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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. The first was constructed in April 2002 at the Neuseway Nature Center in Kinston, NC. This 27 m^2 (290 ft^2), 3% pitched roof is composed of 10 cm (4 in) deep soil substrate planted with a variety of species of *delosperma* and *sedum*. A second greenroof was constructed atop a storage building of Wayne Community College in Goldsboro, NC. This essentially flat, 70 m^2 (750 ft^2) greenroof is constructed with soil substrate depths of 5 cm (2 in) and 10 cm (4 in) and is planted with the same variety of vegetation as the greenroof in Kinston, NC. Both greenroofs are compared to a control roof on site of typical design for research purposes. As of July 2003, sampling equipment is fully operational at the Neuseway Nature Center Greenroof in Kinston and is partially installed and operational at the WCC Greenroof in Goldsboro, NC. Installation will complete in Goldsboro in August 2003. Storm water runoff quality data is limited, but early results indicate higher concentrations of nitrogen and phosphorus present in runoff from the greenroof than in rainfall at the site; these

higher concentrations of nitrogen and phosphorus may be due to the amount of organic matter within the soil media. Storm water runoff quantity data indicates the average rain event retained by the WCC Greenroof in Goldsboro, NC is approximately 1.3 cm to 1.5 cm (0.50 in to 0.60 in) based off six rain events in April and May 2003. Up to a 90% reduction was seen in the peak flow of the WCC Greenroof in April 2003. Five plant species are recommended at this time for eastern and central North Carolina: *Delosperma Nubigenum, Sedum Reflexum, Sedum Album, Sedum Album Murale,* and *Sedum Sexangulare.*

Keywords. Greenroof, Neuse River Basin, Best Management Practice (BMP), Stormwater, Water Retention, Plant Growth, Water Quality, Total Nitrogen, Total Phosphorus, Runoff.

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 (U.S. EPA, 1996). Congress then amended the CWA in 1987 to also require NPDES permits for storm water discharges. Storm water is a significant contributor to the degradation of our waters due to the large concentrations of a variety of contaminants entering our streams and rivers. Pollutants 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 (U.S. EPA, 1996). 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).

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. However, many of these BMPs require a significant 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 nation must construct storm water BMPs, but some highly congested areas may not have the available area to construct typical BMPs such as constructed wetlands and bio-retention areas. A new option for BMPs is the greenroof; they utilize the thousands of square feet available on rooftops that would not otherwise be available on the ground. While greenroofs are unfamiliar in the United States, they are commonly found throughout Europe; Germany is one of the leading countries on greenroof technology. One of the significant functions of greenroofs is flood peak mitigation; 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

There are two types of greenroofs: intensive greenroofs and extensive greenroofs. Each has a similar profile, as shown in Figure 1. The plant layer consists of drought-resistant and robust plants selected specifically for the intended soil depth and climate region; the vegetation layer is roof planting soil media adapted to the plant level, either lightweight or heavier weighted media is used; the filter sheet and drainage layer prevent fine particles from being washed out of the substrate soil and retains rainwater for dry periods; the moisture retention/protection mat and root barrier provide protection and retain moisture and nutrients while preventing roots from affecting the waterproofing efficiency (ZinCo GmbH, 2000). Extensive greenroofs have soil depths typically between 5 cm (2 in) and 15 cm (6 in) and require little to no maintenance as the vegetation simply relies on precipitation and requires no further irrigation. Types of vegetation present on extensive greenroofs are those which can retain large amounts of water, typically types of mosses, sedums, and other plants native to the region; vegetation height usually ranges from 5 cm to 13 cm (2 in to 5 in). Intensive greenroofs have much deeper soil due to more elaborate vegetation. Maintenance is required of

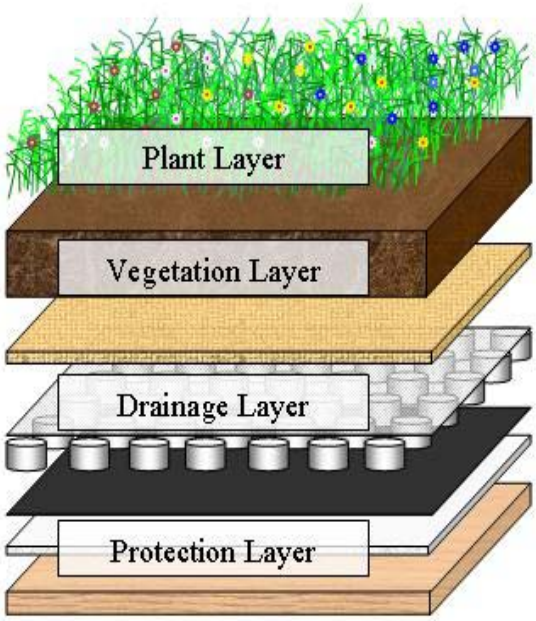

Figure 1. The profile of a typical greenroof.

intensive greenroofs, usually with regular irrigation and fertilization. The soil depth can support vegetation such as small shrubs and trees; vegetation heights range anywhere from 1 m (3 ft) to 5 m (15 ft). Intensive greenroofs are more expensive than extensive greenroofs, due to the deeper soil, the resulting added structure reinforcement, and long-term maintenance.

As the only source of water for extensive greenroofs is 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^{+2}-N), 30-50% of orthophosphorus (OP), and 70-90% for total Kjeldahl nitrogen (TKN) and ammonia as nitrogen (NH_3-N) found in storm water runoff (Wu, 1998). Studies in Monroe County, New York have also demonstrated the amounts 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 (Johnston, 1996). Animal production is also a contributing factor to atmospheric deposition. The high concentration of animal production in eastern North Carolina has contributed to higher concentrations of total nitrogen (TN) seen in rainfall at locations within 3 km of animal production systems (Robarge, 1998). This may be an important consideration for this research study as both research sites are located in eastern North Carolina.

