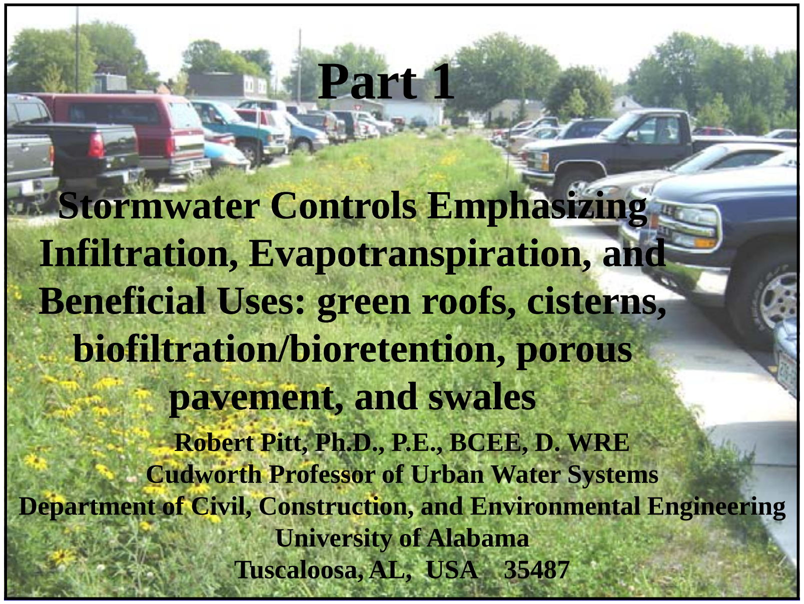

Part 1

Stormwater Controls Emphasizing Infiltration, Evapotranspiration, and Beneficial Uses: green roofs, cisterns, biofiltration/bioretention, porous pavement, and swales

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Watershed-Based Stormwater Controls

Multiple names for a similar goal/design process:

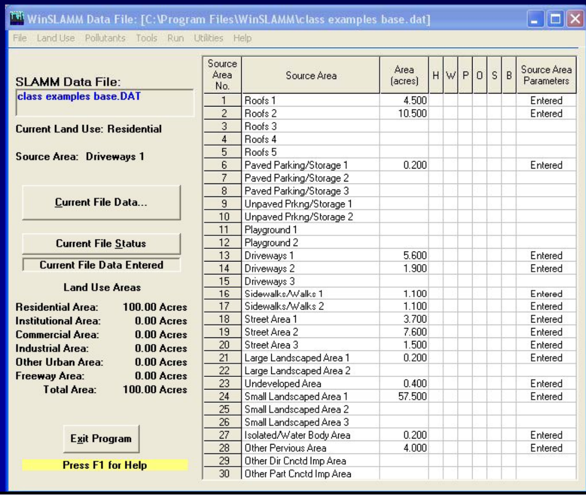
- Low Impact Development (LID)
- Conservation Design
- Water Sensitive Urban Design (WSUDs)
- Sustainable Urban Drainage Systems (SUDS)
- Distributed Runoff Controls (DRC)

These approaches emphasize infiltration, however, other stormwater treatment approaches will also likely be required to meet the wide range of beneficial use objectives of urban receiving waters.

Conservation Design Approach for New Development

- **Better site planning to maximize resources of site**
- **Emphasize water conservation and water reuse on site**
- **Encourage infiltration of runoff at site but prevent groundwater contamination**
- **Treat water at critical source areas and encourage pollution prevention (no zinc coatings and copper, for example)**
- **Treat runoff that cannot be infiltrated at site**

Modeling examples in this module will use this basic medium density residential area, based on the average of many actual neighborhoods surveyed in Wisconsin, normalized to 100 acres.



WinSLAMM Data File: [C:\Program Files\WinSLAMM\class examples base.dat]

File Land Use Pollutants Tools Run Utilities Help

SLAMM Data File:
class examples base.DAT

Current Land Use: Residential

Source Area: Driveways 1

Current File Data...

Current File Status

Current File Data Entered

Land Use Areas

Residential Area: 100.00 Acres
Institutional Area: 0.00 Acres
Commercial Area: 0.00 Acres
Industrial Area: 0.00 Acres
Other Urban Area: 0.00 Acres
Freeway Area: 0.00 Acres
Total Area: 100.00 Acres

Exit Program

Press F1 for Help

Source Area No.	Source Area	Area (acres)	H	W	P	O	S	B	Source Area Parameters
1	Roofs 1	4.500							Entered
2	Roofs 2	10.500							Entered
3	Roofs 3								
4	Roofs 4								
5	Roofs 5								
6	Paved Parking/Storage 1	0.200							Entered
7	Paved Parking/Storage 2								
8	Paved Parking/Storage 3								
9	Unpaved Prkng/Storage 1								
10	Unpaved Prkng/Storage 2								
11	Playground 1								
12	Playground 2								
13	Driveways 1	5.600							Entered
14	Driveways 2	1.900							Entered
15	Driveways 3								
16	Sidewalks/Walks 1	1.100							Entered
17	Sidewalks/Walks 2	1.100							Entered
18	Street Area 1	3.700							Entered
19	Street Area 2	7.600							Entered
20	Street Area 3	1.500							Entered
21	Large Landscaped Area 1	0.200							Entered
22	Large Landscaped Area 2								
23	Undeveloped Area	0.400							Entered
24	Small Landscaped Area 1	57.500							Entered
25	Small Landscaped Area 2								
26	Small Landscaped Area 3								
27	Isolated/Water Body Area	0.200							Entered
28	Other Pervious Area	4.000							Entered
29	Other Dir Cnctd Imp Area								
30	Other Part Cnctd Imp Area								

The file descriptions can be exported to a file under the “file” option:

