LID Conference, College Park, Maryland. September 2004

WinSLAMM and Low Impact Development

Robert Pitt
Department of Civil and Environmental Engineering
The University of Alabama, Tuscaloosa, AL 35487

John Voorhees
EarthTech
Madison, WI

Introduction

This short paper summarizes the possible levels of performance that may be achieved by various “low impact development” practices, as incorporated in WinSLAMM, the Source Loading and Management Model.

Most stormwater needs to be treated to prevent harm to surface and groundwaters. One approach is to treat the runoff from critical source areas before it mixes with the runoff from less polluted areas. The general features of critical source areas appear to be large paved areas, heavy vehicular traffic, and outdoor use or storage of problem pollutants. The control of runoff from relatively small critical areas may be the most cost-effective approach for treatment/reduction of stormwater toxicants. However, in order for a treatment device to be useable, it must be inexpensive, both to purchase and maintain, and effective. Outfall stormwater controls, being located at the outfalls of storm drainage systems, treat all the flows that originate from the watershed. The level of treatment provided, of course, is greatly dependent on many decisions concerning the design of the treatment devices. Source area controls are, of course, physically smaller than outfall controls but may be difficult to locate on a crowded site, and there could be a great number of them located in a watershed. In all cases, questions must be answered about the appropriate level of control needed, where the control should be provided, and what controls should be used. These questions can best be answered by using a comprehensive stormwater quality management model.

Table 1 shows the stormwater control measures that are available in WinSLAMM. The results of recent research are currently being used to expand WinSLAMM. This matrix of controls illustrates how some source area controls can be used at both source areas and at outfalls. Infiltration, filtration, and sedimentation controls can be used at both source areas and at outfalls, even though the sizes and specific designs of the specific practices must be varied to fit the site and to handle the specific flows.

Table 1. Source Area, Drainage System, and Outfall Control Options Currently Available in WinSLAMM[1]

	Infiltration trenches	Biofiltration/rain gardens	Cisterns/ rain barrels	Wet detention pond	Grass drainage swale	Street cleaning	Catch-basins	Porous pavement

Roof	X	X	X	X				
Paved parking/storage	X	X	X	X				X
Unpaved parking/storage	X	X		X				
Playgrounds	X	X	X	X				X
Driveways		X	X					X
Sidewalks/walks		X	X					X
Streets/alleys		X				X		
Undeveloped areas	X	X		X				
Small landscaped areas	X	X						
Other peRvious areas	X	X		X				
Other impeRvious areas	X	X	X	X				X
Freeway lanes/shoulders	X	X		X				
Large turf areas	X	X		X				
Large landscaped areas	X	X		X				
Drainage system		X			X		X	
Outfall	X	X		X				

[1] Development characteristics affecting runoff, such as roof and pavement draining to grass instead of being directly connected to the drainage system, are included in the individual source area descriptions.

The following discussion presents a general overview of some of these modeling features, along with selected case study examples.

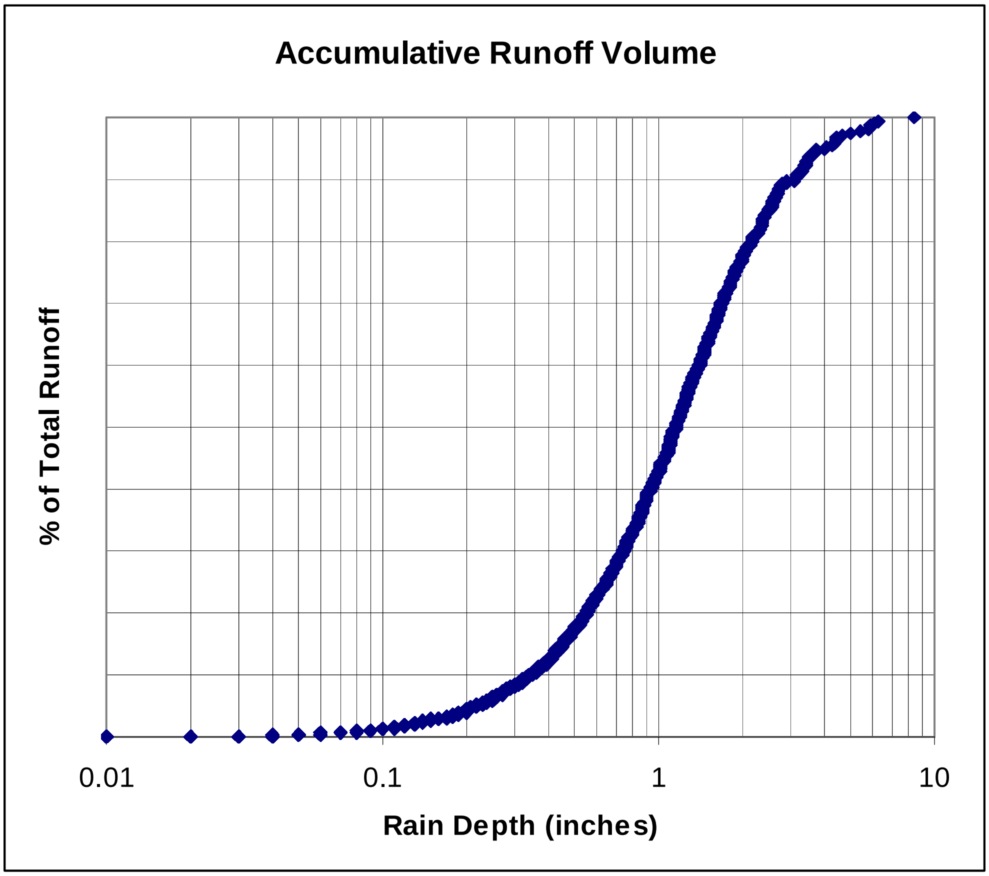
Baltimore Rain Conditions

The following tables summarize the 50 year period of recorded rains at the Baltimore airport from 1950 through 1999. About 41 inches of rain per year occur, over about 100 individual events (from 0.01 to 8.51 inches). The average rain duration is about 7 hours and the average interevent time is about 3 days. The rains are about evenly spread over all seasons.