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 (Liesecke, 1998). At the research site in Hannover-Herrenhausen, Germany, it was determined that 5 cm (2 in) and 10 cm (4 in) soils had retained approximately 65% and 70% of the precipitation during summer months, respectively (Liesecke, 1998). In winter months, the 5 cm (2 in) and 10 cm (4 in) soils had each retained approximately 50% of the precipitation (Liesecke, 1998). Water retention rates are higher during summer months due to higher evapotranspiration rates. On average, extensive soils ranging from 5 cm (2 in) to 10 cm (4 in) retained approximately 50% of the annual precipitation. Average annual precipitation for Hannover-Herrenhausen, Germany is 64 cm (26 in), compared to the annual average precipitation of 110 cm (43 in) in eastern North Carolina.

The City of Portland, Oregon, began their EcoRoof (another name for Greenroof) program in 1996 and has since been able to collect water quality and storm water runoff data from 2 research sites in the city. Between 1997 and 1999, a greenroof with 5-8 cm (2-3 in) soil depth was seen to retain up to 100% rainfall in summer months, when evapotranspiration rates are high, and averaged 20% rainfall retention in winter months, when evapotranspiration rates are low (Liptan, 2003).

Study Objectives

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

- Finding an optimal depth of soil for desirable plant growth;
- Identifying vegetation types that thrive in central and eastern North Carolina rooftop environments;
- Discovering whether greenroofs can be used as nutrient reduction BMPs and if so, what removal efficiency should be assigned to greenroofs;
- Estimating the percent precipitation retained by the greenroof and therefore flood peak mitigation.

Methodology

This research project tests greenroofs in eastern North Carolina, shown in Figure 2. Highlighted in red (dark grey), the City of Raleigh and the home of North Carolina State University are in Wake County. Highlighted in blue (light grey) are the counties in which the cities of Goldsboro and Kinston are located, Wayne County and Lenoir County. Both research sites fall within the Neuse River Basin. Each is being studied for flood peak mitigation, water quality improvement, and plant growth.

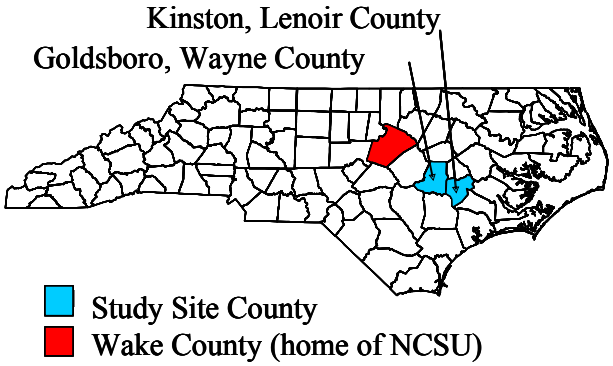

Figure 2: Map of North Carolina illustrating locations of research sites.

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 3) 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; half the greenroof has a soil depth of 5 cm (2 in) and the other half of the greenroof has a soil media depth of 10 cm (4 in). The media depths have been arranged to resemble a checkerboard pattern with each matching soil substrate depth diagonally across from the other. The plant species researched at this site include *delosperma nubigenum, sedum reflexum, sedum sexangulare, sedum album, sedum acre*, *sedum album chloroticum,* and *sedum album murale*, *sedum spurium fuldaglut*, *sedum grisebachil*, and *delosperma cooperi.*

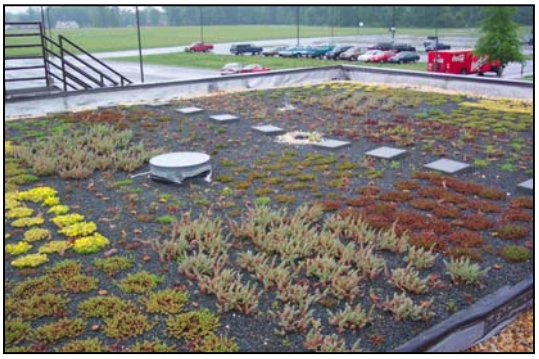

Figure 3. WCC Greenroof in Goldsboro (April 2003).

The approximate 27 m^2 (290 ft^2) greenroof at the Neuseway Nature Center in Kinston, NC, was constructed in April 2002 (see Figure 4). 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 is transporting the soil media to the rooftop; very primitive techniques using buckets transported the soil medium to the rooftop. As more greenroofs are built throughout the country, more efficient methods for transporting media to the rooftop are expected to develop. The Neuseway Nature Center Greenroof has a 3% pitch greenroof consists of 10 cm (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.

Figure 4. Neuseway Nature Center Greenroof (May 2003).

The drainage layer (refer to Figure 1 for the typical greenroof profile) 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™ has storage pockets 40 mm (1.6 in) thick and also requires a filter fabric; Hydrodrain 300™ is similar to the Floradrain FD40™, but it also has a non-woven filter fabric system already incorporated into its design. While the Floradrain FD40™ has a storage capacity of 9.8 L/m^2 ($0.2gal/ft^2$), the Hydrodrain 300™ has negligible storage. 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 and is composed of 55% Perma Till (Stalite 3/8" expanded slate), 30% Rootzone Sand, and 15% approved compost. The soil mix has 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 variety of plants was purchased from Emory Knoll Farms in Street, Maryland.