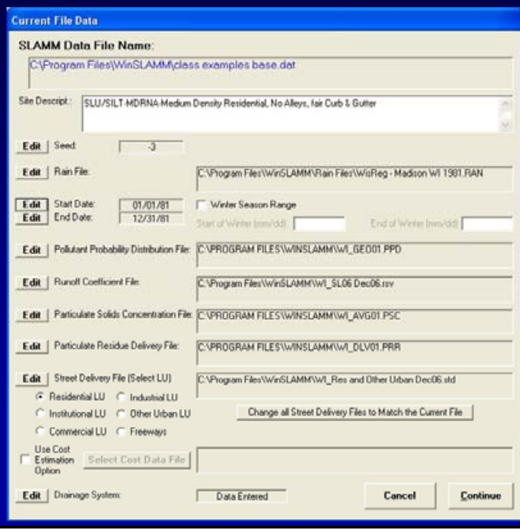
```
Data file name:  Class examples base
SLAMM Version 9.4.6
Rain file name:  C:\Program Files\WinSLAMM\Rain Files\WisReg - Madison WI 1981.RAN
Particulate Solids Concentration file name:  C:\PROGRAM FILES\WINSLAMM\WI_AVG01.PSC
Runoff Coefficient file name:  C:\Program Files\WinSLAMM\WI_SL06 Dec06.rsv
Particulate Residue Delivery file name:  C:\PROGRAM FILES\WINSLAMM\WI_DLV01.PRR
Residential Street Delivery file name:  C:\Program Files\WinSLAMM\WI_Res and Other Urban Dec06.std
Institutional Street Delivery file name:  C:\Program Files\WinSLAMM\WI_Com Inst Indust Dec06.std
Commercial Street Delivery file name:  C:\Program Files\WinSLAMM\WI_Com Inst Indust Dec06.std
Industrial Street Delivery file name:  C:\Program Files\WinSLAMM\WI_Com Inst Indust Dec06.std
Other Urban Street Delivery file name:  C:\Program Files\WinSLAMM\WI_Res and Other Urban Dec06.std
Freeway Street Delivery file name:  C:\Program Files\WinSLAMM\Freeway Dec06.std
Apply Street Delivery Files to Adjust the After Event Load Street Dirt Mass Balance:  False
Pollutant Relative Concentration file name:  C:\PROGRAM FILES\WINSLAMM\WI_GEO01.PPD
Seed for random number generator:  -3
Study period starting date:  01/01/81        Study period ending date:  12/31/81
Date:  11-01-2009                            Time:  17:11:32
Fraction of each type of Drainage System serving study area:
      1.   Grass Swales 0
      2.   Undeveloped roadside 0
           Curb and Gutters, 'valleys', or sealed swales in:
            3.   Poor condition (or very flat) 0
            4.   Fair condition 1
            5.   Good condition (or very steep) 0
Site information:
SLU/SILT-MDRNA-Medium Density Residential, No Alleys, fair Curb & Gutter

                           |<===== Areas for each Source (acres) =====>|
                           Resi-   Institu- Commercial Industrial  Other
                          dential  tional     Areas      Areas     Urban
Source Area                Areas    Areas                          Areas
Roofs 1                    4.500    0.000     0.000      0.000     0.000
Roofs 2                   10.500    0.000     0.000      0.000     0.000
Roofs 3                    0.000    0.000     0.000      0.000     0.000
Roofs 4                    0.000    0.000     0.000      0.000     0.000
Roofs 5                    0.000    0.000     0.000      0.000     0.000
Paved Parking/Storage 1    0.200    0.000     0.000      0.000     0.000
Paved Parking/Storage 2    0.000    0.000     0.000      0.000     0.000
Paved Parking/Storage 3    0.000    0.000     0.000      0.000     0.000
```

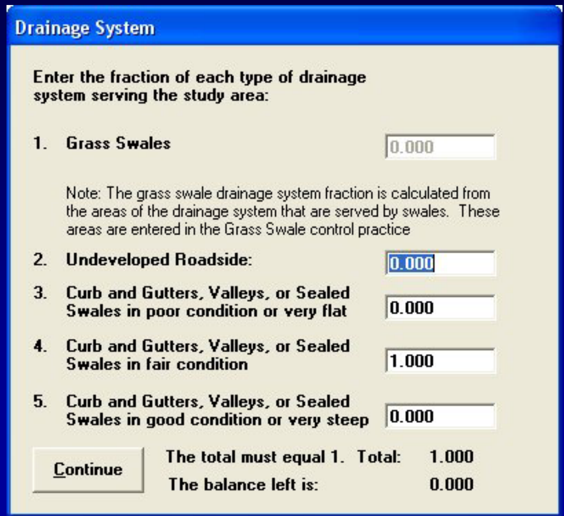
The following is a summary of the source area descriptions for this area:

Class examples base.dat					
	area (ac)				
Roofs 1	4.5	pitched	directly connected		
Roofs 2	10.5	pitched	draining to silty soils		
Paved parking/storage 1	0.2		directly connected		
Driveways 1	5.6		directly connected		
Driveways 2	1.9		draining to silty soils		
Sidewalks/walks 1	1.1		directly connected		
Sidewalks/walks 2	1.1		draining to silty soils		
Street area 1	3.7	2.0 curb mi	30.5 ft width	smooth texture	accum rate and initial load calculated by program
Street area 2	7.6	4.0 curb mi	31.3 ft width	intermediate texture	accum rate and initial load calculated by program
Street area 3	1.5	0.8 curb mi	30.9 ft width	rough texture	accum rate and initial load calculated by program
Large landscaped area 1	0.2		silty soil		
Undeveloped area	0.4		silty soil		
Small landscaped area 1	57.5		silty soil		
Isolated/water body area	0.2			isolated area generating no runoff	
Other pervious area	4		silty soil		
total residental area:	100				

