Technical Note

Bioretention Outflow: Does It Mimic Nonurban Watershed Shallow Interflow?

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Abstract: Bioretention, a key structural practice of low impact development (LID), has been proved to decrease peak flow rates and volumes, promote infiltration and evapotranspiration, and improve water quality. Exactly how well bioretention mimics predevelopment (or "natural") hydrology is an important research question. Do bioretention outflow rates mirror shallow groundwater interevent stream recharge flow associated with natural or nonurban watersheds? Streamflow from three small, nonurban watersheds, located in Piedmont, part of central North Carolina, was compared with bioretention outflow from four cells also in North Carolina's Piedmont region. Each benchmark watershed drained to a small stream, where flow rate was monitored for an extended period of time. After normalizing the flow rates and volumes by watershed size, data were combined to form two data sets: bioretention outflow and stream interevent flow. Results indicate that there is no statistical difference between flow rates in streams draining undeveloped watersheds and bioretention outflow rates for the first 24 h following the commencement of flow. Similarly, there is no statistical difference between the cumulative volumes released by the two systems during the 48 h following the start of flow. These results indicate that bioretention cells behave comparably to watersheds in natural or nonurban conditions, with respect to both flow rates and flow volumes, and suggest that bioretention outflows may mirror post–storm event shallow groundwater interevent stream recharge flow. Solely considering bioretention outflow as a conjugate to runoff may be a misinterpretation of a flowrate that actually resembles shallow interflow. **DOI:** 10.1061/(ASCE)HE.1943-5584.0000315. *© 2011 American Society of Civil Engineers.*

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Introduction

As precipitation falls to the ground it may infiltrate, be taken up by plants, and return to the atmosphere through evapotranspiration, or leave the site as surface runoff (the hydrologic cycle). The conversion of a nonurbanized site to urban use greatly alters the hydrological characteristics of the land. Increases in impervious surfaces and soil compaction reduce infiltration rates, thereby decreasing groundwater recharge and increasing the volume and velocities of surface runoff (Meyer 2005). Streams draining developed areas receive these larger volumes of storm flow in a shorter time period than under predevelopment conditions, creating a flash flood-prone hydrology that is detrimental to in-stream biota (Sala and Inbar 1992; Rose and Peters 2001; Nelson et al. 2006; Vicars-Groening and Williams 2007; Wheeler et al. 2005). Additionally, runoff from urban areas is laden with sediment, nutrients, heavy metals, and pesticides, leading to the degradation of stream water quality (Line and White 2007; Widianarko et al. 2000; Wheeler et al. 2005; Phillips and Bode 2004).

Low impact development (LID) has been introduced as a method of mitigating the negative impacts of urbanization and conventional storm-water management (Coffman et al. 1993). Goals of LID include reducing impervious surfaces, retaining runoff on-site, promoting the infiltration and evapotranspiration of storm water, and replicating predevelopment hydrologic conditions as closely as possible (Davis 2005; Chang 2010). One often overlooked component of the hydrologic cycle is shallow interflow, or water that recharges streams after an event by way of shallow groundwater. It is also known as "return flow." These goals are met through implementing a variety of management practices, including soil modification and amendments, vegetated areas and swales, permeable pavement, bioretention, and conservation of environmentally sensitive areas (riparian buffers, wetlands, steep slopes, etc.) (Dietz 2007; USEPA 2000). In addition to hydrologic benefits, LID also provides water quality improvements and has been shown to significantly reduce the total mass of pollutants leaving a site (Davis 2005).

Bioretention, a key LID practice, has been proven to decrease peak flow rates and volumes, promote infiltration and evapotranspiration, and improve water quality by removing sediments, nutrients, and other pollutants from storm water (Davis 2008, 2005; Hunt et al. 2006; Li et al. 2009). Bioretention can serve as a tool to transform the hydrologic relationship between a developed site and its receiving stream. A study performed by

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Davis (2008) showed that water leaving bioretention systems via the underdrains often continued for several days at very low velocities following a precipitation event. This hydrologic behavior is very similar to that of an undeveloped or nonurban site that slowly releases shallow interflow and runoff from a storm event over the course of several days. If a bioretention system releases water to a stream in the same manner as a stream in natural or nonurban conditions that receives interflow, then the bioretention system is replicating natural, predevelopment hydrology. Should all bioretention cells behave similarly to those studied by Davis (2008), the widespread installation of this practice would be fundamental in restoring predevelopment hydrology in developed areas. Most analysts consider bioretention outflow conjugate to runoff; however, outflow from properly designed bioretention cells may more closely resemble shallow interflow (at least with respect to delivery to a stream). This is of particular importance in regions with clayey underlying soils, where "true" infiltration, and subsequent recharge of the shallow groundwater is restricted.

