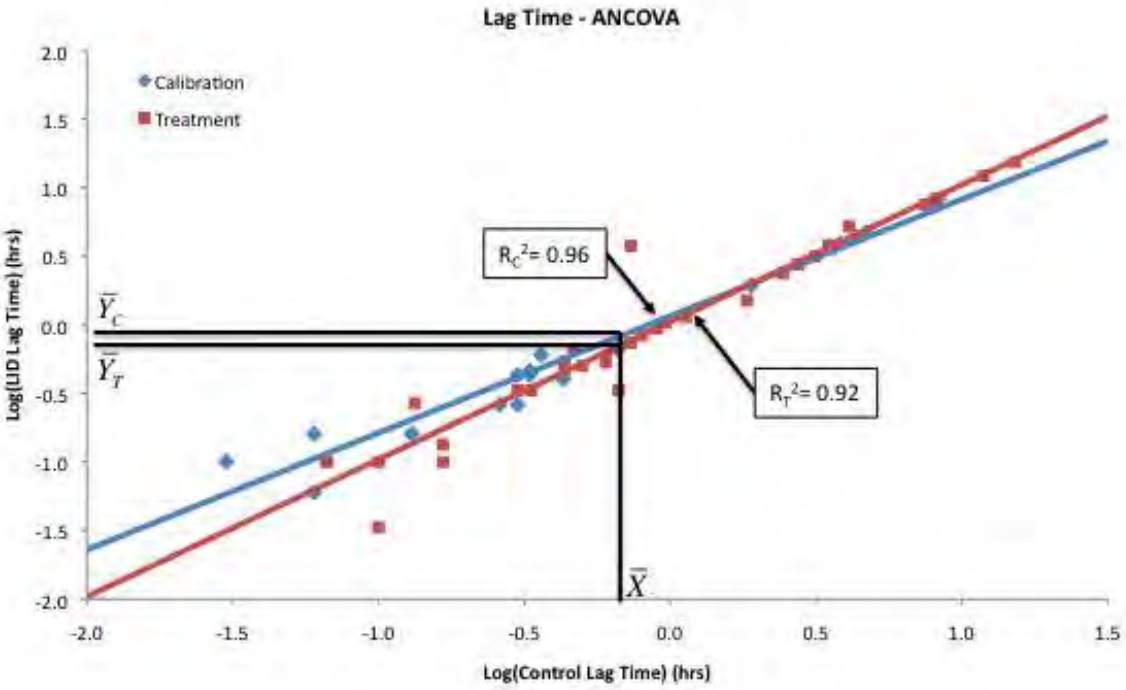


Figure 2-9: Full ANCOVA model for lag time

Runoff Depth

Mean runoff depth in the LID catchment significantly decreased by 52% during the post-retrofit period (Table 2-7) (Figure 2-10). The slopes and intercepts of the calibration and treatment regression lines are significantly different. Decreases in runoff depth were not consistent across all values, unlike observations reported by Bedan and Clausen (2009). In the full ANCOVA model for runoff depth, the greater slope of the treatment regression line and magnitude of the difference at lower values of runoff depth indicates greater decreases at smaller runoff depths and little to no change at greater runoff depths.

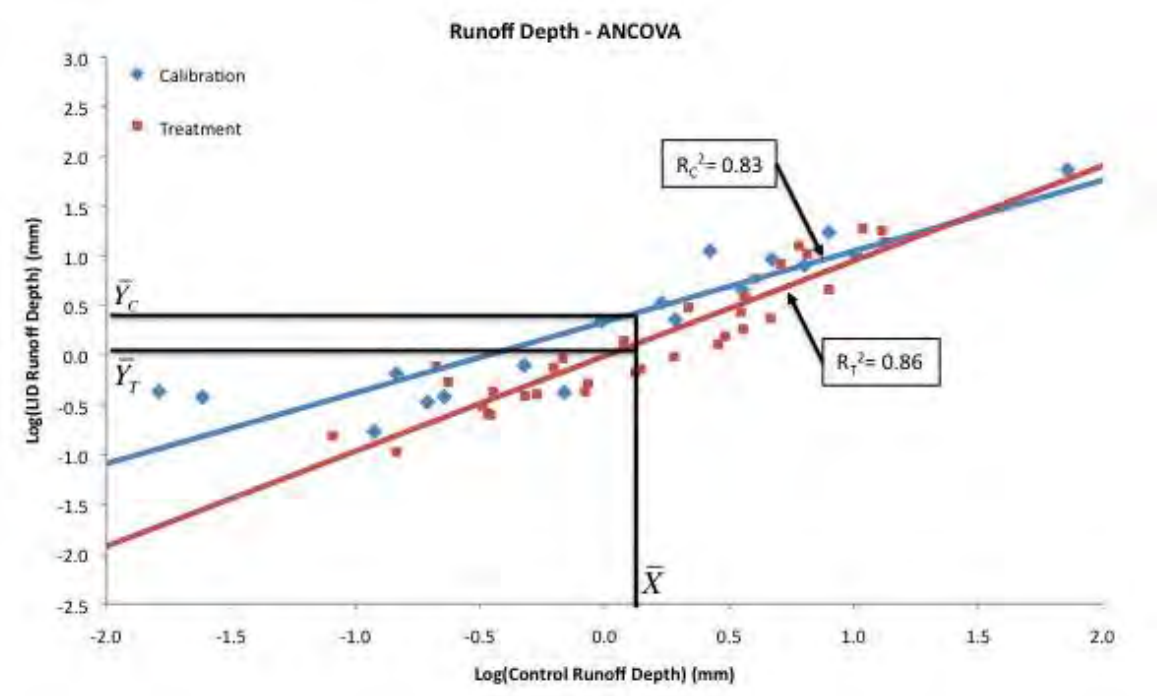


Figure 2-10: Full ANCOVA model for runoff depth

This relationship was investigated further by comparing runoff depth means with respect to storm size and intensity in the LID and control catchments. LID mean runoff depth was not significantly different from control mean runoff depth for rainfall amounts greater or less than the 50th and 75th percentile storms (Table 2-8). However, mean runoff depths in the LID catchment were significantly less than the control catchment for storms with hourly *intensities* less than the 50th percentile storm (Table 2-9). For storms with intensities above the 75th percentile, mean runoff depth in the LID catchment was significantly greater than mean runoff depth in the control drainage area. This suggests the capacity of the LID SCMs to mitigate runoff depth is driven by storm intensity rather than storm depth in this study.

Table 2-8: Runoff depth means by rainfall depth during treatment monitoring

Rainfall Depth (P)	n	Mean Runoff Depths (mm)		p-value
		LID	Control	
P < 50th	19	0.6	0.7	0.6720^{NS}
P > 50th	15	7.3	5.9	0.1534 ^{NS}
P < 75th	27	1.8	1.6	0.7544 ^{NS}
P > 75th	7	10.3	8.5	0.3394 ^{NS}

^{NS}Not Significant

Table 2-9: Runoff depth means by storm intensity treatment monitoring

Storm Intensity (I)	n	Mean Runoff Depths (mm)		p-value
		LID	Control	
I < 50th	17	1.9	2.5	0.0569*
I > 50th	17	5.2	3.5	0.2381 ^{NS}
I < 75th	30	2.6	2.5	0.2518 ^{NS}
I > 75th	4	10.7	7.1	0.0118*

*Significant
^{NS}Not Significant

Although the permeable pavement loading ratios were abnormally high, it is unlikely that insufficient storage volume within the SCMs caused the systems to have a minimal impact on runoff depth for storms with hourly intensities greater than 7.4 mm/hr. Assuming exfiltration to the underlying soil does not occur during a storm, as-built design rainfall events for the BRC, PP I and PP II were 33 mm (1.3 in), 24 mm (0.95 in) and 27 mm (1.05 in), respectively (Table 2-2). Underlying soils beneath the SCMs were 95% - 98% sand (Table B-4), indicating exfiltration potential from the BRC and permeable pavement was high and likely occurred. During larger and more intense storms, resulting runoff moved swiftly along the existing curb and gutter and at a greater depth, which may have overwhelmed the flow diverters, thus providing no opportunity for infiltration for 39% of the DCIA.

Clogging of the permeable pavement was likely the primary cause for the SCMs reduced effectiveness on storm intensities greater than 7.4 mm/hr. Streets are documented sources of woody debris, leaf litter, fine solids and sediment, particularly in residential areas (Sartor et al., 1974; Sartor and Gaboury, 1984; Bannerman et al., 1993). Bean et al. (2007a) found that fine particles clogging the void space of the permeable pavement surface reduced median infiltration rates by three orders of magnitude, from 20,000 mm/hr to 80 mm/hr. The parking stalls were maintained with a high suction vacuum truck approximately every four months, however leaf litter from adjacent deciduous trees and fine sediment accumulation at the surface of the permeable pavers was observed throughout treatment monitoring and likely reduced the infiltration rate.

The decrease mean runoff depth observed in this study was similar to other findings reported in the literature for BRCs and permeable pavement. Fassman and Blackbourn (2010) found a permeable pavement installation over tight clay soils reduced runoff volume by 28% with a 4.3:1 loading ratio. In North Carolina, all runoff was eliminated from a permeable pavement parking lot constructed over sandy soils when underdrains were removed from the system (Bean et al., 2007b). At the watershed outlet of an LID residential neighborhood with permeable pavement and BRCs, Bedan and Clausen (2009) reported a 42% reduction in runoff depth despite impervious cover increasing from 0% to 21%. Line et al. (2012) reported a 34% reduction in runoff volume from a commercial LID watershed (76% imperviousness) with just one-third of the site draining to properly functioning LID SCMs.

Runoff threshold is the rainfall depth at which runoff is generated and was determined by the x-intercept of the regression line from a rainfall depth vs. runoff depth plot. All paired data points from post-construction monitoring were used in the analysis. LID and control runoff thresholds were 5.2 mm and 3.5 mm, respectively (Figures 2-11 and 2-12). The greater runoff threshold in the LID catchment is due to the BRC and permeable pavement installations that provided infiltration and depressional storage. These thresholds are very similar to those observed by Hood et al. (2007) in Connecticut, where runoff thresholds from residential LID and traditional watersheds were 6.0 mm and 3.0 mm, respectively.

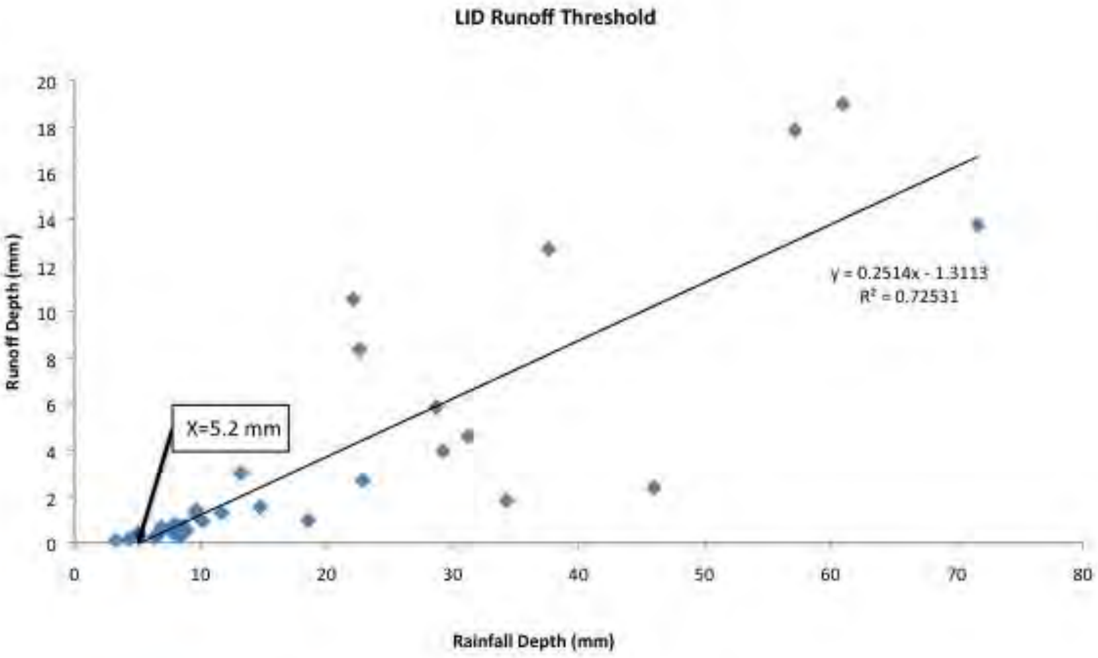


Figure 2-11: Runoff threshold in the LID catchment

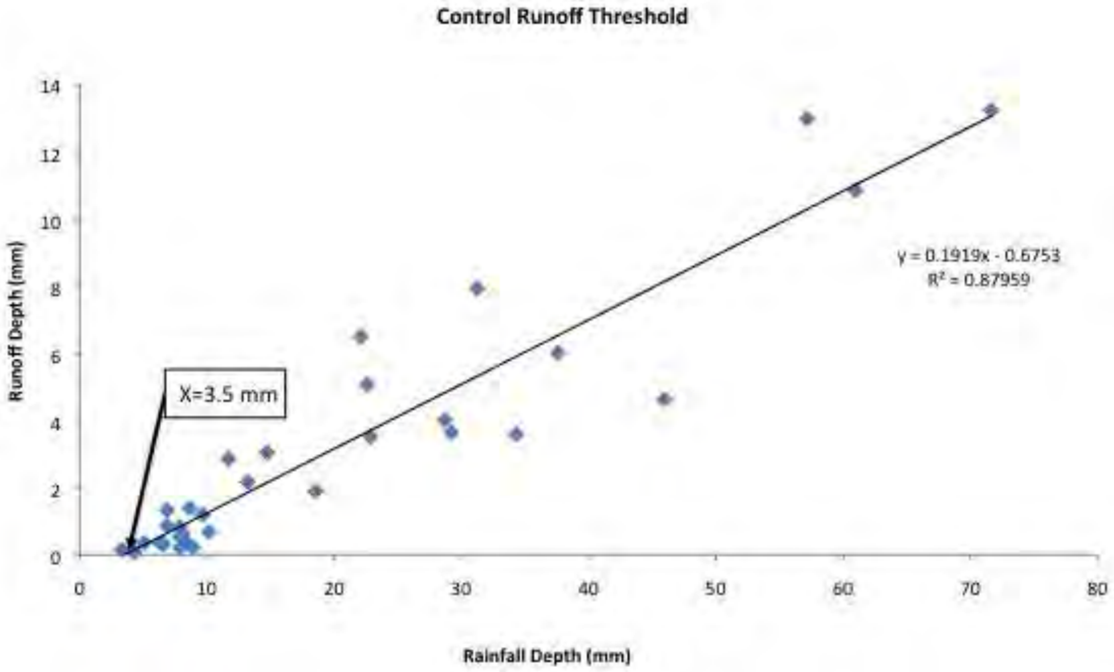


Figure 2-12: Runoff threshold in the Control catchment

Runoff Coefficients

Runoff coefficient is a metric that shows the fraction of rainfall that is converted to runoff and is determined by dividing runoff depth by rainfall depth for a single storm. Line and White (2007) and Leopold (1991) have shown that runoff coefficients increase with impervious cover and urbanization in a watershed. Mean runoff coefficients in the LID and control catchments during calibration monitoring were 0.22 and 0.14, respectively (Table 2-7). The larger mean runoff coefficient observed pre-retrofit in the LID catchment is due to the greater DCIA fraction. Line et al. (2002) reported a runoff coefficient of 0.57 for a residential drainage area with 25% DCIA in the Piedmont region of North Carolina, which is substantially greater than runoff coefficients reported in this study. The difference is due to higher slopes (2%-10%) and sandy loam soils in the watershed monitored by Line et al. (2002). As noted previously, soils in the study area were very sandy, and the topography was flat (0.5% - 0.7% slopes).

In the reduced ANCOVA model for runoff coefficient, the intercepts of the calibration and treatment regression lines are significantly different (Figure 2-13). LID runoff coefficient was significantly decreased by 47% (Table 2-7). Post-retrofit, the mean runoff coefficient was 0.13 in the LID catchment. Hood et al. (2007) reported a mean runoff coefficient of 0.07 from a residential LID watershed with no DCIA and a TIA of 21%. During larger, more intense storms LID SCMs have been shown to be less effective at mitigating the hydrologic impacts of urbanization when compared to smaller storms (Hood et al., 2007; Li et al., 2009).

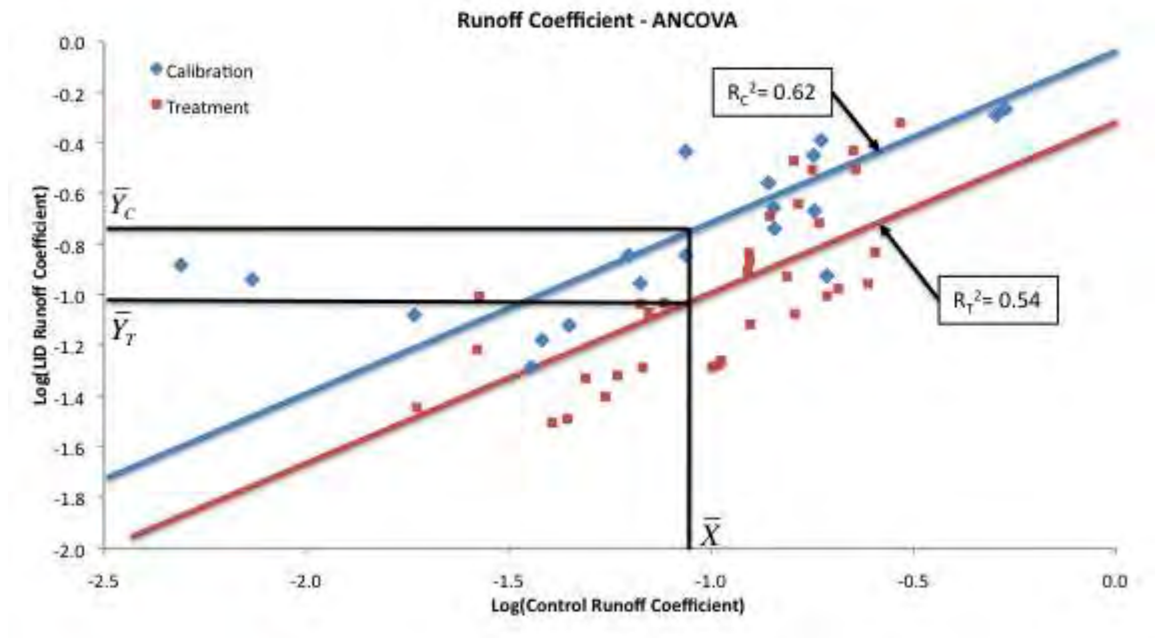


Figure 2-13: Reduced ANCOVA model for runoff coefficient

Runoff coefficients from treatment monitoring were sorted by 50th percentile rainfall depth (</>12.7 mm) and hourly intensity (</>2.7 mm/hr) (Table 2-10). Mean runoff coefficients were lowest in both catchments for smaller storms (<12.7 mm), and differences between the control and LID coefficients did not vary by storm intensity. The SCMs provided the greatest decrease of rainfall converted to runoff when compared to the control catchment for larger storms (>12.7 mm) with low rainfall intensities (<2.7 mm/hr), which is evidenced by a 33% difference in mean runoff coefficient.

