

URBAN Waterways

Level Spreader Update: *Performance and Research*

This publication presents an update on the research findings on level spreaders in North Carolina. Level spreaders are structural stormwater practices that are often employed upslope of riparian buffers (RB) and vegetative filter strips (VFS).

Publications that provide an overview on level spreaders include *Urban Stormwater Structural Best Management Practices*, AG-588-01, and *Level Spreaders: Overview, Design, and Maintenance*, AG-588-09W, of the Urban Waterways series. A companion Urban Waterways publication to this fact sheet reviews the design, construction, and maintenance of level spreaders (*Level Spreader Update: Design, Construction, and Maintenance*, AG-588-20W).

Urbanization in North Carolina has led to construction of impervious surfaces such as rooftops, roads, and parking lots. These surfaces cause changes in the hydrologic cycle, including reduced groundwater recharge, limited evapotranspiration, and greater stormwater runoff. Low impact development (LID) techniques such as reducing impervious surfaces, using clustered developments, building on the site's least permeable soils, and using structural stormwater best management practices (BMPs) can help mitigate these impacts. Common BMPs used in LID include bioretention areas, permeable pavement, cisterns, and green roofs. Another

practice that may have potential for use as a part of LID is the level spreader-vegetative filter strip (LS-VFS).

REVIEW OF TERMINOLOGY

Level spreaders may be located upslope of riparian buffers (LS-RB) or vegetative filter strips (LS-VFS). Requirements for LS-RB or LS-VFS systems include a flow splitter, an overflow (or bypass) conveyance, a forebay, a blind swale, and a level spreader. An appropriately sized flow-splitting device should be installed at the inlet to the LS-RB or LS-VFS. All runoff generated by rainfall above the design intensity (typically 1 inch per hour) must be diverted to a bypass swale. The remaining runoff enters a forebay, to still flow and remove sediment from stormwater. The stormwater runoff is conveyed from the forebay to the blind swale. When the blind swale fills, flow diffuses along the length of the level spreader (Figure 1). Infiltration of stormwater and removal of particulate pollutants are expected as runoff flows through the riparian buffer or vegetative filter strip downslope of the level spreader.