Monitoring

Each greenroof site is equipped with two Sigma 900Max™ Automatic samplers, with one sampler being for the greenroof and one sampler for the control roof at each site. A Solarex Solar Panel and a 12-volt battery power the samplers. The Sigma 900Max Automatic samplers are stored in a large, secured green box. As of July 2003, sampling equipment is fully operational at the Neuseway Nature Center in Kinston, NC and is partially installed at the WCC Greenroof in Goldsboro, NC. The WCC Greenroof has sampling equipment for the greenroof, but not the control; the control sampling equipment is temporarily out of service. Each rooftop has a single drain leading to a galvanized steel box (a weir box).

Figure 5. Sampling equipment for WCC control roof. Weir box is on left side; green sampler storage box is on right.

Figure 5 is a photograph of the green box and the weir box for the control roof at the WCC Greenroof. Each weir box in Goldsboro stores approximately 0.05 m^3 (0.5 ft^3) before rainwater begins to flow over the laboratory tested 30° sharp crested weir. The greenroof weir box in Kinston has a storage volume of 0.009 m^3 (0.33 ft^3) before rainwater flows over the 23° weir; the control weir box in Kinston stores approximately 0.035 m^3 (1.25 ft^3) of rainwater before rainwater flows over its 30° weir.

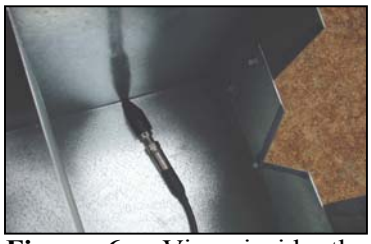

Figure 6. View inside the weir box with baffle, pressure transducer, and weir plate.

Each weir box is also equipped with one baffle at the center point to steady the water flow over the weir. Storm water flows over a laboratory tested weir plate as it flows from the steel box and then exits the site. Inside each weir box, a pressure transducer measures the height of the water above the weir notch. Figure 6 illustrates the inside of the weir box with pressure transducer and baffle. When the water level is above the weir notch, water is flowing over the weir.

The automatic samplers are programmed to retrieve a 50 mL sample in intervals of 23 L (5 gallon) of flow over the weir. Flow over the weir is calculated using the following equation:

$$Q = C_{wt}(8/15)[\tan(\theta/2)]\ \sqrt{(2GH^{5/2})}$$

Where: Q = flow over weir (cfs)
C_{wt} = triangular weir coefficient(unitless)
G = gravity (ft/s)
H = height above weir (ft)
θ = angle of weir (rad).

There is an approximate 24-hr holding period before samples are collected and then taken to a lab for analysis. Samples are analyzed in Raleigh, NC, by Tritest, Inc. The following analyses are performed on the water quality samples: (1) Total Kjeldahl Nitrogen in Water (TKN) [EPA 351.2], (2) Nitrate-Nitrite in Water (NO_3^{2+}-NO^{2-}) [EPA 353.2], (3) Total Nitrogen (TN), (4) Nitrate in Water (NO_3^{2+}) [EPA 353.2], (5) Ammonia in Water (NH_3) [EPA 350.1], (6) Total Phosphorus (TP) [EPA 365.4], and (7) Orthophosphate (OP) [EPA 365.2]. One of the focuses of water quality within the Neuse River and Tar-Pamlico Basins of North Carolina is to reduce nitrogen and phosphorus loadings. Thus, the greenroof will compare water quality results for nitrogen and phosphorus with the control roof and rainfall at each site. Therefore, the water quality analysis will demonstrate the water quality improvements with regards to atmospheric deposition of nutrients at these two sites in the Neuse River Basin.

The Sigma 900Max™ sampler records flow data and level data in 5-minute intervals. A Global Water Instruments, Inc. rain gage is also installed at each site and records data in 5-minute intervals though the sampler. After each rain event greater than 1.3 cm (0.50 in), samples are collected and data is downloaded from both the greenroof and the control roof 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. This roof was used to measure plant growth instead of the greenroof at the Neuseway Nature Center in Kinston because different soil media depths could be studied here to reflect the plant growth in relation to the soil media depth. A comparison between plant growth of the 5 cm (2 in) and the 10 cm (4 in) soil depth was observed and recorded. Figure 7 illustrates the technique used to measure percent coverage; this photo is of *delosperma nubigenum* coverage in 5 cm (2 in) soil. A circular tube of an approximate diameter of 40 cm (16 in) was randomly placed on each section of species for the respective soil depth, this was repeated so 3 measurements were recorded for each species. Plant growth was estimated among 3 different species. Three students recorded individual estimates, and after all estimates were taken, the three estimates for each plant species were averaged to determine the percent coverage for each species for each soil depth.

Figure 7. *Delosperma Nubigenum* in 5 cm Soil Media (January 2003).

Results and Analysis

As of July 2003, hydrologic and water quality data has been gathered for the WCC Greenroof in Goldsboro; however, due to some system malfunctions, no data has been collected for the control roof at this point. As of July 2003, water quality data has been gathered for both the control roof and the greenroof at the Neuseway Nature Center in Kinston, NC. Due to leaks in the gutters draining the greenroof (to be repaired by August 2003), no reliable hydrologic data is available for this roof at this time. However, water quality data is available for concentrations of nutrients in Kinston.

Water Quality Results

Water quality results have been gathered for two rain events in May 2003; this is the only reliable data available. However, as there are only two rain events to gather information from, all data in this report regarding water quality is preliminary data. No conclusions can be made from these water quality results; I the coming months, more data will be gathered to make an accurate conclusion.

