3.4: RESEARCH ON TECHNICAL PERFORMANCE AND BENEFITS

A NORTH CAROLINA FIELD STUDY TO EVALUATE GREENROOF RUNOFF QUANTITY, RUNOFF QUALITY, AND PLANT GROWTH

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Abstract

Recent federal and state regulations require storm water runoff to be treated by structural controls in ultra-urban development. Several practices have been used in North Carolina; however, a less common storm water management practice is the greenroof. Two extensive greenroofs have been constructed within the Neuse River Basin of North Carolina. Each greenroof retained approximately 60% of the total recorded rainfall during a nine-month observation period. The average peak flow reduction for both greenroofs was approximately 85%. Water quality data indicated higher concentrations of TN and TP were present in the greenroof runoff than in the control roof runoff and in the rainfall at each greenroof site. This may be a result of N and P leaching from the soil media; the soil media is composed of 15% compost. Preliminary results from a soil column test of three different greenroof soil media indicate that leaching can be reduced with less organic matter present in the soil media. Vegetation growth observed after the first year showed that growth was significantly higher ($\alpha <$ 0.05) in 100 mm (4 in.) deep soil media than in 50 mm (2 in.) deep soil media.

Introduction

In 1972, amendments were made to the Federal Water Pollution Control Act—known as the Clean Water Act (CWA)—to prohibit the discharge of polluted waters unless the discharge was authorized by a National Pollutant Discharge Elimination System (NPDES) permit (9). Congress then amended the CWA in 1987 to also require NPDES permits for storm water discharges (9). Storm water is a major contributor to the degradation of our waters due to the large concentrations of a variety of contaminants entering our streams and rivers. Pollutants

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range from pesticides and nutrients to oils and petroleum products to construction chemicals and sediment. The result of these pollutants infecting our nation's waters can be seen in fish kills, contamination of drinking water supplies, and destruction of wildlife habitats. Phase I of the NPDES Storm Water Program was developed in 1990, establishing the initial permit applications for storm water discharges (9). Published in 1999, the Phase II Final Rule of the NPDES Storm Water Program intensified the requirements of storm water NPDES permits across the nation, thus adding greater importance to the development of storm water Best Management Practices (BMPs) (8).

Storm water BMPs have become one of the major tools to improve storm water runoff quality. BMPs such as bio-retention areas, wet and dry detention ponds, constructed wetlands, and sand filters are commonly seen throughout North Carolina (NC). However, many of these BMPs require a large amount of surface area to construct and, therefore, are infeasible in congested, highly impervious areas such as downtown city environments. As a result of the Phase II Final Rule, towns and cities across the United States must construct storm water BMPs, but some highly congested areas may not have the available surface area to construct typical BMPs such as constructed wetlands and wet ponds. A new option for BMPs is the greenroof; greenroofs utilize thousands of square feet available on rooftops that would not otherwise be available on the ground. One of the significant benefits of greenroofs is reducing the volume of runoff, resulting in reduced pollutant loadings; thus serving as a prime BMP for highly congested areas where rooftop areas are one of the only options for siting BMPs.

Background on Pollutant Loads and Greenroofs

As the only source of water for the extensive greenroofs in NC has been precipitation, the pollutant source of interest is atmospheric deposition. Recent research has revealed that much of the nitrogen and phosphorus entering water bodies results from atmospheric deposition. Studies in Charlotte, NC, found that atmospheric deposition accounted for 10-30% of total phosphorus (TP) and nitrate as nitrogen (NO_3 as N), 30-50% of orthophosphorus (OP), and 70-90% for total Kjeldahl nitrogen (TKN) and ammonia as nitrogen (NH_3 as N) found in storm water runoff (12). Studies in Monroe County, New York have also demonstrated the amount of nutrients found in atmospheric deposition. An estimated 65% of TP and nearly 100% of the TKN entering the Irondequoit Creek basin was due to atmospheric deposition (3). Animal production is also a contributing factor to atmospheric deposition. The high concentration of animal production in eastern NC has contributed to higher concentrations of total nitrogen (TN) seen in rainfall at locations within 3 km (1.9 miles) of animal production systems (6). This may be an important consideration for this research study as both research sites are located in eastern NC.