To determine if bioretention outflow behaves similarly to natural or nonurban stream conditions, streamflow data from three nonurban watersheds were compared to outflow data from four bioretention cells in the same geophysical region of North Carolina, the Piedmont. Instantaneous flow rates and cumulative volumes were determined at 3-, 6-, 12-, 24-, 30-, 36-, 42- and 48-h intervals after flow began. Flow rates were normalized by the drainage area, as well as by rainfall depth. The normalized bioretention and streamflow data were statistically compared using confidence intervals (CIs) and the Wilcoxon Sum Rank test. The objective of this study was to demonstrate that outflow leaving a bioretention cell is analogous to the interflow/runoff water released to streams by nonurban land.

Site Descriptions

Three streams were selected for flow data analyses. All three streams and their watersheds were located in the Piedmont of North Carolina, in northwest Chatham County (see Fig. 1) and are summarized in Table 1.

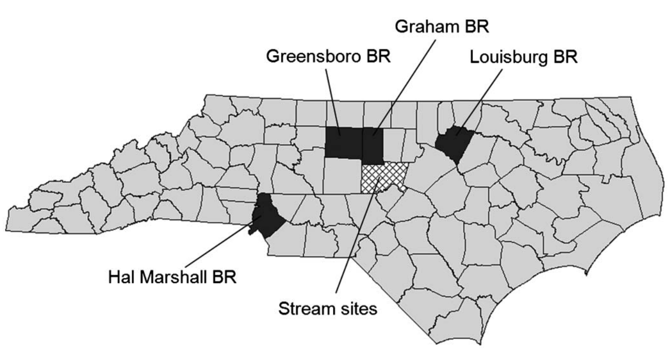

Fig. 1. Locations of bioretention (BR) and stream sites used in this study

Site 1 is located at 35.828 N, –79.372 W, along an unnamed, intermittent tributary of South Fork Cane Creek, which drains to the Haw River. The watershed for Site 1 totals 77.5 ha and includes the following land uses: pasture (64.4%), forest (33.3%), open water (1.5%), and impervious surfaces (0.8%). Pasture land is used to raise beef cattle; and impervious surfaces include driveways, buildings, and paved roads. Soil types for each watershed were determined using Natural Resources Conservation Service (NRCS) soil maps and classifications (NRCS 2008). The predominant soil type (63.7%) within the watershed is Cid-Lignum complex, which is classified as a silt loam in the first 0.127 m of the soil profile, and as a Channery silt loam at profile depths greater than 0.127 m. Other soil types present include Nanford-Badin complex (33.9%), a silt loam in the top 0.178 m of the profile and a silt clay at 0.178 m or greater, and Georgeville silt clay loam (0.9%), classified as a silt clay loam in the top 0.178 m of the profile and as a clay below 0.178 m.

The second site, Site 2, located at 35.786 N, –79.406 W, drains an unnamed, intermittent tributary of Nick Creek. The 49.7 ha watershed is consists of beef cattle pasture (57.4%), cropland (31.3%), residential (4.9%), forest (4.8%), and impervious (1.6%) land uses. The cropland is conventionally tilled and sowed and the residential areas include small houses, sheds, and barns. Soils consist primarily (63.1%) of Georgeville silt clay loam, but also include Cid-Lignum complex (27.5%), Georgeville silt loam (4.8%), classified as a silt loam in the first 0.178 m of the profile, a silt clay loam at 0.178–0.254 m and a clay at depths greater that 0.254 m, and Nanford-Badin complex (4.6%).