Baltimore (BWI) 1950 through 1999 Rain Statistics

	rain depth (in)	rain duration (hrs)	average rain intensity (in/hr)	time between rains (days)
Min.	0.01	1	0	0.04
Max.	8.51	105	1.22	32.8
Average	0.41	7.3	0.06	3.3
St. dev.	0.60	7.9	0.09	3.4
COV	1.5	1.1	1.5	1.0
Average sum/year	40.8	728	6.2	335
Average number of events/year	100			

The runoff distribution by season indicated relatively even patterns throughout the year, as shown in the following two tables. There does not appear to be a dry season, or an unusually wet season. However, the summer and the fall seasons seem to have more large rains compared to the winter and spring seasons. Over this 50 year period of rain, most of the annual runoff is associated with rains larger than 1 inch. As shown on the following plot, the median runoff event is about 1.25 inches of rain. For typical medium density residential areas, 80% of the runoff occurs in the range of about 0.35 to 2 inches of rain, the steepest part of this curve, while only 5% of the runoff is associated with rains larger than 4 inches.



Plot showing accumulative runoff (100% full scale) against rain depth (Baltimore rains and typical medium density residential areas with silty soils).

This graph can be used to identify the classes of rains that should be targeted for specific types of stormwater controls and shows that the southern Chesapeake Bay region rainfall can be divided into the following categories, with possible management approaches relevant for each category of rain:

- Common rains having relatively low pollutant discharges are associated with rains less than about 0.35 in. in depth. These are key rains when runoff-associated water quality violations, such as for bacteria, are of concern. In most areas, runoff from these rains should be totally captured and either re-used for on-site beneficial uses or infiltrated in upland areas. For most areas, the runoff from these rains can be relatively easily removed from the surface drainage system. Many of the annual rains, by number, occur in this category; however, they only contribute about 10% of the annual runoff, for typical medium density residential areas.

- Rains between 0.35 and 3 in. are responsible for about 80% of the runoff pollutant discharges and are key rains when addressing mass pollutant discharges. The smaller rains in this category can also be removed from the drainage system and the runoff re-used on site for beneficial uses or infiltrated to replenish the lost groundwater infiltration associated with urbanization. The runoff from the larger rains should be treated to prevent pollutant discharges from entering the receiving waters.

- Rains greater than 3 in. are associated with drainage design and are only responsible for relatively small portions of the annual pollutant discharges. Extensive pollution control designed for these events would be very costly, especially considering the relatively small portion of the annual runoff associated with the events. However, discharge rate reductions are important to reduce habitat problems in the receiving waters. The infiltration and other treatment controls used to handle the smaller storms in the above categories would have some benefit in reducing pollutant discharges during these larger, rarer storms.

- In addition, extremely large rains also infrequently occur that exceed the capacity of the drainage system and cause local flooding. The largest Baltimore area storm was about 8.5 inches during this 50 year period. These very large storms, while very destructive, are sufficiently rare that the resulting environmental problems do not justify the massive stormwater quality controls that would be necessary for their reduction. The problem during these events is massive property damage and possible loss of life. These rains typically greatly exceed the capacities of the storm drainage systems, causing extensive flooding. It is critical that these excessive flows be conveyed in “secondary” drainage systems. These secondary systems would normally be graded large depressions between buildings that would direct the water away from the buildings and critical transportation routes and to possible infrequent/temporary detention areas (such as large playing fields or parking lots). Because these events are so rare, institutional memory often fails and development is allowed in areas that are not indicated on conventional flood maps, but would suffer critical flood damage.

This plot indicates how runoff probability distributions can be used for more effective storm drainage design in the future. In all cases, better integration of stormwater quality and drainage design objectives will require the use of long-term continuous simulations of alternative drainage designs in conjunction with upland and end-of-pipe stormwater quality controls. The complexity of most receiving water quality problems prevents a simple analysis. The use of simple design storms, which was a major breakthrough in effective drainage design more than 100 years ago, is not adequate when receiving water quality issues must also be addressed.

The following table illustrates how WinSLAMM can be used to determine reductions in annual runoff yields. RV is the % of rainfall occurring as runoff. It varies widely for different sized rains, with small values for small rains with increasing values for larger rains. The following table shows the annual flow-weighted RV values, as calculated by WinSLAMM and indicates the effects of development controls (impervious areas directly connected to drainage systems) on annual runoff, for different land uses and soils.