The first rain event on 19 May 2003 had a cumulative rainfall of 1.96 cm (0.77 in) in Goldsboro, NC and 4.72 cm (1.86 in) in Kinston, NC. The second rain event on 23 May 2003 had a total rainfall of 3.46 cm (1.36 in) in Goldsboro, NC and 6.05 cm (2.38 in) in Kinston, NC. Figure 8 displays the preliminary water quality results for the two rain events at each research site. This preliminary data shows higher concentrations of nitrogen and phosphorus are present in the greenroof runoff than the rain inflow from each site. For example, in Kinston on 19 May, the inflow of TN was 0.35 mg/L and the outflow from the greenroof was 2.4 mg/L; on 23 May, the inflow of TP was 0.05 mg/L and the outflow from the greenroof was 1.2 mg/L. The same trend was also seen in Goldsboro at the WCC Greenroof: on 19 May the inflow of TP was 0.36 mg/L and the outflow was 5.4 mg/L; on 23 May the inflow of TP was 0.05 mg/L and the outflow from the greenroof was 1.2 mg/L.

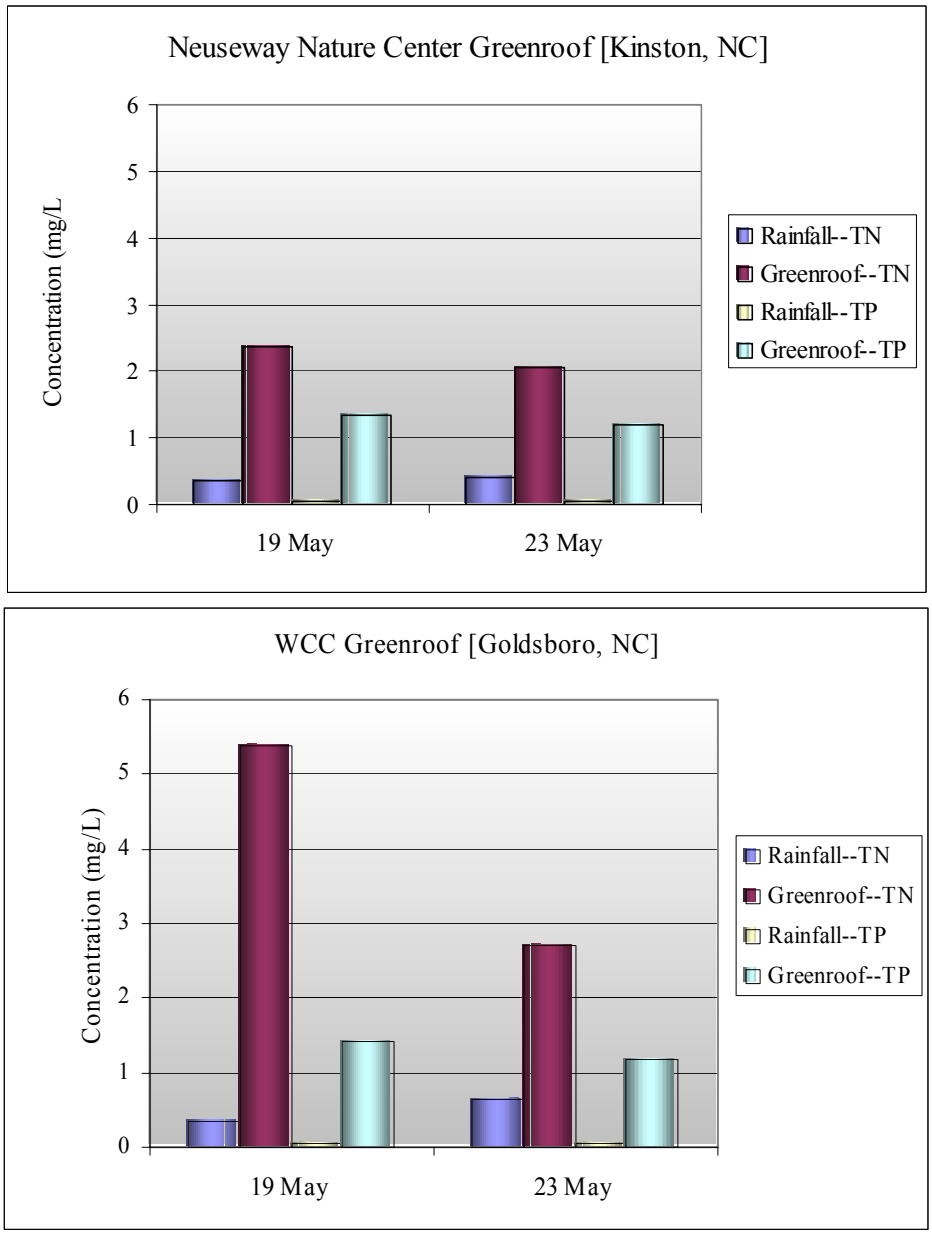

Figure 8. Preliminary water quality results for Goldsboro and Kinston, NC research sites. Results from May 2003. (Top: Neuseway Nature Center; Bottom: WCC Greenroof)

One of the main causes of this may be leaching of nutrients from the compost present in the Stalite Soil Mix; data suggesting this has also been seen at Pennsylvania State University (Berghage, 2003). The soil mix used at the WCC Greenroof and the Neuseway Nature Center has 15% compost cow manure. This initial presence of compost in the soil media indicates a significant level of nutrients present in the soil at the time of construction. However, this organic matter will leach from the soil over time. If levels of nutrients present in greenroof gradually decrease over time, this indicates the level of nutrients present within the soil media is decreasing (i.e. the nutrients are leaching from the soil). This trend of nutrients leaching through soil media has been observed in the City of Portland with decreasing phosphorus concentrations over time (Liptan, 2003). It is possible that future analysis may show supporting evidence that less nutrients emit from the greenroof over time as more nutrients are leached through the soil media.