Site 3 is the third site used to collect stream data. This site is located at 35.834 N, –79.417 W and drains the uppermost portion of Mud Lick Creek. The watershed includes 54.6 ha of beef cattle pasture (80.4%), forest (14.1%), residential (3.7%) and impervious surfaces (1.8%). Soil types within the drainage area include Cid-Lignum complex (85.1%), Georgeville silty clay loam (9.3%), Nanford-Badin complex (4.2%), and Herndon silt loam (1.4%), which is classified as a silt loam in the top 0.229 m of the profile and a silt clay loam at depths greater than 0.229 m.

Four bioretention cells were selected for analyses because of their location within the Piedmont physiographic region of North Carolina and their reliable existing hydrologic data sets. The Hal Marshall (HM) bioretention cell is located in Charlotte, North Carolina, and drains a 0.37 ha impervious asphalt parking lot. The cell is approximately 230 m^2 with underdrains and a media depth of 1.2 m. The North Carolina soil survey indicated that surrounding soils are a Cecil clay loam. Further details and descriptions about the site can be found in Hunt et al. (2008).

The bioretention cell located in Greensboro, North Carolina (GR), drains a 0.2 ha area that contains a shopping center. Surrounding soils are a Madison clay loam with low permeability. Underdrains were included in the design of the cell, which has a surface area-to-watershed size ratio of 5%. Media depth within the cell is approximately 1.2 m. Hunt et al. (2006) contains more details regarding the cell and its watershed.

The Graham (GM) bioretention cell is located in Alamance County. The watershed for this cell is 0.7 ha and consists primarily of residential land use. Although the watershed is not

Table 1. Summary of Site Characteristics for Three Stream Sites

Site name	Drainage area (ha)	Predominant land use(s)	Predominant soil types	Predominant hydrologic soil group
Site 1	77.5	Pasture/forest	Silty clay loam/silty clay	C
Site 2	49.7	Pasture/cropland	Clay/silty clay loam	B
Site 3	54.6	Pasture	Silty clay loam	C

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considered ultraurban, between 79% and 100% of runoff entering the bioretention cell comes from areas paved with asphalt. Surrounding soils are predominantly clay/clay loam. More information about this site may be found in Passeport et al. (2009).

The final bioretention cell analyzed in this study is located in Louisburg, North Carolina (LB). The watershed for this cell is 0.9 ha and approximately 95% impervious. Media depth is 0.75 m, and underdrains were included in the design. Surrounding soils consist of a tight clay with very low permeability. Sharkey (2006) contains more details regarding the site and its corresponding watershed.

Overall Study

All sites selected for this study are located within the Piedmont physiographic region of North Carolina. The soil characteristics are similar for all sites, with in situ soils being predominantly clay-loam for the bioretention sites and silty clay loam for the stream watersheds. Precipitation characteristics among the sites are similar as well, with 30-year annual average precipitation amounts of 1,095, 1,105, 1,158, 1,207, and 1,224 mm for Greensboro, Charlotte, Graham, Louisburg, and Chatham County, respectively (NCSCO 2008).

Flow rate data were collected from stream sites 1 and 2 at 5 min intervals using area-velocity meters. A rectangular weir was used for flow rate measurement at stream site 3, and data were recorded every 5 min. Inflow and outflow flow rate data were collected for all four bioretention cells using a compound v-notch weir with bubbler module at 5 min intervals for sites HM, GR, and LB and at 1 min intervals for site GM.

A range of storm types were used when analyzing flow data. Data collected from bioretention cells corresponded with rainfall depths ranging from 4 mm to 125 mm and occurring at all times of the year. Storms depths for streamflow data ranged from 0.5 mm to 153 mm, with most storms occurring between January and September. Additional storm data for individual sites may be found in Table 2, which shows the time period and number of storms for which data were collected at each individual site.

Data Analyses

Stream Data

Because of recent drought conditions in the region and the small size of the watersheds, all streams were intermittent and baseflow was either nonexistent or negligible during antecedent dry periods. Thus, it was assumed that all flow present in the stream at a given time could be attributed to runoff and/or interflow-produced by the storm event. Flow rate data obtained from each of the stream sites was reported in 5 or 10 min intervals and was used to determine instantaneous flow rates 3, 6, 12, 18, 24, 30, 36, 42, and 48 h after streamflow began. To account for differences in watershed sizes, flow rates were normalized by drainage area, thus giving a flow rate per hectare of watershed and allowing for the comparison of data among sites. Additionally, the flow rate per hectare of watershed was divided by the total rainfall depth of the storm to determine if results differed based on the size of the storm.