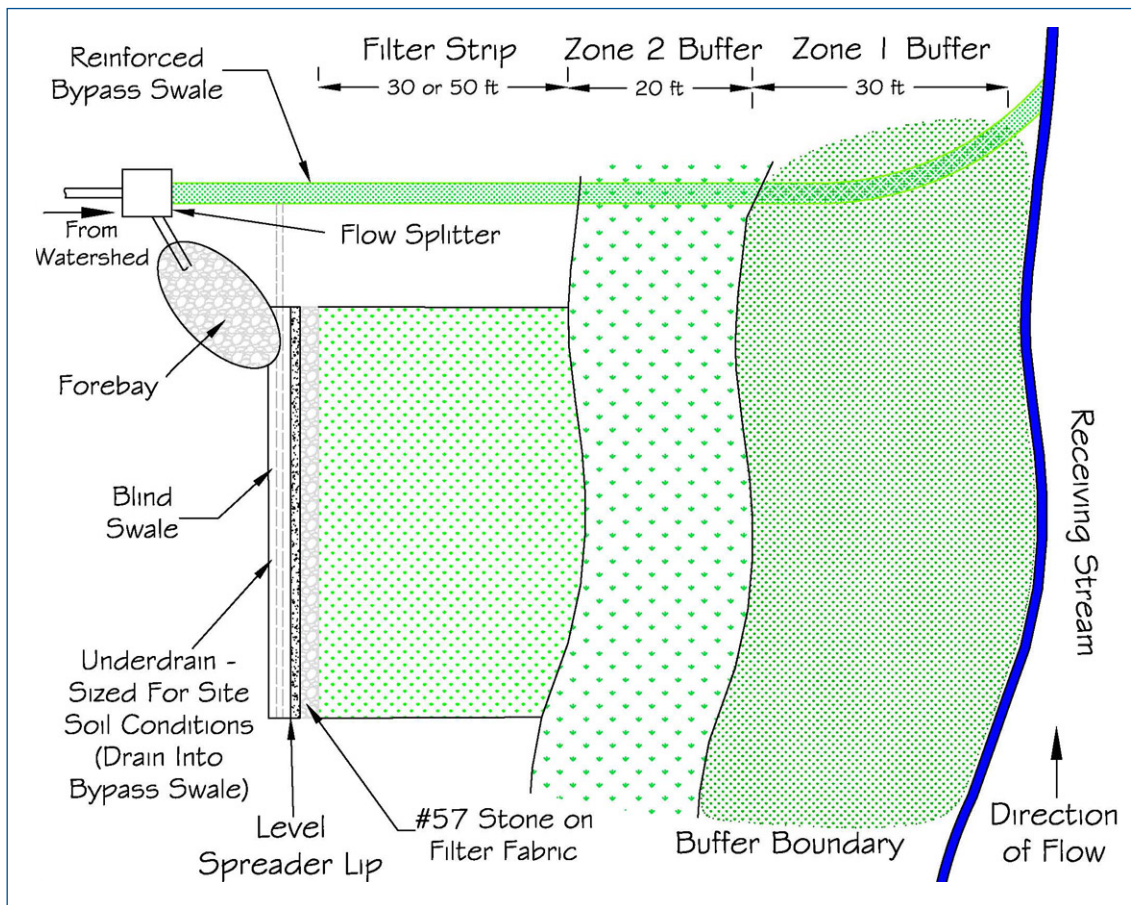


Figure 1. Plan view of level spreader-vegetative filter strip adjacent to riparian buffer

LEVEL SPREADER – RIPARIAN BUFFERS (LS-RB)

State regulations require that flow be diffused as stormwater enters a riparian buffer in the Neuse River basin, Tar-Pamlico River basin, Catawba River mainstem, Randleman Lake watershed, Goose Creek, Six Mile Creek, Waxhaw Creek, and Jordan Lake watershed. These regulations were the reason for the widespread use of level spreader-riparian buffer systems in North Carolina. Riparian buffers are inherently disadvantaged for keeping surface flow diffuse: they cannot be graded, and they naturally contain draws and channels. In nutrient-sensitive watersheds, a total of 50 feet or more of riparian buffer must be maintained. The 30-foot section of buffer closest to the stream may not be manipulated or disturbed.

Hathaway and Hunt (2008) studied 24 LS-RB systems in the North Carolina piedmont and found that *none* were performing as intended, mainly due to failures at the level spreader, although channelization was observed in some of the riparian buffers. This research led to substantial design changes, including the use of a stable material (such as concrete) to construct the level lip, guidelines for level spreader sizing, and

inclusion of a forebay and a flow bypass structure. Recent research on level spreaders has furthered understanding of these systems; updates on hydrologic benefits, water quality benefits, pollutant removal mechanisms, and buffer topography of LS-VFSs will be presented.

LEVEL SPREADER – VEGETATIVE FILTER STRIPS (LS-VFS)

Vegetative filter strips (VFSs), a type of stormwater BMP, have been used for years for agricultural runoff. They are similar to riparian buffers, except that they are located in upland areas. Stormwater is routed through the VFS, which removes nutrients and sediment through physical and biological processes. VFSs may be vegetated with trees and shrubs or with (perhaps frequently mowed) grasses. In North Carolina, the latest regulations *require* the use of grass to receive pollutant removal credit (NCDENR 2007). There are typically fewer design restrictions on LS-VFS systems than on LS-RBs. LS-VFSs allow an engineer to grade the buffer, plant deep-rooted vegetation, and amend soils with coarse particles (sand) or nutrient-sorbing minerals. LS-VFSs may

be engineered to a much greater extent than LS-RB systems. Further information on the various uses of level spreaders in North Carolina can be found in the Urban Waterways fact sheet titled *Level Spreader Update: Design, Construction, and Maintenance* (AG-588-20W).