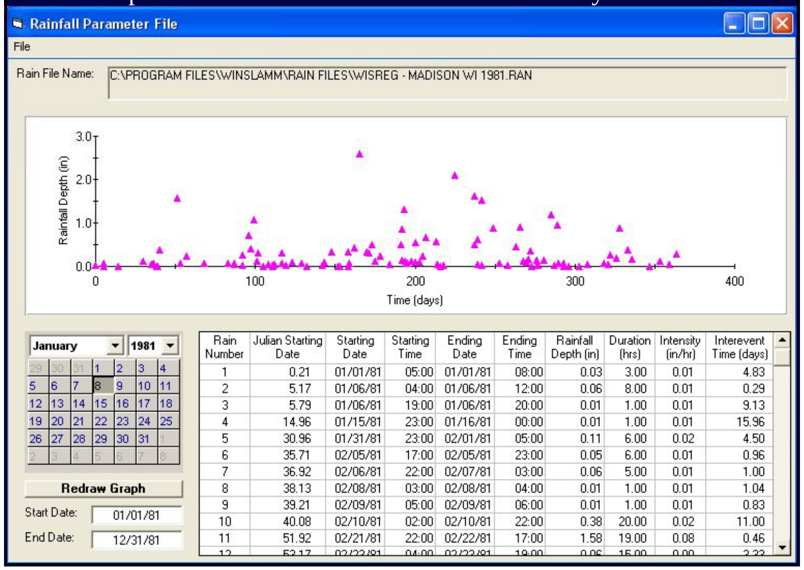
This is the list of data files used with these analyses (calibrated and verified by the USGS, working with the WI DNR, using much regional data):



The following is the basic drainage system. This is changed automatically when swales are added as a drainage control practice.



This is a plot of the 1981 rain events used in the analyses:



Rain Number	Julian Starting Date	Starting Date	Starting Time	Ending Date	Ending Time	Rainfall Depth (in)	Duration (hrs)	Intensity (in/hr)	Interevent Time (days)
1	0.21	01/01/81	05:00	01/01/81	08:00	0.03	3.00	0.01	4.83
2	5.17	01/06/81	04:00	01/06/81	12:00	0.06	8.00	0.01	0.29
3	5.79	01/06/81	19:00	01/06/81	20:00	0.01	1.00	0.01	9.13
4	14.96	01/15/81	23:00	01/16/81	00:00	0.01	1.00	0.01	15.96
5	30.96	01/31/81	23:00	02/01/81	05:00	0.11	6.00	0.02	4.50
6	35.71	02/05/81	17:00	02/05/81	23:00	0.05	6.00	0.01	0.96
7	36.92	02/06/81	22:00	02/07/81	03:00	0.06	5.00	0.01	1.00
8	38.13	02/08/81	03:00	02/08/81	04:00	0.01	1.00	0.01	1.04
9	39.21	02/09/81	05:00	02/09/81	06:00	0.01	1.00	0.01	0.83
10	40.08	02/10/81	02:00	02/10/81	22:00	0.38	20.00	0.02	11.00
11	51.92	02/21/81	22:00	02/22/81	17:00	1.58	19.00	0.08	0.46

Porous Pavement and Paver Blocks

- These have long been used in Europe to reduce flows entering combined sewers.
- They are most useful in areas having little traffic (overflow seasonal parking, walkways and driveways)
- They should not be used in areas of de-icing salt applications, or in critical areas that may cause groundwater contamination

Porous pavement and paver blocks are used in many locations to reduce runoff and for aesthetics

Austin, TX

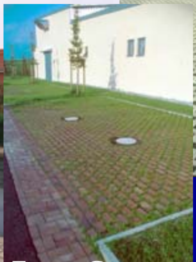
Wolfgang Geiger's Porous Paver Test Rig, Essen, Germany

Porous paver blocks have been used in many locations to reduce runoff to combined sewer systems, thereby reducing overflow frequency and volumes.

Not recommended in areas of heavy automobile use due to groundwater contamination (provide little capture of critical pollutants, plus some manufactures recommend use of heavy salt applications instead of sand for ice control).

Madison, Wisconsin

Malmo, Sweden



Essen, Germany

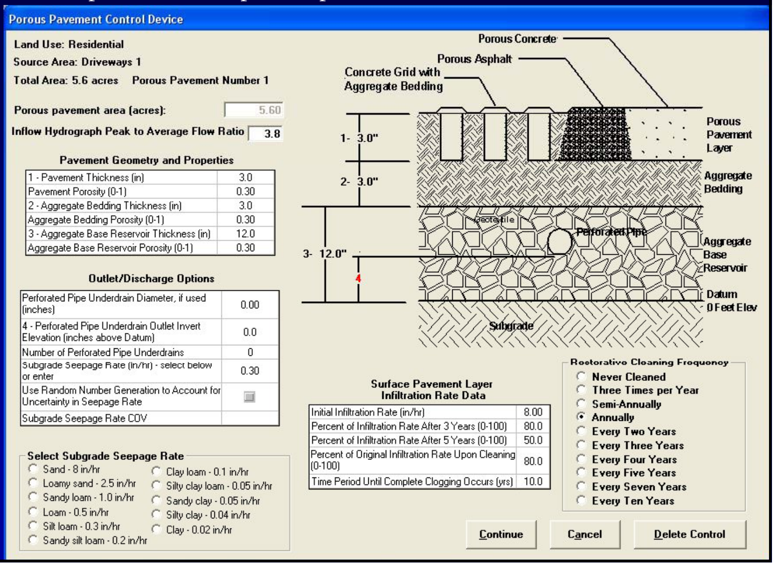
Porous paver blocks and grass reinforcement material should not be used in areas having heavy parking, as the grass cannot thrive if parked on much of the time and soil compaction is still likely.

Another way to reduce runoff is to reduce the amount of paved areas. However, make sure there is sufficient parking and that the streets can handle the expected traffic load. In some cases of heavy use, cars are parked on the sidewalks, forcing pedestrians to walk in the street.