German research conducted from 1985 to 1994 has demonstrated the water retention capabilities of extensive greenroofs. The determining factors for greater water retention are depth of soil and plant selection, as some plant species retain more water than others; water retention is less dependant on the drainage structure (4). At the research site in Hannover-Herrenhausen, Germany, it was determined that 50 mm (2 in.) and 100 mm (4 in.) soils had retained approximately 65% and 70% of the precipitation during summer months, respectively (4). In winter months, the 50 mm (2 in.) and 100 mm (4 in.) soils had each retained approximately 50% of the precipitation (4). Water retention rates are higher during summer months due to higher evapotranspiration rates. On average, extensive soils ranging from 50 mm (2 in) to 100 mm (4 in.) retained approximately 50% of the annual precipitation. Average annual precipitation for Hannover-Herrenhausen, Germany is 640 mm (26 in.), compared to the annual average precipitation of 1100 mm (43 in.) in eastern NC.

Limited research on storm water retention of greenroofs has been performed in the United States (US). The City of Portland began their EcoRoof program in 1996 and has collected research data from two research sites in the city. During a 15-month monitoring period during 2002 and 2003, the water retention of an extensive greenroof with a 100-120 mm (4-5 in.) soil media depth was 69% of the total rainfall (2). Hutchinson *et al.* (2) also showed that the City of Portland observed peak flow reductions of 80% from the greenroof. Research conducted at Michigan State University has shown that 66% of the precipitation was retained by an extensive greenroof studied over an average of 24 rainfall events (7). While this data from Michigan State University and the City of Portland supports German research, no research has been performed in the southeastern US to evaluate performance of the greenroof as a stormwater BMP.

Study Objectives

The primary objective of this research is to help establish design standards for greenroofs in NC. There are currently few greenroof design standards for NC, therefore engineers and designers have very limited guidance for successful greenroof construction in this region. The supporting objectives consist of the following:

- Estimating the percent precipitation retained by the greenroof;

- Estimating the percent peak flow reduction;
- Discovering whether greenroofs can be used as nutrient reduction BMPs and if so, what removal efficiency should be assigned to greenroofs;
- Identifying greenroof vegetation types that thrive in central and eastern NC; and
- Finding an optimal depth of soil for desirable plant growth.

Methodology

This research focuses on two greenroofs in eastern NC, shown in Figure 1. Highlighted in red (dark grey), is Wake County, where the City of Raleigh is located. Highlighted in green (light grey) are Wayne County and Lenoir County, where the cities of Goldsboro and Kinston are located. Both research sites fall within the Neuse River Basin. Each is being studied for precipitation retention, peak flow reduction, water quality improvement, and plant growth.

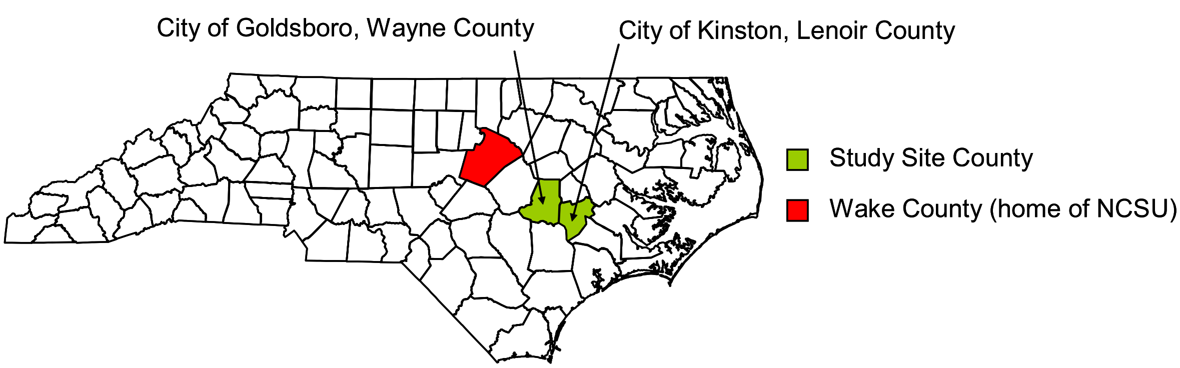

Figure 1. Map of North Carolina illustrating locations of research sites.