Future research is needed on LS-VFSs to refine design guidance and provide designers with tools to understand relationships between VFS design parameters (length, width, slope, vegetation type, soil type) and VFS performance.

OVERVIEW OF RESEARCH

Research on LS-VFSs has been concentrated in the mid-Atlantic states, with a total of nine LS-VFSs studied at six research sites. This section will summarize those studies, including the hydrologic and water quality benefits of LS-VFS stormwater BMPs. Pollutant removal mechanisms will be discussed in the following section.

Table 1. Summary of LS-VFS research sites

Reference	Location	Watershed Size (ac)	Watershed Composition	VFS Width (ft)	VFS Area (ft ²)	VFS Slope (%)	VFS Vegetation	DA:FSA ratio
Franklin et al. 1992	Granville County, NC	3.5 (G1)	Agricultural	100	13000	4	Forested	11.9
		3.2 (G2)	Agricultural	130	24740	9	Forested	5.7
Yu et al. 1993	Charlottesville, VA	9.9	Urban Parking Lot	150	40580	6	Grass	10.6
Line and Hunt 2009	Johnston County, NC	0.86	Urban Highway	56	4700	5.2	Grass	27.9
Hunt et al. 2010	Charlotte, NC	2.15	Urban Residential	150	9700	1.5	Grass	44.8
Winston et al. 2010	Apex, NC	0.52 (A1)	Urban Parking Lot	25	460	6.2	Grass	49.2
		0.52 (A2)	Urban Parking Lot	50	860	7.3	1st 25 ft: Grass Last 25 ft: For- ested	26.3
	Louisburg, NC	0.49 (L1)	Urban Commer- cial and Parking Lot	25	420	4.9	Grass	45
		0.49 (L2)	Urban Commer- cial and Parking Lot	50	930	7	1st 25 ft: Grass Last 25 ft: For- ested	20.2

RESEARCH SITES

Previous research on LS-VFSs has been focused in North Carolina and Virginia. For each of these studies, the watershed size, composition, VFS width, VFS Area, VFS slope, VFS vegetation, and drainage area to filter strip area (DA:FSA) ratio are presented in Table 1. For projects with multiple LS-VFSs (Franklin et al. 1992; Winston et al. 2010), sites are abbreviated as shown in the watershed size column. All sites utilized existing *in-situ* soils, except for the Hunt et al. (2010) study, which had soils amended with coarse-grained sand. Hydrologic and water quality results for these studies are presented in the following sections.

HYDROLOGIC BENEFITS

LS-VFS systems can improve urban hydrology through infiltration of stormwater in the filter strip. This practice reduces the amount of stormwater entering the storm sewer and allows the infiltrated water to be slowly released as groundwater-fed interflow,

where it will become baseflow in a nearby stream or river. In past NC studies, flow volume reductions varied from 28 percent to 92 percent (Table 2). Peak flow rate reduction varied from 23 percent to 89 percent. The best-performing LS-VFSs had low slopes, dense vegetation, and small drainage area to filter strip area ratios. Many factors, including watershed area, watershed imperviousness, filter strip length, watershed area to filter strip area ratio, soil type, and slope may have an impact upon hydrologic performance for LS-VFSs. Further research is needed to determine how each of these design variables affects the hydrologic performance of these systems.

Table 2. Summary of research findings on LS-VFS hydrologic benefits

Site Location	Number of Storm Events	Range of Storm Event Rainfall Depths (in)	Flow Volume Reduction (%)	Peak Flow Rate Reduction (%)
Granville County, NC (G1)	29	0.12 – 3.19	28	36
Granville County, NC (G2)	8	0.20 – 1.18	92	89
Johnston County, NC	13	0.29 - 1.22	49	23
Charlotte, NC	23	0.08 – 3.72	85	Not Measured
Louisburg, NC (L1)	58	0.10 – 2.67	48	61
Louisburg, NC (L2)	58	0.10 – 2.67	41	68