Table 2-10: Runoff coefficients partitioned by 50th percentile rainfall depth (</> 12.7 mm) and 50th percentile hourly rainfall intensity (</> 2.7 mm/hr) during treatment monitoring

	Hourly Intensity < 2.7 mm/hr			Hourly Intensity > 2.7 mm/hr		
		Mean Runoff Coefficient			Mean Runoff Coefficient	
	n[1]	LID	Control	n[1]	LID	Control
Storms < 12.7 mm	11	0.07	0.09	8	0.08	0.09
Storms > 12.7 mm	6	0.10	0.15	9	0.28	0.19

[1] Number of storms in category

Conversely, the SCMs did not have a noticeable impact on runoff coefficients for larger storms (>12.7 mm) with high intensities (>2.7 mm/hr). Here, LID and control runoff coefficients in were 0.28 and 0.19, respectively. This difference is also reflected in the ANCOVA plot where there is substantial scatter of post-retrofit data above the treatment regression line for x-values greater than 0.15 (log[0.15]=-0.82) (Figure 2-13). Similar to observations of runoff depth, runoff coefficients varied by storm intensity, which is likely due to runoff overwhelming the flow diverters and clogging at the surface of the permeable pavement. Also, rainfall depths greater than 12.7 mm with high hourly intensities (>2.7 mm/hr) may have generated runoff from the entire LID drainage area, rather than just the DCIA, thereby increasing the runoff volume observed at the LID outlet.

2.5 Summary and Conclusions

In this study, 52% of DCIA and 69% of TIA was retrofitted with a BRC and permeable pavement. The SCMs were sized based on the contributing DCIA because soils in the study area were very sandy. Results have shown that LID SCMs installed as retrofits within the residential street right-of-way can mitigate some of the hydrologic impacts of existing residential development at a catchment-scale The following conclusions were drawn from this study:

- Post-retrofit, mean peak discharge at the LID outlet decreased by 28%, but had no impact on lag times. The decrease in mean flowrates may have been greater if hydrologic treatment had been applied to the entire DCIA, rather than just 52%. Lag times likely remained unchanged because the infiltration-based LID SCMs did not introduce a large amount a new storage (detention) to the existing drainage area.

- Runoff depth in the LID catchment decreased significantly by 52%, which is comparable to other studies of individual BRC and permeable pavement systems and watershed-scale studies of LID SCMs (Bedan and Clausen, 2009; Line et al., 2012). The LID runoff threshold was 49% greater than the threshold observed in the control catchment, and both were similar to runoff thresholds reported by Hood et al. (2007) for traditional residential and LID watersheds in Connecticut.
- Runoff coefficient in the LID catchment significantly decreased by 47%. Post-retrofit, the LID runoff coefficient was 0.13, which is substantially less than other values reported for traditional residential developments and similar to the runoff coefficient (0.07) reported for a larger residential LID watershed (Line et al., 2002; Hood et al., 2007).
- Permeable pavement maintenance is imperative for systems installed along residential streets where leaf litter and loose sediment are present. Maintenance more frequent than every four months may be necessary. Adequately sized flow diverters should be used to ensure runoff has ample opportunity to infiltrate the surface of the permeable pavers for all storm sizes, particularly when greater loading ratios are used. Alternative curb and gutter configurations and pavement grading that shed water in the direction of the permeable pavement may also be considered.

2.6 References

Bannerman, R. T., Owens, D. W., Dodds, R. B., and Hornewer, N. J. (1993). "Sources of Pollutants in Wisconsin Stormwater." *Water Science and Technology,* 28(3-5), 241-259.

Bean, E. Z. (2005). "A field study to evaluate permeable pavement surface infiltration rates, runoff quantity, runoff quality, and exfiltrate quality." Thesis. North Carolina State University, Raleigh, NC.

Bean, E. Z., W. F. Hunt and D. A. Bidelspach. (2007a). "Field survey of permeable pavement surface infiltration rates. " *J.Irrig.Drainage Eng-ASCE*, 133(3): 249-255.

Bean, E. Z., Hunt, W. F., and Bidelspach, D. A. (2007b). "Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts." *J.Irrig.Drainage Eng-ASCE,* 133(6), 583-592.

Bedan, E. S., and Clausen, J. C. (2009). "Stormwater Runoff Quality and Quantity From Traditional and Low Impact Development Watersheds." *Journal of the American Water Resources Association,* 45(4), 998-1008.

Bender, G., and Terstriep, M. (1984). "Effectiveness of street sweeping in urban runoff pollution control." *Sci.Total Environ.,* 33(1), 185-192.

Brattebo, B. O., and Booth, D. B. (2003). "Long-term stormwater quantity and quality performance of permeable pavement systems." *Water Res.,* 37(18), 4369-4376.

Brown, R. A., and Hunt, W. F.,III. (2011). "Impacts of Media Depth on Effluent Water Quality and Hydrologic Performance of Undersized Bioretention Cells." *J.Irrig.Drainage Eng-ASCE,* 137(3), 132-143.

Clausen, J.C. and J. Spooner, 1993. *Paired Watershed Study Design*. U.S. Environmental Protection Agency, USEPA 841-F-93-009.

Coffman, L.S. 2000. Low-Impact Developmeent Design: A New Paradigm for Stormwater Management Mimicking and Restoring the Natural Hydrologic Regime An Alternative Stormwater Management Technology. Department of Environmental Resources, Prince Georges County, Maryland.

Collins, K. A., Hunt, W. F., and Hathaway, J. M. (2008). "Hydrologic comparison of four types of permeable pavement and standard asphalt in eastern North Carolina." *J.Hydrol.Eng.,* 13(12), 1146-1157.

DeBusk, K. M., Hunt, W. F., and Line, D. E. (2011). "Bioretention Outflow: Does It Mimic Nonurban Watershed Shallow Interflow?" *J.Hydrol.Eng.,* 16(3), 274-279.

Dietz, M. (2007). "Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions." *Water, Air, & Soil Pollution,* 186(1), 351-363.

Fassman, E. A., and Blackbourn, S. (2010). "Urban Runoff Mitigation by a Permeable Pavement System over Impermeable Soils." *J.Hydrol.Eng.,* 15(6), 475-485.

Flint, K. R., and Davis, A. P. (2007). "Pollutant mass flushing characterization of highway stormwater runoff from an ultra-urban area." *J.Environ.Eng.,* 133(6), 616-626.

Gee, G.W. and Bauder, J. W. (1986). “Particle-size analysis.” In Methods of Soil Analysis, Part 1. Agron. Monogr. 9. Klute, A, ed. Soil Science Society of America, Madison, WI. 383-411.

Gee, G. W., and Or, D. (2002). "2.4 Particle-size analysis." *Methods of Soil Analysis: Physical Methods,* 5:255.

Gilbert, J. K., and Clausen, J. C. (2006). "Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut." *Water Res.,* 40(4), 826-832.

Grabow, G., Spooner, J., Lombardo, L., Line, D., and Tweedy, K. (1998). *Has Water Quality Improved?: Use of SAS for Statistical Analysis of Paired Watershed, upstream/downstream and before/after Monitoring Designs.* No. X825012. US EPA-NCSU-CES Grant, Raleigh, NC.

Hood, M. J., Clausen, J. C., and Warner, G. S. (2007). "Comparison of Stormwater Lag Times for Low Impact and Traditional Residential Development1." *JAWRA Journal of the American Water Resources Association,* 43(4), 1036-1046.

Hunt, W. F., Jarrett, A. R., Smith, J. T., and Sharkey, L. J. (2006). "Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina." *Journal of Irrigation and Drainage Engineering-Asce,* 132(6), 600-608.

ISCO Flowlink Software V 5.10.206. (2005). Teledyne ISCO, Inc. Lincoln, NE.

ISCO Open Channel Flow Measurement Handbook: Sixth Edition. (1978). Teledyne ISCO, Inc. Lincoln, NE.

Jennings, D. B., and Jarnagin, S. T. (2002). "Changes in anthropogenic impervious surfaces, precipitation and daily streamflow discharge: a historical perspective in a mid-atlantic subwatershed." *Landscape Ecol.,* 17(5), 471-489.

Lee, J. G., and Heaney, J. P. (2003). "Estimation of urban imperviousness and its impacts on storm water systems." *J.Water Resour.Plann.Manage.,* 129(5), 419-426.

Leopold, L. B. (1968). *Hydrology for urban land planning: A guidebook on the hydrologic effects of urban land use.* United States Department of the Interior. Washington D.C.

Leopold, L. B. (1991). "Lag times for small drainage basins." *Catena,* 18(2): 157-171.

Line, D., White, N., Osmond, D., Jennings, G., and Mojonnier, C. (2002). "Pollutant export from various land uses in the upper Neuse River Basin." *Water Environ.Res.,* 74(1), 100-108.

Line, D. E., and White, N. M. (2007). "Effects of development on runoff and pollutant export." *Water Environ.Res.,* 79(2), 185-190.

Line, D.E., Brown, R. A., Hunt, W. F., and Lord, W. G. (2012). "Effectiveness of LID for Commercial Development in North Carolina*" J. Environ. Eng.* 138(6), 680-688.

Luell, S. K., Hunt, W. F., and Winston, R. J. (2011). "Evaluation of undersized bioretention stormwater control measures for treatment of highway bridge deck runoff." *Water Science and Technology,* 64(4), 974-979.

NCDENR. (2004). "Assessment Report: Biological Impairment in the Burnt Mill Creek Watershed." North Carolina Department of Environment and Natural Resources, Division of Water Quality-Planning Branch. Raleigh, NC.

Passeport, E., Hunt, W. F., Line, D. E., Smith, R. A., and Brown, R. A. (2009). "Field Study of the Ability of Two Grassed Bioretention Cells to Reduce Storm-Water Runoff Pollution." *Journal of Irrigation and Drainage Engineering-Asce,* 135(4), 505-510.

Pitt, R., Field, R., Lalor, M., and Brown, M. (1995). "Urban Stormwater Toxic Pollutants - Assessment, Sources, and Treatability." *Water Environ.Res.,* 67(3), 260-275.

Pitt, R., Chen, S. E., Clark, S. E., Swenson, J., and Ong, C. K. (2008). "Compaction's impacts on urban storm-water infiltration." *J.Irrig.Drain.Eng.,* 134(5), 652-658.

SAS Institute Inc (version 9.2) [Software]. (2008). The SAS system for Windows.

Sartor, J. D., Boyd, G. B., and Agardy, F. J. (1974). "Water pollution aspects of street surface contaminants." *Journal (Water Pollution Control Federation),* 458-467.

Sartor, J., and Gaboury, D. (1984). "Street sweeping as a water pollution control measure: lessons learned over the past ten years." *Sci.Total Environ.,* 33(1), 171-183.

Schueler, T. R. 1992. "Mitigating the Adverse Impacts of Urbanization on Streams: A Comprehensive Strategy for Local Government." *Watershed Restoration Sourcebook.* Publication #92701, Metropolitan Washington Council of Governments. Washington, D.C.

Schueler, T. R. 1994. "The Importance of Imperviousness." *Watershed Protection Techniques*, 1(3): 100–11.

State Climate Office of North Carolina. (2012). 1971-2000 Climate Normals. Available: < http://www.nc-climate.ncsu.edu/cronos/normals.php>. Accessed 15 November 2012.

UACDC. 2010. *Low Impact Development: a design manual for urban areas.* University of Arkansas Press. University of Arkansas Community Design Center. Fayetteville, AR.

US EPA. (2009). History of the Clean Water Act. Laws, Regulations, Guidance, and Dockets. United States Environmental Protection Agency. Available at: http://www.epa/gov/lawsregs/laws.cwahistory/html. Accessed 22 October 2011.

Walsh, C. J. (2000). "Urban impacts on the ecology of receiving waters: a framework for assessment, conservation and restoration." *Hydrobiologia,* 431(2), 107-114.

Walsh, C. J., Sharpe, A. K., Breen, P. F., and Sonneman, J. A. (2001). "Effects of urbanization on streams of the Melbourne region, Victoria, Australia. I. Benthic macroinvertebrate communities." *Freshwat.Biol.,* 46(4), 535-551.

Walsh, C. J. (2004). "Protection of in-stream biota from urban impacts: minimize catchment imperviousness or improve drainage design?" *Marine and Freshwater Research,* 55(3), 317-326.

Wardynski, B. J., Winston, R. J., and Hunt, W. F. (2012). "Internal water storage enhances exfiltration and thermal load reduction from permeable pavement in the North Carolina mountains." *J.Environ.Eng., 139(2), 187-195.*

CHAPTER 3: CATCHMENT-SCALE EVALUATION OF THE WATER QUALITY IMPACTS OF RESIDENTIAL STORMWATER STREET RETROFITS IN WILMINGTON, NORTH CAROLINA

3.1 Abstract

Low Impact Development (LID) is a design approach that utilizes Stormwater Control Measures (SCMs) to maintain and restore the natural hydrologic regime of an urban watershed through infiltration, runoff treatment at the source, and minimization of impervious surfaces. This paired watershed study evaluated the impacts of LID SCMs on water quality at a catchment-scale. In February 2012, a pair of bioretention cell (BRC) bumpouts, two permeable pavement parking stalls and a tree filter device were installed to treat residential street runoff in Wilmington, North Carolina. In the LID catchment, 94% of the directly connected impervious area (DCIA) and 91% of the total drainage area was retrofitted for water quality improvement. Underlying soils in the study area were Baymeade Urban and Leon Urban sands. Post-retrofit, LID concentrations of TKN, TP, TSS, Cu, Pb and Zn significantly decreased by 62%, 38%, 82%, 55%, 89% and 76%, respectively. Concentrations of $NO_{2,3}$-N and TAN did not change. Mass exports of TKN, TAN,

$O\text{-}PO_4^{-3}$, TP, TSS, Cu, Pb and Zn significantly decreased by 78%, 61%, 55%, 73%, 91%, 53%, 88% and 77%, respectively. $NO_{2,3}$-N load decreased by 46%, though this was not significant. Most improvements in water quality were due to dramatic decreases of particulate and particulate-bound pollutant loads. This was attributed to first flush retention of runoff by the BRC and permeable pavement that treated 52% of the DCIA and treatment by the tree filter unit that serviced 42% of the DCIA. This study has shown that a limited number of LID SCMs installed within a medium density residential street right-of-way over sandy soils can mitigate some water quality impacts of existing development.

3.2 Introduction

Impervious land cover associated with urbanization has led to increases in stormwater runoff volumes and pollutant loads entering surface waters (Jennings and Jarnagin, 2002; Line and White, 2007). Ten percent imperviousness in a watershed can negatively impact nearby streams, rivers, lakes and estuaries, and a strong correlation has been shown between the fraction of impervious cover in a watershed and the degree to which the receiving water body is impaired (Schueler, 1992; Schueler, 1994; Novotny, 2003). The National Water Quality Inventory estimates 44% of stream km, 64% of lake ha and 30% of estuary km^2 are impaired, with urban runoff listed as a primary source of impairment (US EPA, 2009).

Most municipal streets and roadways are directly connected to conventional storm sewer networks with curb and gutter drainage systems. Street surfaces are sources of stormwater runoff volume and pollutants as well as pathways for the transport of pollutants from adjoining land areas (Bannerman et al., 1993). Directly connected impervious area (DCIA) is the primary contributor of runoff volume and pollutant loads in small rainfall events (<25.4 mm) (Walsh, 2000; Walsh et al., 2004; Flint and Davis, 2007). Organic and inorganic particulate material including sediment, heavy metals, nutrients, leaf litter, woody debris, polycyclic aromatic hydrocarbons (PAHs), gross solids and pathogens are pollutants that accumulate on streets and roadways (Bannerman et al., 1993; Barrett et al., 1998; Wu et al., 1998).

Street sweeping is utilized by many cities and towns to control debris on the roadway and to reduce pollutant loads. However, evaluations of street sweeping operations have shown this practice is largely for aesthetics rather than providing a noticeable water quality benefit (Bender and Terstriep, 1984). This is because the fine solids and sediment fraction on the street surface is less than 250 μm and contains nearly all of the pollutant load (Sartor and Gaboury, 1984). Conventional street sweeping operations readily remove leaf litter, debris and coarse sediment, but do not effectively remove fine particles; rather, the sweeper brush redistributes them over the whole roadway (Sartor et al., 1974; Sartor and Gaboury, 1984).