Site Descriptions

The greenroof at Wayne Community College (WCC) in Goldsboro, NC, was constructed in May 2002 and is approximately 70 m^2 (750 ft^2). This essentially flat greenroof (see Figure 2a) took approximately 50 person-hours to construct. The original rooftop of this storage building was divided into two equal halves for research purposes; one half remained unchanged and became the control for the experiment and the other half was transformed into the WCC Greenroof. Two soil media depths are being studied at this site for their effect on plant growth; half the greenroof has a soil media depth of 50 mm (2 in.) and the other half of the greenroof has a soil media depth of 100 mm (4 in.). The plant species researched at this site are *Delosperma cooperi, Delosperma nubigenum, Sedum album, Sedum album chloroticum, Sedum album murale, Sedum grisebachil, Sedum reflexum, Sedum sexangulare,* and *Sedum spurium fuldaglut.*

The approximate 27 m^2 (290 ft^2) greenroof at the Neuseway Nature Center in Kinston, NC, was constructed in April 2002 (see Figure 2b). The greenroof was constructed atop an additional room that was built onto the Nature Center during its renovation and construction phase. This greenroof took approximately 40 person-hours to construct. The most time consuming task was transporting the soil media to the rooftop; primitive techniques using buckets and pulleys transported the soil medium to the rooftop. As more greenroofs are built throughout NC, more efficient methods for transporting media to the rooftop are expected to develop. The Neuseway Nature Center Greenroof has a 3% pitch greenroof and consists of 100 mm (4 in) deep soil media and is planted with the same variety of plants used at the WCC Greenroof. This greenroof is also be compared with the remaining 180 m^2 (1820 ft^2) of the rooftop of the Nature Center. The plant species researched at this site are *Sedum album, Sedum album murale, Sedum floriferum, Sedum reflexum, and Sedum sexangulare.*

(a)

(b)

Figure 2. (a) WCC Greenroof in Goldsboro, NC, almost 1 year after construction (April 2003). (b) Neuseway Nature Center Greenroof in Kinston, NC, 1 year after construction (May 2003).

The drainage layer differed for each greenroof site. At the WCC Greenroof, Hydrodrain 300™ was used; Floradrain FD40™ with a System Filter SF™ layer was used at the Neuseway Nature Center greenroof. Floradrain FD40™ had storage pockets 40 mm (1.6 in.) thick and also required a filter fabric; Hydrodrain 300™ was similar to the Floradrain FD40™, but it also had a non-woven filter fabric system already incorporated into its design. While the Floradrain FD40™ had a storage capacity of 4 L/m^2 (0.1 gal/ft^2), the Hydrodrain 300™ had negligible storage (1). The Moisture Retention Mat, Root Barrier, and the drainage layers were donated for the Neuseway Nature Center Greenroof and purchased for the WCC Greenroof from American Hydrotech, Inc. The Perma Till Lightweight Roof Garden Soil Mix was donated by Carolina

Stalite Company and was composed of 55% Perma Till (Stalite 3/8" expanded slate), 30% Rootzone Sand, and 15% approved compost. The soil mix had a dry bulk density of 993 kg/m^3 (62 lbs/ft^3) and a saturated drained bulk density of 1250 kg/m^3 (78 lbs/ft^3). The vegetation was purchased from Emory Knoll Farms in Street, Maryland.

Monitoring

Each greenroof site was equipped with two Sigma 900Max™ automatic samplers, with one sampler for the greenroof and one sampler for the control roof at each site. A Solarex Solar Panel and a 12-volt battery powered the samplers. Each Sigma 900Max™ automatic sampler was stored in a large, secured green box. Each rooftop had a single drain leading to a galvanized steel box equipped with a weir plate. Figure 3a is a photograph of the green box and the weir box for the control roof at the WCC Greenroof. The weir boxes in Goldsboro each had a 30^o weir to measure flow from the greenroof and the control roof; the control weir on the weir box in Kinston was 30^o and the greenroof weir was 23^o. The smaller angle was selected for the greenroof due to the smaller surface area of the greenroof and, the resulting low flows expected. Each weir box was also equipped with one baffle at the center point to steady the water flow over the weir. Storm water flowed over the weir plate as it dispensed from the steel box and then exited the site. Inside each weir box, a level sensor measured the height of the water above the weir notch. Figure 3b illustrates the inside of the weir box with the level sensor and baffle. When the water level is above the weir notch, water is flowing over the weir. The Sigma 900Max™ samplers then equate the water level above the weir notch into a flow rate. The automatic samplers were programmed to retrieve a 50 mL sample in intervals of 23 L (5 gallon) of flow over the weir. Water quality samples were taken from the greenroof runoff and the control roof runoff.