The total rainfall depth was multiplied by the watershed area for each storm event to produce the total possible volume of precipitation-induced flow that could enter the stream. The total volume of streamflow produced by an individual storm was divided by the total possible precipitation volume. This value, once multiplied by 100, represents the percentage of total possible precipitation volume that appears as streamflow.

Based on flow monitoring data collected at each site, total storm volumes and cumulative volumes for each time interval were calculated for each storm event. The percentage of total volume passed by the stream at each time interval was determined using the following equation:

$$\mathrm{STVol}_{\mathrm{passed}} = \frac{\mathrm{STVol}_{\mathrm{cumulative}}}{\mathrm{STVol}_{\mathrm{total}}} \cdot 100 \tag{1}$$

where $\mathrm{STVol}_{\mathrm{passed}}$ = percent of the total storm volume passing the stream monitoring point at a given time interval i (%), $\mathrm{STVol}_{\mathrm{cumulative}}$ = cumulative volume passing the stream monitoring point at time period i (L), and $\mathrm{STVol}_{\mathrm{total}}$ = total volume passing the stream monitoring point during the entire storm (L).

Bioretention Data

A total of 23, 10, 4, and 25 storms were analyzed for the GR, GM, HM, and LB bioretention cells, respectively. The total rainfall depth and total outflow volume were recorded for each storm event. Additionally, outflow rates and cumulative volumes were documented at 3-, 6-, 12-, 18-, 24-, 30-, 36-, 42-, and 48-h intervals after outflow began. As with the streamflow data, the outflow rates were normalized by the cells' drainage area and the total rainfall depth of the storm.

The total possible precipitation volume was also calculated for each storm by multiplying the rainfall depth by the drainage area. The percent of total storm volume that was released from each bioretention system was calculated for each storm event using the following equation:

$$\mathrm{BRVol}_{\mathrm{passed}} = \frac{\mathrm{BRVol}_{\mathrm{cumulative}}}{\mathrm{BRVol}_{\mathrm{total}}} \cdot 100 \tag{2}$$

where $\mathrm{BRVol}_{\mathrm{passed}}$ = percent of the total storm volume released by bioretention underdrains at a given time interval i (%), $\mathrm{BRVol}_{\mathrm{cumulative}}$ = cumulative volume released by bioretention underdrains at time period i (L), and $\mathrm{BRVol}_{\mathrm{total}}$ = total volume released by bioretention underdrains during the entire storm (L).

Table 2. Summary of Storm Characteristics for Bioretention and Stream Sites

		Monitoring period	Number of storms	Storm depth range (cm)
Bioretention	GR	February 2004–September 2004	23	0.51–12.50
	GM	April 2007–September 2007	10	0.41–4.78
	HM	January 2005–May 2005	4	0.64–3.99
	LB	May 2004–November 2004	25	0.43–6.55
Streams	1	March 2008–September 2008	19	0.71–9.65
	2	February 2008–September 2008	29	0.13–15.34
	3	January 2008–September 2008	29	0.05–15.32

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Statistical Analyses

Streamflow rate data from all three sites were compiled to produce one comprehensive data set. Hydrologic data from the four bioretention cells were also combined to produce one data set. Two forms of data analyses were performed: the comparison of CIs to determine the statistical relationship between variables, and the Wilcoxon Rank Sum test to determine statistical significance.

Because data did not follow a specified distribution, CIs were generated for each variable using the nonparametric bootstrap method (Davison and Hinkley 1997). The bootstrap method of generating CIs is applied to a single data set and uses a resampling procedure to simulate what the results might be if the experiment was performed multiple times (Miller 2004). When applied to a data set, this method randomly selects a value from the data set, returns the value to the data set, then randomly selects another value. This process is repeated a defined number of times, n. For this application, n was set to 100,000, as this number of repetitions produced consistent results when performed multiple times on the same data set. This selection-and-replacement method was used to generate a 95% two-sided CI about the median for each variable.

The Wilcoxon Rank Sum test was also applied to the data, with each time step being treated as a separate data set. An alpha (α) value of 0.05 was used to determine statistical significance.