Low Impact Development (LID) is an integrated design approach intended to mimic pre-development hydrology and water quality by discretely locating impervious surfaces and utilizing Stormwater Control Measures (SCMs) to capture and treat runoff at the source (Prince Georges County, 1999; Coffman, 2000; Davis et al., 2006; Dietz, 2007). For the most part, studies of LID practices, such as bioretention cells (BRCs), permeable pavements and tree filter units, have focused on individual systems or side-by-side comparisons to refine design and regulatory standards (Brattebo and Booth, 2003; Hunt et al., 2006; Brown and Hunt, 2011; Wardynski et al., 2013). Water quality evaluations have shown particulate pollutants are effectively removed by BRCs, and pollutant retention is driven by hydrology as dramatic reductions in mass export are observed frequently with less substantial concentration reductions reported (Li and Davis, 2009; Brown and Hunt, 2011). Permeable pavements have been shown to readily removed TSS and heavy metals (Cu, Pb, Zn) from influent runoff through filtration and sedimentation (Pratt et al., 1989; Pratt et al., 1995; Dierkes et al., 2002; Brattebo and Booth, 2003).

Limited peer-reviewed literature is available on the water quality impacts of LID SCMs at a watershed or catchment-scale. From a residential LID watershed, Bedan and Clausen (2009) reported pollutant mass exports of TKN, TAN, Pb, Zn and pathogens decreased post-construction although mass exports of TP and TSS increased. Line et al. (2012) characterized nutrient and sediment exports from three commercial watersheds in North Carolina: (1) a site with no SCMs, (2) a site with a wet detention basin and (3) an LID site with undersized permeable pavement, BRC and stormwater wetland installations. The LID site provided a greater mass load reduction for TKN, TAN, TP and TSS than the site with a conventional wet detention basin.

Streets and roadways make up approximately 25% of the urban landscape and represent the majority of the impervious cover owned and maintained by municipalities (UACDC, 2010). Traditionally, roadways have been designed to provide maximum traffic flow and adequate drainage to prevent flooding in the driving lane with little regard for control and treatment of runoff. Limited, but usable, space exists within the right-of-way to install SCMs, which includes the roadway, sidewalk and adjoining plaza area. It is becoming increasingly important to quantify the impacts of SCMs on existing residential development runoff quality as municipalities comply with total maximum daily load (TMDL) requirements or address goals for other watershed management plans. This study examined the impacts of LID SCM retrofits installed within the medium density residential street right-of-way on water quality at a catchment-scale.

3.3 Materials and Methods

Site Description

The project site is located in Wilmington, North Carolina. Wilmington (population 110,000) is located in the southern coastal plain between the Cape Fear River and the Atlantic. Normal mean temperatures in summer and winter range from 23.9° – 27.2° C and 7.7° – 12.7° C, respectively (NC Climate Office, 2012). The study site is part of the Burnt Mill Creek watershed of the Cape Fear River Basin. The Burnt Mill Creek watershed is on North Carolina's 303(d) list, with toxicity and sedimentation cited as the primary causes of impairment (NCDENR, 2004). Two residential street catchments, a control and retrofit (LID) were selected in for use in a paired watershed study (Figure 3-1). The control and LID drainage areas are 0.35 ha (0.86 ac) and 0.53 ha (1.31 ac), respectively. The straight-line distance between the catchments is 0.5 km (0.3 mi).

Both catchments are considered to be medium-density residential with street surfaces, sidewalks, driveways, rooftops and open space; they are serviced by conventional curb and gutter drainage systems. Control and LID housing densities are 25.7 home/ha (10.5 homes/ac) and 28.3 homes/ha (11.5 homes/ac), respectively. Impervious cover is the same in each catchment at 60%. However, the directly connected impervious area (DCIA) (street surface) in the LID catchment is 24%, which is substantially greater than 16% DCIA observed in the control catchment (Table 3-1). The catchment outlets are existing stormwater catch basins. The control outlet is located at the northwest corner of the intersection of 8th Street and Orange Street, and the LID outlet is located at the southwest corner of 12th Street and Dock Street.

New Hanover County Orthophoto

Figure 3-1: Control and LID retrofit drainage areas in Wilmington, NC

Table 3-1: Summary of catchment areas and imperviousness

Parameter	**Catchment**	
	LID	**Control**
Drainage Area (m^2) (%)	5,300	3,480
Impervious Fraction	3,180 (60%)	2,088 (60%)
Street Surface (DCIA)	1,278 (24%)	557 (16%)
Rooftop	1,378 (26%)	1218 (35%)
Sidewalk	530 (10%)	313 (9%)
Open Space	2,120 (40%)	1,392 (40%)
Slope	0.5%	0.7%
Soil Series	Baymeade Urban	Leon Urban
USDA Soil Class	Sand	Sand
Outlet Location	N 34.235293 W 77.934061	N 34.233696 W 77.939200
Receiving Water Body	Burnt Mill Creek	
River Basin	Cape Fear	

The New Hanover County soil survey indicates underlying soils in the control and LID catchments are Baymeade Urban and Leon Urban, respectively (Figure 3-1). Particle size distribution analysis (PSA) using the hydrometer method (Gee and Bauder, 1986) showed the USDA texture classification for the underlying soils is sand (Gee and Or, 2002). Infiltration rates in sandy urban soils range from 50 mm/hr (2 in/hr) to 460 mm/hr (18 in/hr), and are greatly impacted by compaction (Pitt et al., 2008). Maximum longitudinal slopes in the control and LID drainage areas are similar at 0.7% and 0.5%, respectively.

LID SCM Retrofits

LID SCMs constructed in February 2012 included a pair of BRC bumpouts, four permeable pavement parking spaces installed in two separate sections and one tree filter box installed along Dock Street and 12th Street (Figure 3-2, 3-4, 3-5). Post-retrofit TIA decreased from 60% to 58% and DCIA decreased from 24% to 12%. BRC bumpouts were constructed just west of the intersection of Jasmine Street and Dock Street to treat runoff from Dock Street. The BRCs extend 1.8 m (6 ft) into the existing roadway to create 3.5 m (11.5 ft) driving lanes (east and west bound) for the added benefit of traffic calming and pedestrian safety. Four permeable pavement parking stalls 7 m x 2.4 m (23 ft x 8 ft) each were installed in two separate sections on 12th Street between Dock Street and Orange Street to treat runoff from 12th Street. Permeable pavement loading ratios (drainage area/SCM surface area) of 7.8 and 6.6 are atypical, and the impacts of loading ratios this large have not been reported in the literature. Flow diverters were installed along the curb and gutter at 3.6 m intervals to force runoff into the parking areas (Figure 3-3).

Figure 3-2: Clockwise from top: BRC bumpouts along Dock Street, tree filter device at intersection of 12th Street and Dock Street, and permeable pavement parking stalls on 12th Street

A Filterra® tree filter device was installed on Dock Street at the southwest corner of the intersection with 12th Street to treat runoff from Jasmine Street and Dock Street that is down-slope of the bioretention bumpouts. The tree filter treats any overflow from the BRC bumpouts. The devices function as rapid flow-through filters such that ponding at the surface does not occur. Lenth et al. (2010) measured infiltration rates of ten Filterra™ devices with varying maintenance periods (recent – 2 years) and found infiltration rates from 2200 mm/hr (86 in/hr) to 5200 mm/hr (205 in/hr) with up to 110 mm (4.5 in) of sediment accumulation at the surface. Volume reduction is negligible because the concrete lining does not allow exfiltration to occur.

The BRC, permeable pavement and Filterra® unit combined to treat 94% of the street surface and 91% of the total drainage area for potential water quality improvement (Table 3-2).

Table 3-2: Summary of LID SCM design parameters

Parameter	**BRC**[a]	**Filterra®**	**PP I**[b]	**PP II**[c]
Surface Area	19 m^2	3 m^2	34 m^2	34 m^2
Street Surface Area	160 m^2	539 m^2	265 m^2	226 m^2
Loading Ratio[d]	8.4:1	180:1	7.8:1	6.6:1
Street Surface Area Treated	13%	42%	21%	18%
Total Catchment Area Treated	12%	22%	30%	27%
As Built Design Rainfall Event[e]	33 mm	N/A	24 mm	27 mm
Underdrain	No	Yes	No	No

[a] Bioretention Cell on Dock Street

[b] North permeable pavement parking area on 12th Street

[c] South permeable pavement parking area on 12th Street

[d] Calculated as drainage area/SCM surface area

[e] Runoff from given rainfall depth that is stored in SCM before overflow occurs, assuming no infiltration to underlying soils

Figure 3-3: Flow diverters installed on permeable pavement parking stalls along curb and gutter of 12th Street

Figure 3-4: Post-retrofit areal photo with approximate watershed boundary *(Google Maps)*

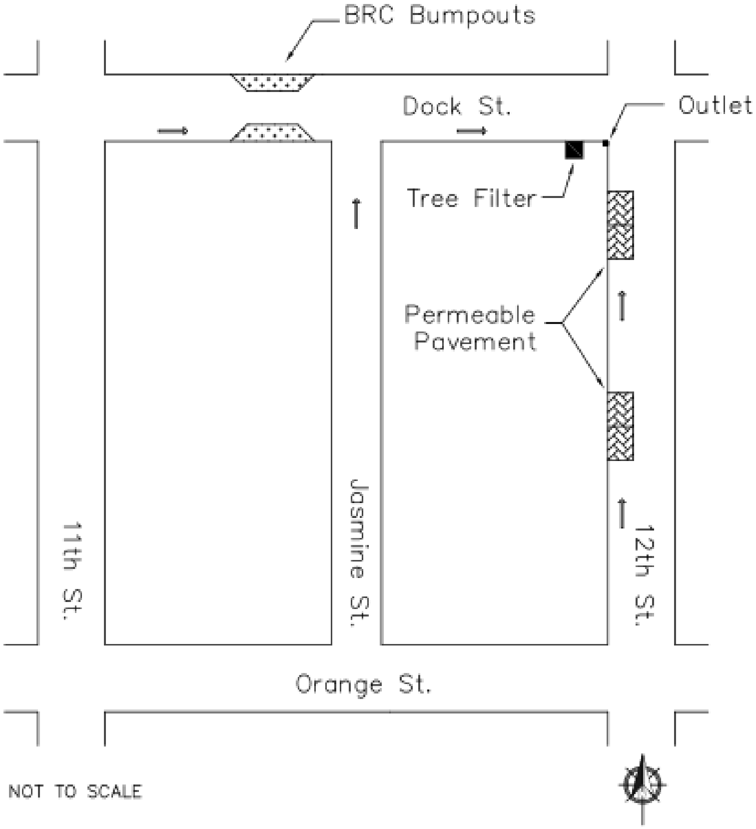


Figure 3-5: Layout of LID SCMs with arrows indicating direction of flow (not to scale)

Monitoring Design

The paired watershed study design was used to evaluate the hydrologic impacts of the LID SCM retrofits (Clausen and Spooner, 1993; Grabow et al., 1999). This approach requires two watersheds: control and treatment (LID) and two monitoring periods: calibration and treatment. During the calibration period, management practices in the catchments remained the same (no SCMs), the SCMs were installed in the LID catchment and treatment monitoring began post-construction (Table 3-3). The paired watershed approach is underpinned by a quantifiable and predictable (linear) relationship between the catchments. A relationship is developed during the calibration period, and is considered valid until the SCM treatment is applied to the LID catchment, at which time a new relationship between the catchments is developed during the second period of monitoring (Clausen and Spooner, 1993).

Table 3-3: Paired watershed study design

Period	**Catchment**	
	LID	**Control**
Calibration	No SCMs	No SCMs
Treatment	SCMs	No SCMs

Monitoring equipment was installed at the catchment outlets in May 2011. Manual and HOBO™ Tipping Bucket rain gauges were installed on a wooden post free of trees and overhead obstructions at the LID station (Table 3-4). An ISCO 6712™ portable sampler logged rainfall data from the tipping bucket. Hydrologic data were recorded by installing V-notch weirs and weir boxes inside the existing catch basins (Figure 3-6). Forty-five degree and 60° V-notch weirs were installed at the control and LID stations, respectively. The weir boxes were fitted with a 1 m (3.3 ft) long contracted rectangular weir to pass discharges from large storms. ISCO 730™ bubbler flow modules connected to ISCO 6712™ portable samplers were used to monitor discharge and total runoff volume by measuring stage above the weir at two minute intervals.

Table 3-4: Summary of monitoring equipment

Equipment	LID	Control
Location	Southwest corner of intersection of 12th and Dock St	Northwest corner of intersection of 8th and Orange St.
Structure	60° V-notch weir	45° V-notch weir
Flow Monitoring Device	ISCO 730™ Bubbler Module	ISCO 730™ Bubbler Module
Sampling Device	ISCO 6712™ Portable Sampler	ISCO 6712™ Portable Sampler
Rain Gauges	Manual and HOBO™ Tipping Bucket	NA[a]

[a]Control station located 0.5 km from LID station

Figure 3-6: V-notch weir and weir box installed inside existing catch basin

Sampling Protocol

The ISCO 6712™ portable samplers were programmed to suction 200 mL aliquots per specified runoff volume that was deposited into a 1 L bottle (Figure 3-7). Each sampler contained 24 1 L bottles. A minimum of 10 aliquots (2 L) was needed for a full set of water quality analyses to be conducted. The samplers were programmed to collect samples from rainfall events ranging from 6 mm to 380 mm (0.25 in to 1.5 in). Runoff samples were suctioned from the base of the weir box, 10 cm (4 in) behind the weir in an area of well-mixed flow.

Figure 3-7: Retrofit station with JoBox ™, rain gauges, and weir box inside existing catch basin (left), two ISCO 6712™ portable samplers with ISCO CDMA Cellular Phone Modem™ installed inside retrofit JoBox™(right)

Water quality samples were collected within 24 hours of a rainfall event. Total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total ammoniacal nitrogen (TAN), nitrate-nitrite-nitrogen ($NO_{2,3}$-N), total phosphorous (TP), and ortho-phosphate ($O\text{-}PO_4^{-3}$) samples were analyzed by the North Carolina Center for Applied Aquatic Ecology at NCSU in Raleigh, NC. Total nitrogen (TN) concentrations were calculated by summing TKN and $NO_{2,3}$-N; organic nitrogen (ON) concentrations were determined by subtracting TAN from TKN for each sampled storm event. Total polycyclic aromatic hydrocarbons ($\sum$PAHs), copper (Cu), lead (Pb) and zinc (Zn) samples were analyzed by the NCDENR Environmental Chemistry Lab in Raleigh, NC.

Both labs were located approximately 210 km (130 mi) from the study site. Laboratory analytical methods are listed in Table 3-5.

Table 3-5: Laboratory analytical methods and reporting limits

Pollutant	**Pollutant Name**	**Analytical Method**	**RL**[a]	**Unit**
$NO_{2,3}$-N	Nitrate + Nitrite Nitrogen	SM 4500-NO3-F[b]	0.0056	mg/L
TKN	Total Kjeldahl Nitrogen	EPA 351.1[c]	0.14	mg/L
TAN	Total Ammoniacal Nitrogen	SM 4500-NH3-H[b]	0.007	mg/L
ON	Organic Nitrogen	= TKN - TAN	NA	mg/L
TN	Total Nitrogen	= TKN + $NO_{2,3}$-N	NA	mg/L
O-PO_4^{-3}	Orthophosphate	SM 4500-P-F[b]	0.006	mg/L
TP	Total Phosphorus	SM 4500-P-F[b]	0.01	mg/L
TSS	Total Suspended Solids	SM 2540 D[b]	1	mg/L
Cu	Copper	EPA 200.8[c]	2	µg/L
Pb	Lead	EPA 200.8[c]	10	µg/L
Zn	Zinc	EPA 200.7[c]	10	µg/L
∑PAH	Polycyclic Aromatic Hydrocarbons	EPA 625/8270/3510[c]	10-50	µg/L

[a] Reporting Limit
[b] Eaton et al., 1995
[c] US EPA, 1993

Upon arrival in Wilmington, both stations were checked to ensure the weirs were clear of debris and the samplers had collected adequate paired samples. Individual 1-liter bottles with aliquots were poured into a 24 L mixing vessel. The mixing vessel was agitated to re-suspend particulates and pollutants. From the mixing vessel, a plastic TSS bottle (1000 mL) and total metals bottle (500 mL) was filled. Nitric acid ampoules were added to each metals sample bottle. A pre-acidified plastic nutrients bottle (125 mL) was filled, and approximately 30 mL of water was filtered through a 0.45 µm filter into a glass bottle for O-PO_4^{-3} analysis. Latex gloves were used while sampling, and samples were placed on ice immediately for transportation to the laboratories (Figure 3-8).

Figure 3-8: Sample bottles placed on ice for transport (left) and research vehicle with sampling equipment (right)

Monitoring Challenges

The primary monitoring challenge was keeping the weirs and weir boxes clear of debris. Leaf litter, woody material, trash and coarse sediment that accumulated on the street surface (Figure 3-3) were frequently deposited in the base of the weir box during a storm (Figure 3-9). This was more common at the control station during fall and winter sampling seasons. Debris was removed from the weirs and weir boxes during each site visit. In October 2011 the City of Wilmington was required to make existing crosswalks ADA compliant, including the western crosswalk at the intersection of 8th Street and Orange Street, which was 1 m (3 ft) upslope of the control station. This required the control station to be removed in November 2011, ending calibration monitoring. The ADA crosswalk was installed incorrectly in December 2011 allowing runoff to bypass the catch basin where the control station had been installed. In May 2012 the ADA crosswalk was corrected and runoff from the control catchment was directed into the original catch basin enabling treatment monitoring to begin.