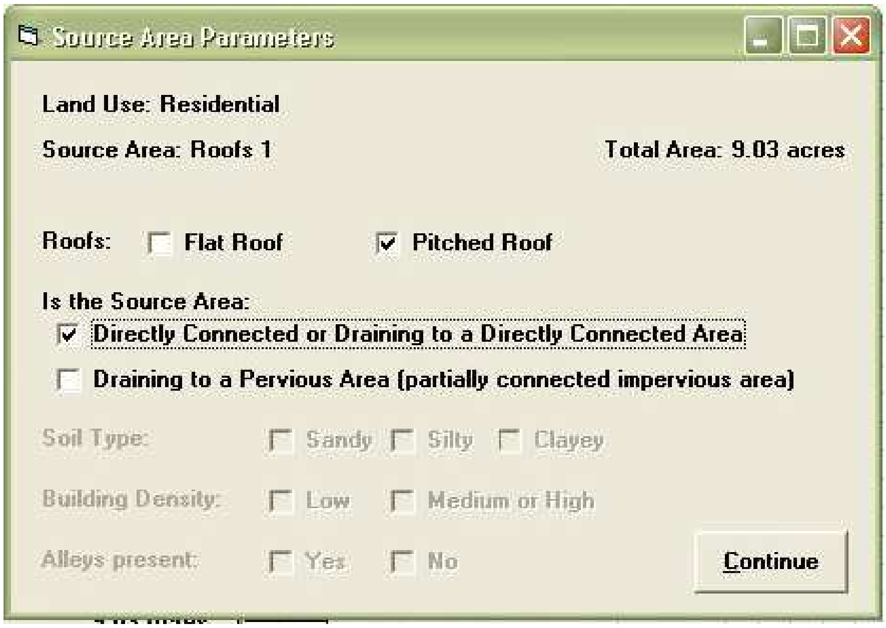
		% Pervious	% Impervious (directly connected)	% Impervious (disconnected)	Clay RV	Silt RV	Sand RV
Residential	Ultra low density	90.4	5.6	4.0	0.11	0.09	0.05
	Low density						
	typical	79.6	14.9	5.5	0.16	0.14	0.11
	connected	79.6	20.4	0	0.22	0.20	0.17
	disconnected	79.6	7.0	13.4	0.12	0.10	0.07
	Medium density						
	typical	62.3	24.2	13.5	0.26	0.23	0.19
	connected	62.3	37.7	0	0.35	0.34	0.32
	disconnected	62.3	12.8	24.9	0.19	0.14	0.11
	High density						
	typical	47.0	39.9	13.1	0.37	0.34	0.32
	connected	47.0	53.0	0	0.46	0.45	0.43
	disconnected	47.0	13.5	39.5	0.29	0.24	0.21
Commercial (shopping center)		8.28	91.72	0	0.72	0.72	0.72
Industrial		16.7	62.8	20.5	0.52	0.52	0.52

(medium)							
Institutional		36.4	61.3	2.3	0.49	0.49	0.49
Open urban area		95.1	4.9	0	0.10	0.08	0.05
Freeway	Paved drainage	49.5	50.5	0	0.43	0.41	0.40
	Grass swale	49.5	0	50.5	0.40	0.29	0.05

Medium Density Residential Area Biofiltration Example

Development Characteristics (disconnection of impervious areas)

The following screen appears after the area value is entered for most impervious areas. This screen describes the basic roof slope and if the roof drainage is directly connected to the drainage (as in this example), or allowed to drain to the pervious area, for roofs. If draining to the pervious area, the soil type is needed. If the soil is clayey, then the building density is needed (not needed for sandy or silty soils). If medium or high density, then the model asks about the presence of backyard alleys. Clayey soils, higher building densities, and alleys all decrease the benefits of disconnecting roof runoff.



Land Use: Residential

Source Area: Roofs 1

Total Area: 9.03 acres

Roofs: ☐ Flat Roof ☑ Pitched Roof

Is the Source Area:

☑ Directly Connected or Draining to a Directly Connected Area

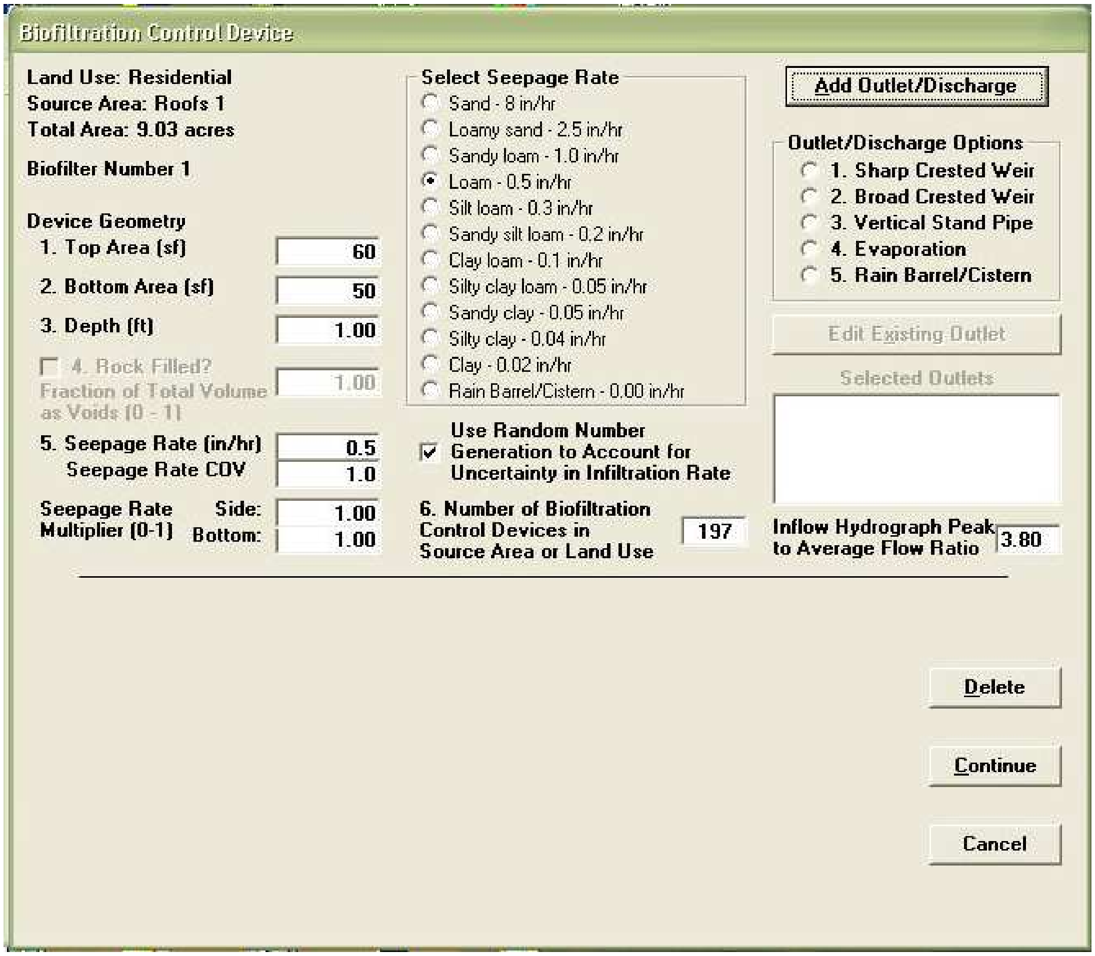
☐ Draining to a Pervious Area (partially connected impervious area)

Soil Type: ☐ Sandy ☐ Silty ☐ Clayey

Building Density: ☐ Low ☐ Medium or High

Alleys present: ☐ Yes ☐ No

After this information is entered and "continue" is pressed, it is possible to select site specific control options (besides the development characteristics reflected above). In the following example, the "B" option (for biofiltration) is selected for the roof 1 area, bringing up the following biofiltration device screen. This screen can be used to describe many different types of stormwater control devices. This example is for "rain gardens" located at each of the 197 homes in this 100 acre area. Each rain garden is about 60 ft^2 in area, serving each 2,000 ft^2 of roof. A loam soil having a 0.5 in/hr seepage rate (but with a seepage rate coefficient of variation of 1.0, reflecting typical storm-to-storm variability in soil infiltration rates) is used for each device in this example.



Biofiltration Control Device

Land Use: Residential
Source Area: Roofs 1
Total Area: 9.03 acres

Biofilter Number 1

Device Geometry
1. Top Area (sf): 60
2. Bottom Area (sf): 50
3. Depth (ft): 1.00
☐ 4. Rock Filled? Fraction of Total Volume as Voids (0 - 1): 1.00
5. Seepage Rate (in/hr): 0.5
Seepage Rate COV: 1.0
Seepage Rate Multiplier (0-1) Side: 1.00
Seepage Rate Multiplier (0-1) Bottom: 1.00

Select Seepage Rate
○ Sand - 8 in/hr
○ Loamy sand - 2.5 in/hr
○ Sandy loam - 1.0 in/hr
● Loam - 0.5 in/hr
○ Silt loam - 0.3 in/hr
○ Sandy silt loam - 0.2 in/hr
○ Clay loam - 0.1 in/hr
○ Silty clay loam - 0.05 in/hr
○ Sandy clay - 0.05 in/hr
○ Silty clay - 0.04 in/hr
○ Clay - 0.02 in/hr
○ Rain Barrel/Cistern - 0.00 in/hr