WATER QUALITY BENEFITS

Major pollutants of concern in North Carolina include total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS). NCDENR gives credit to stormwater BMPs based upon their removal rates for these three pollutants. Concentration reduction data are available for six LS-VFSs (Table 3). LS-VFSs perform very well for TSS concentration reductions, with reductions between 51 percent to 84 percent at six different sites. These values are similar to TSS removal in bioretention cells and stormwater wetlands, and are due to sedimentation in the filter strip. TN concentration “reductions” are small in magnitude, varying between -17 percent to 32 percent. TP concentration reductions ranged from -27 percent to 40 percent. At Louisburg, inlet TP concentrations were made up mostly of ortho-P,

Table 3. Summary of research findings on level spreader pollutant concentration reductions

Site Location	TN (%)	TP (%)	TSS (%)
Charlottesville, VA	NM ¹	40	84
Johnston County, NC	14	-11	70
Apex, NC (A1)	16	33	65
Apex, NC (A2)	32	40	72
Louisburg, NC (L1)	-17	-27	51
Louisburg, NC (L2)	18	-2	67

¹Not Measured

a soluble form of phosphorus that is difficult to remove in filter strips. This is contrasted with results at Apex, where a majority of influent TP concentrations were in the particle-bound state and were captured via sedimentation.

Although concentration reduction is still a commonly used metric for stormwater BMPs, many have argued that it is a poor indicator of BMP performance. Load reduction, which

accounts for both concentration and volume reductions, is a better indicator of how a BMP functions to improve water quality. The load reduction metric con-

POLLUTANT REMOVAL

Pollutant removal is often presented as a reduction in either concentrations or loads. A *load* is a mass of pollutant determined by multiplying the flow-weighted *concentration* or event mean concentration by runoff volume. In stormwater, *concentration units* are nearly always mg/L; *measures of load* are g, kg, and lb. North Carolina’s nutrient removal requirements for nitrogen and phosphorus are based on loads.

veys the benefits that LS-VFS provide due to infiltration. Data are available for load (mass) reductions for four LS-VFSs in NC (Table 4). The LS-VFSs reduced the amount of nitrogen entering the storm drainage network by 49 percent to 62 percent, phosphorus by 32 percent to 48 percent, and total suspended solids by 47 percent to 89 percent.

One “boutique” pollutant that is important in the mountains of North Carolina is stormwater temperature. During the summer months, heat is transferred between thermally enriched pavement and rooftops to stormwater. Thermally enriched urban stormwater travels to streams, where it can cause short-term spikes in stream temperature, which are detrimental to stream health. The Louisburg LS-VFSs discussed above were also tested for stormwater temperature reduction. Stormwater temperature was reduced across both L1 and L2, but was not reduced enough to consistently meet the 21°C trout threshold (Winston et al. 2011). Mean thermal loads were also reduced by roughly 70 percent for both L1 and L2, which shows the ability of the LS-VFS to mitigate thermal load.

MECHANISMS OF POLLUTANT REMOVAL

The mechanisms of LS-VFS pollutant removal are filtration, sedimentation, plant uptake, adsorption, and possibly biological treatment. For removal of sediment-bound pollutants, the major mechanism is sedimentation. The LS-VFS is *specifically designed* to decrease flow velocities and increase contact time between the vegetation-soil interface and stormwater. This mechanism (sedimentation) causes a decrease in sediment transport capacity of the flow, which results in sediment accumulation in the VFS (Gharabaghi, 2002). Filtration of solids by the grass may also be important for sediment removal (Dillaha et al., 1986). Flow is stilled in both the forebay and the blind channels, facilitating greater TSS removal. Generally, as filter strip width increases, sedimentation will occur to a greater extent (Yu et al., 1993; Lee et al., 2003). TP may also be well mitigated by VFSs; typically greater than 50 percent of phosphorus in urban stormwater is particle-bound (various N.C. research projects).