Results and Discussion

Confidence Intervals

The similarities in soils and precipitation characteristics, as well as the normalization of flow data by watershed and storm size, allow for accurate comparisons between the stream and bioretention sites. CIs were generated about the median for both data sets to compare flow rates per hectare, flow rates per hectare per centimeter of rainfall, and the percent of total precipitation volume that appears as storm flow.

Fig. 2 displays the CIs for stream and bioretention data for each specified time interval. As shown in the graph, CIs generated from bioretention outflow data closely mimic those created using streamflow data for each time interval. For all time intervals prior to 24 h

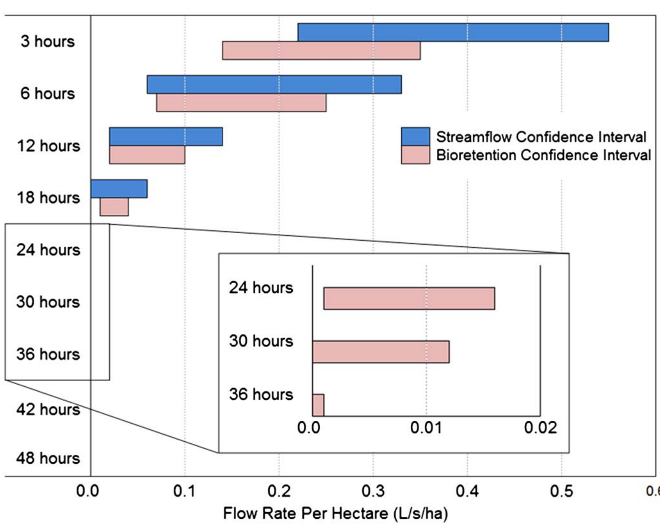

Fig. 2. Streamflow and bioretention 95% CIs about the median for flow rate per watershed hectare, for 3-, 6-, 12-, 18-, 24-, 30-, 36-, 42-, and 48-h intervals after flow began

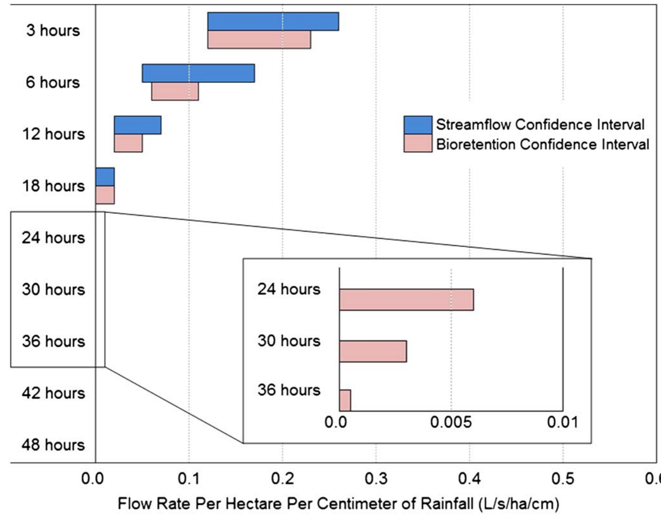

Fig. 3. Ninety-five percent CIs about the median for bioretention and streamflow rates, normalized by watershed area and storm rainfall depth for 3-, 6-, 12-, 18-, 24-, 30-, 36-, 42-, and 48-h intervals after flow began

the CIs for bioretention data are slightly lower than the CIs for streamflow data, yet still very similar. Streamflow data consistently produced CIs of [0, 0] at intervals greater than 24 h, while bioretention CIs were consistently [0, 0] after 36 h of flow. These data characteristics indicate that bioretention cells dampen storm flow more than natural watershed conditions, releasing outflow at lower rates and for longer durations.

Flow rates were also normalized by rainfall depth. CIs generated for bioretention and streamflow data normalized by watershed size and rainfall depth are displayed in Fig. 3.

When normalized by watershed size and rainfall depth, bioretention flow rates are comparable to streamflow rates for all time intervals prior to 24 h, as all bioretention outflow CIs for time intervals less than 24 h fall completely within the streamflow CIs. After 24 h, streamflow CIs were [0, 0]. Bioretention CIs were [0, 0] after 36 h, indicating that bioretention cells generally release outflow within 36 h after outflow begins, whereas a natural watershed releases streamflow within 24 h after flow begins. The fact that bioretention cells tend to release water for approximately 12 h longer may signify that water moves more slowly through a bioretention system than through a natural watershed.