Figure 3-9: Debris clogging control weir (left) and removing organic material from control weir box (right)

Data Processing

Hydrologic data were reviewed using FLOWLINK Version 5.0 software (ISCO, 2005) and compared to field notes. Rainfall intensities and total depths were adjusted by a scaling factor developed from the discrepancy (deficit) recorded by the tipping bucket and manual rain gauges. Storms were removed from the data set when paired data points were not collected due to power failure, equipment malfunction or weir obstructions. During pre-retrofit monitoring, all laboratory analysis of storms sampled for $\sum$PAH indicated concentrations were below the practical reporting limits (PQL); therefore $\sum$PAH sampling was suspended for the second period of monitoring. For other pollutant concentrations that were less than the PQL, one-half the value of the PQL was used for calculations and statistical analysis. Pollutant loads for each storm were calculated in units of grams/hectare (g/ha) using Equation 3-1 for statistical analysis. Annual mass export rates were estimated in units of kilograms/hectare/year (kg/ha/yr) using the ratio method shown in Equation 3-2.

$$L = \frac{Q \times C_P}{A_{WS} \times 1000} \qquad \text{Equation 3-1}$$

Where,

L = Pollutant load (g/ha)

Q = Storm runoff volume (L)

C_p = Pollutant concentration (mg/L)

A_{WS} = Watershed area (ha)

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

Equation 3-2

Where,

L_{annual} = estimated annual load (kg/ha/yr)

$L_{measured}$ = pollutant load measured (kg/ha)

P_{annual} = long term average annual rainfall (mm)

$P_{measured}$ = rainfall measured during monitoring (mm)

Statistical Analysis

SAS Version 9.3™ was used for all statistical analyses (SAS Institute, 2012). Data sets from the calibration and treatment periods were log transformed and tested separately using analysis of variance (ANOVA) for a significant linear relationship with metrics from the LID and control catchments as covariates (control = x, LID = y). The residuals of regression were inspected graphically for normality and constant variance. Skew coefficients and the Shapiro-Wilk goodness-of-fit test were also used to assess residual normality. Analysis of covariance (ANCOVA) was used to detect significant impacts on the slopes and intercepts of concentration and mass load regressions for each water quality constituent. No significant differences in slopes were observed, thus the reduced ANCOVA model with constant slopes was used for all water quality analyses. A significant difference in intercepts of calibration and treatment regression lines implied the LID SCM treatment had a significant impact on that water quality parameter.

Least squared means (LSM) analysis was used to quantify significant changes in pollutant concentrations and loads from calibration to treatment monitoring. Percent reductions were calculated using Equation 3-3.

$$Change(\%) = [1 - \frac{10^{\bar{Y}_T}}{10^{\bar{Y}_C}}] \times 100 \qquad \text{Equation 3-3}$$

Where,

$\bar{Y}_T$ = LID LSMean during treatment monitoring

$\bar{Y}_C$ = LID LSMean during calibration monitoring

Significant linear relationships did not exist for O-PO_4^{-3}, Pb, Zn and TSS concentrations during the calibration period, thus statistical comparisons were made between the control and LID drainage areas using paired post-retrofit water quality data. Differences in paired data points from the LID and control catchments were checked for normality using the Shapiro-Wilk goodness-of-fit test. If the differences were not normally distributed, the raw data sets were log transformed and tested again. Differences that were determined to be approximately normal were tested for a significant difference with a Student's t-test. In instances where the paired differences remained non-normally distributed, the Wilcoxon signed rank test was used for data with a single outlier and the sign test was used when two or more outliers were present.

3.4 Results and Discussion

Precipitation

Normal annual rainfall at Wilmington International Airport (ILM) is 1,448 mm (57 in) distributed relatively uniformly throughout the year (NC State Climate Office, 2012). The calibration and treatment monitoring periods occurred from 10 May 2011 to 31 October 2011 and 8 June 2012 to 13 February 2013, respectively. Total rainfall recorded during the calibration and treatment periods was 436 mm and 811 mm, respectively. Storms less than 6 mm (0.25 in) were not sampled for water quality analysis. A six-hour antecedent dry period was used to separate discrete rainfall events. During calibration monitoring, six events were sampled in summer and three in fall (Table 3-6). Post-retrofit, water quality samples were collected for all four seasons.

Table 3-6: Seasonal distribution of sampling events

Period	Spring	Summer	Fall	Winter
Calibration	-	6	3	-
Treatment	2	5	5	4

Similar rainfall characteristics were observed in both monitoring periods. Mean storm depth during the calibration period was 21.3 mm (0.84 in) compared to 19.3 mm (0.76 in) recorded during treatment monitoring. The difference in mean rainfall depth was primarily caused by 143 mm (5.6 in) of rainfall from Hurricane Irene that occurred on 26 August 2011. Rainfall depth from the 50th percentile storm (12.7 mm) (0.5 in) was used to partition rainfall data (Tables 3-7). Bean (2005) reported rainfall depth percentiles for Wilmington, NC.

Table 3-7: Precipitation summary for calibration and treatment periods (all units in mm)

Period	n[a]	Range	50th Percentile		Mean	Median	Total
			<12.7	>12.7			
Calibration	9	7.1 - 143	3 (33%)	6 (67%)	33.5	19.1	436
Treatment	16	7.9 - 72	6 (38%)	10 (62%)	24.1	16.8	811

[a]Number of storms sampled for water quality during monitoring period

Pre-retrofit, data collection was limited due to crosswalk construction in the control catchment (see *Monitoring Challenges)*. Ideally, the calibration and treatment monitoring periods would have lasted for one year or more each, as outlined by Clausen and Spooner (1993). The watersheds in this study were small urban drainage areas located 0.5 km apart with similar land use, imperviousness, topography, soil and nearly identical climate and weather patterns. The only difference between the catchments during this study was the SCM treatment. It was determined that data collected during the shortened calibration period established predictable relationships between the catchments sufficient to utilize ANCOVA to make valid statistical comparisons.

Nutrients – Nitrogen

For the most part, median pollutant concentrations were less than the computed means due several events with spikes in concentrations in runoff at both monitoring stations. During treatment monitoring, TKN concentrations from the LID catchment significantly decreased by 62% (Table 3-8) (Figure 3-10). The median LID TKN concentration was 0.45 mg/L, which is more than three times less than median TKN concentration of 1.48 mg/L reported by Line et al. (2002) for traditional residential development in North Carolina. The median control TKN concentration was 1.14 mg/L. Dissolved nitrogen pollutant concentrations of TAN and $NO_{2,3}$-N remained unchanged after the SCMs were installed (Figure 3-11). Sources of TKN and TAN in residential watersheds include organic material, animal wastes and atmospheric deposition on rooftops, driveways and roads (Bannerman et al., 1993). LID TAN concentrations were similar to those reported for LID commercial and residential sites (Table 3-8). The decrease in LID TKN concentration was likely due to particulate ON capture (leaf litter and woody debris) by the SCMs. Median $NO_{2,3}$-N concentrations at the control and LID outlets were 0.14 mg/L and 0.07 mg/L, respectively, which are less than $NO_{2,3}$-N concentrations observed at other residential sites and well below a previously suggested irreducible concentration (0.7 mg/L) defined by Schueler and Holland (2000) (Table 3-8). $NO_{2,3}$-N in runoff tends to originate from commercial fertilizer use (Bannerman et al., 1993). In both drainage areas monitored, there was minimal ornamental landscaping and lawn area, and fertilizer use was not documented.

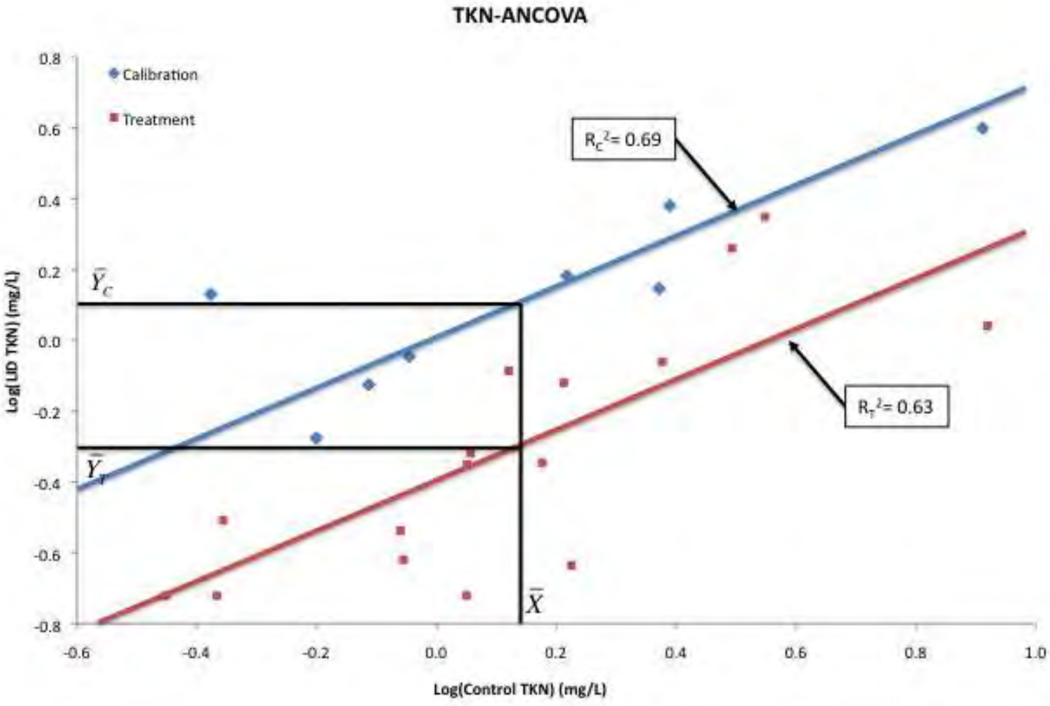


Figure 3-10: Reduced ANCOVA model for TKN concentration (mg/L)

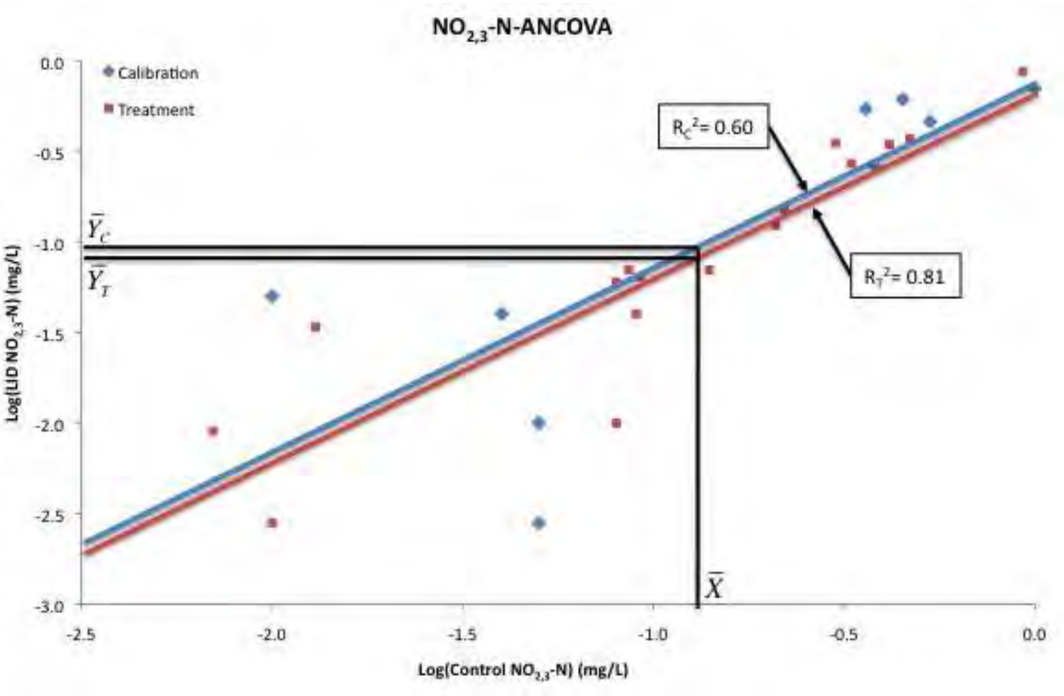


Figure 3-11: Reduced ANCOVA model for $NO_{2,3}$-N concentration (mg/L)

Table 3-8: Summary of nutrient and sediment concentrations at the catchment outlets (mg/L)

Station	Duration (yr)	n[a]	TKN	TAN	$NO_{2,3}$-N	TSS	$O\text{-}PO_4^{-3}$	TP
Control	1.14	25						
Mean			1.92	0.20	0.25	53	0.23	0.44
Median			1.14	0.06	0.14	42	0.10	0.22
LID-Calibration	0.47	9						
Mean			1.52	0.07	0.30	50	0.21	0.29
Median			1.35	0.04	0.26	54	0.11	0.21
LID-Treatment	0.67	16						
Mean			0.66	0.04	0.18	11	0.12	0.21
Median			0.45	0.03	0.07	7	0.10	0.17
LSM Difference[b]			-62%*	0%[NS]	0%[NS]	-82%[T]*	-54%[S]*	-38%[NS]
US Residential[1]			1.51	-	0.48	172	0.12	0.26
NC Residential[2]			1.48	0.34	0.49	42	-	0.40
LID Residential[3]			1.30	0.04	0.40	11	-	0.29
LID Commercial[4]			0.69	0.06	0.56	18	0.01	0.06

*Significant

[NS] Not Significant

[T] Paired t-test used for statistical comparison

[S] Sign rank test used for statistical comparision

[a] Number of events sampled
[b] Negative sign "-" implies reduction
[1] Claytor and Schueler, 1996
[2] Line et al., 2002
[3] Bedan and Clausen, 2009
[4] Line et al., 2012

Overall, annual nitrogen mass export rates from the catchments in this study were less than those reported for residential development in North Carolina and the U.S. (Table 3-9). This is primarily due to the sandy soils in the study area, which is reflected by the low runoff coefficients (runoff/rainfall) of the control and LID watersheds. At the LID outlet, mass exports of TKN and TAN significantly decreased by 78% and 61%, respectively. $NO_{2,3}$-N mass export rate decreased by 47%; although this was not significant. Post-retrofit, annual LID TKN load was five times less than the untreated control drainage area (0.5 kg/ha/yr compared to 2.6 kg/ha/yr). TKN and $NO_{2,3}$-N loads at the LID station were similar to those reported by Bedan and Clausen (2009) for a residential LID watershed in Connecticut. TAN mass export from the LID catchment was 0.1 kg/ha/yr, which is nearly the same as TAN load for an undeveloped watershed in North Carolina (Table 3-9). Decreases in TAN and $NO_{2,3}$-N loads were due to reductions in runoff volume after construction of the LID SCMs, as evidenced by the decrease in LID runoff coefficient from 0.22 to 0.13.

Table 3-9: Summary of nutrient and sediment export rates (kg/ha/yr)

Station	Runoff Coefficient	n[a]	TKN	TAN	$NO_{2,3}$-N	TSS	$O\text{-}PO_4^{-3}$	TP
Control	0.14	24	2.6	0.3	0.4	113	0.2	0.6
LID-Calibration	0.22	8	2.8	0.2	0.3	157	0.3	0.7
LID-Treatment	0.13	16	0.5	0.1	0.1	12	0.1	0.2
LSM Difference[b]			-78%*	-61%*	-46%^{NS}	-91%*	-55%*	-73%*
LID Residential[1]	0.07		0.9	0.0	0.3	8	-	0.2
NC Residential[2]	0.57		20.7	2.4	3.2	387	-	2.3
NC Undeveloped[3]	0.21		5.3	0.2	1.0	349	-	0.5

---

*Significant
[NS]Not Significant
[a]Number of events used to evaluate pollutant loads
[b]Negative sign "-" implies reduction
[1]Bedan and Clausen, 2009; Hood et al., 2007
[2]Line et al., 2002
[3]Line and White, 2007

Nutrients – Phosphorus

Post-retrofit, O-PO_4^{-3} concentrations in the LID catchment were 54% less than those observed in the control catchment (Table 3-8). However, mean O-PO_4^{-3} concentrations in both drainage areas were skewed by several events with spikes in O-PO_4^{-3} concentrations. Median O-PO_4^{-3} concentrations (0.10 mg/L) in LID catchment remained unchanged compared to those observed at the control station (0.11 mg/L) and pre-retrofit conditions (0.10 mg/L)(Table 3-8). Dissolved O-PO_4^{-3} originates from fertilizers and lawns in residential watersheds, and can also be leached from soils that have reached their phosphorus sorption capacity (Waschbusch et al., 1999). Median O-PO_4^{-3} concentrations observed in this study were nearly the same as those reported by Claytor and Schueler (1996) for residential sites in the U.S. LID TP concentration decreased by 38%. While not statistically significant at $\alpha=0.05$, this reduction was significant at $\alpha=0.10$ ($p=0.0823$). The modest decrease in TP concentration was mainly due to sediment retention by the SCMs.

Post-retrofit, mass export of O-PO_4^{-3} and TP at the LID outlet significantly decreased by 55% and 73%, respectively (Table 3-9). Annual LID TP load was three times less than TP load from the control catchment (0.2 kg/ha/yr compared to 0.6 kg/ha/yr). LID TP mass export was the same as the TP load reported by Bedan and Clausen (2009) for a residential LID watershed and 11.5 times less than a residential watershed with no SCMs studied by Line et al. (2002). The majority of TP load reduction from the LID catchment was due to substantial reductions in runoff volume, some treatment of runoff was observed, evidenced by the 38% decrease in TP concentration.