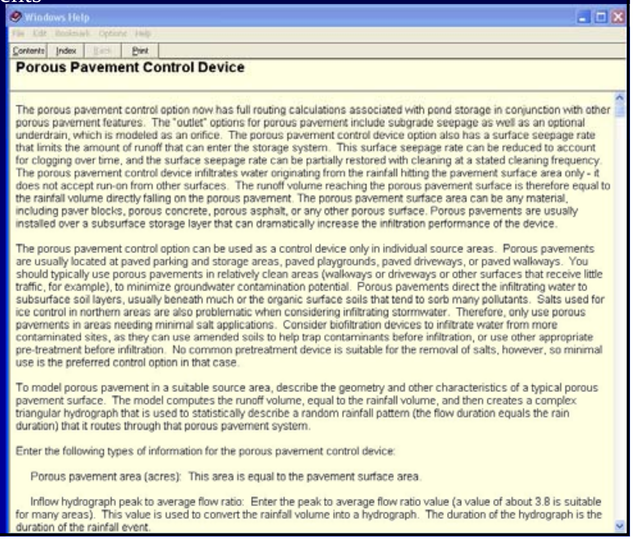
Modeling Porous Pavements

- Porous pavement (or paver blocks or turf-reinforcers) can be modeled at the source areas.
- In this example, paver blocks are used for the directly connected driveways.
- The pavers are 3 inches thick and are on another 3 inches of sand. That is in turn on 12 inches of an aggregate base for storage.
- Degradation in performance occurs with clogging. The values used are described in the help file.

Main input screen for porous pavement



Extensive help files (F1) are available that explain the controls and input requirements


Windows Help

File Edit Bookmark Options Help

Contents Index Back Print

Porous Pavement Control Device

The porous pavement control option now has full routing calculations associated with pond storage in conjunction with other porous pavement features. The "outlet" options for porous pavement include subgrade seepage as well as an optional underdrain, which is modeled as an orifice. The porous pavement control device option also has a surface seepage rate that limits the amount of runoff that can enter the storage system. This surface seepage rate can be reduced to account for clogging over time, and the surface seepage rate can be partially restored with cleaning at a stated cleaning frequency. The porous pavement control device infiltrates water originating from the rainfall hitting the pavement surface area only - it does not accept run-on from other surfaces. The runoff volume reaching the porous pavement surface is therefore equal to the rainfall volume directly falling on the porous pavement. The porous pavement surface area can be any material, including paver blocks, porous concrete, porous asphalt, or any other porous surface. Porous pavements are usually installed over a subsurface storage layer that can dramatically increase the infiltration performance of the device.

The porous pavement control option can be used as a control device only in individual source areas. Porous pavements are usually located at paved parking and storage areas, paved playgrounds, paved driveways, or paved walkways. You should typically use porous pavements in relatively clean areas (walkways or driveways or other surfaces that receive little traffic, for example), to minimize groundwater contamination potential. Porous pavements direct the infiltrating water to subsurface soil layers, usually beneath much or the organic surface soils that tend to sorb many pollutants. Salts used for ice control in northern areas are also problematic when considering infiltrating stormwater. Therefore, only use porous pavements in areas needing minimal salt applications. Consider biofiltration devices to infiltrate water from more contaminated sites, as they can use amended soils to help trap contaminants before infiltration, or use other appropriate pre-treatment before infiltration. No common pretreatment device is suitable for the removal of salts, however, so minimal use is the preferred control option in that case.

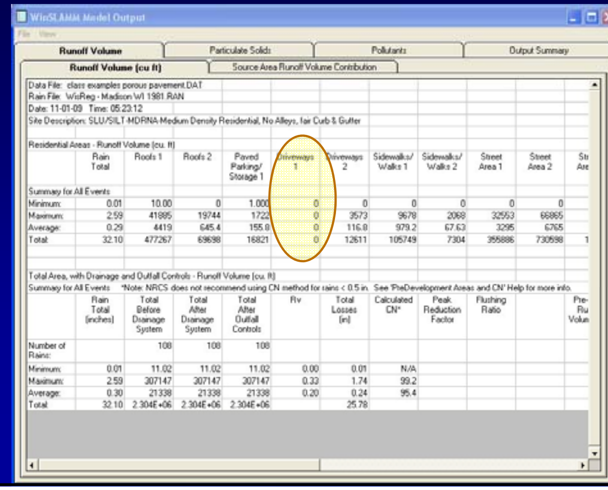
To model porous pavement in a suitable source area, describe the geometry and other characteristics of a typical porous pavement surface. The model computes the runoff volume, equal to the rainfall volume, and then creates a complex triangular hydrograph that is used to statistically describe a random rainfall pattern (the flow duration equals the rain duration) that it routes through that porous pavement system.

Enter the following types of information for the porous pavement control device:

Porous pavement area (acres): This area is equal to the pavement surface area.

Inflow hydrograph peak to average flow ratio: Enter the peak to average flow ratio value (a value of about 3.8 is suitable for many areas). This value is used to convert the rainfall volume into a hydrograph. The duration of the hydrograph is the duration of the rainfall event.

Runoff volume summary for source areas showing complete control for the driveways that have porous paver blocks. The storage base can be reduced and re-analyzed, if desired.


WinSLAMM Model Output

File View

Runoff Volume | Particulate Solids | Pollutants | Output Summary

Runoff Volume (cu ft) | Source Area Runoff Volume Contribution

Data File: class examples porous pavement.DAT
Rain File: WisReg - Madison WI 1981.RAN
Date: 11-01-09 Time: 05:23:12
Site Description: SLU/SILT-MDRNA-Medium Density Residential, No Alleys, fair Curb & Gutter

Residential Areas - Runoff Volume (cu. ft)

	Rain Total	Roofs 1	Roofs 2	Paved Parking/ Storage 1	Driveways 1	Driveways 2	Sidewalks/ Walks 1	Sidewalks/ Walks 2	Street Area 1	Street Area 2	Str Are
Summary for All Events											
Minimum:	0.01	10.00	0	1.000	0	0	0	0	0	0	
Maximum:	2.59	41885	19744	1722	0	3573	9678	2068	32553	66865	
Average:	0.29	4419	645.4	155.8	0	116.8	979.2	67.63	3295	6765	
Total:	32.10	477267	69698	16821	0	12611	105749	7304	355886	730698	1

Total Area, with Drainage and Outfall Controls - Runoff Volume (cu. ft)
Summary for All Events *Note: NRCS does not recommend using CN method for rains < 0.5 in. See 'PreDevelopment Areas and CN' Help for more info.