The difference in flows from the streams and the bioretention underdrains could also be attributed to the difference in precision of flow measurement. Bioretention outflow, as measured, used v-notch weirs specifically designed for accurate measurement of low flows. Streamflow at sites 1 and 3 was measured using an area-velocity meter, while site 2 was measured with a weir. During data collection, it was documented that the weir leaked regularly. The inability of the streamflow-measuring equipment to accurately record low flow levels most likely resulted in readings of "no flow" when flow levels decreased below the lowest detectable level. As the monitoring equipment at bioretention cells was specifically designed to accurately read these low flows, statistics would indicate that bioretention cells released water over a longer period of time than streams draining undeveloped areas.

Although the watersheds for the stream sites are nonurban, they contain primarily agricultural land, which produces slightly more runoff than natural forested conditions (Schoonover et al. 2006). One might speculate that when bioretention outflow is compared with shallow interflow-produced flow from a fully forested

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Table 3. Ninety-Five Percent CIs about the Median for Percent of Total Precipitation Volume Appearing as Streamflow/Outflow

	95% confidence interval	
	Lower limit	Upper limit
Watershed streamflow	4.94%	14.59%
Bioretention outflow	9.66%	21.75%

watershed, the duration of flow and the CIs may match even more closely.

To determine if bioretention cells reduce storm flow volumes similarly to an undeveloped watershed, CIs were generated for the percent of the total precipitation volume (a storm's total rainfall depth multiplied by the watershed area) that appears as streamflow/outflow. The streamflow and bioretention CIs overlap substantially (Table 3), indicating that the percent of total precipitation volume emerging as outflow from a bioretention cell ($BRVol_{passed}$) is similar to the amount that appears as streamflow from a nonurban watershed ($STVol_{passed}$). The fact that the bioretention outflow CI is somewhat larger than the streamflow CI is most likely attributable to the increased opportunity for water loss via infiltration or evapotranspiration in the natural, more pervious stream watershed (as opposed to the smaller, highly impervious bioretention watershed). The substantial overlap in CIs, however, further supports the hypothesis that bioretention successfully mimics the hydrologic conditions of an undeveloped watershed.

Additional Statistical Analyses

In addition to generating CIs, a two-sided Wilcoxon Rank Sum test was performed on the data. Data for bioretention outflow and streamflow were compared at 3, 6, 12, 18, 24, 30, 36, 42, and 48 h after flow began, to determine if statistically significant differences existed between the two data sets (streamflow versus bioretention outflow at each time interval). This analysis was performed on data sets normalized by watershed area and on those normalized by watershed area and storm rainfall depth.

Bioretention outflow and storm flow in a stream, when normalized by watershed area, are not significantly different at 3, 6, 12, 18, or 24 h after flow began. At 30, 36, 42, and 48 h, the data are significantly different and the Wilcoxon Rank Sum test was reapplied to these time intervals as a one-sided test. It was found that the bioretention outflow was significantly greater than the streamflow data at each of the four intervals. The results were similar for data normalized by watershed area and storm precipitation depth; however, the bioretention data were significantly greater than the streamflow data at 24 h as well as at the 30, 36, 42, and 48 h times.

These results support the preliminary conclusions drawn from the CI analyses and show that outflow from bioretention is not significantly different from streamflow produced by a nonurban watershed for the first 24 h after the beginning of flow. The fact that bioretention typically releases water over 36 h as opposed to 24 h for stream interflow explains why bioretention outflow is significantly greater than streamflow at the 30-, 36-, 42-, and 48-h intervals.

The data also indicate that the size of the storm only affects the similarity between bioretention outflow and storm flow reaching a natural stream at the 24-h interval. When normalized only by watershed size, there is a significant difference between bioretention outflow and streamflow at 24 h; however, when normalized by watershed size and total rainfall depth, bioretention outflow and streamflow are not significantly different.

Fig. 4 demonstrates the relationship between median bioretention outflow and median streamflow normalized by watershed area.