Hydrologic Results

As of June 2003, several rain events have been measured at the WCC Greenroof in Goldsboro and the Neuseway Nature Center in Kinston. However, due to significant amounts of water leaking from the gutters and not reaching the weir box, accurate flows and volumes of rainwater draining from the greenroof at the Neuseway Nature Center cannot be made at this time. Repairs will be made to the drainage system by August 2003 and accurate data will be available after this time. Therefore, all hydrologic data presented in this report is from the WCC Greenroof in Goldsboro, NC.

Hydrologic data began collection in Spring 2003; results are shown in this report for April and May 2003 in Figures 9 and 10. Three rain events are shown for April 2003 in Figure 9, all within a period of five days. The first rain event on 7 April 2003 had a total rainfall of 2.3 cm (0.89 in) with runoff from the greenroof of 0.56 cm (0.22 in); the second storm on 8 and 9 April 2003 had a cumulative rainfall of 2.6 cm (1.02 in) and a runoff amount of 1.45 cm (0.57 in) from the greenroof. The third rain event [separated from the second rain event by approximately 12 hours] of 9, 10, and 11 April 2003 had a total rainfall of 4.2 cm (1.63 in) and a greenroof runoff amount of 1.32 cm (1.11 in). Table 1 displays the hydrologic retention of the April rain events for the WCC Greenroof.

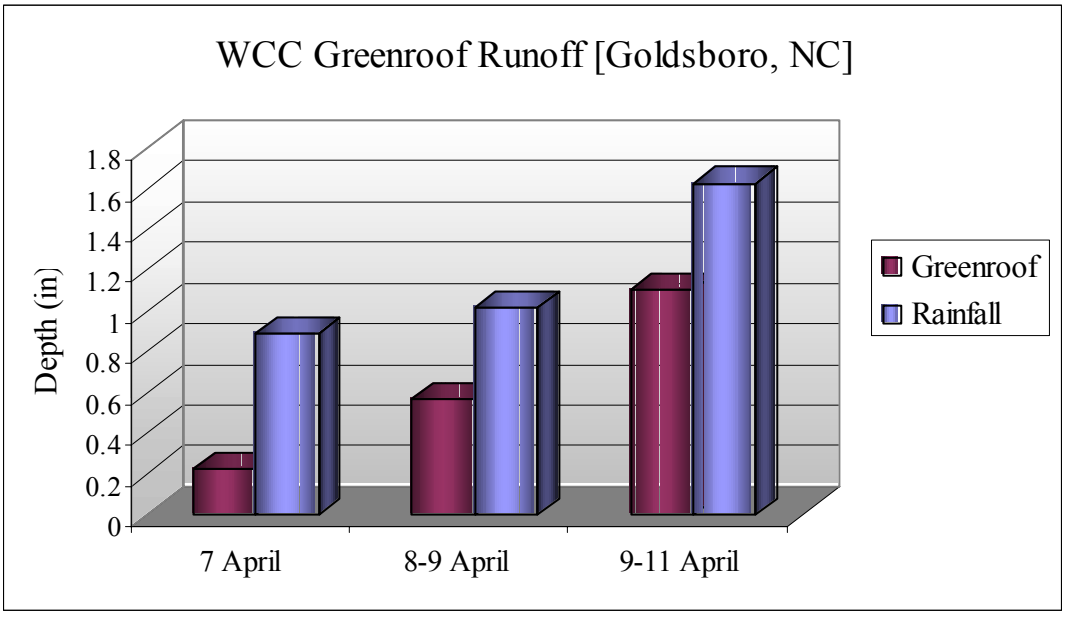

Figure 9. Hydrologic Retention for the WCC Greenroof in April 2003.

Table 1. April 2003 Hydrologic Retention for the WCC Greenroof in Goldsboro, NC

Storm Event	*Rainfall (in)*	*Greenroof Runoff (in)*	*Retained (in)*	*% Retained*
7 April 2003	0.89	0.22	0.67	75
8-9 April 2003	1.02	0.57	0.45	44
9-11 April 2003	1.63	1.11	0.52	32

As shown in Table 1, the percent retained for each storm decreased with each respective rain event. However, as the percent retained decreased, the amount of rainwater retained was approximately 1.38 cm (0.55 in) for all three rain events. Therefore, these early results suggest the greenroof can retain an approximate rain event of 1.38 cm (0.55 in) or less.

The hydrologic results for May 2003 are illustrated in Figure 10. For these three rain events, the first on 6 May 2003 is an isolated event; however the last two storm events are separated by 3 days. The three day interval is greater than that of all the storms in April 2003. The first rain event on 6 May 2003 had a cumulative rainfall of 1.96 cm (0.77 in) with a greenroof runoff of 0.33 cm (0.13 in). The second rain event had a total rainfall of 0.78 cm (0.31 in) with no runoff from the greenroof; the third rain event had a rainfall of 1.96 cm (0.77 in) with a runoff amount of 0.28 cm (0.11 in). Table 2 displays the hydrologic retention for the rain events in May 2003.