☑ Use Random Number Generation to Account for Uncertainty in Infiltration Rate

6. Number of Biofiltration Control Devices in Source Area or Land Use: 197

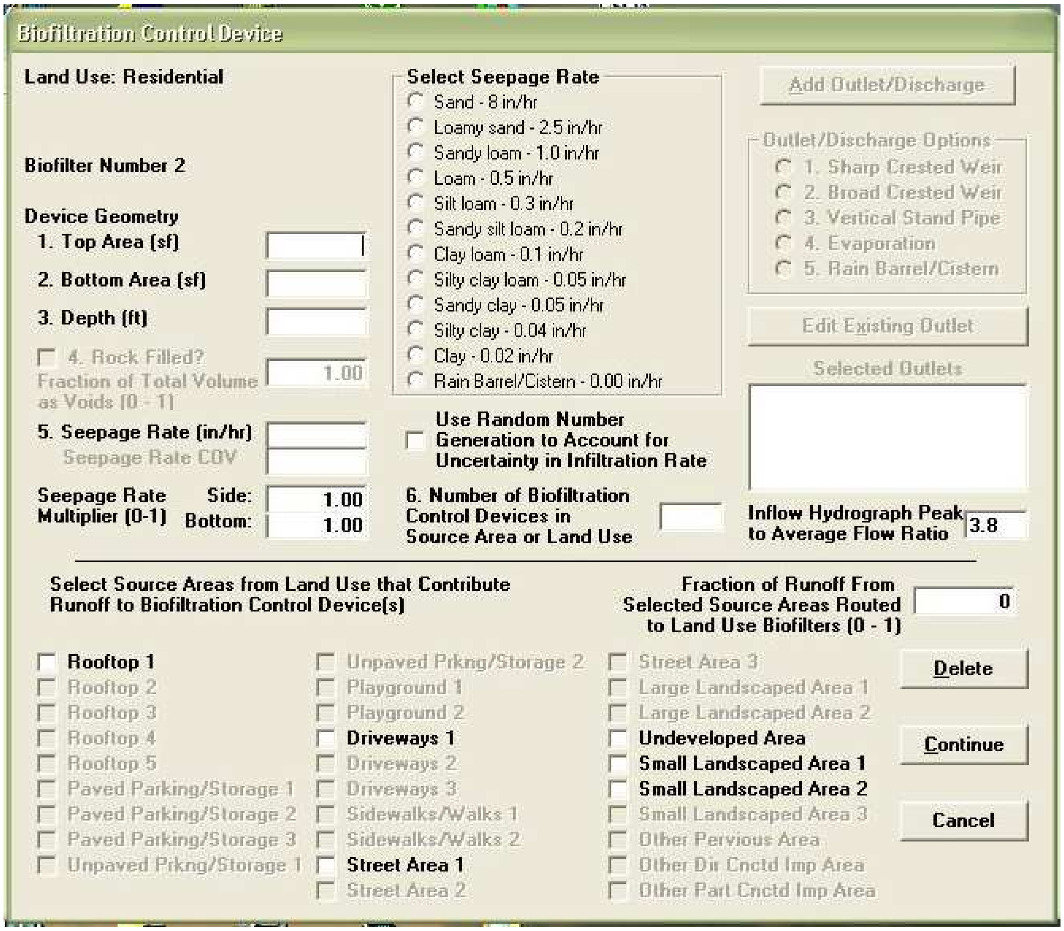
Outlet/Discharge Options
○ 1. Sharp Crested Weir
○ 2. Broad Crested Weir
○ 3. Vertical Stand Pipe
○ 4. Evaporation
○ 5. Rain Barrel/Cistern

Selected Outlets

Inflow Hydrograph Peak to Average Flow Ratio: 3.80

The outlet structures for the biofiltration devices can be simply described as broad-crested weir overflows, with the approximate downstream perimeter as the weir length and several inches for the width. The model routes the flows from the roofs through the biofiltration devices using the modified puls routing procedure (and the specified inflow hydrograph shape), incorporating infiltration, evaporation, and overflows, as described. A rain barrel or cistern is used when calculating the effects of beneficial uses of the runoff water (such as for toilet flushing, irrigation, or other safe use).

The following screen shows biofiltration controls for a complete land use. It is similar to the source area biofiltration screen, except that it also lists the available source areas in the bottom area of the form. It is therefore possible to combine some of the source areas together for control, such as rooftop and driveway runoff combined. In addition, it is possible to designate only a fraction of the combined flows to the biofiltration areas. As an example, a fraction of the roof runoff and driveway runoff can be directed to a cistern for storage of runoff for later use during dry weather for on-site irrigation (or toilet flushing, etc.). In the rain barrel/cistern “outlet/discharge” option, monthly water uses are entered so the model can track water use and re-filling of the tanks during storms.



Biofiltration Control Device

Land Use: Residential

Biofilter Number 2

Device Geometry
1. Top Area (sf) ☐
2. Bottom Area (sf) ☐
3. Depth (ft) ☐
☐ 4. Rock Filled?
Fraction of Total Volume as Voids (0 - 1) 1.00
5. Seepage Rate (in/hr) ☐
Seepage Rate COV ☐
Seepage Rate Multiplier (0-1) Side: 1.00
Bottom: 1.00

Select Seepage Rate
○ Sand - 8 in/hr
○ Loamy sand - 2.5 in/hr
○ Sandy loam - 1.0 in/hr
○ Loam - 0.5 in/hr
○ Silt loam - 0.3 in/hr
○ Sandy silt loam - 0.2 in/hr
○ Clay loam - 0.1 in/hr
○ Silty clay loam - 0.05 in/hr
○ Sandy clay - 0.05 in/hr
○ Silty clay - 0.04 in/hr
○ Clay - 0.02 in/hr
○ Rain Barrel/Cistern - 0.00 in/hr

☐ Use Random Number Generation to Account for Uncertainty in Infiltration Rate

6. Number of Biofiltration Control Devices in Source Area or Land Use ☐

Add Outlet/Discharge

Outlet/Discharge Options
○ 1. Sharp Crested Weir
○ 2. Broad Crested Weir
○ 3. Vertical Stand Pipe
○ 4. Evaporation
○ 5. Rain Barrel/Cistern

Edit Existing Outlet

Selected Outlets

Inflow Hydrograph Peak to Average Flow Ratio 3.8

Select Source Areas from Land Use that Contribute Runoff to Biofiltration Control Device(s)

Fraction of Runoff From Selected Source Areas Routed to Land Use Biofilters (0 - 1) 0