	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Total After Outfall Controls	Rv	Total Losses (in)	Calculated CN*	Peak Reduction Factor	Flushing Ratio		Pre-Ru Volum
Number of Rains:		108	108	108							
Minimum:	0.01	11.02	11.02	11.02	0.00	0.01	N/A				
Maximum:	2.59	307147	307147	307147	0.33	1.74	99.2				
Average:	0.30	21338	21338	21338	0.20	0.24	95.4				
Total:	32.10	2.304E+06	2.304E+06	2.304E+06		25.78					

Roof Runoff Control

- Runoff disconnections
- Rain gardens for roof runoff
- Green roofs to reduce flows and to provide benefits to the building
- Capture of roof runoff for beneficial uses

One of the simplest and most effective approaches for the control of stormwater is to reduce the amount of impervious areas that are directly connected to the drainage system. This can be accomplished by using less paved and roof areas (hard to do and meet design objectives), disconnect the impervious areas, or reduce the runoff from the impervious areas by infiltration, or other, methods. Reducing the runoff volume also reduces the pollutant discharges, reduces peak flows, and reduces combined sewer overflows.


Disconnected roof drain


Directly connected roof drain

Roof drain disconnections

Calculated Benefits of Various Roof Runoff Controls (compared to typical directly connected residential pitched roofs)

Annual roof runoff volume reductions	Birmingham, Alabama (55.5 in. annual rain)	Seattle, Wash. (33.4 in.)	Phoenix, Arizona (9.6 in.)
Flat roofs instead of pitched roofs	13%	21%	25%
Cistern for reuse of runoff for toilet flushing and irrigation (10 ft. diameter x 5 ft. high)	66	67	88
Planted green roof (but will need to irrigate during dry periods)	75	77	84
Disconnect roof drains to loam soils	84	87	91
Rain garden with amended soils (10 ft. x 6.5 ft.)	87	100	96

On-going Millburn, NJ, Monitoring Project to Evaluate Performance and Groundwater Problems Associated with Required Dry Wells

"Green Roof" in Portland, OR

Green Roofing

Extensive Green Roof

- Lighter
- <6” media depth
- Planted with sedums or native plant species
- Saturated weights from 12-50lbs/sq.ft.

Intensive Green Roof

- Heavier
- >12” media depth
- Wider variety of plants which need more care and irrigation
- Saturated weights from 80-100lbs/sq.ft.

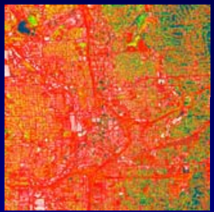
Benefits of Green Roofing

- Reduce Heat Island Effect
- Reduce Air Pollution and Greenhouse Gas Emission
- Improved human health and comfort
- Enhanced Stormwater Management and Water Quality
- Improved Quality of Life

Information courtesy of the Environmental Protect Agency – http://www.epa.gov/heatisland/mitigation/greenroofs.htm

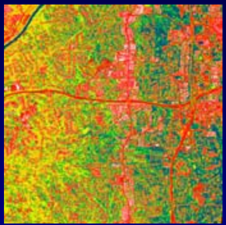
http://www.coolflatroof.com/pics/green-roof-blocks.jpg

Urban Heat Island Effect – Atlanta, GA

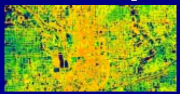


Urban Temp. - Day

Can a green roof make the urban look like the suburban?

