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INVESTIGATING LEVEL SPREADER – VEGETATED FILTER STRIP SYSTEMS FOR STORMWATER MANAGEMENT

Author/s:

Dr. William F. Hunt, Associate Professor and Extension Specialist, North Carolina State University.

Mr. Ryan J. Winston, Extension Associate, North Carolina State University.

Abstract

Traditional construction practices lead to degradation of watershed hydrology through increased flow in pipe networks, increased flow volumes, decreased groundwater recharge, and increased peak flow rates. Recent regulations in North Carolina have led to the use of level spreaders in combination with vegetative filter strips as an end-of-pipe method to reduce erosion and decrease stresses on riparian buffers. However, little research has been done to evaluate their effectiveness. A total of four level spreaders were studied at two sites, Apex and Louisburg, NC. At each site, stormwater from small, impervious watersheds (0.4 ha or less) was conveyed to two level spreaders. Flow was released along the length of the level spreaders and into two vegetative filter strips. This study evaluated the hydrologic and water quality benefits of level spreader – vegetative filter strip systems. Differing buffer widths and vegetation types were examined. Hydrologic results show that flow volumes were reduced by 50% or more, and peak flow rates were reduced by 70% or more. The systems reduced TSS and sediment bound nitrogen and phosphorus forms. Load reduction was observed for all pollutants studied. A level spreader – vegetative filter strip can function as an effective LID/ WSUD practice.

1. INTRODUCTION

To mitigate problems associated with land development, engineers and land use planners have designed and implemented (so called in the USA) Low Impact Development (LID) practices. In Australia, the term Water Sensitive Urban Design (WSUD) is used. Common WSUD/LID practices include bioretention areas, cisterns (water harvesting), permeable pavement, vegetated swales, and reduction of impervious areas. WSUD practices employ a number of mechanisms to improve water quality and reduce runoff before it enters natural water bodies. A goal of these practices is to remove pollutants common to urban stormwater. WSUD practices are also designed to mitigate peak flows, runoff volume, and time to peak, all of which help meet target hydrologic processes of the watershed.

A WSUD practice that is being used in the state of North Carolina is the level spreader/vegetated buffer system (LS/VBS). The term "level spreader" was first described by Smolen et al. (1988) as "a non-erosive outlet for concentrated runoff constructed to disperse flow uniformly across a slope." A level spreader is designed to receive upslope pipe flow, and create downslope diffuse flow through a vegetated buffer (Hathaway and Hunt, 2008). Design requirements for level spreaders have been produced in several states such as North Carolina (NC DENR, 2007), but past research on their effectiveness in urban areas is limited.

Line and Hunt (2009) examined one LS-VFS system located in a highway interchange in the coastal plain of North Carolina. The authors found the LS-VFS system reduced inflow volumes by 49% for the 14 storms examined. This was attributed to infiltration through the 7.3-m wide and 17.1-m long Bermuda grass filter strip. Earlier work by Yu et al. (1993) for six storm events in Virginia found primarily good pollutant removal for two level spreaders (23-m and 46-m long) on a mass basis. Most recently, in Charlotte, NC, Hunt et al. (2010) evaluated a large VFS relative to its contributing drainage area (11%) and found 85% of inflow volume to be retained by the LS-VFS system. To date, these are the only three peer-reviewed studies on LS-VFS systems receiving urban stormwater runoff.

2. STUDY SITE DESCRIPTIONS

Two sites were monitored in the Piedmont region of North Carolina. The first site was in Apex, North Carolina which is located in the Neuse river basin, while the second site was in Louisburg, North Carolina, which is part of the Tar-Pamlico river basin. Each site watershed was approximately 0.40 ha (1 acre) or less in drainage area, with 66% and 89% imperviousness, respectively, at the Louisburg and Apex sites. Prior to BMP construction, both watersheds drained to curb cuts. Stormwater was then allowed to flow into grassy areas, and eventually to ephemeral streams. Sites were surveyed extensively, and designs were created for two level spreaders at each site. Per North Carolina Department of Environmental and Natural Resources (NCDENR) 2007 design guidance, each level spreader was 3.96 m (13 ft) in length, and was constructed level across its length, in order to disperse flow across the length of the filter strip. Construction of the BMPs was completed in January 2008, and monitoring began in March 2008. Sites were monitored for one year.