☐ Rooftop 1
☐ Rooftop 2
☐ Rooftop 3
☐ Rooftop 4
☐ Rooftop 5
☐ Paved Parking/Storage 1
☐ Paved Parking/Storage 2
☐ Paved Parking/Storage 3
☐ Unpaved Prkng/Storage 1
☐ Unpaved Prkng/Storage 2
☐ Playground 1
☐ Playground 2
☐ Driveways 1
☐ Driveways 2
☐ Driveways 3
☐ Sidewalks/Walks 1
☐ Sidewalks/Walks 2
☐ Street Area 1
☐ Street Area 2
☐ Street Area 3
☐ Large Landscaped Area 1
☐ Large Landscaped Area 2
☐ Undeveloped Area
☐ Small Landscaped Area 1
☐ Small Landscaped Area 2
☐ Small Landscaped Area 3
☐ Other Pervious Area
☐ Other Dir Cnctd Imp Area
☐ Other Part Cnctd Imp Area

The following table illustrates a typical WinSLAMM analysis for a Birmingham, AL, area using a series of low impact development controls. Runoff occurs during all rains, even during the smallest 0.01 inch event (although the Rv for this event is only 0.01), when all areas are directly connected to the drainage system and no infiltration or biofiltration controls are used. When the infiltration devices are used, runoff only occurs for rains greater than about 0.5 inches. The runoff volume is even reduced during the largest 4 inch rain by about 10 percent when using these controls. The control benefits for suspended solids mass discharges are similar. They are greater than the benefits for runoff volume for the moderate rains (0.50 to 1.50 inches), but the suspended solids reductions are actually slightly less than the volume reductions for the larger rains. This is likely because of the infiltration of relatively clean roof runoff in the "rain gardens" compared to infiltration of runoff from other areas, and the significantly increased suspended solids discharges from landscaped areas during these large rains. It is therefore reasonable to expect about 80%, or greater, runoff and suspended solids reductions for all rains up to about 0.75 inches in depth with this example control scenario.

Rain depth (inches)	Rv with no controls and all pavement and roofs are directly connected	Rv with biofiltration controls and with disconnected pavement and roofs	% runoff volume reductions with controls	Suspended solids with no controls and all pavement and roofs are directly connected (lbs/ac)	Suspended solids with biofiltration controls and with disconnected pavement and roofs (lbs/acre)	% suspended solids reductions with controls
0.01	0.01	0.00	100%	<0.1	0	100%
0.05	0.06	0.00	100%	<0.1	0	100%
0.10	0.11	0.00	100%	0.15	0	100%
0.25	0.22	0.00	100%	3.6	0	100%

0.50	0.28	0.01	96%	10	0.12	99%
0.75	0.31	0.08	74%	16	2.5	84%
1.00	0.32	0.16	50%	23	8.6	63%
1.50	0.35	0.24	31%	40	27	33%
2.00	0.38	0.28	26%	61	49	20%
2.50	0.42	0.34	19%	87	76	13%
3.00	0.44	0.37	16%	110	100	10%
4.00	0.50	0.45	10%	180	170	6%

This area was further evaluated using a continuous series of Birmingham, AL, rains over a 37 year period (1953 through 1989) that contained 4,011 separate rains ranging from 0.01 to 13.58 inches in depth. The minimum rain duration was 1 hour (by definition), while the maximum duration was 93 hours (the median was 4 hours). The interevent times ranged from 6 hours (used to define separate rain events) to 44 days (the median was 1.9 days).

The following table summarizes these results for several alternatives. The “as-built” condition is based on actual conditions in the Birmingham area derived from neighborhood surveys and aerial photographic measurements. The “totally connected” condition is this same area, but assuming that all roofs and driveways are directly connected to the drainage system, while the “totally disconnected” condition assumes that these paved and roof areas all drain to the clayey soils. The “skinny street” option reduces the measured street widths from 35 to 20 ft, keeping the same street lengths, and increasing the landscaped areas by the reduction in street area. The swales and roof garden option is similar to the above evaluation, but the last option shown also had amended soils in the swales and roof gardens to increase the infiltration rates to about 0.5 in/hr (loam conditions).

The current (partially connected) conditions produce about 10% less runoff and about the same amount of suspended solids compared to totally connected conditions. If the current conditions were built with skinny streets, the runoff reductions would slightly improve to about 13%. Substantial runoff and suspended solids reductions (about 60 to 65%) would occur for totally disconnected conditions, plus the use of rain gardens to improve roof runoff and the use of amended soils in both the rain gardens and swales to improve infiltration in the clayey soils.

	Flow-weighted Rv	Suspended solids discharges (lb/ac/yr)
Totally connected	0.34	1390
As built and surveyed	0.31	1380
% reduction	9%	0%
As built, but with “skinny” streets	0.30	1430
% reduction	13%	3% increase
Totally disconnected	0.27	1380
% reduction	21%	<1%
Totally disconnected with swales	0.25	1060
% reduction	26%	24%
Totally disconnected, swales, roof rain gardens, and amended soils	0.12	590
% reduction	65%	58%

Obviously, these are only predictions for a single area and the specific results would vary substantially for other areas having different rains, soils, and development characteristics. However, this example does illustrate how WinSLAMM can be used to calculate expected benefits of different types of biofiltration controls in a typical medium density residential area.