(a) (b)

Figure 3. (a) Sampling equipment for WCC control roof. Weir box is on the left and green sampler storage box is on the right. (b) View inside the weir box with baffle, level sensor, and weir plate.

There was an approximate 24-hr holding period before samples were collected and then taken to a laboratory for analysis. Samples were analyzed in Raleigh, NC, by Tritest, Inc. The following analyses were performed on the water quality samples: Total Kjeldahl Nitrogen in Water (TKN) [EPA 351.2], Nitrate-Nitrite in Water (NO_3-NO_2) [EPA 353.2], Total Nitrogen (TN), Ammonia in Water (NH_3) [EPA 350.1], Total Phosphorus (TP) [EPA 365.4], and Orthophosphate (OP) [EPA 365.2] (10, 11). One of the focuses of water quality within the Neuse River Basin of North Carolina is to reduce nitrogen and phosphorus loadings (5). Thus, the greenroof will compare water quality results for nitrogen and phosphorus with the control roof and rainfall at each site.

The Sigma 900Max™ sampler recorded flow data and level data in 5-minute intervals. A Global Water Instruments, Inc. rain gage was also installed at each site and recorded rainfall data in 5-minute intervals though the sampler. After each rain event, samples were collected and data was downloaded from both the greenroof and the control roof automatic samplers.

Plant Growth

Percent coverage of several plant species at the WCC Greenroof was determined in May 2003, one year after the initial planting in May 2002. A comparison between plant growth of the 50 mm (2 in.) and the 100 mm (4 in.) media depth was observed and recorded. Plant growth was measured as the percent coverage of the soil media, i.e. in the planar view looking down onto the vegetation. A circular tube of an approximate diameter of 400 mm (16 in.) was randomly placed on each section of plant species for the respective media depth, this was repeated so 2 measurements were recorded for each species. Three different observers recorded their coverage estimates independently; percent coverage was estimated for 3 different species.

Results and Analysis

Hydrologic Results

Water retention data and peak flow reduction data were gathered at the WCC Greenroof in Goldsboro, NC, for nine consecutive months from April 2003 to December 2003. Due to technical problems at the research site, water retention data and peak flow reduction data were gathered for only four months at the Nature Center Greenroof in Kinston, NC. Kinston data is available for July (only a portion of July is available), August, November, and December 2003. Table 1 displays a summary of the results for each greenroof research site. Water retention was calculated for each individual rain event by subtracting the depth of greenroof runoff (mm) from the depth of rainfall (mm) of each rain event. The term *retention* refers to the amount of precipitation that is temporarily stored within the system and then lost due to evapotranspiration. Runoff data for either control roof was not used due to technical problems and unreliable data.

Greenroof Location	Total Rainfall	Total Rainfall Retained	Percent Retained	Average Peak Rainfall	Average Greenroof Runoff	Percent Reduction
Goldsboro, NC	901 mm (35.5 in.)	556 mm (21.9 in.)	62%	38 mm/hr (1.5 in./hr)	8.3 mm/hr (0.3 in./hr)	78%
Kinston, NC	262 mm (10.3 in.)	166 mm (6.5 in.)	63%	42 mm/hr (1.7 in./hr)	5.6 mm/hr (0.2 in./hr)	87%

Greenroof Location	Observation Period for Each Greenroof Site
Goldsboro, NC	Consecutively from April 2003 to December 2003
Kinston, NC	July 2003†, August 2003, November 2003, and December 2003

†Data is only partially available for July 2003

Table 1. Summary of water retention data and peak flow reduction data for each greenroof site.

Both greenroofs retained a statistically significant portion of the rainfall ($\alpha < 0.05$). Figure 4 displays the monthly retention rates for the WCC Greenroof in Goldsboro, NC. Variations of the percent retained depended on how much rainfall fell during each month and on the rainfall patterns within each respective month. For example, a month where the rainfall events were evenly spaced apart with several days between each rain event would have a higher retention rate than a month with numerous rainfall events within only a few consecutive days. Storms of higher intensity would also result in reduced retention rates.