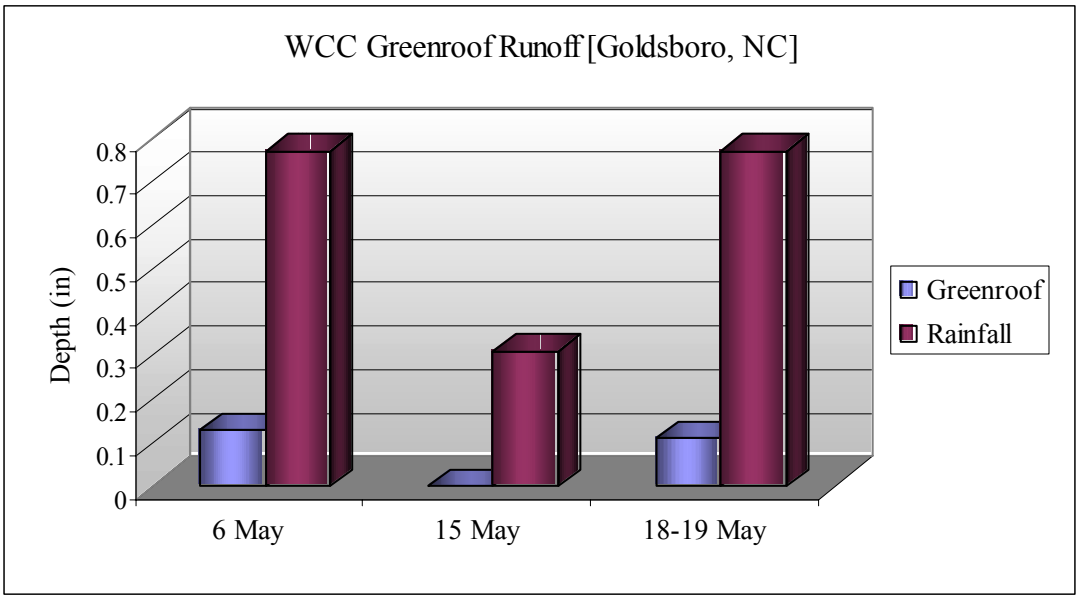

Figure 10. Hydrologic Retention for the WCC Greenroof in May 2003.

Table 2 illustrates that the smaller rain event of 0.79 cm (0.31 in) was completely retained by the greenroof, as expected from the April 2003 results. The May 2003 results indicate there may be better retention when there has been an adequate amount of time between storm events. However, the amount retained for both the first and last rain event was similar to the amount retained from the April 2003 rain events. Results from May 2003 indicate a slightly greater storage capacity than shown in April 2003 with an average retention of 1.6 cm (0.65 in).

Table 2. May 2003 Hydrologic Retention for the WCC Greenroof in Goldsboro, NC

Storm Event	*Rainfall (in)*	*Greenroof Runoff (in)*	*Retained (in)*	*% Retained*
6 May 2003	0.77	0.13	0.64	83
15 May 2003	0.31	0.00	0.31	100
18-19 May 2003	0.77	0.11	0.66	86

Figures 9 and 10 illustrate the amount of rainwater retained by the WCC Greenroof in Goldsboro, NC. In addition to retaining rainwater, the greenroof also reduced the peak flow. Figure 11 illustrates the reduction in peak flow for April 2003; the three rain events are the same three displayed in Figure 9 and Table 1. Through Figure 11, the reduction in peak flow of the greenroof from the flow of rainfall is visible, as well as the delay in runoff. A typical rooftop would have runoff immediately during the event, but the greenroof delays runoff; the peak flow and the time to peak are both reduced.

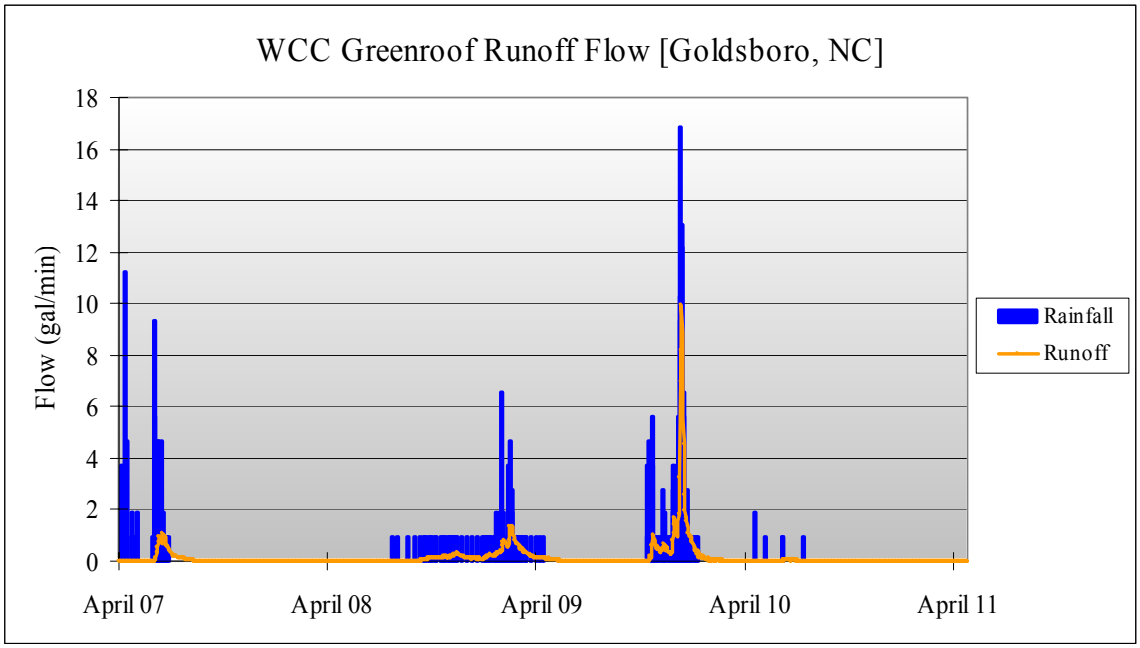

Figure 11. Flow Results for the WCC Greenroof in April 2003.