Mechanisms for oxyanion removal in the surface flow of a LS-VFS system are not well established. Ortho-P (PO_4^{3-}), nitrate (NO_3^-), and nitrite (NO_2^-) are oxyanions, and are repulsed by the negative charge of soil particles. Therefore, they remain dissolved

Table 4. Summary of research findings on level spreader pollutant mass reductions.

Site Location	Volume Reduction (%)	TN	TP	TSS
Granville County, NC (G1)	28	NM	32	47
Johnston County, NC	49	62	48	83
Louisburg, NC (L1)	48	49	46	73
Louisburg, NC (L2)	41	51	47	89

constituents as they pass through VFSs, and removal on a concentration basis is neither expected nor observed. Ortho-P may be removed by direct precipitation or adsorption onto soil surfaces through reactions with iron, aluminum, or calcium (by cation bridging) (Crites, 1985). Plant uptake of nitrate-nitrite nitrogen may occur in the root zone, but did not occur to a great extent at the Apex, NC, and Louisburg, NC, sites (Imsande and Touraine, 1994; Winston et al., 2010).

For the Louisburg and Apex sites as with most urban stormwater, TN concentrations are dominated by the concentrations of TKN, rather than $\text{NO}_{2,3}\text{-N}$. Since TKN was effectively removed (due to reduction of organic nitrogen, a particulate) at the Apex and Louisburg sites, TN was reduced. Therefore, TN concentration reduction for LS-VFSs is likely. Perhaps the major pollutant load removal mechanism is infiltration, which results in substantial reduction in outflow, especially for small- to medium-sized and low- to moderate-intensity storms.

VEGETATIVE FILTER STRIP TOPOGRAPHY

VFS topography may play a role in performance of LS-VFS systems (Dosskey et al., 2002). Variations in topography within the buffer cause reconcentration of the diffuse flow provided by the level spreader, reducing the effective buffer area. Reconcentration leads to increased stormwater velocity and decreased contact between the stormwater and the soil-vegetation matrix. The stormwater effectively short-circuits the VFS, which reduces the performance of the buffer. This

theory was field tested at the Louisburg LS-VFS site by visiting each site during two rainfall events. Pin flags were placed on a 2-foot-by-2-foot grid throughout both the 25-foot- and 50-foot-wide VFSs. At each pin flag, a visual inspection was made to determine whether surface flow was occurring (Figure 2).

The results for a storm event on 2/18/2009 at the Louisburg site are presented in Figures 3 and 4. In Figure 3, nearly all of the 25-foot grassed VFS was used to convey surface flow. This is due to both (1) vegetation type (grass) and (2) negligible cross-slope in the filter strip. Similar results were observed for the grassed portion of the 50-foot VFS (left of the dashed line in Figure 4). However, as flow encounters the microtopography around tree trunks in the forested portion of the VFS (right of the dashed line), reconcentration of flow occurs, and only 1/7th of the width of the buffer is used to convey flow. This leads to a reduced treatment area for this BMP. In general, grassed filter strips with little cross-slope



Figure 2. Determination of surface flow during effective buffer area study

appear to provide greater treatment than wooded buffers because reconcentration of flow is less likely to occur.