Both greenroofs significantly reduced the peak flow of runoff from the greenroof ($\alpha < 0.05$). Figure 5 displays the reduction of peak flow observed for a single rain event in April 2003 at the WCC Greenroof in Goldsboro, NC. The peak flow of the greenroof runoff, measured in mm/hr (in./hr), was compared with the peak rainfall rate, measured in mm/hr (in./hr). The average peak flow values displayed in Table 1 are the average peak flows for the entire monitoring period of each greenroof. Figure 5 displays the peak flow reduction of a 23 mm (0.9 in.) rainfall event on 7 April 2003. The WCC Greenroof retained 75% of the rainfall for this event; the peak rainfall was 37 mm/hr (1.5 in./hr) and the peak runoff from the greenroof was 3.7 mm/hr (0.2

in./hr), illustrating a 90% reduction in peak flow. The reduction of peak flow from the greenroof is clear and a delay of approximately four hours was observed between when the rainfall began and when runoff was observed from the greenroof.

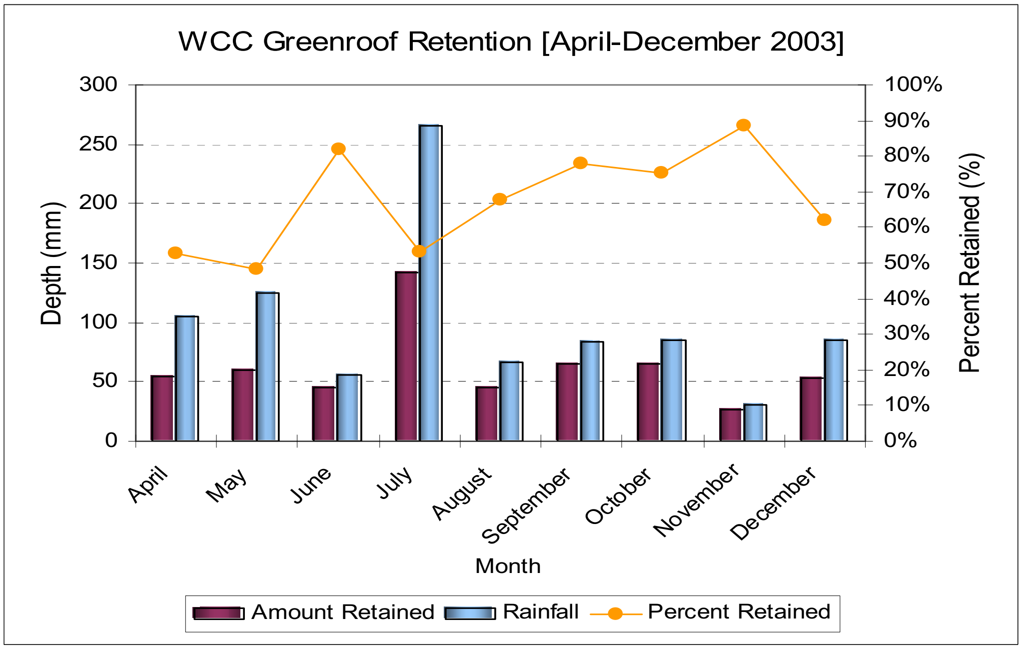

Figure 4. Monthly retention rates at WCC Greenroof in Goldsboro, NC.