The delay in time to peak is most easily seen for the first of the three rain events on 7 April 2003. While rainfall began at 8:00am, runoff was not seen until 10:15am, resulting in a delay of approximately two hours until runoff flowed from the greenroof; an average rooftop would have had runoff visible almost immediately after rainfall began. On 7 April 2003, the peak flow of rainfall was 174 L/s (11 gpm) and the peak flow of greenroof runoff was 17 L/s (1.1 gpm). This is a 90% reduction in the peak flow; the time to peak flow of the greenroof was also delayed approximately 4.5 hours. On 8-9 April 2003, the peak rainfall rate was 103 L/s (6.5 gpm) and the peak flow of the greenroof runoff was 21 L/s (1.3 gpm). In this rain event, the peak flow was reduced 80%; the time to peak flow of the greenroof was delayed approximately 1 hour. The third rain event of this series from 9 April to 11 April had a peak rainfall of 270 L/s (17 gpm) and the peak flow of the greenroof was 157 L/s (9.9 gpm); the delay to peak flow of the greenroof was less than one half hour. While the peak

flow did not have a substantial delay on this third and final rain event of the series, the peak flow was reduced by 40%.

Plant Growth Results

Estimated percent coverages were determined for three species atop the WCC Greenroof in Goldsboro. Two depths soil depths are currently being studied: 5 cm (2 in) and 10 cm (4 in) and are shown in Figure 12 after the first year's growth in May 2003. Figure 12 illustrates the area of roof that will be studied for plant growth in the 5 cm (2 in) and 10 cm (4 in) soil media depths. This area comprises 1/3 of the total roof area. Other sections of the rooftop were replanted in early May 2003 after some plant species did not flourish in the North Carolina climate; therefore, four species were planted in sparse areas of the rooftop. However, the area shown in Figure 12 remained undisturbed for research purposes.

Measurements were made for plant coverage of the following plant species: *Delosperma Nubigenum, Sedum Album,* and *Sedum Reflexum*. In the spring of 2003, it was discovered that half of the rooftop actually had a soil media depth of 8 cm (3 in) when it was designed to be 5 cm (2in) and 10 cm (4 in) depths. This was an initial constraint in the effort to record repetitive measures of the 5cm (2 in) and 10 cm (4 in) media depths, but this became an opportunity to measure the growth of the selected species for a depth of 8 cm (3 in) in addition to the original selected soil media depths.

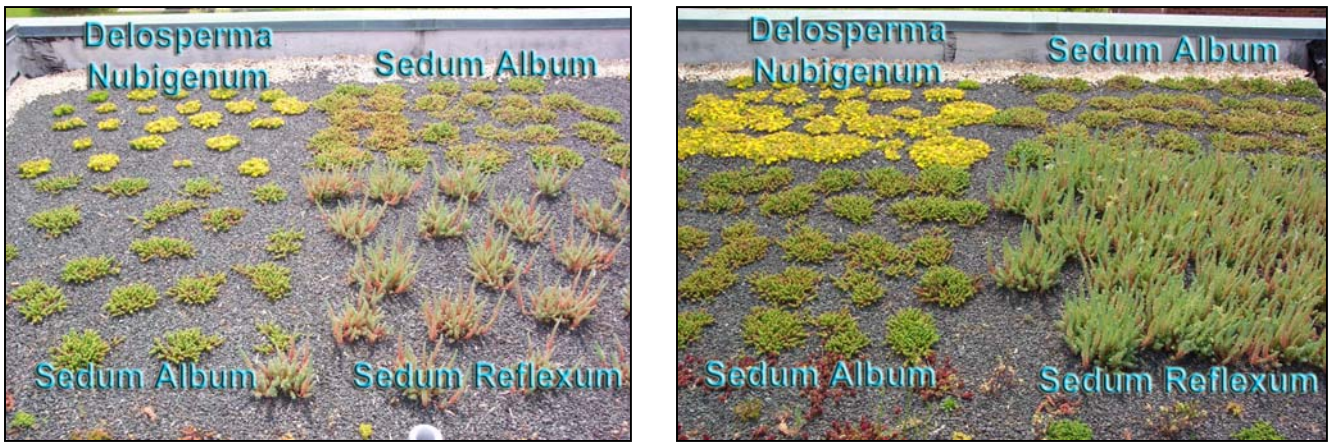

Figure 12. Plant growth after one year at the WCC Greenroof in Goldsboro, NC. 5 cm (2 in) soil media depth (left); 10 cm (4 in) soil media depth (right). May 2003.

The average plant spacing in Goldsboro is 30-45 cm (12-14 in) on center. Though not being researched for percent coverage of plant growth, the average plant spacing for the Neuseway Nature Center Greenroof is closer than in Goldsboro, approximately 25-30 cm (8-10 in). Several plant species have flourished at both the Neuseway Nature Center in Kinston, NC and the WCC Greenroof in Goldsboro, NC. These species include *delosperma nubigenum*, *sedum album, sedum reflexum*, *sedum sexangulare*, and *sedum album murale*. Other species have also grown well throughout the first year, such as *sedum spurium fuldaglut*, and *sedum floriferum*. Some species that have not grown well in the North Carolina climate are *sedum album chloroticum, sedum grisebachil, sedum acre,* and *delosperma cooperi.*

Figure 13 displays the results of the percent coverage comparison of *delosperma nubigenum, sedum reflexum,* and *sedum album* after one year of growth in May 2003. On average, there was a 40% difference in percent coverage between the 5 cm (2 in) and the 10 cm (4 in) soil media depth, with more coverage on the deeper soil. On average, between the three selected species, there was a 23% difference between the 5 cm (2 in) media depth and the 8 cm (3 in) media depth; a 17% difference was seen between the 8 cm (3 in) and the 10 cm (4 in) media depth. On average, plant coverage in the 8 cm (3 in) media depth is closer to coverage in the 10 cm (4

in) than the 5 cm (2 in) media depth. While the results described above are based on an average, the results for the individual plant species are slightly different, as shown below in Figure 13. Figure 13 illustrates that while the percent coverage of *delosperma nubigenum* increases approximately 30% from 8 cm (3 in) to 10 cm (4 in). Unlike *sedum reflexum*, sedum album has a large increase from 5 cm (2 in) to 8 cm (3 in) of approximately 40% with only an increase of approximately 10% from 8 cm (3 in) to 10 cm (4 in). This shows that some species may have the same approximate growth rate for 8 cm (3 in) and 10 cm (4 in), but others may not have such a closely related growth rate. For example, if high percent coverage is desired for the first year in 8 cm (3 in) deep soil media, *Delosperma Nubigenum* and *Sedum Album* would both be good choices. *Sedum Reflexum,* however, would be a much better selection for 10 cm (4 in) than 8 cm (3 in).