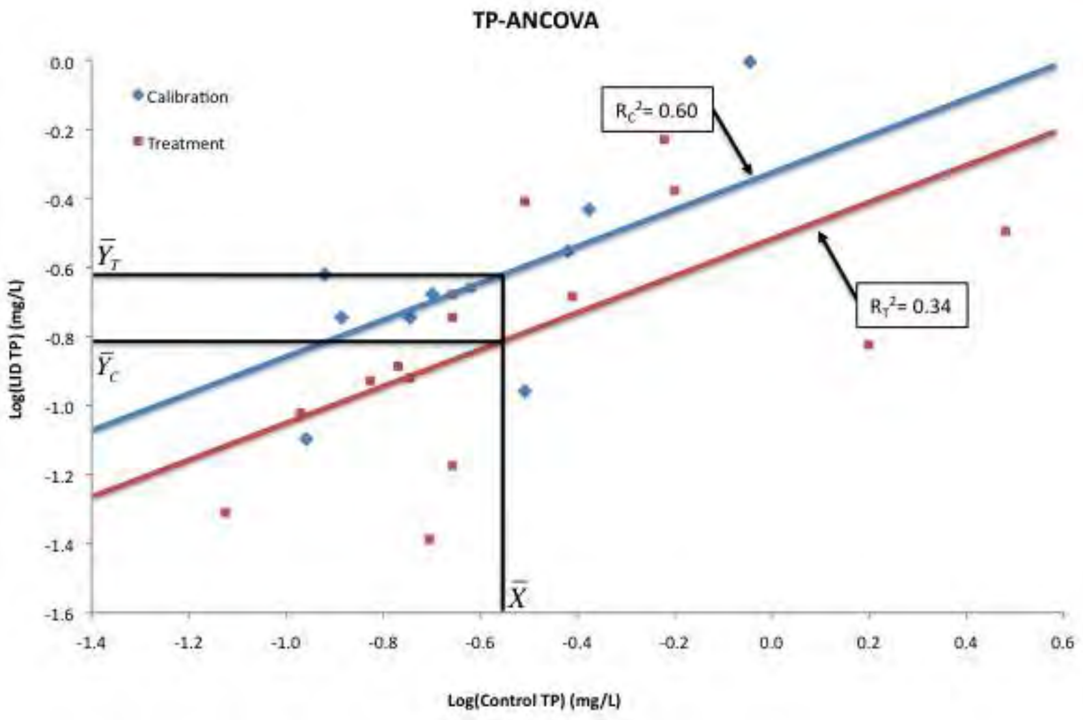


Figure 3-12: Reduced ANCOVA model for TP load (g/ha)

Total Suspended Solids

Mean LID TSS concentration decreased from 50 mg/L to 11 mg/L, post-retrofit and was significantly less than TSS concentration (53 mg/L) observed at the control station (Table 3-8). LID TSS concentration was nearly the same as those observed by Line et al. (2012) and Bedan and Clausen (2009) from commercial and residential LID sites, respectively . TSS concentrations during the calibration period were similar to those reported by Line et al. (2002) at a residential watershed in North Carolina. However, mass export rates of TSS from both catchments in this study were less than half of TSS loads observed by Line et al. (2002), suspectedly due to the flat topography and sandy soils of drainage areas in this study that generated low runoff coefficients (Table 3-9). Post-retrofit, TSS load at the LID outlet significantly decreased by 91% (Figure 3-

13) (Table 3-9). The dramatic decrease in TSS load is due to runoff treatment and volume reduction. At the LID outlet, annual TSS load was 12 kg/ha/yr, which was similar to TSS loads observed by Bedan and Clausen (2009) where a low runoff coefficient of 0.07 was also reported.

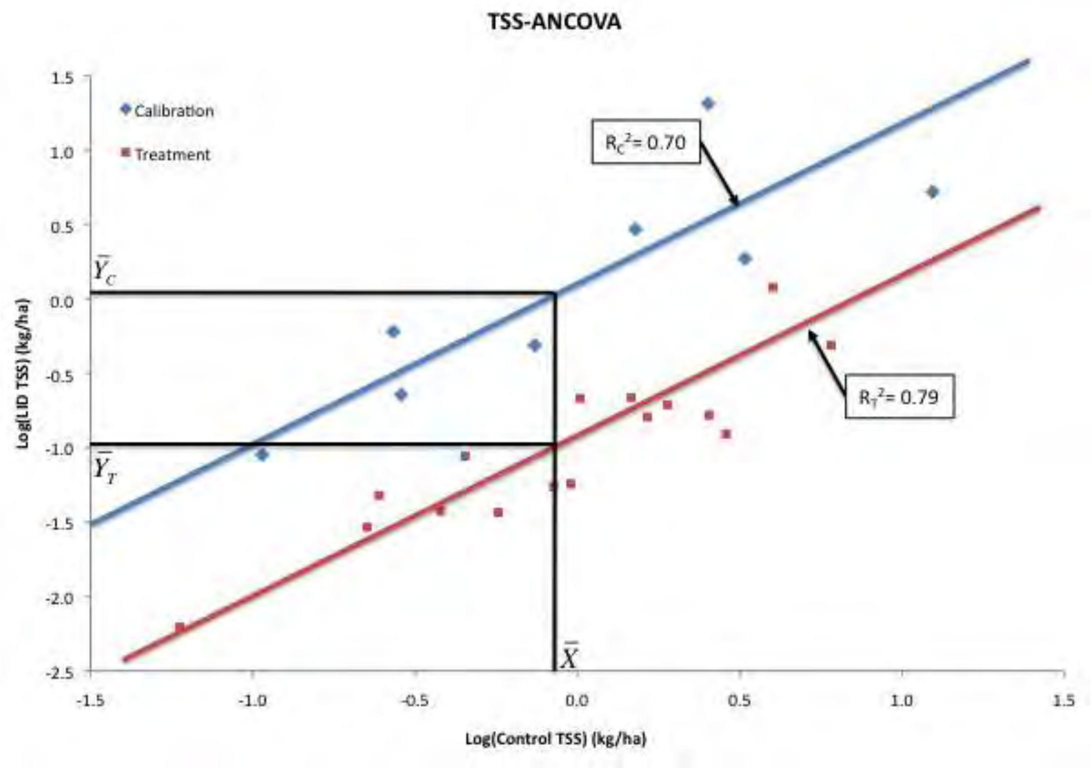


Figure 3-13: Reduced ANCOVA model for TSS load (kg/ha)

Metals – Cu, Pb and Zn

In residential watersheds, Cu, Pb and Zn in runoff have been linked to vehicular brake wear, aged exterior paint and tire wear, respectively (Bannerman et al., 1993; Davis et al., 2001). Cu concentrations in the LID catchment significantly decreased by 55% (p=0.0051) (Table 3-10) (Figure 3-14). LID concentrations of Pb and Zn were significantly less than those observed in the control catchment by 89% and 76%, respectively. In general, metals concentrations observed in this study were less than the average concentrations reported by Claytor and Schueler (1996) for residential streets across the U.S. Post-retrofit, Cu, Pb and Zn concentrations in the LID catchment were similar to those reported by Bedan and Clausen (2009) from a residential LID watershed. Mass exports of Cu, Pb and Zn at the LID outlet significantly decreased by 53%, 88%, and 77%, respectively. Large reductions of heavy metals loads were due to decreases in concentration and runoff volume leaving the LID catchment.

Table 3-10: Summary of metals concentrations at the catchment outlets (μg/L)

Station	Duration (yr)	n[a]	Cu	Pb	Zn
Control	1.14	25			
Mean			16	37	84
Median			13	35	70
LID-Calibration	0.47	9			
Mean			14	22	85
Median			14	14	65
LID-Treatment	0.67	16			
Mean			6	4	21
Median			5	2	18
LSM Difference[b]			-62%*	-89%[T]*	-76%[T]*
NURP Residential[1]			25	51	173
LID Residential[2]			6	1	17
NC Parking Lots[3]			13	5	72

*Significant

[T] Paired t-test used for statistical comparison

[a] Number of events sampled

[b] Negative sign "-" implies reduction

[1] Claytor and Schueler, 1996

[2] Bedan and Clausen, 2009

[3] Hunt et al., 2008

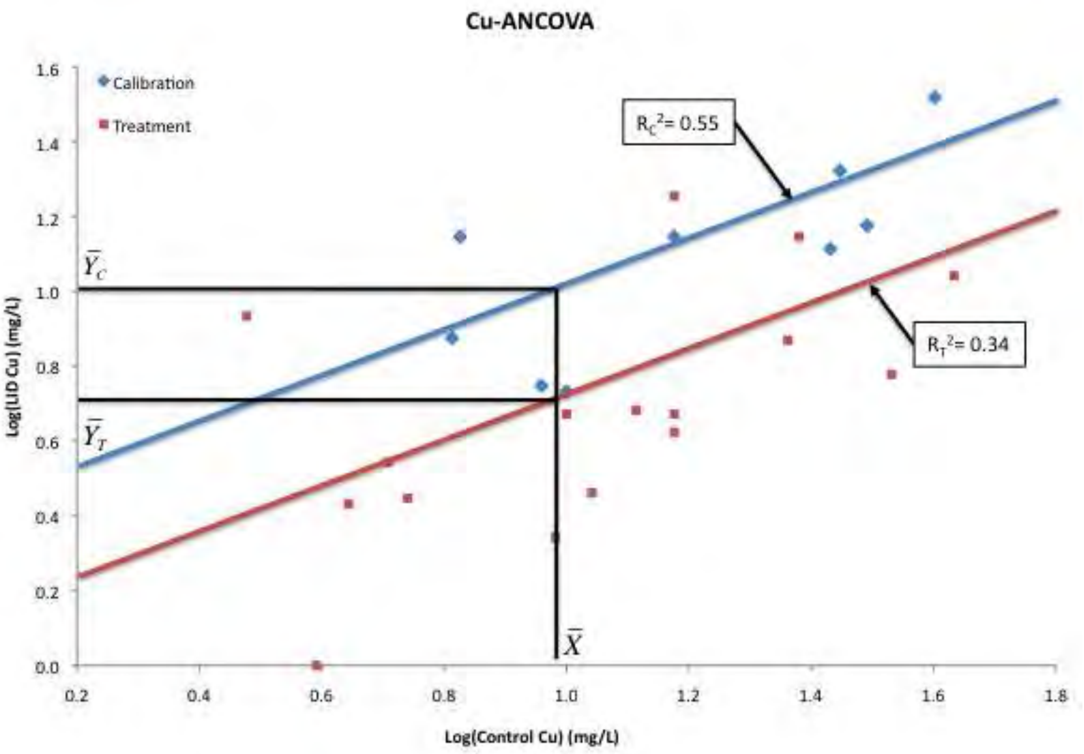


Figure 3-14: Reduced ANCOVA model for Cu concentrations (mg/L)

First Flush Phenomenon

The first flush nature of pollutant loading likely impacted this study as concentrations leaving the LID catchment were lowered for all particulate or particulate-bound pollutants, post-retrofit (TKN, TP, TSS, Cu, Pb, Zn). Changes in dissolved pollutant concentrations (TAN, $NO_{2,3}$-N and O-PO_4^{-3}) were not observed. The first flush phenomenon suggests most of the pollutant load contained in urban runoff is delivered during the first part of a storm (Bertrand-Krajewski et al., 1999; Sansalone et al., 2005). Evaluations of highway runoff have shown that TSS and heavy metals produce a substantial first flush of pollutant load (Sansalone and Buchberger, 1997). In Maryland, Flint and Davis (2007) found that 81%-86% of TKN, $NO_{2,3}$-N, TP, TSS, Cu, Pb and Zn mass loads were contained in the first 13 mm (0.5 in) of runoff. Assuming exfiltration to the underlying soil does not occur during a storm, as-built design rainfall events for the BRC, PP I and PP II were 33 mm (1.3 in), 24 mm (0.95 in) and 27 mm

(1.05 in), respectively (Table 3-2). Prior to construction of the LID SCMs, 13 mm (0.5 in) of runoff at the LID watershed outlet corresponded to 30 mm (1.2 in) of rainfall based on regression analysis of a rainfall vs. runoff plot. Of the 16 events sampled for water quality post-retrofit, 12 were less than 30 mm and 11 were less than the minimum design rainfall event (24 mm) of the BRC and permeable pavement. This means that for 69% of for the storms monitored, the SCMs could have captured all influent runoff. The SCMs likely retained a large fraction of the first flush of pollutants from the beginning stages of a storm or smaller storms entirely, and because underdrains were not installed in the BRC or permeable pavement, all influent runoff exfiltrated to the underlying soil. This contributed to the decrease in particulate pollutant concentrations and all pollutant loads observed in the LID catchment.

The BRC and permeable pavement parking areas combined to treat 52% of the DCIA and 69% of the total catchment. Runoff volume and pollutant load reductions observed in this study were similar to other studies of LID SCMs. Permeable pavement has been documented to reduce runoff volume by 28% with a 4.3:1 loading ratio over soils with low permeability (Fassman and Blackbourn, 2010). Bean et al. (2007b) found that permeable pavement installed over sandy soil eliminated all runoff and subsequent pollutant loads when the underdrains were removed. Field studies have shown BRCs can capture runoff volume and pollutant loads from small storms entirely (Li and Davis, 2009; Li et al., 2009; Brown and Hunt, 2011). The tree filter device, which treated 42% of the DCIA and 22% of the total catchment, also contributed to reductions in particulate pollutant concentrations and loads. The primary treatment processes within the Filterra® unit are filtration and sedimentation. Yu and Stafford (2007) found that Filterra® units removed 85% of influent TSS, 16% of Cu and 50% of Zn. Some nutrient retention was also reported for TKN (20%) and TP (55%), which was mainly attributed to particulate ON and TSS capture. The combined impacts of first flush volume and pollutant retention in the BRC and permeable pavement and high level of particulate retention in the tree filter unit resulted in significant reductions of all pollutant loads, except $NO_{2,3}$-N.

Impacts to In-stream Biota

Benthic macroinvertebrates are used to assess water quality impairment in streams and have been used to evaluate the performance of SCMs (Barbour et al., 1999). McNett et al. (2010) used qualitative benthic macroinvertebrate health and corresponding in-stream nutrient and sediment concentrations in North Carolina to establish water quality thresholds and evaluate SCM effectiveness. “Good” water quality thresholds in coastal North Carolina for TN and TP are 0.73 mg/L and 0.09 mg/L, respectively. TN concentrations from the untreated control catchment exceeded 0.73 mg/L for 80% (13 of 16) of the events sampled (Figure 3-15). At the LID outlet, TN concentrations were less than the 0.73 mg/L threshold for 70% (10 of 16) of the events sampled after the SCMs were installed. For TP, just one of the events sampled at the control site had concentrations less than 0.09 mg/L; LID TP concentrations were less than 0.09 mg/L for 3 of 16 (19%) events sampled (Figure 3-16). Bannerman et al. (2004) suggested the target effluent TSS concentration from SCMs to be 25 mg/L. TSS concentrations at the control outlet exceeded 25 mg/L in 75% (13 of 16) of the storms sampled (Figure 3-17). At the LID outlet, TSS concentrations for 90% (14 of 16) of the storms sampled were less than the 25 mg/L threshold.

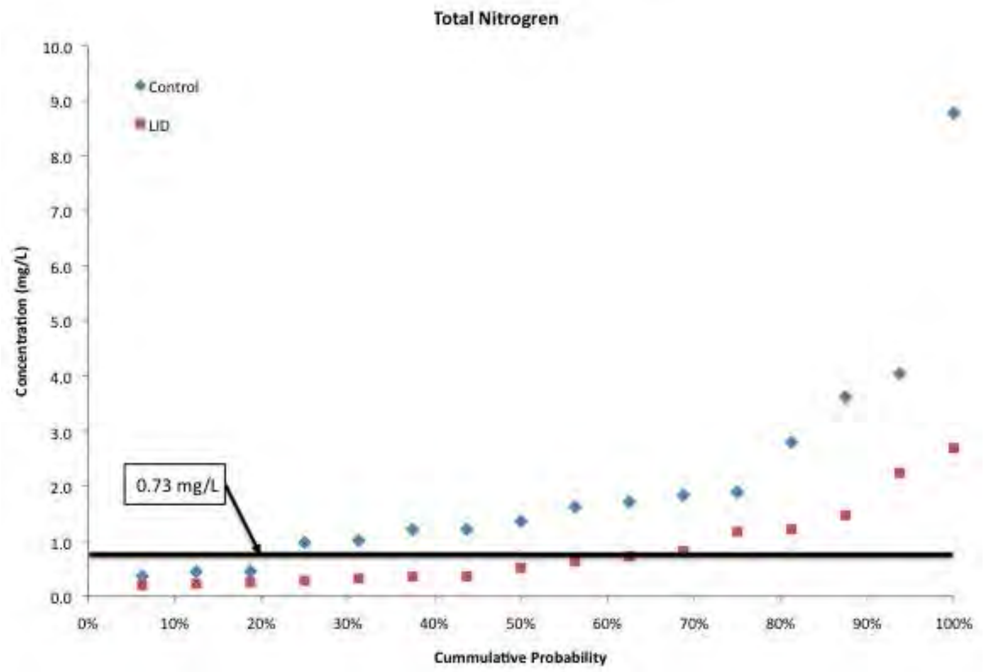


Figure 3-15: TN concentration cumulative probability with 0.73 mg/L water quality threshold