At each site, stormflow from the watershed was conveyed to a forebay, in order to settle out solids and remove trash and debris from the system. Inlet pipes were used to convey flow from the forebay to the “blind” swales, which are located behind the level spreaders. Once the blind swales fill, flow is released into the vegetative filter strips. Two filter strips were studied at each site: one 7.6 m long, grass filter strip, and one 15.2 m half grass, half wooded filter strip, each length corresponded to NCDENR (2007) guidance . Figure 1 shows a level spreader – vegetative filter strip (LS-VFS) in Apex, North Carolina.

After the water passed through the buffer, the remaining surface flow was recollected in a trough downslope of the level spreader. Flow then passed from the trough to a weir box. A drainage pipe conveyed flow from the weir box offsite. This monitoring scheme is repeated four times, once for each of the level spreaders (Figure 1).

Figure 1. Level Spreader-VFS (a), Recollection Trough, and Weir Box(b).

Soil conditions contribute to the functioning of this LID practice, since it is almost solely dependent on infiltration for hydrologic and water quality improvements. The soils at both the Apex and Louisburg sites are classified as sandy loam. However, there is a tight clayey confining layer at a depth of 60 cm in Apex, which causes a perched water table during extended wet periods. Also, the soil in Apex was disturbed during construction of the parking lot that serves as the watershed, resulting in mixing of fines throughout the soil profile. Infiltration rates were measured at both sites using a double ring test; infiltration rates at Louisburg (5 cm/h) were five times greaterthan those in Apex (1cm/h).

2.1 Collecting Data

Inflow rates were calculated using the USDA- NRCS curve number methodology, because each watershed was highly impermeable and reliable precipitation was collected on site. At the outlet, hydrologic measurements were made downslope of the VFSs. As described above, outflow was intercepted in a triangular cross section wooden trough. A weir box situated at one end of the trough was used to measure flow rates. A 30° V-notch weir was used in each weir box, in combination with an ISCO 730 bubbler flow module. The flow module recorded stage measurements on a two minute interval. Flow rates at the outlet were calculated using the stage-discharge relationship for a 30° V-notch weir, given below in equation 1:

$$Q=0.676*H^{2.5} \qquad [1]$$

Following the calculation of flow rates, inlet and outlet flow volumes were calculated as the area under the hydrograph.

Flow-weighted composite water quality samples were taken using ISCO 6712 ™ automated samplers from three locations at each site, in order to quantify improvement or degradation in water quality across the system. During this study, samples were analyzed for the following parameters: Total Kjeldahl Nitrogen (TKN), nitrate-nitrite nitrogen (NO_3+NO_2), total nitrogen (TN), ammonia nitrogen (NH_3N), total phosphorous (TP), orthophosphate (Ortho P), and total suspended solids (TSS). The inlet water quality sample intake was located in the center of the forebay, where mixing of incoming stormwater from the watershed occurred. Outlet sample intakes were located in each weir box downslope of the VFSs. The inlet water quality samples were used as a baseline for all comparisons, as they represented untreated stormwater runoff.

3. RESULTS

3.1 Hydrologic Results

Monitoring was undertaken from March 2008-March 2009. In Louisburg, fifty eight events large enough to create inflow were monitored. Due to minor equipment failures, some storm events were not captured. Thirty three storm events with precipitation depth <1.27 cm, fifteen events between 1.27 cm and 2.54 cm, and four events >2.54 cm have been monitored. Median rainfall depth was 1.08 cm, with lower and upper extremes of 0.1 cm and 6.78 cm, respectively. Hydrology results for this site show reduction in flow volumes for all but one storm event studied. Flow volume and peak flow reduction by storm size are shown (Figure 2). For both the 7.6 m buffer and the 15.2 m buffer, percent volume reduction and percent peak flow reduction appear strongly correlated to the size of the rainfall event. As precipitation depth increases, the effectiveness of the level spreader – vegetated filter strip system decreases. For storm events less than 1.25 cm, this system infiltrates more than 70% of flow volumes and reduces peak flow rate by greater than 70%. However, general trends indicate that as rainfall depth increases, volume reduction and peak flow reduction decrease. Therefore, a LS-VFS system will function more effectively during smaller rainfall events, similar to the conclusion of Li et al. (2009) for bioretention areas.