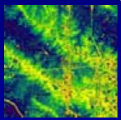


Suburban Temp. - Day

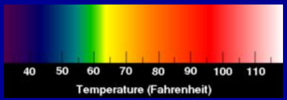


Urban Temp. - Night

→

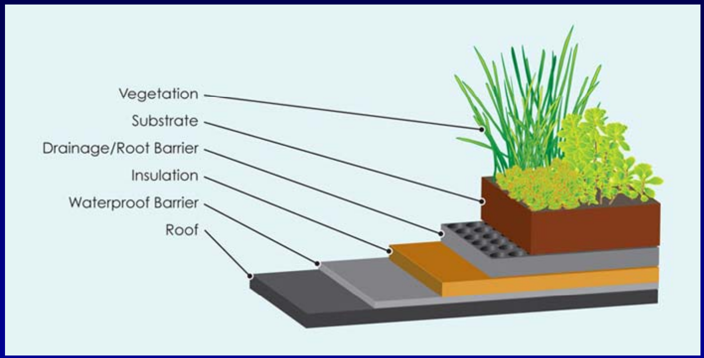


Suburban Temp. - Night



Images Courtesy of NASA

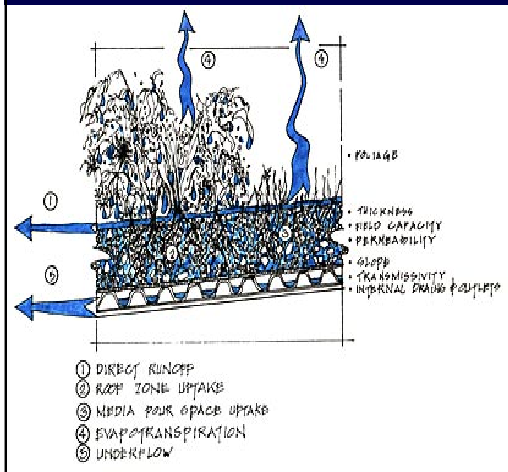
Green Roof Design



Cross-section of a typical green roof illustrating the key components

http://www.greensulate.com/green_roofs_intensive.php

Function of a Green Roof



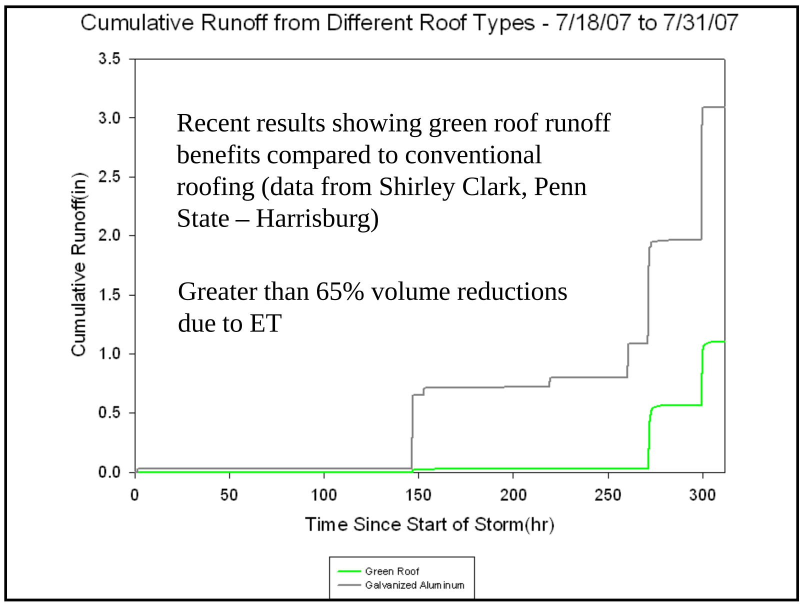
- The storage of water in the substrate
- Absorbing water in the root zone
- Capturing and holding precipitation in the plant foliage where it is returned to the atmosphere through transpiration and evaporation
- Slowing the velocity of direct runoff as it infiltrates through layers of vegetated cover

http://www.lid-stormwater.net/greenroofs_benefits.htm

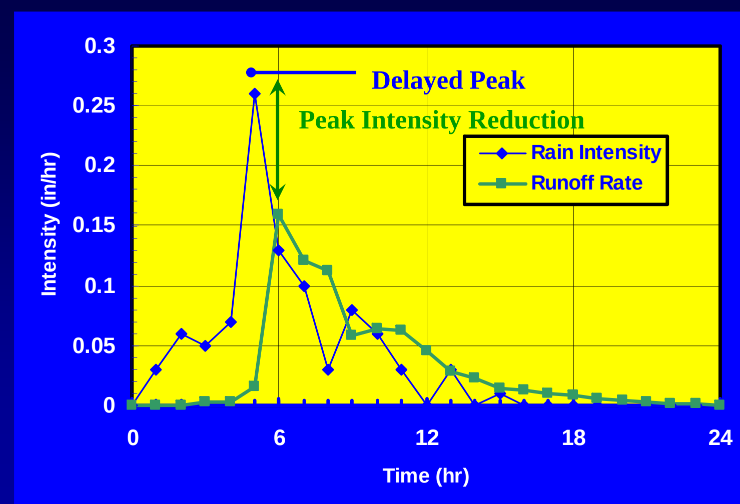
Central Alabama	Average daily ET_o reference conditions (inches/day) (irrigated alfalfa)
January	0.035
February	0.048
March	0.072
April	0.102
May	0.156
June	0.192
July	0.186
August	0.164
September	0.141
October	0.096
November	0.055
December	0.036

Evapotranspiration (ET) is the major rain abstraction mechanism available for green roofs, besides some detention storage and evaporation.

Plant	Crop Coefficient Factor (Kc)	Root Depth (ft)
Cool Season Grass (turfgrass)	0.80	1
Common Trees	0.70	3
Annuals	0.65	1
Common Shrubs	0.50	2
Warm Season Grass	0.55	1
Prairie Plants (deep rooted)	0.50	6