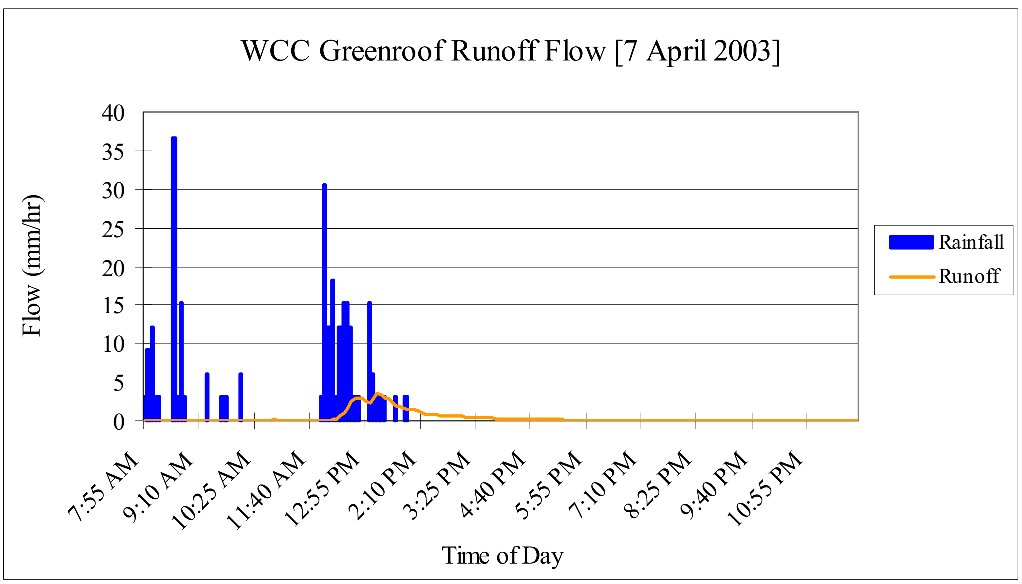

Figure 5. Peak flow reduction of greenroof runoff at WCC Greenroof in Goldsboro, NC.

Water Quality Results

Water quality data is available for a total of nine rain events throughout the sampling period between April and December 2003. It was initially hypothesized that the greenroofs would improve the water quality of storm water runoff. Samples of greenroof runoff, control roof runoff, and rainfall were analyzed for TKN as N, NO_3-NO_2 as N, NH_3 as N, TN, TP, and OP. Contrary to the original hypothesis, there was no improvement of water quality in the greenroof runoff when compared to the rainfall and the control roof runoff. The nutrients of main concern were TN and TP because each greenroof is located within the Neuse River Basin of North Carolina; recent regulations require the amount of nitrogen (N) and phosphorus (P) in storm water runoff to be minimized (5). Figure 6 displays the TN concentrations (mg N/L) at the WCC Greenroof in Goldsboro, NC and Figure 7 displays the TN mass loadings (g N) at the WCC Greenroof.

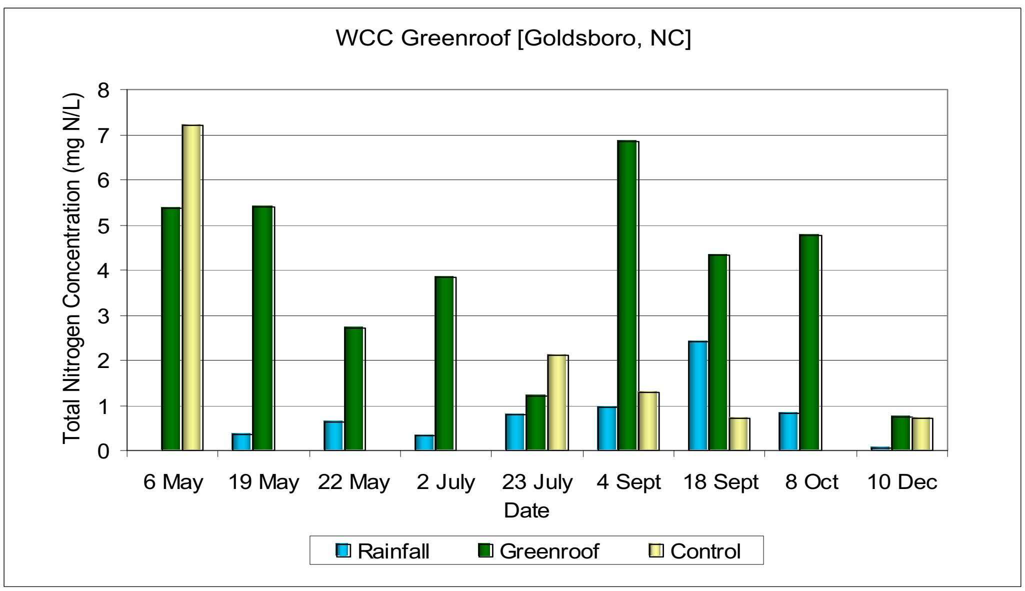

Figure 6. TN concentrations in 2003 at the WCC Greenroof in Goldsboro, NC.