Birmingham Southern College Fraternity Row Stormwater Options

The new “fraternity row” area at Birmingham Southern College offers several opportunities for stormwater management, including the beneficial reuse of this water for later irrigation of landscaped areas. The following table lists the approximate areas associated with each surface in the drainage area that includes the new buildings, and parking area:

Drainage Area Surface Characteristics

	Acres	% of Total
Roadways	0.24	6.6%
Parking	0.89	24.5
Walks	0.25	6.9
Roofs	0.58	16.0
Landscaping	1.67	46.0
Total:	3.63	100.0

SLAMM was used to predict the runoff conditions for this site, if built as planned, and to quantify the advantages of several possible stormwater management options that could be used at this location. The model used local Birmingham, AL, data, specifically local soil information from the Jefferson County Soil Survey, and the NOAA rain data extracted from EarthInfo CDROMS. The 1976 rain year was used in this analysis, as that year has been shown to be reasonably similar to long-term average rain conditions. The March 29, 1999 Site Grading and Drainage Plan, prepared by Nimrod Long and Associates, landscaped architects for the project, was used for area and slope measurements.

The following discussion examines several options, specifically targeting roof runoff and parking area runoff, the major sources of runoff from this area. In addition, the use of grass swales and porous walkways was also examined to provide further runoff reductions.

1) Roof Runoff Storage and Rain Garden Areas

The runoff from the rooftops was estimated to contribute about 30% of the annual runoff volume for this drainage area. Each building has about 4,000 ft^2 of roof area. A recommended approach is to capture as much of the rainwater as possible, using underground storage tanks. Any overflow from the storage tanks would then flow into rain gardens to encourage infiltration, with any excess entering the conventional stormwater drainage system. The storage tanks can be easily pumped into currently available irrigation tractors, which have 500 gal tanks. The total roof runoff from the six buildings is expected to be slightly more than 100,000 ft^3 (750,000 gal) water per year. With a cost of about $1.50 per 100 ft^3, this would be valued at about $1,500 per year. It is expected that the storage tanks would have a useful life of at least 20 years, with a resultant savings of at least $30,000. One source for plastic underground water storage tanks (Chem-Tainer, New York; http://www.chemtainer.com/new/prices/dynamic-prices.asp) lists their cost at about $1500 for 300 ft^3 units.

The efficiency of these storage units is based on their expected use. The following table lists the assumed average water use, in gal per day, for the roof runoff for each house. This was calculated assuming pumped irrigation near the buildings, with each house irrigating about ½ acre of turf. If tanker tractors were used so water could be delivered to other locations on campus, the water use would be greater, and the efficiency of the system would increase.

	Irrigation (inches per month on turf)	Average use for ½ acre (gal/day)
January	1	230
February	1	230
March	1.5	340
April	2	460
May	3	680

June	4	910
July	4	910
August	4	910
September	3	680
October	2	460
November	1.5	340
December	1	230
Total	28	

The following table shows the estimated fraction of the annual roof runoff that would be used for this irrigation for different storage tank volumes per building (again assuming pumped irrigation to ½ acre per building):

Tankage Volume per Building (ft^3)	**Fraction of Annual Roof Runoff used for Irrigation**
1,000	56%
2,000	56
4,000	74
8,000	90
16,000	98

With this irrigation schedule, there is no significant difference between the utilization rates for 1,000 and 2,000 ft^3 of storage tankage per building. Again, with the tanker tractor rigs, the utilization could be close to 100% for all tank sizes, depending on the schedule for irrigation for other campus areas: larger tanks would only make the use of the water more convenient and would provide greater reserves during periods of dry weather. Also, small tanks would overflow more frequently during larger rains. For this reason, at least 1,000 ft^3 of tankage (3 or 4 of the 300 ft^3 tanks) per building is recommended for this installation.

Any overflow from the underground storage tanks should be directed to small bioretention areas in relatively flat ground. Each bioretention area ("rain gardens") should be about 100 to 200 ft^2 in area, and 2 to 4 separate units should be provided for each of these building. Each roof runoff rain garden should be a depression about 1 ft deep, with a 6 inch diameter standpipe about 9 inches above the bottom to capture the overflow and direct it to the storm drainage system. The downslope edge of the rain gardens should be slightly lower in elevation than the other edges, to allow overflow of the water towards surface channels. In order to enhance infiltration in the rain gardens, and to protect groundwater, the soil should be excavated to a depth of at least 1-1/2 ft below the bottom of the rain garden. A 50/50 mixture of sand and peat moss should be placed in the excavation up to the bottom of the rain garden.

Many rain gardens are showcases for native plants that can tolerate wetter conditions. However, successful rain gardens can also be constructed with simple turf covers.

2) Parking Area Bioretention Areas

There are two main areas available for treating the runoff from the parking area. The drainage from this area is split, with about half being directed to each end. The water then enters an inlet where a pipe carries the water down a fill slope. On the north end of the parking area, the pipe exits the bottom of the slope in a small depression at the bottom of the hill. This area can be easily converted to a bioretention area, with amended soils. This unit could be about 700 ft^2 at the top, tapering down to about 250 ft^2 at a depth of 3 ft. A vertical pipe riser would extend up by about 2.5 ft from the planned inlet location. The soil should be further excavated by another 1-1/2 to 2 ft and replaced with an amended soil mixture of 50/50 sand and peat moss (or compost). In this location, a perforated drain pipe should be placed at the bottom of this replaced fill, connected to the stormwater inlet.