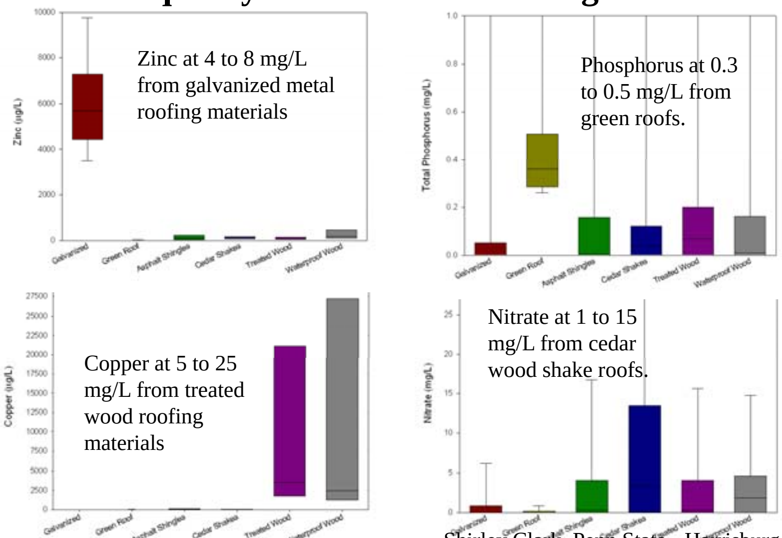


October 25 Rain Event



Graph Courtesy of Al Jarrett, Penn State Center for Green Roof Research

Runoff quality from different roofing materials

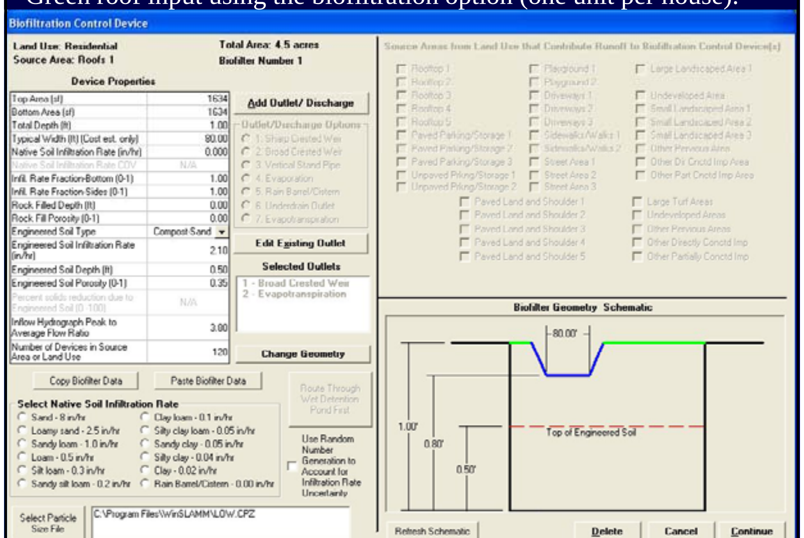


Shirley Clark, Penn State - Harrisburg

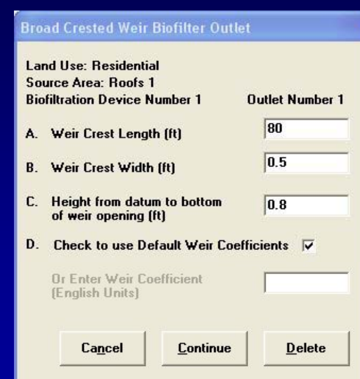
Modeling Green Roofs

- Green roofs are modeled in WinSLAMM by using the biofiltration/bioretention source controls.
- The device area is the area of the roofs (or less if only a portion of the roofs are to be planted).
- The broad crested weir outlet is needed to provide an overflow above a few inches of surface storage on top of the growing media.
- Evapotranspiration is the only rainfall abstraction and monthly average ET values are entered, along with “crop” factors and root depths. According to recent USGS research, the crop factors for small urban area plantings are greater than values usually published in the agricultural research.
- There is obviously no “natural soil” infiltration.

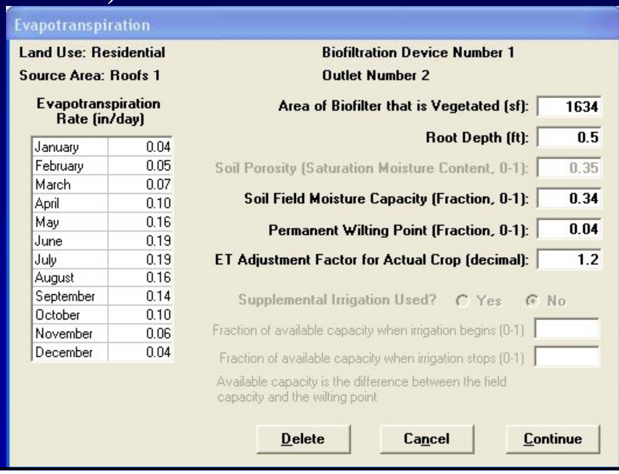
Green roof input using the biofiltration option (one unit per house).



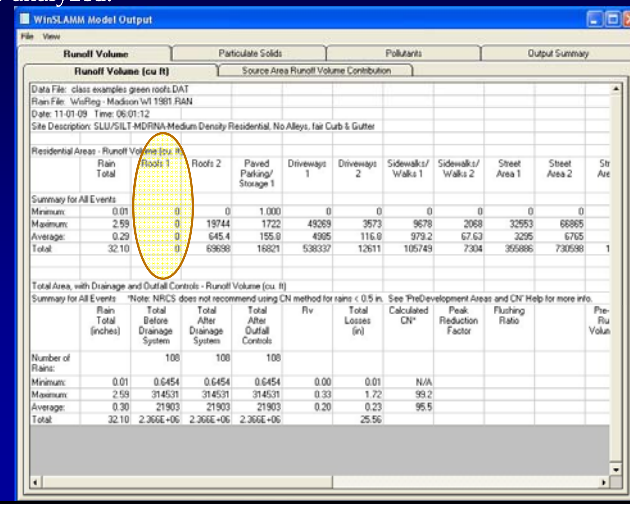
The required broad crested weir outlet (the weir length is the downslope edge of the building):



Evapotranspiration and plant information (see ET calculation paper for typical soil and plant information; as noted earlier, the crop factors are likely larger for these harsh conditions compared to reported agricultural data).



Runoff volume results showing complete runoff reduction for the green roofs. The substrate or storage volumes can be reduced, then re-analyzed.



Ancient temple site at top of hill that had roof runoff cistern, Kamiros, Rhodes (ancient Greece, 7th century BC)

The homes of important officials had water delivered through clay pipes

Ancient clay pipe at Kamiros, Rhodes (ancient Greece, 7th century BC)

Regular citizens had to hand carry water from the cistern at the top of the hill back down to their homes

Cistern tank, Kamiros, Rhodes, collected roof runoff from adjacent temple located at top of the hill.

Steps alongside cistern allowing jugs to be filled from holes in wall to cistern.