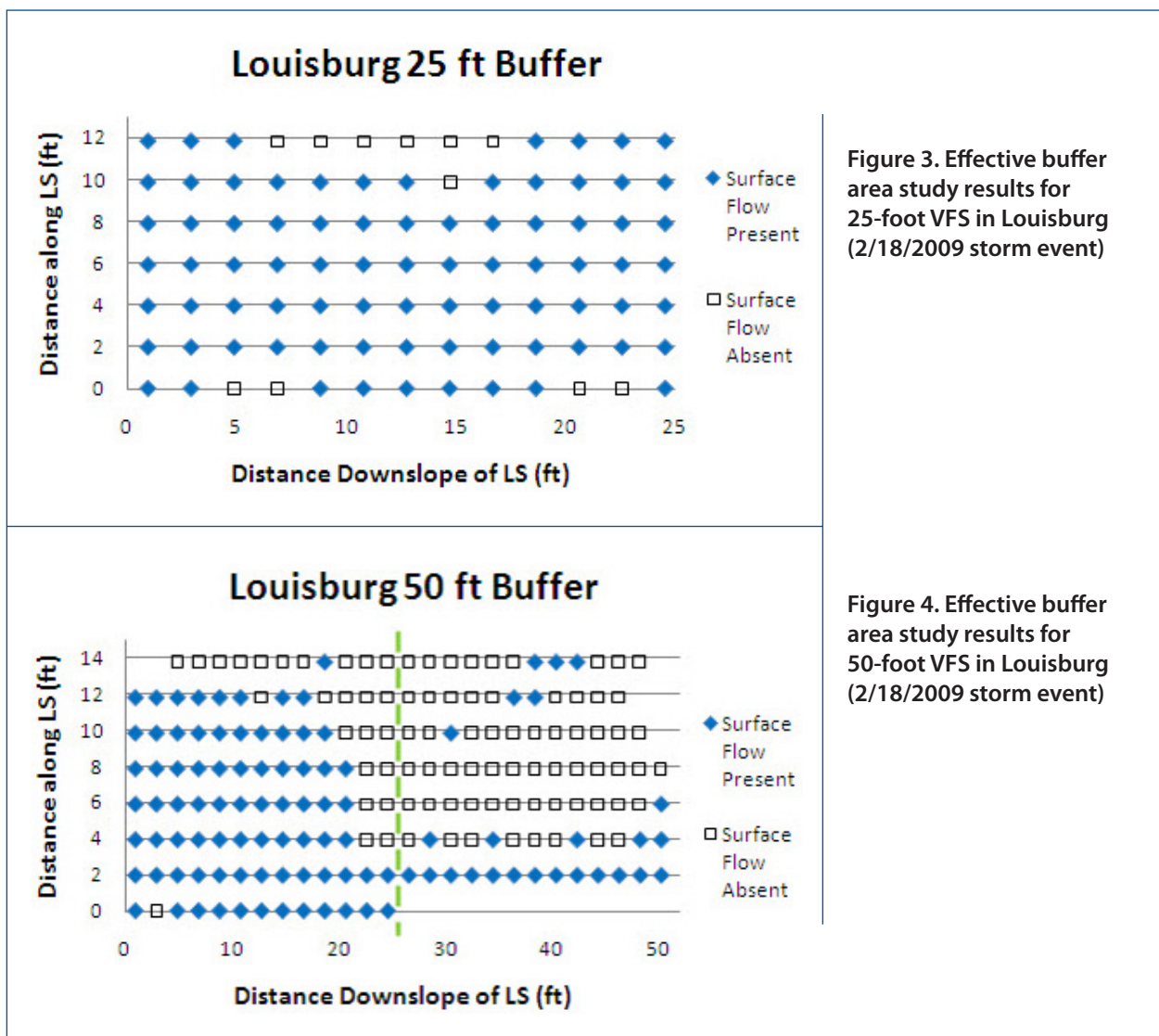


Figure 3. Effective buffer area study results for 25-foot VFS in Louisburg (2/18/2009 storm event)

Figure 4. Effective buffer area study results for 50-foot VFS in Louisburg (2/18/2009 storm event)

SUMMARY

LS-VFSs in urban watersheds are still relatively unresearched. Further research is required to improve design standards for these systems. Pollutant removal needs to be quantified as a function of filter strip width, slope, hydraulic loading, soil type, and vegetation type. Future research also needs to include soil amendments and modeling efforts to better understand and predict the capability of these

systems. While many design details remain, studies have shown that a variety of LS-VFS systems reduced runoff and associated pollutant loads. LS-VFS BMPs are likely to become more popular in the coming years because they are effective for pollutant removal and are relatively inexpensive to install and maintain. For more details on level spreaders, see *Level Spreader Update: Design, Construction, and Maintenance* (AG-588-20W), part of the Urban Waterways series.

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