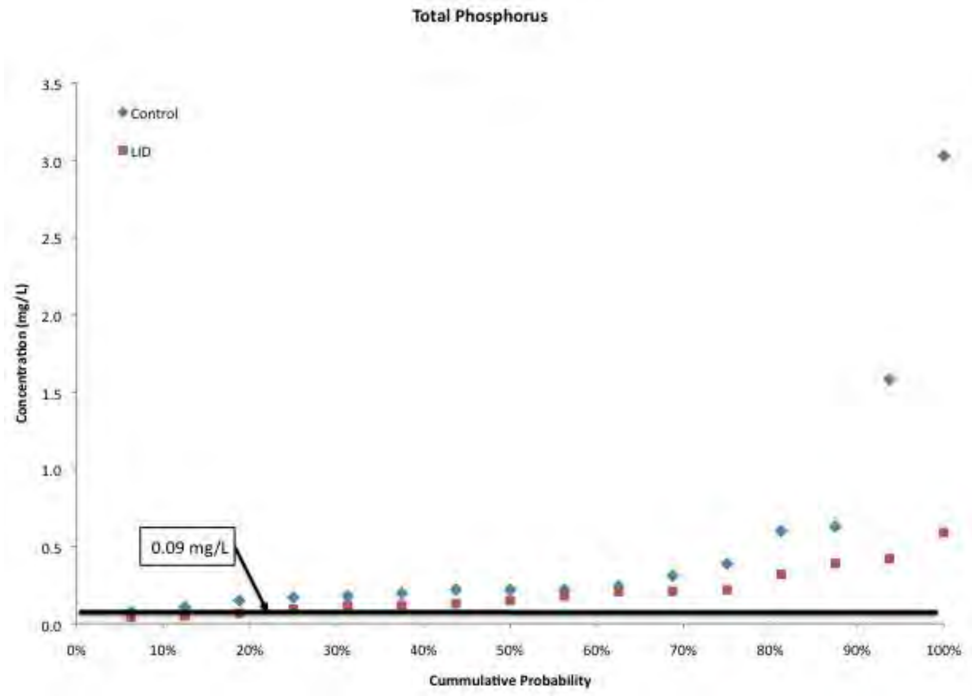


Figure 3-16: TP cumulative probability with 0.09 mg/L water quality threshold

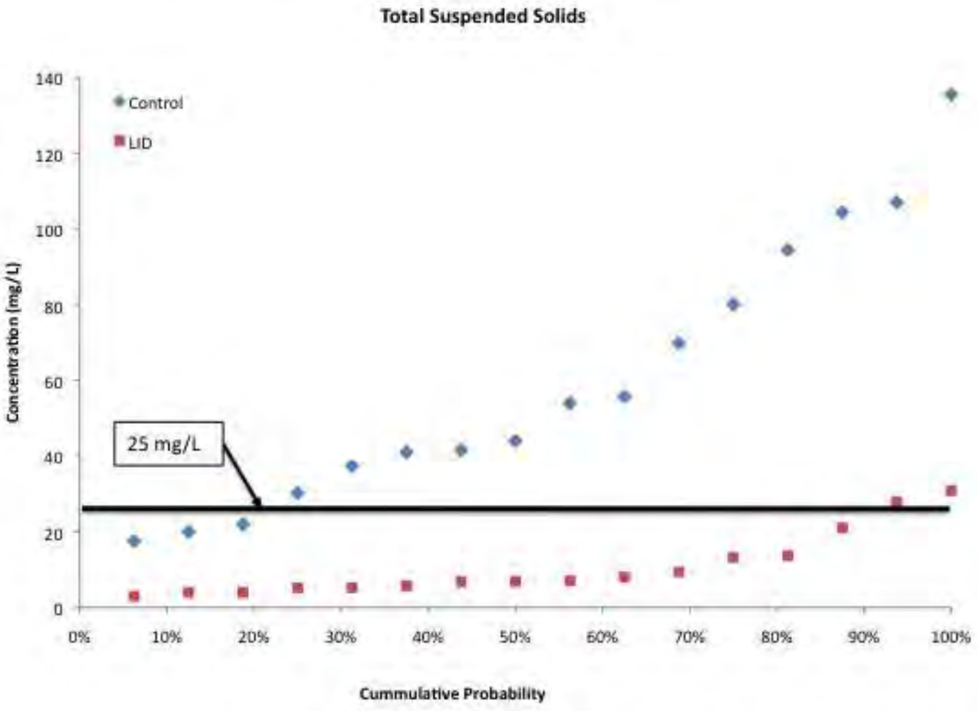


Figure 3-17: TSS concentration cumulative probability with 25 mg/L water quality threshold

3.5 Summary and Conclusions

This study has shown that strategically placed LID SCMs installed within the street right-of-way can mitigate some the water quality impacts of existing residential development in drainage areas with sandy soils. The following conclusions were drawn from this study:

- At the LID site post-retrofit, concentrations of TKN, TSS, Cu, Pb and Zn significantly decreased by 62%, 82%, 55%, 89% and 76%, respectively. TP concentration significantly decreased by 38% at α=0.10. Concentrations of $NO_{2,3}$-N and TAN did not change. TKN concentration reductions were due to particulate ON capture. Mean LID outlet concentrations of O-PO_4^{-3} were 55% less than those observed in the control drainage area, but median O-PO_4^{-3} concentrations not were different between the drainage areas or pre-retrofit conditions. Decreases in TP concentration were likely due to TSS retention by the SCMs.

- Mass exports of TKN, TAN, O-PO_4^{-3}, TP, TSS, Cu, Pb and Zn were significantly decreased by 78%, 61%, 55%, 73%, 91%, 53%, 88% and 77%, respectively. $NO_{2,3}$-N load decreased by 46% (although not significantly). Dramatic reductions of particulate and particulate-bound pollutant loads implied water quality treatment and runoff volume reduction. This was attributed to first flush retention of runoff by the BRC and permeable pavement that treated 52% of the DCIA and treatment by the tree filter unit serviced 42% of the DCIA.
- TN concentrations at the LID outlet were less than the "good" water quality threshold established by McNett et al. (2010) for 10 of 16 (70%) events sampled, compared to just 3 of 16 events (20%) at the control outlet. TP concentrations were below 0.09 mg/L for 1 of 16 (6%) and 3 of 16 (19%) sampling events at the control and LID sites, respectively. LID TSS concentrations were below the 25 mg/L target threshold for 90% of sampling events, while control TSS concentrations exceeded 25 mg/L in 75% of the events sampled.
- In this study the LID SCMs were installed over very sandy soils and seemed to be adequately sized to retain and treat the majority of pollutants in runoff for most of the storms observed. Future residential street retrofit projects in watersheds with less permeable soils should consider sizing the SCMs for the entire contributing drainage area in lieu of just the DCIA.
- Dissolved nutrient concentrations and loads, namely $NO_{2,3}$-N, were not greatly impacted by the SCMs. This is not uncommon in studies of SCMs; $NO_{2,3}$-N retention in BRCs and permeable pavement systems has been problematic, frequently effluent concentrations are greater than those observed at the inlet. In areas where $NO_{2,3}$-N is the primary pollutant

of concern or where fertilizers are used regularly, other SCMs specifically modified to create denitrifying conditions should be considered.

3.6 References

Bannerman, R. T., Owens, D. W., Dodds, R. B., and Hornewer, N. J. (1993). "Sources of Pollutants in Wisconsin Stormwater." *Water Science and Technology,* 28(3-5), 241-259.

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

Bean, E. Z. (2005). "A field study to evaluate permeable pavement surface infiltration rates, runoff quantity, runoff quality, and exfiltrate quality." Thesis. North Carolina State University, Raleigh, NC.

Bean, E. Z., W. F. Hunt and D. A. Bidelspach. (2007a). "Field survey of permeable pavement surface infiltration rates. " *J.Irrig.Drainage Eng-ASCE*, 133(3): 249-255.

Bean, E. Z., Hunt, W. F., and Bidelspach, D. A. (2007b). "Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts." *J.Irrig.Drainage Eng-ASCE,* 133(6), 583-592.

Bedan, E. S., and Clausen, J. C. (2009). "Stormwater Runoff Quality and Quantity From Traditional and Low Impact Development Watersheds." *Journal of the American Water Resources Association,* 45(4), 998-1008.

Bender, G., and Terstriep, M. (1984). "Effectiveness of street sweeping in urban runoff pollution control." *Sci.Total Environ.,* 33(1), 185-192.

Brattebo, B. O., and Booth, D. B. (2003). "Long-term stormwater quantity and quality performance of permeable pavement systems." *Water Res.,* 37(18), 4369-4376.

Brown, R. A., and Hunt, W. F.,III. (2011). "Impacts of Media Depth on Effluent Water Quality and Hydrologic Performance of Undersized Bioretention Cells." *J.Irrig.Drainage Eng-ASCE,* 137(3), 132-143.

Clausen, J.C. and J. Spooner, 1993. *Paired Watershed Study Design*. U.S. Environmental Protection Agency, USEPA 841-F-93-009.

Coffman, L.S. 2000. Low-Impact Developmeent Design: A New Paradigm for Stormwater Management Mimicking and Restoring the Natural Hydrologic Regime An Alternative Stormwater Management Technology. Department of Environmental Resources, Prince Georges County, Maryland.

Collins, K. A., Hunt, W. F., and Hathaway, J. M. (2008). "Hydrologic comparison of four types of permeable pavement and standard asphalt in eastern North Carolina." *J.Hydrol.Eng.,* 13(12), 1146-1157.

DeBusk, K. M., Hunt, W. F., and Line, D. E. (2011). "Bioretention Outflow: Does It Mimic Nonurban Watershed Shallow Interflow?" *J.Hydrol.Eng.,* 16(3), 274-279.

Dietz, M. (2007). "Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions." *Water, Air, & Soil Pollution,* 186(1), 351-363.

Fassman, E. A., and Blackbourn, S. (2010). "Urban Runoff Mitigation by a Permeable Pavement System over Impermeable Soils." *J.Hydrol.Eng.,* 15(6), 475-485.

Flint, K. R., and Davis, A. P. (2007). "Pollutant mass flushing characterization of highway stormwater runoff from an ultra-urban area." *J.Environ.Eng.,* 133(6), 616-626.

Gee, G.W. and Bauder, J. W. (1986). “Particle-size analysis.” In Methods of Soil Analysis, Part 1. Agron. Monogr. 9. Klute, A, ed. Soil Science Society of America, Madison, WI. 383-411.

Gee, G. W., and Or, D. (2002). "2.4 Particle-size analysis." *Methods of Soil Analysis: Physical Methods,* 5 255.

Gilbert, J. K., and Clausen, J. C. (2006). "Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut." *Water Res.,* 40(4), 826-832.

Grabow, G., Spooner, J., Lombardo, L., Line, D., and Tweedy, K. (1998). *Has Water Quality Improved?: Use of SAS for Statistical Analysis of Paired Watershed, upstream/downstream and before/after Monitoring Designs.*

Gregory, J., Dukes, M., Jones, P., and Miller, G. (2006). "Effect of urban soil compaction on infiltration rate." *J.Soil Water Conserv.,* 61(3), 117-124.

Hood, M. J., Clausen, J. C., and Warner, G. S. (2007). "Comparison of Stormwater Lag Times for Low Impact and Traditional Residential Development1." *JAWRA Journal of the American Water Resources Association,* 43(4), 1036-1046.

Hunt, W. F., Jarrett, A. R., Smith, J. T., and Sharkey, L. J. (2006). "Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina." *Journal of Irrigation and Drainage Engineering-Asce,* 132(6), 600-608.

ISCO Flowlink Software V 5.10.206. (2005). Teledyne ISCO, Inc. Lincoln, NE.

ISCO Open Channel Flow Measurement Handbook: Sixth Edition. (1978). Teledyne ISCO, Inc. Lincoln, NE.

Jennings, D. B., and Jarnagin, S. T. (2002). "Changes in anthropogenic impervious surfaces, precipitation and daily streamflow discharge: a historical perspective in a mid-atlantic subwatershed." *Landscape Ecol.,* 17(5), 471-489.

Lee, J. G., and Heaney, J. P. (2003). "Estimation of urban imperviousness and its impacts on storm water systems." *J.Water Resour.Plann.Manage.,* 129(5), 419-426.

Leopold, L. B. (1968). *Hydrology for urban land planning: A guidebook on the hydrologic effects of urban land use.* United States Department of the Interior. Washington D.C.

Leopold, L. B. (1991). "Lag times for small drainage basins." *Catena,* 18(2): 157-171.

Line, D., White, N., Osmond, D., Jennings, G., and Mojonnier, C. (2002). "Pollutant export from various land uses in the upper Neuse River Basin." *Water Environ.Res.,* 74(1), 100-108.

Line, D. E., and White, N. M. (2007). "Effects of development on runoff and pollutant export." *Water Environ.Res.,* 79(2), 185-190.

Line, D.E., Brown, R. A., Hunt, W. F., and Lord, W. G. (2012). "Effectiveness of LID for Commercial Development in North Carolina*" J. Environ. Eng.* 138(6), 680-688.

Luell, S. K., Hunt, W. F., and Winston, R. J. (2011). "Evaluation of undersized bioretention stormwater control measures for treatment of highway bridge deck runoff." *Water Science and Technology,* 64(4), 974-979.

NCDENR. (2004). "Assessment Report: Biological Impairment in the Burnt Mill Creek Watershed." North Carolina Department of Environment and Natural Resources, Division of Water Quality-Planning Branch. Raleigh, NC.

Passeport, E., Hunt, W. F., Line, D. E., Smith, R. A., and Brown, R. A. (2009). "Field Study of the Ability of Two Grassed Bioretention Cells to Reduce Storm-Water Runoff Pollution." *Journal of Irrigation and Drainage Engineering-Asce,* 135(4), 505-510.

Pitt, R., Field, R., Lalor, M., and Brown, M. (1995). "Urban Stormwater Toxic Pollutants - Assessment, Sources, and Treatability." *Water Environ.Res.,* 67(3), 260-275.

Pitt, R., Chen, S. E., Clark, S. E., Swenson, J., and Ong, C. K. (2008). "Compaction's impacts on urban storm-water infiltration." *J.Irrig.Drain.Eng.,* 134(5), 652-658.

Sansalone, J.J., Hird, J.P., Cartledge, F.K., and Tittlebaum, M.E. (2005). Event-based stormwater quality and quantity loadings from elevated urban infrastructure affected by transportation. Water Environment Research, 77(4), 348-365.

SAS Institute Inc (version 9.2) [Software]. (2008). The SAS system for Windows.

Sartor, J. D., Boyd, G. B., and Agardy, F. J. (1974). "Water pollution aspects of street surface contaminants." *Journal (Water Pollution Control Federation),* 458-467.

Sartor, J., and Gaboury, D. (1984). "Street sweeping as a water pollution control measure: lessons learned over the past ten years." *Sci.Total Environ.,* 33(1), 171-183.

Schueler, T. R. 1992. "Mitigating the Adverse Impacts of Urbanization on Streams: A Comprehensive Strategy for Local Government." *Watershed Restoration Sourcebook.* Publication #92701, Metropolitan Washington Council of Governments. Washington, D.C.

Schueler, T. R. 1994. "The Importance of Imperviousness." *Watershed Protection Techniques*, 1(3): 100–11.

Sparks, D.L. (2003). Environmental Soil Chemistry. 2nd Ed. San Diego, California: Elsevier.

State Climate Office of North Carolina. (2012). 1971-2000 Climate Normals. Available: < http://www.nc-climate.ncsu.edu/cronos/normals.php>. Accessed 15 November 2012.

UACDC. 2010. *Low Impact Development: a design manual for urban areas.* University of Arkansas Press. University of Arkansas Community Design Center. Fayetteville, AR.

US EPA. (2009). History of the Clean Water Act. Laws, Regulations, Guidance, and Dockets. United States Environmental Protection Agency. Available at: http://www.epa/gov/lawsregs/laws.cwahistory/html. Accessed 22 October 2011.

Walsh, C. J. (2000). "Urban impacts on the ecology of receiving waters: a framework for assessment, conservation and restoration." *Hydrobiologia,* 431(2), 107-114.

Walsh, C. J., Sharpe, A. K., Breen, P. F., and Sonneman, J. A. (2001). "Effects of urbanization on streams of the Melbourne region, Victoria, Australia. I. Benthic macroinvertebrate communities." *Freshwat.Biol.,* 46(4), 535-551.

Walsh, C. J. (2004). "Protection of in-stream biota from urban impacts: minimize catchment imperviousness or improve drainage design?" *Marine and Freshwater Research,* 55(3), 317-326.

Wardynski, B. J., Winston, R. J., and Hunt, W. F. (2013). "Internal water storage enhances exfiltration and thermal load reduction from permeable pavement in the North Carolina mountains." *J.Environ.Eng., 139(2), 187-195.*

Waschbusch RJ, Selbig WR, Bannerman RT. (1999). Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin. *USGS Water Resour. Invest.* Rep. 99–4021.

CHAPTER 4: FURTHER CONSIDERATIONS AND RESEARCH

4.1 Design Considerations

Residential Street SCM Sizing

This study has shown that LID SCMs installed over sandy urban soils can mitigate some of the hydrologic and water quality impacts of existing residential development. The pair of BRC bumpouts and permeable pavements were designed to capture a water quality volume based on the DCIA. This was a valid design approach over sandy soil because most runoff from impervious areas like rooftops and sidewalks that are not directly connected to the outlet likely infiltrated prior to entering the street. Designs of residential street retrofits for projects over less permeable soils should consider sizing the SCMs for the entire contributing drainage area in lieu of only the DCIA to ensure the actual water quality volume is captured. Underdrains may also be necessary in systems over impermeable soils to dewater the SCMs.

SCM Placement within the Watershed

Placement of SCMs in medium and high-density residential areas largely depends on available space, existing utility location and target hydrologic or water quality needs. When peak discharge mitigation or runoff volume reduction is the objective, SCMs that provide depressional storage throughout the drainage area should be used. Increased depressional storage has been shown to maintain or restore pre-development hydrology by providing detention and infiltration throughout a watershed, which enhances ground water recharge and natural base flow to streams (Davis et al., 2009; DeBusk et al., 2011). This includes BRCs, grassed swales and infiltrating trenches. This study has shown that it is necessary to apply hydrologic treatment to the entire DCIA to have a substantial impact on peak discharge. Placement of SCMs near the watershed outlet is important and may also result in more pronounced hydrologic benefits, however an even distribution of SCMs throughout the watershed is ideal because it more closely replicates what may be observed in an undeveloped watershed. For water quality, that a tree filter unit is a sufficient for particulate pollutant retention. However, tree filter units do not seem to provide noticeable reductions in dissolved pollutant concentrations of $NO_{2,3}$-N, TAN or O-PO_4^{-3}.

Curb and Gutter Configuration at Permeable Pavement Installations

In this study, flow diverters (16 mm tall) were installed at 3.6 m intervals along the permeable pavement parking areas. Results indicate runoff moving along the existing curb and gutter overwhelmed the flow diverters during storms with greater rainfall depths and intensities. For future permeable pavement projects on residential streets, alternative curb and gutter configurations should be considered. Increasing the elevation of the concrete gutter may be a viable option. Perhaps more ideal would be to install the gutter and permeable pavement on a slope away from the curb. Of course, there would be other pavement grading implications associated with this design, but they may be worthwhile given the likely increase in runoff volume retention of the permeable pavement if more runoff is allowed to infiltrate.