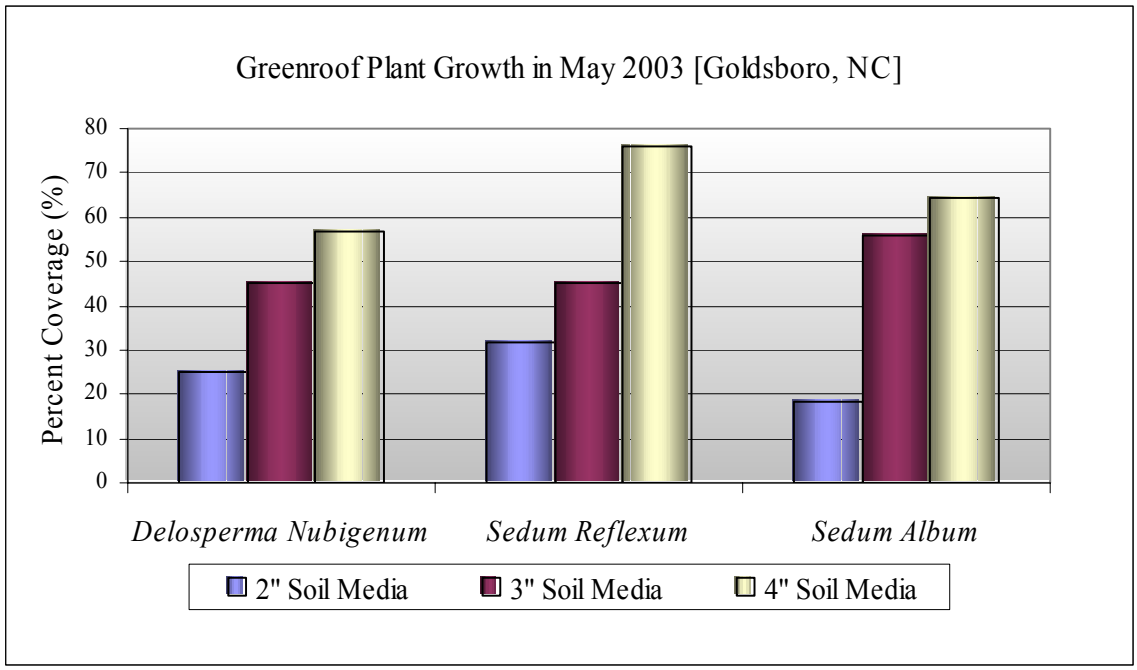

Figure 13. Plant growth after one year at the WCC Greenroof in Goldsboro, NC. Original plant spacing is 30-45 cm on center. May 2003.

Another point of concern is weed growth. Researchers at Michigan State University found that weed growth is more prominent in deeper soil and would therefore be more of a problem in a 10 cm (4 in) soil media depth rather than a 5 cm (2 in) soil substrate depth (Rowe, 2003). However, if there is an ample amount of rainfall, weeds can also develop in 5 cm (2 in) of media (Rowe, 2003). The soil substrate and climate will play a factor in weed growth at any location. At the WCC Greenroof in Goldsboro, NC, red carpet weeds were observed in October 2002 in both the 5 cm (2 in) and the 10 cm (4 in) media depths with more weeds present in the 10 cm (4 in) depth. The weeds do eventually wilt and die due to possible temperature changes and other effects resulting from season change; however, until that point, the weeds create competition for the growth of the extensive greenroof plants.

Conclusions

As of July 2003, sampling equipment is fully installed and operational at the Neuseway Nature Center Greenroof and the control roof in Kinston, NC. Sampling equipment is fully operational at the WCC Greenroof in Goldsboro, NC; however, the control site is not operational at this time due to technical difficulties. More data will be collected for analysis within the coming months and throughout the next year and will provide more evidence for strong conclusions. As a result of lack of data, conclusions at this point are tentative.

Because water quality data is lacking at this time, it can only be concluded that the greenroof presently has higher concentrations of nitrogen and phosphorus leaving the greenroof than entering it through rainfall. However there is a trend indicative that the higher concentrations of nitrogen and phosphorus may decrease over time as more nutrients leach out of the soil media; however, no conclusions can be made at this time. Hydrologic data from the WCC Greenroof in Goldsboro, NC indicate that the average amount of rainfall the greenroof can retain before runoff occurs is approximately 1.3 cm to 1.5 cm (0.50 in to 0.60 in). For three storm events in series in April 2003, the average reduction in peak flow was 70%. The WCC Greenroof has an average of 8 cm (3 in) of soil media with Hydrodrain 300™ as the drainage layer.

Five plant species are recommended for growth in eastern and central North Carolina: *delosperma nubigenum, sedum reflexum, sedum album, sedum album murale,* and *sedum sexangulare.* On average, percent coverage of *delosperma nubigenum, sedum reflexum,* and *sedum album* after one year's growth in 5 cm (2 in) soil media was 25%; percent coverage in 8 cm (3 in) soil media was 48%; percent coverage in 10 cm (4 in) soil media was 65%.

As more data is gathered and analyzed in the coming months, design standards will begin to be developed with respect to plant selection, drainage mediums, soil media composition, and soil media depth.

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