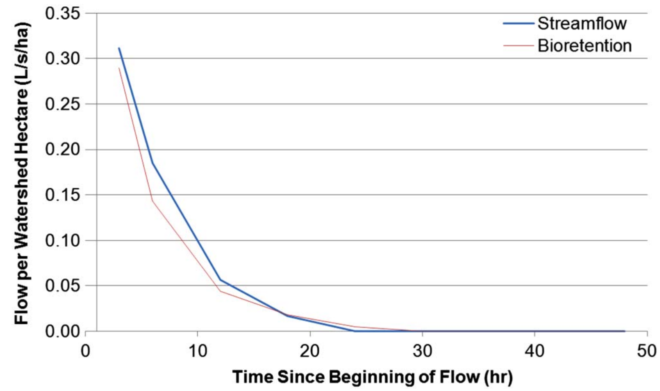

Fig. 4. Median flow rate for bioretention outflow and storm flow and shallow interflow entering nonurban streams, normalized by watershed area at 3, 6, 12, 18, 24, 30, 36, 42, and 48 h after flow begins

Prior to the 18-h interval, the median streamflow per watershed hectare is slightly greater than the median bioretention outflow per watershed hectare. After the 18-h interval, streamflow is slightly less than the bioretention outflow. The figure also illustrates that the streamflow generally ends approximately 24 h after flow begins, whereas bioretention outflow typically ends between the 30 to 36-h periods.

Because a major objective of LID is to reduce the volume of runoff, data were also analyzed to determine if nonurban watersheds and bioretention cells release storm flow volumes in a comparable manner. As described previously, total storm volumes ($BRVol_{total}$, $STVol_{total}$) and cumulative volumes ($BRVol_{cumulative}$, $SRVol_{cumulative}$) for each time interval were calculated for each storm event. The volumes received by natural streams ($STVol_{passed}$) and released by bioretention cells ($BRVol_{passed}$) at each time interval are not statistically different. These data confirm that the rate at which volumes of storm flow (runoff plus shallow interflow recharge) are released from nonurban watersheds and bioretention cells are comparable. This further illustrates that these cells are hydrologically analogous to nonurbanized watersheds.

Conclusions

In comparing CIs of shallow interflow-produced streamflow and bioretention outflow, the hydrologic characteristics of a nonurbanized watershed and a bioretention system are very similar. Outflow from bioretention cells analyzed in this study had CIs very similar to those generated from streamflow data. This is true for flow data normalized by watershed size, but even more so for data normalized by watershed size and rainfall depth, because CIs for these data match very closely when compared. Based on generated CIs, bioretention also mimics natural stream hydrology in terms of flow volumes.

Applying the Wilcoxon Rank Sum test to flow data for nonurban streams and bioretention cells provided additional statistical evidence that bioretention outflows and postevent flows from undeveloped watersheds are similar with regard to flow rates and volumes. When normalized by watershed area, outflow from bioretention cells was statistically similar to storm flow reaching a stream from an undeveloped watershed for the first 24 h after storm flow/outflow began. After 24 h, outflow from bioretention cells was significantly greater than storm flow in a natural stream, suggesting that bioretention cells release water over a longer period of time than shallow interflows from undeveloped watersheds. The watersheds selected for streamflow measurements in this study

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primarily contain agricultural land (pasture), which produces more runoff than forested land. If bioretention outflow is compared with streams draining forested watersheds, it is possible that statistical similarity will exist for the entire 48 h after the beginning of flow. Statistical analyses also confirmed that cumulative volumes, expressed as a percent of total storm flow volume, released by undeveloped watersheds and bioretention cells at given time intervals after flow began are not significantly different.

The results produced by this study suggest that a nonurbanized watershed processes runoff similarly to a bioretention cell, and releases water to the draining stream in the same manner that the bioretention cell produces outflow. Because a primary objective of LID is to mimic predevelopment hydrology, the fact that bioretention cell outflow is comparable to shallow interflow from nonurbanized/natural watershed/stream systems establishes bioretention as a vital component of LID. To date, bioretention outflow has always been considered conjugate to runoff, but this study suggests that at least some fraction of bioretention outflow more closely resembles infiltrated water that becomes shallow interflow. As LID metrics evolve, the rate at which filtration-based practices like bioretention release water to the storm conveyance network should be factored into the analysis of how well bioretention cells function. This will be particularly important in locations with very tight underlying soils that restrict "true" infiltration.

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