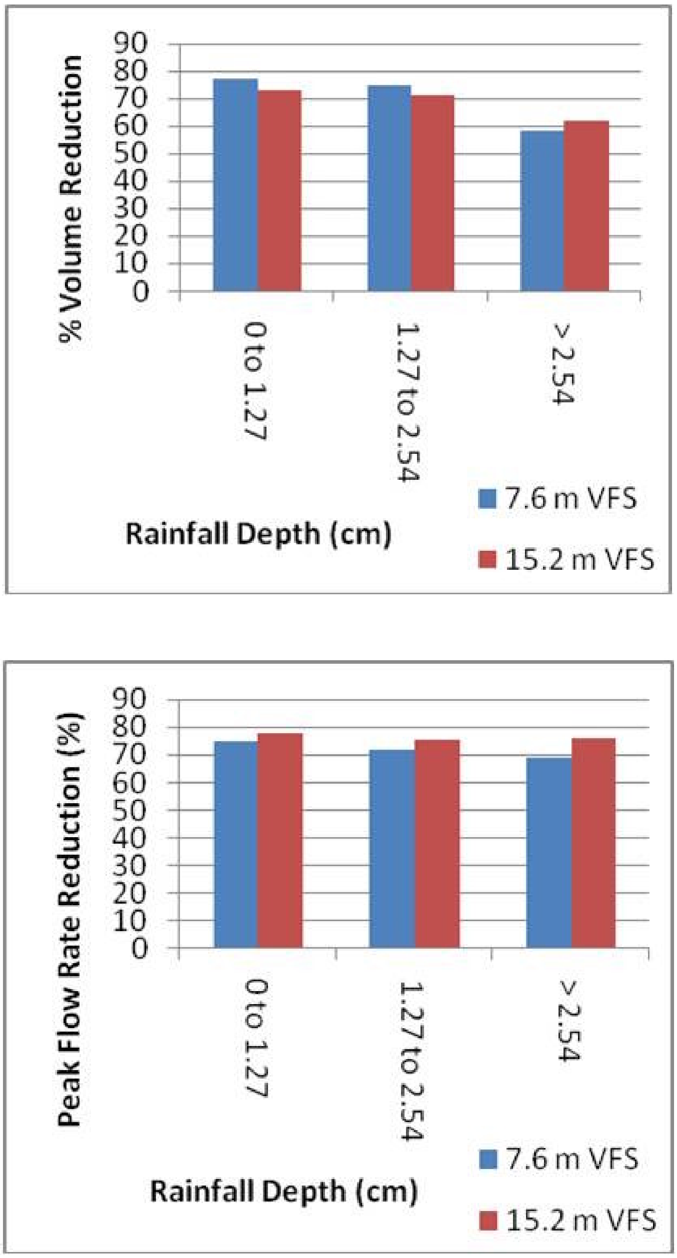

Figure 2. Volume Reduction (a) and Peak Flow Rate Reduction (b) for Louisburg, NC Site.

3.1 Water Quality Results

Monitoring for the water quality portion of this study was completed in March 2009. For a water quality event to occur, a minimum of 0.5 cm of rainfall was required. Therefore, many of the storm events analyzed above in the hydrology section were not large enough to be considered a "water quality event." In Apex, a total of 21 water quality events were monitored, and 23 events were captured in Louisburg. Concentration results for this study for both the Apex and Louisburg sites are given in Figure 3.