The stormwater from the southern half of the parking lot drains towards an inlet near a new flat area behind the parking area, above the fill slope. It is recommended that a biofiltration area be constructed on this flat area to treat this parking area runoff. The surface area of this rain garden could be about 500 ft^2, with a depth of about 3 ft and a bottom area of about 450 ft^2. Again, the soil should be excavated to 1-1/2 to 2 ft and replaced with an amended soil. The excavated soil should be placed towards the uphill side to level the current depression. A subsurface drain should be placed at the bottom of this fill and connected to the drainage system. A 2-1/2 ft stand pipe would also direct any excess water to the drainage system. Water would enter this area by a pipe connected to the current manhole containing the downslope pipe. This new pipe would be located below this downslope pipe to preferentially direct water to the biofiltration area. Any excess water would cause a backwater into the manhole, which would then enter the existing pipe directed down the slope.

Originally, additional bioretention devices were considered for the islands in the parking areas. However because of the existing curb lines, this was not considered practical, especially considering the other suitable bioretention areas described above.

These two main bioretention areas for the parking area are expected to provide between 65 to 95% reductions in the annual stormwater volume, depending on how successful the soil amendments can be incorporated in the fill material.

3) Combinations of all Controls

The following tables summarize the annual stormwater runoff volume and suspended (particulate) solids reductions expected for different stormwater control options on this site. Several grass swales will be used for on-site stormwater conveyance that will provide additional treatment. The following tables also consider the use of porous paver walkways. If these are not possible, then the walkways should be slightly sloped to direct the runoff away from the paved areas and towards the grass swales. The use of the underground storage tanks for roof runoff irrigation use, plus rain gardens, should result in almost complete removal of this flow source. The parking area bioretention areas should result in about 75% reductions compared to no controls, and porous pavers (or re-directing their runoff to grass areas) should result in almost complete control from that source. The overall runoff volume reduction for all of these controls is expected to be slightly greater than 80% for the annual series of rains. These controls will also reduce larger peak flows during rarer design storms. With no controls, the annual flows would be about 8 times larger than before site development. With these controls, the increased runoff volumes would be reduced to about 1.4 times as large.

The suspended solids (SS) discharges are somewhat different. The roofs only produce a very small fraction of the total site SS discharges, with most coming from the parking areas, landscaped areas, and the streets. The use of all controls would lower the annual SS discharges to a value less than for predevelopment conditions. Without controls, the SS discharges would be about 15% greater than prior to development. Unfortunately, construction site erosion is likely to produce a very large increase in SS discharges compared to conditions either before development, or after the site is stabilized.

Birmingham Southern College Fraternity Row Stormwater Management Options

Runoff Volume (cubic feet per year)

	roofs	parking	walks	streets	Land-scaped	total before drainage	total after drainage	Rv
Base condition (natural soil, Bodine, Fullerton, urban, "B") with grass swales					46138	46138	46138	0.06
Developed with no controls	110583	173859	37292	35795	21226	378747	378747	0.52
% contribution for source area	29	46	10	9	6	100	100	

Grass swales (half of site) and porous pavers for walks	110583	173859	0	35795	21226	341461	257661	0.35
% contribution for source area	32	51	0	10	6	100	75	
% reduction compared to no controls	0	0	100	0	0	10	32	33
Grass swales (half of site) and porous pavers for walks and roof disconnections	7371	173859	0	35795	21226	238243	166359	0.23
% contribution for source area	3	73	0	15	9	100	70	
% reduction compared to no controls	93	0	100	0	0	37	56	56
Grass swales (half of site) and porous pavers for walks and bioretention for roofs and parking	89	44275	0	35795	21226	101382	65653	0.09
% contribution for source area	0	44	0	35	21	100	65	
% reduction compared to no controls	100	75	100	0	0	73	83	83

Suspended Solids (lbs/year)

	roofs	parking	walks	streets	Land-scaped	total before drainage	total after drainage
Base condition (natural soil, Bodine, Fullerton, urban, "B") with grass swales					1758	1758	1758
Developed with no controls	34	915	173	482	809	2386	1991
% contribution for source area	1	38	7	19	34	100	83
Grass swales (half of site) and porous pavers for walks	34	915	0	482	809	2241	1368
% contribution for source area	2	41	0	22	36	100	61
% reduction compared to no controls	0	0	100	0	0	6	31
Grass swales (half of site) and porous pavers for walks and roof disconnections	2	915	0	482	809	2208	1249
% contribution for source area	0	41	0	22	37	100	57
% reduction compared to no controls	93	0	100	0	0	7	37
Grass swales (half of site) and porous pavers for walks and bioretention for roofs and parking	0	166	0	482	809	1457	842
% contribution for source area	0	11	0	33	56	100	58
% reduction compared to no controls	100	82	100	0	0	39	58

Conclusions

WinSLAMM can be used to evaluate a wide range of stormwater controls, both at source areas and at outfalls. It uses a long-term continuous simulation typically approaching 50 years of local rain conditions. The implementation of source area development options (connections of impervious surfaces), infiltration and bioretention controls, and rain barrels and cisterns (and associated water reuse), along with public works and conventional structural practices, enables the evaluation of numerous stormwater options. WinSLAMM has been verified for most of these controls at full-scale monitoring locations at several locations in the US, mostly in Wisconsin and in Alabama. The development of the model has been on-going for about 30 years and is strongly based on actual field research, funded by the EPA, Environment Canada, and many state and local agencies. As with all models, local calibration and verification is needed for the best reliability. The case studies presented in this paper are meant as only examples illustrating a few of the many model options. It is likely that the results will vary based on local rainfall, soil, and development conditions. Further information about WinSLAMM is available at:
http://unix.eng.ua.edu/~rpitt/SLAMMDETPOND/MainSLAMMDETPOND.html