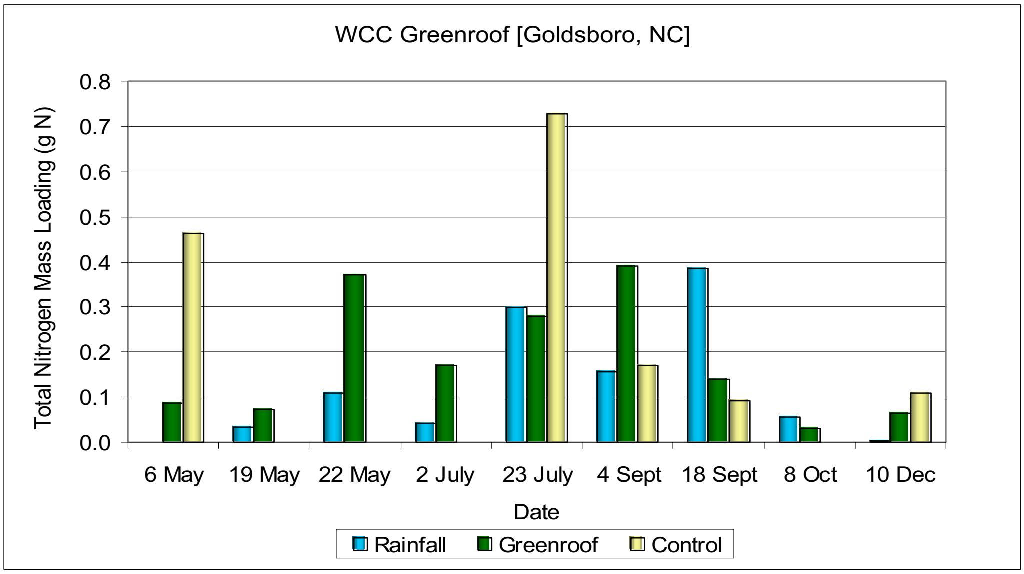

Figure 7. TN mass loadings in 2003 at the WCC Greenroof in Goldsboro, NC.

The water quality data for the Nature Center Greenroof in Kinston, NC was very similar to the water quality data for the WCC Greenroof; therefore, the Kinston data was not displayed. At the WCC Greenroof, the concentration of TN was significantly higher in the greenroof runoff than in the rainfall ($\alpha < 0.05$) and there was no statistical difference between the concentration of TN in the greenroof runoff and the control roof runoff. There was no statistically significant difference between the mass loading of TN neither in the greenroof runoff and the rainfall nor between the greenroof runoff and the control roof runoff at the WCC Greenroof. This data does not illustrate any visible trends in the concentration of TN or in the mass loading of TN in the greenroof runoff. However, it is possible that as more data is gathered, a trend of decreasing TN concentrations over time, for example, may be observed. Unlike the TN concentrations, the concentration of TP in the greenroof runoff was significantly higher than the concentration of TP in the rainfall and the control roof runoff ($\alpha < 0.05$). The mass loading of TP was also significantly higher in the greenroof runoff than the rainfall ($\alpha < 0.05$). However, there was no statistical difference between the mass loading of TP in the greenroof runoff and the control roof runoff.

The results indicate that N and P are leaching from the greenroof soil media. The Carolina Stalite Soil Mix is composed of 15% compost; the compost serves as an additional source of N and P to the system. A small laboratory column study was performed at NC State University to determine the leaching effects of N and P from three different greenroof soil media. Results show that less N and P leaches from greenroof soil media with less organic matter present in the soil mix. Additional results indicated that while higher concentrations of TN may be present in the first several rainfall events, the concentration of TN will decrease to a minimum over time.

Plant Growth Results

Between the two greenroof field sites, eleven different vegetation species were planted to determine which species would thrive in the NC environment. Of the eleven species, four did not grow well enough to be recommended for further use in NC: *Delosperma cooperi, Sedum acre, Sedum album chloroticum,* and *Sedum grisebachil.* Conversely, seven species did grow well in the NC climate and are recommended for further use: *Delosperma nubigenum, Sedum album, Sedum album murale, Sedum floriferum, Sedum reflexum, Sedum sexangulare* and *Sedum spurium fuldaglut.*

Estimated percent coverage was determined for three species atop the WCC Greenroof in Goldsboro after the first year of growth. Two soil media depths were studied: 50 mm (2 in.) and 100 mm (4 in.). Figure 8 displays the results of the percent coverage comparison of *Delosperma nubigenum, Sedum reflexum,* and *Sedum album* after one year of growth in May 2003.