4.2 Further Research

Retrofitting with other SCMs and New Residential Development

Other SCMs that have shown promise in mitigating the impacts of urban development include grassed swales and filter strips. In areas with adequate space and slope, filter strips and grassed swales constructed similarly to those along interstate highways, could be a feasible low-cost SCM for residential street runoff providing conveyance and treatment. Although there are ample SCM retrofit opportunities, a watershed or catchment-scale analysis of SCMs incorporated into the street right-of-way of *new* high density residential development should be considered. During new construction, additional grading and curb and gutter configurations that are designed to efficiently direct runoff into SCMs may lead to more runoff being treated. For highly impervious (>50%) residential and commercial sites, multiple infiltrating SCMs may not provide enough detention to decrease post-development peak discharges and runoff volume or increase lag times. Therefore, a hybrid system of LID SCMs and detention facilities may lead to effective pollutant treatment and a hydrologic response that closely mimics undeveloped conditions.

Cost Analysis

Project cost is an important practical consideration municipalities face when retrofitting existing development for stormwater treatment within their jurisdiction. A benefit of this project was the limited number of SCMs used to reach a high level of pollutant removal and subsequently lower cost. A detailed cost analysis of this project in comparison with other types of stormwater treatment such as wet detention ponds, catch basin filter inserts or large-scale combined sewer treatment facilities would be a valuable asset to municipalities. Using actual data collected from each treatment type and project cost, stormwater treatment could be analyzed in metrics of kilogram TN removed per hectare per dollar ($) spent or runoff volume (m^3) retained per hectare per dollar ($) spent. This would allow municipalities to better allocate resources to optimize pollutant removal and cost.

APPENDICES

Appendix A: Additional Construction Photos

Figure A-1: BRC excavation on Dock Street and existing utilities

Figure A-2: BRC media and mulch installation on Dock Street

Figure A-3: Proof of Filterra® unit installation for University Accounting Office

Figure A-4: Filterra® unit installation at the intersection of 12th Street and Dock Street

Figure A-5: Filterra® unit underdrain installation

Figure A-6: Recently completed crosswalk at the intersection of 12th Street and Dock Street

Figure A-7: Permeable pavement excavation and #57 stone placement

Figure A-8: #78 stone placement and recently installed PICP pavers

Figure A-9: Completed permeable pavement parking stalls with flow diverters along existing curb and gutter

Figure A-10: Coastal North Carolina green roof

Appendix B: LID SCM Design Summary Tables

Table B-1: BRC Design Summary

BRC Characteristics	
Vegetative Cover	Shrubs/Perennials
BRC Area	19 m^2 (205 ft^2)
Watershed Area	160 m^2 (1722 ft^2)
Street Surface Area Treated	13%
Surface Storage	4 m^3 (138 ft^3)
Watershed % Impervious	100%
Loading Ratio	8.4:1
BRC Abstraction Value	
Surface Storage Design Event	3.8 cm (1.5 in)
Surface Layer Depth	Multch: 5 cm (2 in)
Fill Media Depth	0.6 m (2 ft)
Fill Media Characteristics	4.5% Gravel, 87.4% Sand, 7% Silt, 1.1% Clay
Fill Media K_{sat}	7 cm/hr (2.75 in/hr) @ 85% compaction
Underdrain to Outlet	No

Table B-2: Tree Filter Design Summary

Tree Filter Characteristics	
Vegetation	Crepe Myrtle
Surface Area	3 m^2 (32 ft^2)
Watershed Area	539 m^2 (5,800 ft^2)
Street Surface Area Treated	42%
Watershed % Impervious	100%
Loading Ratio	180:1
Surface Layer Depth	Mulch: 7.6 cm (3 in)
Fill Media Depth	0.75 m (2.5 ft)
Fill Media Characteristics	Filterra® Mix
Underdrain to Outlet	Yes

Table B-3: Permeable Pavement Design Summary

Permeable Pavement (I and II) Design Characteristics	
Surface Area	PP I: 34 m^2 (366 ft^2) PP II: 34 m^2 (366 ft^2)
Watershed Area	PP I: 265 m^2 (2,852 ft^2) PP II: 226 m^2 (2,433 ft^2)
Street Surface Area Treated	PP I: 21% PP II: 18%
Watershed % Impervious	100%
Loading Ratio	PP I: 7.8:1 PP II: 6.6:1
Subsurface Storage Design Event	38 mm (1.5 in)
PICP Thickness	76 mm (3 in)
#78 Stone Thickness	76 mm (3 in)
#57 Stone Thickness	0.3 m (12 in)
Underdrain to Outlet	No

Table B-4: Underlying soil characteristics

Parameter	**Catchment**		
	CONTROL	**LID**	**LID**
Sample ID	CRTL	PP	BRC
Silt	1.8%	3.7%	0.0%
Clay	2.6%	1.6%	2.0%
Sand	95.6%	94.7%	98.0%
USDA Texture	**Sand**	**Sand**	**Sand**

Appendix C: Water Quality ANCOVA Plots

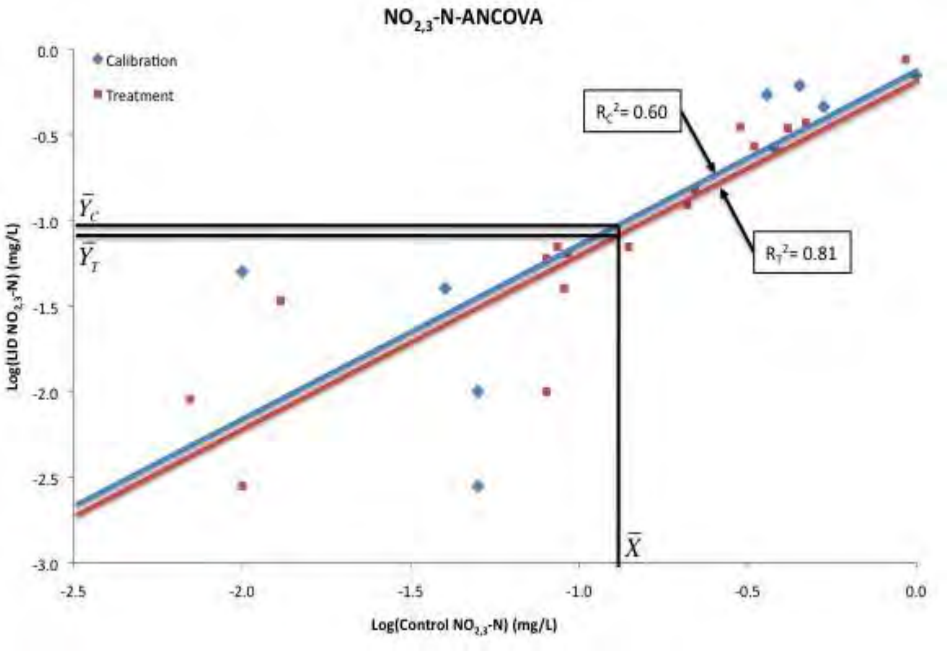


Figure C-2: Reduced ANCOVA model for TKN load (g/ha)

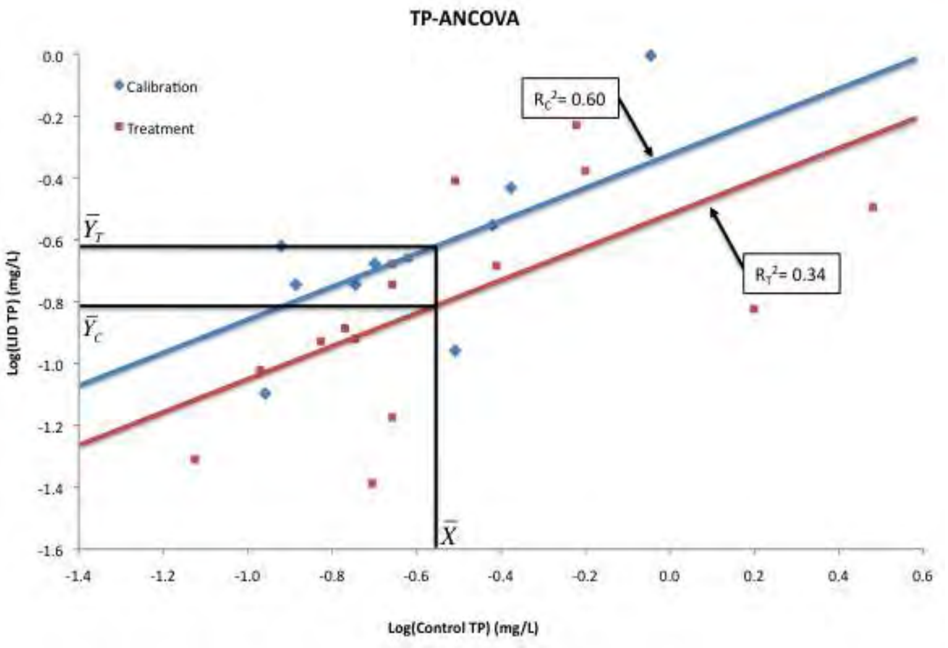


Figure C-3: Reduced ANCOVA model for TAN concentration (mg/L)

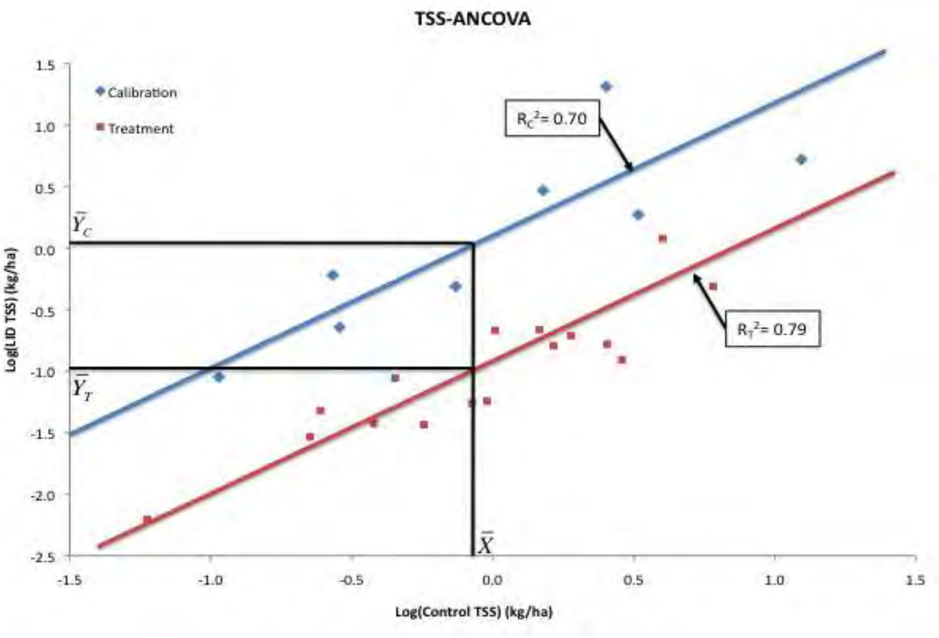


Figure C-4: Reduced ANCOVA model for TAN load (g/ha)

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

Figure 3-x: Reduced ANCOVA model for TN concentration (mg/L)

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

Figure C-5: Reduced ANCOVA model for TN load (g/ha)

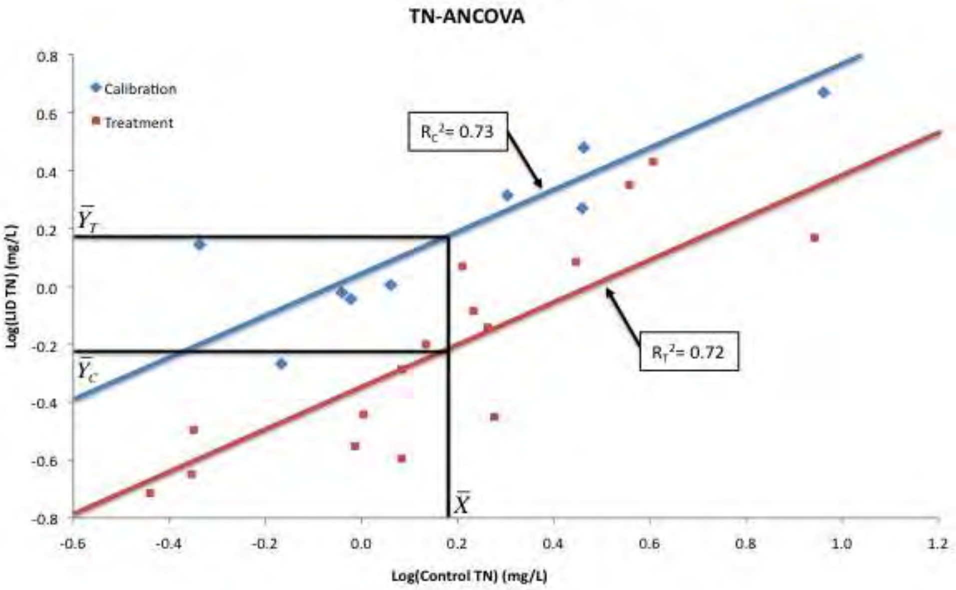


Figure C-6: Reduced ANCOVA model for $NO_{2,3}$-N load (g/ha)

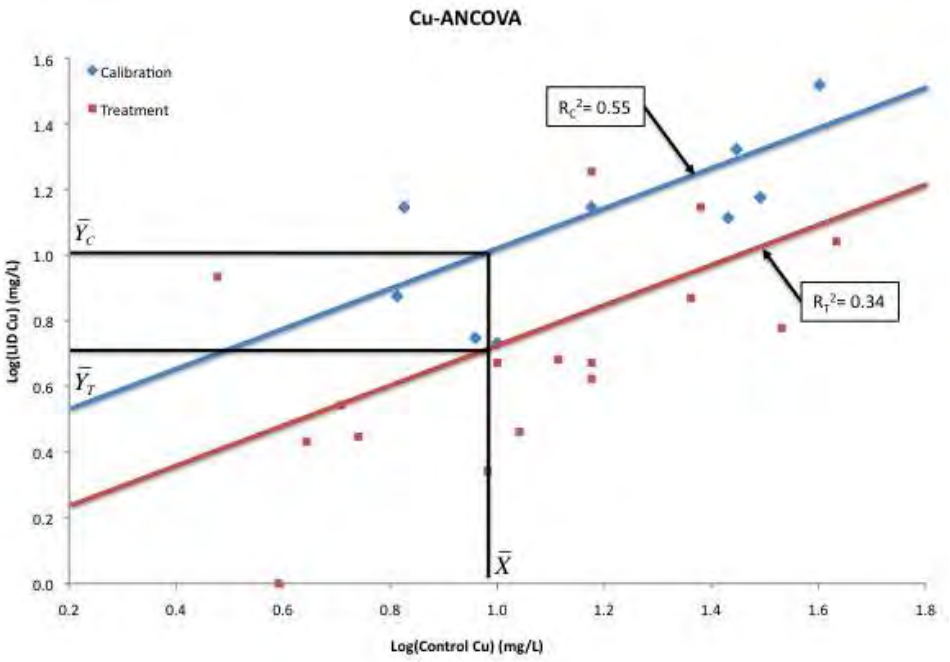


Figure C-7: Reduced ANCOVA model for ON concentration (mg/L)

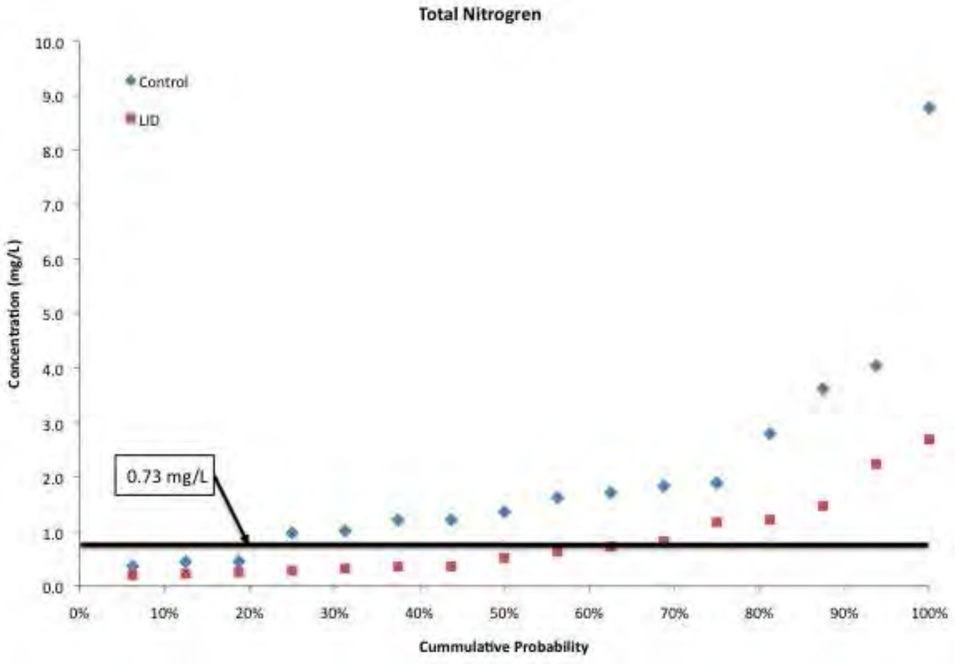


Figure C-8: Reduced ANCOVA model for ON load (g/ha)