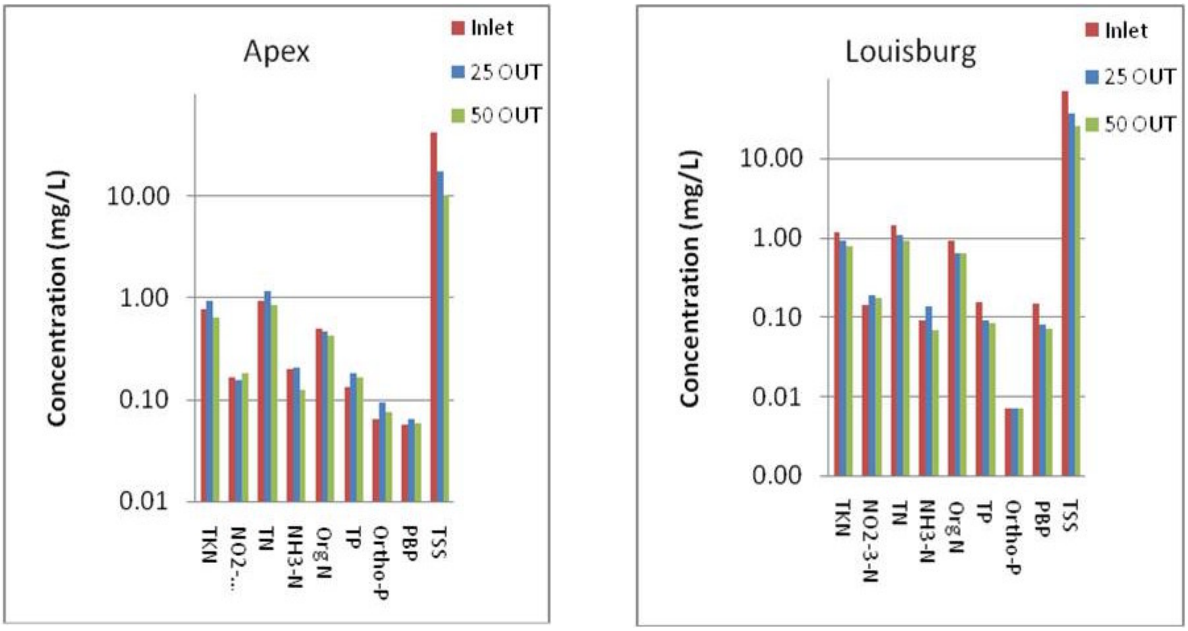

Figure 3. Inflow and Outflow Concentrations.

The terms inlet, 25 OUT, and 50 OUT refer to the inlet of the system, the outlet of the 7.6 m (25 ft) buffer, and the outlet of the 15.2 m (50 ft) buffer, respectively. In general, the Apex inlet concentrations were higher than those in Louisburg, and therefore percent reductions in concentration at Apex were generally greater than those in Louisburg. Median concentrations of TKN, TN, Org-N, TP, PBP, and TSS were all reduced for both buffer lengths in Apex. For Louisburg, median concentrations were reduced for TKN, TN, Org-N, and TSS. In all cases, the 15.2 m VFS reduced concentrations to a greater extent than did the 7.6 m VFS. This conclusion shows the importance of filter strip length. On a concentration basis, results for NO_{2-3}-N and NH_3-N were mixed at both sites. Nitrate-nitrogen was generally not reduced for either VFS length, NH_3-N was only reduced for the 15.2 m VFS length. This result is similar to that seen in Yu et al. (1993), where a level spreader-vegetated buffer system performed poorly for soluble pollutants.

As shown above, this LID practice does not remove pollutants to a large extent on a concentration basis. However, every pollutant was reduced on a mass basis at the Louisburg site. This is due to the large volumetric reductions, and the aforementioned concentration reductions. For all pollutants studied, reductions in mass were greater than 59%. Overall, the results summarized above are very promising, and show that this system can be used to effectively remove pollutants on a mass basis before they enter downstream rivers, lakes, or estuaries.

4. SUMMARY CONCLUSIONS

Results indicate that LS-VFS systems may perform well in urbanized areas, allowing for greater infiltration, evapotranspiration, and groundwater recharge. For the four systems studied, results show that performance is directly tied to precipitation depth, with larger rainfall events resulting in reduced system performance. Water quality results also show promise for reduction in concentration of the major pollutants in NC: TN, TP, and TSS. Load basis calculation of water quality showed greater than 55% reduction in mass across the LS-VFSs in Louisburg, regardless of buffer width.

Flow volume reduction appears to be similar for the 7.6 m and 15.2 m VFSs. Since the downslope half of each 50 ft buffer was forested, it is believed that reconcentration of flow caused a decrease in the effectiveness of the buffer. The microtopography surrounding trees and woody vegetation caused the initially dispersed stormwater to channelize, which increased velocity of flow.

Results show that a LS-VFS system can provide significant peak flow reduction. In some cases, peak flows were reduced by an order of magnitude. LS-VFS systems may positively affect downstream water bodies by reducing erosive forces through reduction in flow velocities.

A LS-VFS system is a viable LID practice for the management of urban stormwater runoff. Level spreaders may be an especially cost effective method to reduce flow volumes and peak flow rates and reducing pollutant loads. Maintenance and construction of these systems are very simple. Overall, this practice may prove a valuable addition to the suite of LID practices currently in use.

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