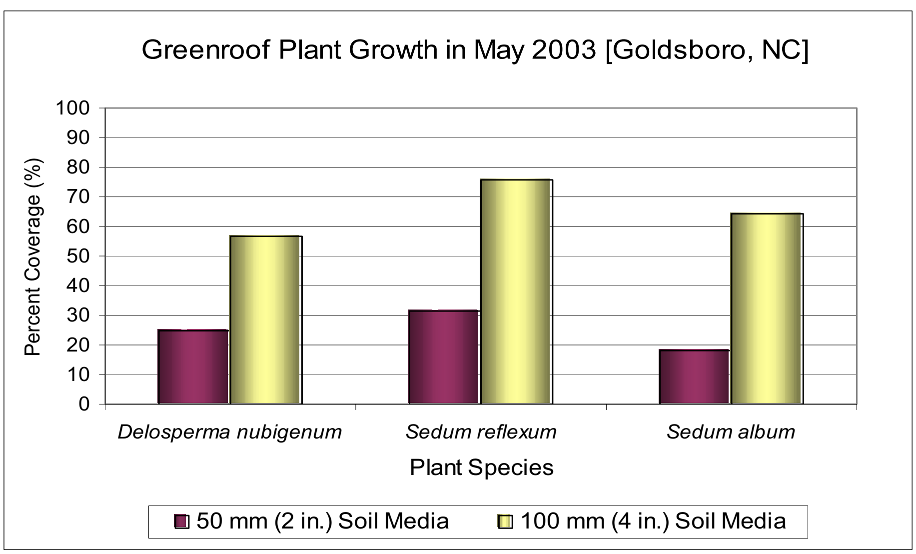

Figure 8. Plant growth after the first year at the WCC Greenroof in Goldsboro, NC. Average plant spacing is 300-450 mm (12-14 in.) on center.

The percent coverage was significantly higher in the 100 mm (4 in.) deep soil media than the 50 mm (2 in.) deep soil media ($\alpha < 0.05$). Also, the growth of *Sedum reflexum* was determined to be significantly higher than both *Delosperma nubigenum* and *Sedum album* ($\alpha < 0.05$); there was no significant difference between the growth of *Delosperma nubigenum* and *Sedum album*.

Conclusions

The greenroof functions as an excellent BMP for water retention and peak flow reduction. On average, each greenroof retained approximately the first 15 mm (0.6 in.) of rainfall events throughout the sampling period between April and December 2003. The WCC Greenroof in Goldsboro, NC retained 62% of the total recorded rainfall during the sampling period; the Nature Center Greenroof in Kinston, NC retained 63% of the total recorded rainfall during the sampling period. Average peak flow reduction from the WCC Greenroof was 78% and the average peak flow reduction of the Nature Center Greenroof was 87%.

Water quality data indicated higher concentrations of TN and TP were present in the greenroof runoff than in the rainfall and the control roof runoff. The TN mass loadings vary because the mass loading is dependant upon the concentration of TN in each source and the volume of each source (source: rainfall, greenroof, and control roof). The TP mass loadings in the greenroof runoff were typically higher than the mass loadings present in the control roof runoff and the rainfall; however, no statistical difference was observed between the mass loading of TP in the greenroof runoff and the mass loading of TP in the control roof runoff. As the concentrations of TN and TP are higher in the greenroof than the rainfall serving as the input to the system, it was hypothesized that N and P was leaching from the soil media. The Carolina Stalite Soil Mix was composed of 15% compost; the compost serves as an additional source of N and P to the system. If soil media effects on N and P concentrations were reduced, then mass loadings of N and P in the greenroof runoff would be reduced due to the reduction in runoff volume from the greenroof.

A small laboratory column study at NC State University indicated that greenroof soil media with less organic matter present in the soil mix will result in less leaching of N and P. Results from this column study also indicated that concentrations of TN may decrease in greenroof runoff over time. In future design of greenroofs, especially in locations where water quality of runoff is a concern, the composition of the soil media should be taken into consideration when selecting the soil mix. Greenroof soil medias with less organic matter present in the mix will have less leaching of N and P.

Extensive greenroof plant species recommended for growth in North Carolina are *Delosperma nubigenum, Sedum album, Sedum album fuldaglut, Sedum album murale, Sedum floriferum, Sedum reflexum,* and *Sedum sexangulare*. The percent coverage of *Delosperma nubigenum,* *Sedum reflexum,* and *Sedum album* after the first year of growth were significantly higher (α < 0.05) in the 100 mm (4 in.) deep soil media than the 50 mm (2 in.) deep soil media.

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