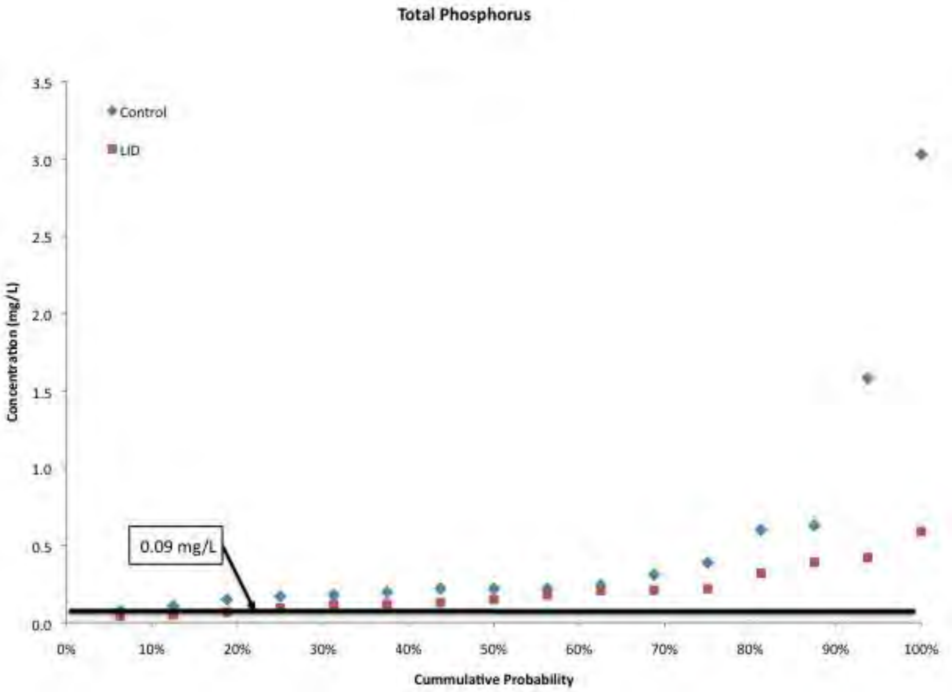


Figure C-9: Reduced ANCOVA model for O-PO$_4^{-3}$ load (g/ha)

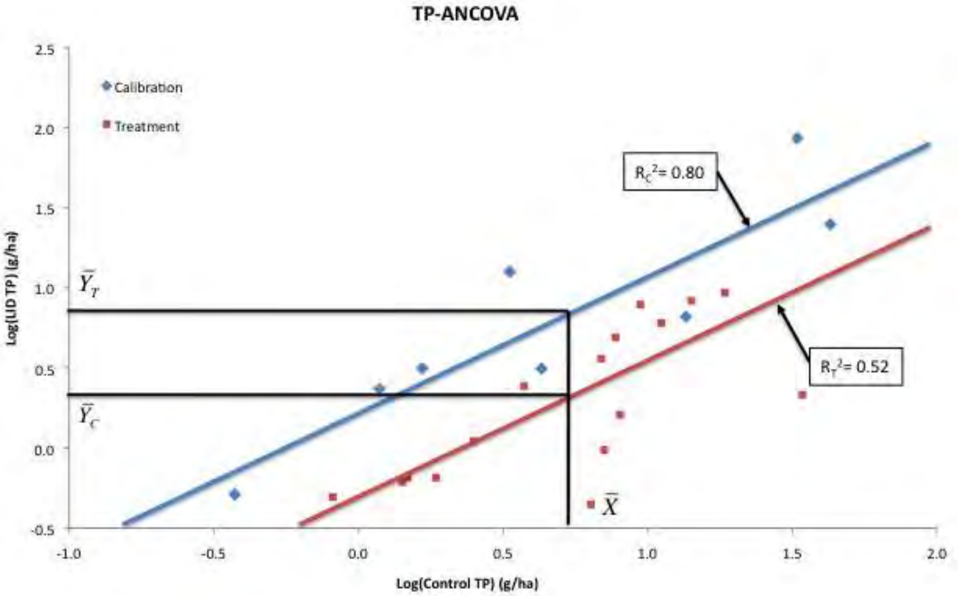


Figure C-10: Reduced ANCOVA model for TP load (g/ha)

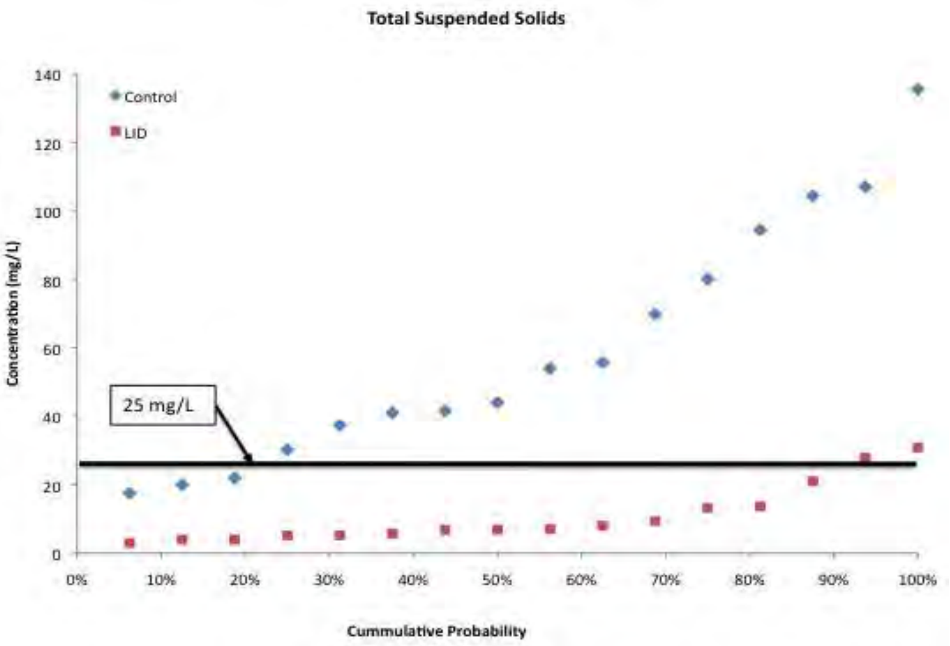


Figure C-11: Reduced ANCOVA model for Cu load (g/ha)

Figure C-12: Reduced ANCOVA model for Pb load (g/ha)

Figure C-13: Reduced ANCOVA model for Zn load (g/ha)

Appendix D: Raw Data Summary

Table D-1: Calibration nitrogen summary

Date	TKN (mg/L)		NO_3+NO_2 (mg/L)		NH_3N (mg/L)	
	CONTROL	LID	CONTROL	LID	CONTROL	LID
6/23/11	8.15	3.97	1.00	0.70	0.88	0.12
6/29/11	2.35	1.40	0.53	0.46	0.22	0.14
7/21/11	2.45	2.40	0.45	0.61	0.43	0.21
7/24/11	1.65	1.52	0.36	0.54	0.14	0.02
8/21/11	0.77	0.75	0.38	0.26	0.11	0.04
8/26/11	0.63	0.53	0.05	0.01	0.08	0.05
9/22/11	0.42	1.35	0.04	0.04	0.03	0.04
10/12/11	0.90	0.90	0.01	0.05	0.02	0.02
10/18/11	0.90	0.90	0.05	0.00	0.02	0.02
Mean	**2.02**	**1.52**	**0.32**	**0.30**	**0.21**	**0.07**
Median	**0.90**	**1.35**	**0.36**	**0.26**	**0.11**	**0.04**

Table D-2: Treatment nitrogen summary

Date	TKN (mg/L)		NO_3+NO_2 (mg/L)		NH_3N (mg/L)	
	CONTROL	LID	CONTROL	LID	CONTROL	LID
6/11/12	3.53	2.23	0.08	0.01	0.12	0.04
6/13/12	0.87	0.29	0.14	0.07	0.06	0.03
7/9/12	3.11	1.82	0.93	0.87	0.49	0.10
7/10/12	1.32	0.82	0.30	0.35	0.05	0.03
7/11/12	1.14	0.48	0.22	0.15	0.03	0.02
8/20/12	8.30	1.10	0.47	0.37	1.84	0.07
9/8/12	1.50	0.45	0.33	0.27	0.16	0.04
9/30/12	1.63	0.76	0.08	0.06	0.06	0.03
10/1/12	0.88	0.24	0.09	0.04	0.03	0.02
10/27/12	0.44	0.31	0.01	0.01	0.02	0.02
11/19/12	0.35	0.19	0.01	0.00	0.04	0.03
12/13/12	1.12	0.45	0.09	0.07	0.04	0.04
1/17/13	1.12	0.19	0.09	0.06	0.03	0.03
1/31/13	2.38	0.87	0.42	0.34	0.08	0.09
2/8/13	1.68	0.23	0.21	0.12	0.03	0.03
2/13/13	0.43	0.19	0.01	0.03	0.01	0.01
Mean	**1.86**	**0.66**	**0.22**	**0.18**	**0.19**	**0.04**
Median	**1.23**	**0.45**	**0.12**	**0.07**	**0.04**	**0.03**

Table D-3: Calibration sediment and phosphorus summary

Date	Ortho-P (mg/L)		Total-P (mg/L)		TSS (mg/L)	
	CONTROL	**LID**	**CONTROL**	**LID**	**CONTROL**	**LID**
6/23/11	0.51	0.73	0.90	0.99	60	72
6/29/11	0.22	0.19	0.38	0.28	92	79
7/21/11	0.18	0.37	0.42	0.37	122	78
7/24/11	0.14	0.11	0.31	0.11	30	24
8/21/11	0.06	0.20	0.11	0.08	11	14
8/26/11	0.06	0.06	0.13	0.18	4	43
9/22/11	0.06	0.07	0.12	0.24	19	56
10/12/11	0.11	0.06	0.20	0.21	16	54
10/18/11	0.10	0.08	0.18	0.18	28	28
Mean	**0.16**	**0.21**	**0.31**	**0.29**	**42**	**50**
Median	**0.11**	**0.11**	**0.20**	**0.21**	**28**	**54**

Table D-4: Treatment sediment and phosphorus summary

Date	Ortho-P (mg/L)		Total-P (mg/L)		TSS (mg/L)	
	CONTROL	**LID**	**CONTROL**	**LID**	**CONTROL**	**LID**
6/11/12	0.14	0.15	0.63	0.42	104	31
6/13/12	0.05	0.07	0.17	0.13	56	7
7/9/12	NS	NS	0.60	0.59	136	13
7/10/12	0.11	0.16	0.24	0.22	18	3
7/11/12	0.07	0.14	0.22	0.18	37	6
8/20/12	2.86	0.22	3.03	0.32	107	21
9/8/12	0.13	0.11	1.58	0.15	44	4
9/30/12	0.13	0.32	0.31	0.39	54	8
10/1/12	0.06	0.10	0.18	0.12	41	4
10/27/12	0.07	0.08		0.12	22	7
11/19/12	0.05	0.07	0.11	0.10	30	14
12/13/12	0.11	0.16	0.22	0.21	42	9
1/17/13	0.03	0.04	0.22	0.07	70	7
1/31/13	0.09	0.10	0.39	0.21	94	28
2/8/13	0.05	0.05	0.20	0.04	80	5
2/13/13	0.02	0.03			20	3
Mean	**0.26**	**0.12**	**0.58**	**0.22**	**60**	**11**
Median	**0.07**	**0.10**	**0.23**	**0.18**	**49**	**7**

Table D-5: Calibration metals summary

Date	Copper (Cu) (ug/L)		Lead (Pb) (ug/L)		Zinc (Zn) (ug/L)	
	CONTROL	LID	CONTROL	LID	CONTROL	LID
6/23/11	40	33	40	26	180	190
6/29/11	31	15	35	14	110	65
7/21/11	28	21	58	32	120	120
7/24/11	27	13	18	11	55	62
8/21/11	9.1	5.6	7.2	4.3	33	32
8/26/11	10	5.4	50	2.6	80	17
9/22/11	6.7	14	25	52	38	120
10/12/11	15	14	27	43	52	120
10/18/11	6.5	7.5	24	8.8	54	37
Mean	**19**	**14**	**32**	**22**	**80**	**85**
Median	**15**	**14**	**27**	**14**	**55**	**65**

Table D-6: Treatment metals summary

Date	Copper (Cu) (ug/L)		Lead (Pb) (ug/L)		Zinc (Zn) (ug/L)	
	CONTROL	LID	CONTROL	LID	CONTROL	LID
6/11/12	24	14	42	5.6	170	35
6/13/12	11	2.9	39	2.1	70	12
7/9/12	15	4.2	37	2.5	59	16
7/10/12	15	4.7	8.7	1	64	18
7/11/12	43	11	53	3.8	170	36
8/20/12	34	6	110	7.9	120	28
9/8/12	13	4.8	31	3.3	64	13
9/30/12	15	18	48	1	89	20
10/1/12	10	4.7	43	1	73	5
10/27/12	5.1	3.5	9.5	1	33	14
11/19/12	3.9	1	15	1	37	15
12/13/12	5.5	2.8	17	2.2	56	22
1/17/13	9.6	2.2	34	2.4	79	13
1/31/13	23	7.4	87	30	180	54
2/8/13	3	8.6	42	1	77	17
2/13/13	4.4	2.7	12	2.9	39	20
Mean	**15**	**6**	**39**	**4**	**86**	**21**
Median	**12**	**5**	**38**	**2**	**72**	**18**

Table D-7: Hydrologic data summary

Appendix E: Example SAS Code

```
*ANCOVA;

data concentration;
input period $ TKNCRTL TKNLID NO3CRTL NO3LID NH3CRTL NH3LID TNCRTL TNLID
ONCRTL      ONLID OPCRTL OPLID TPCRTL TPLID     TSSCRTL     TSSLID CuCRTL
CuLID PbCRTL PbLID ZnCRTL ZnLID;
logTKNCRTL=log10(TKNCRTL);
logTKNLID=log10(TKNLID);
logNO3CRTL=log10(NO3CRTL);
logNO3LID=log10(NO3LID);
logNH3CRTL=log10(NH3CRTL);
logNH3LID=log10(NH3LID);
logTNCRTL=log10(TNCRTL);
logTNLID=log10(TNLID);
logONCRTL=log10(ONCRTL);
logONLID=log10(ONLID);
logOPCRTL=log10(OPCRTL);
logOPLID=log10(OPLID);
logTPCRTL=log10(TPCRTL);
logTPLID=log10(TPLID);
logTSSCRTL=log10(TSSCRTL);
logTSSLID=log10(TSSLID);
logCuCRTL=log10(CuCRTL);
logCuLID=log10(CuLID);
logPbCRTL=log10(PbCRTL);
logPbLID=log10(PbLID);
logZnCRTL=log10(ZnCRTL);
logZnLID=log10(ZnLID);
cards;

*TKN;
proc glm data=concentration;
title 'TKN - ANCOVA';
class period;
model logTKNLID=logTKNCRTL period period*logTKNCRTL/solution;
lsmeans period/pdiff;
run;

proc glm data=concentration;
class period;
model logTKNLID=logTKNCRTL period/solution;
lsmeans period/pdiff;
run;


*NO3;
proc glm data=concentration;
title 'NO3 - ANCOVA';
class period;
model logNO3LID=logNO3CRTL period period*logNO3CRTL/solution;
```

```
lsmeans period/pdiff;
run;
proc glm data=concentration;
class period;
model logNO3LID=logNO3CRTL period/solution;
lsmeans period/pdiff;
run;

*LID and Control Pairwise comparisons;

data pairedconcentration;
input period $ TKNCRTL TKNLID NO3CRTL NO3LID NH3CRTL NH3LID TNCRTL TNLID
ONCRTL      ONLID OPCRTL OPLID TPCRTL TPLID     TSSCRTL     TSSLID CuCRTL
CuLID PbCRTL PbLID ZnCRTL ZnLID;
logTKNCRTL=log10(TKNCRTL);
logTKNLID=log10(TKNLID);
logNO3CRTL=log10(NO3CRTL);
logNO3LID=log10(NO3LID);
logNH3CRTL=log10(NH3CRTL);
logNH3LID=log10(NH3LID);
logTNCRTL=log10(TNCRTL);
logTNLID=log10(TNLID);
logONCRTL=log10(ONCRTL);
logONLID=log10(ONLID);
logOPCRTL=log10(OPCRTL);
logOPLID=log10(OPLID);
logTPCRTL=log10(TPCRTL);
logTPLID=log10(TPLID);
logTSSCRTL=log10(TSSCRTL);
logTSSLID=log10(TSSLID);
logCuCRTL=log10(CuCRTL);
logCuLID=log10(CuLID);
logPbCRTL=log10(PbCRTL);
logPbLID=log10(PbLID);
logZnCRTL=log10(ZnCRTL);
logZnLID=log10(ZnLID);
TKNdiff=TKNCRTL-TKNLID;
NO3diff=NO3CRTL-NO3LID;
NH3diff=NH3CRTL-NH3LID;
TNdiff=TNCRTL-TNLID;
ONdiff=ONCRTL-ONLID;
OPdiff=OPCRTL-OPLID;
TPdiff=TPCRTL-TPLID;
TSSdiff=TSSCRTL-TSSLID;
Cudiff=CuCRTL-CuLID;
Pbdiff=PbCRTL-PbLID;
Zndiff=ZnCRTL-ZnLID;
logTKNdiff=logTKNCRTL-logTKNLID;
logNO3diff=logNO3CRTL-logNO3LID;
logNH3diff=logNH3CRTL-logNH3LID;
logTNdiff=logTNCRTL-logTNLID;
logONdiff=logONCRTL-logONLID;
logOPdiff=logOPCRTL-logOPLID;
```

```
logTPdiff=logTPCRTL-logTPLID;
logTSSdiff=logTSSCRTL-logTSSLID;
logCudiff=logCuCRTL-logCuLID;
logPbdiff=logPbCRTL-logPbLID;
logZndiff=logZnCRTL-logZnLID;
cards;

proc univariate data=pairedconcentration plot normal;
title 'Post-retrofit comparison';
var OPdiff logOPKdiff;
histogram/normal;
run;
quit;
```