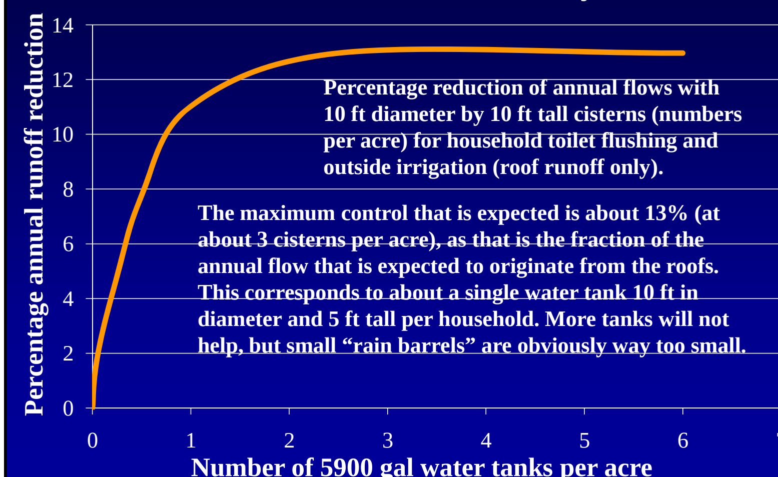
Beneficial use of stormwater as a local resource needs to be seriously considered

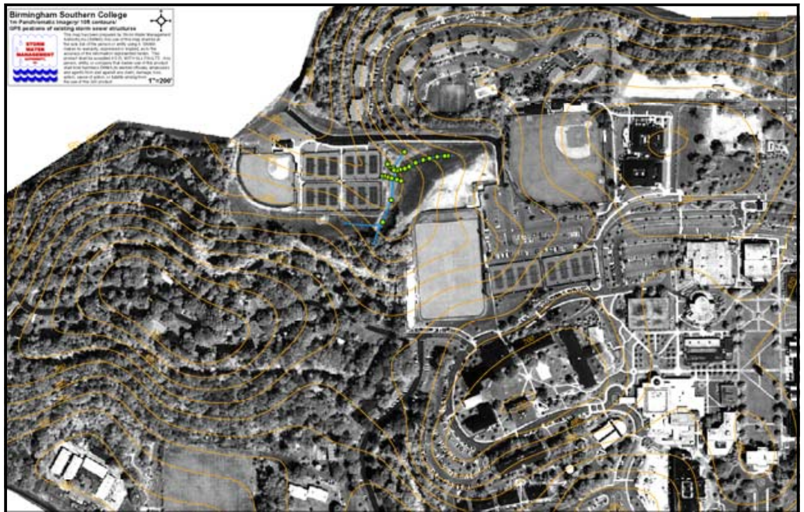
Prince George's County photo

The water tank cisterns modeled for the Kansas City area were about 10 ft in diameter and 10 ft tall. The expected per household water use (gallons/day) from cisterns for toilet flushing and outside irrigation (ET deficit only) for the KC study area is:

January	113 gal/day	July	428
February	243	August	479
March	126	September	211
April	175	October	71
May	149	November	71
June	248	December	71

Number of water tanks and annual flow volume reductions for Kansas City test area





Birmingham Southern College Campus
(map by Jefferson County Stormwater Management Authority)

Birmingham Southern College Fraternity Row (new construction at existing site)

	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

Supplemental Irrigation

	Inches per month (example)	Average Use for 1/2 acre (gal/day)
Late Fall and Winter (Nov-March)	1 to 1-1/2	230 - 340
Spring (April-May)	2 to 3	460 - 680
Summer (June-August)	4	910
Fall (Sept-Oct)	2 to 3	460 - 680
Total:	28 (added to 54 inches of rain)	

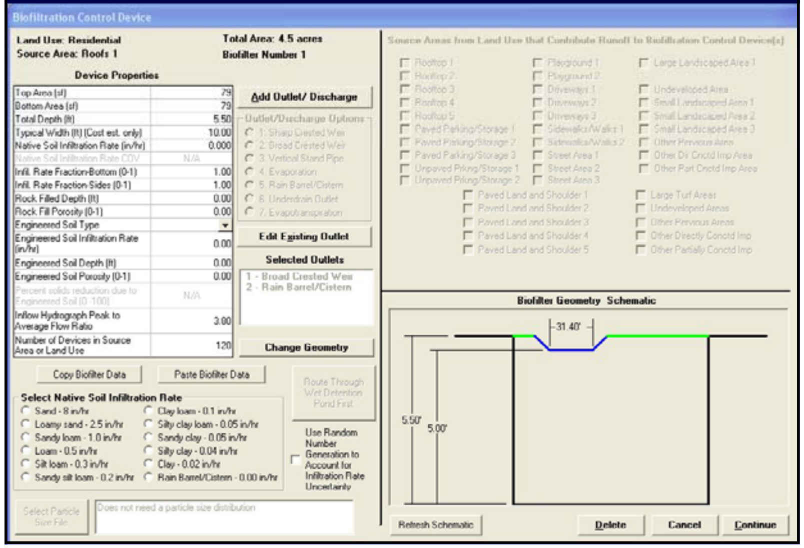
Capture and Reuse of Roof Runoff for Supplemental Irrigation

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

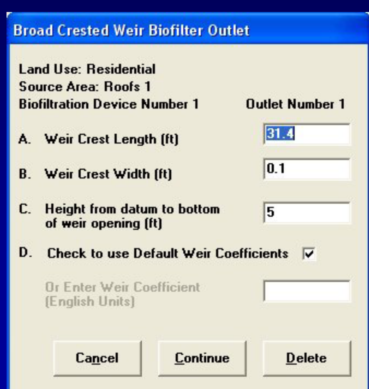
Modeling Beneficial Uses with a Cistern

- In this example, the beneficial uses of the roof runoff are toilet flushing and irrigation of the lawns and gardens surrounding the homes.
- The toilet flushing use was determined to be 71 gal/day per household based on regional census and water use data.
- Irrigation was calculated to supply the deficit between the monthly ET and rainfall values for turf grass. Additional discharges to the landscaping is possible if enhanced infiltration is desired.
- A simple tank 10 ft in diameter and 5 ft tall per house was used in this example.
- The cistern/rain barrel option was selected under the native soil infiltration rates (this turns all infiltration off, obviously!).

Cistern modeling using the biofiltration control option:



The broad crested weir is always required to provide an overflow from the tank. In actual cases, overflows will be through an overflow pipe. In this example, the weir length is the circumference of the tank. The total tank height must extend several inches above the bottom of the weir opening.



Biofilter Cistern/Rain Barrel

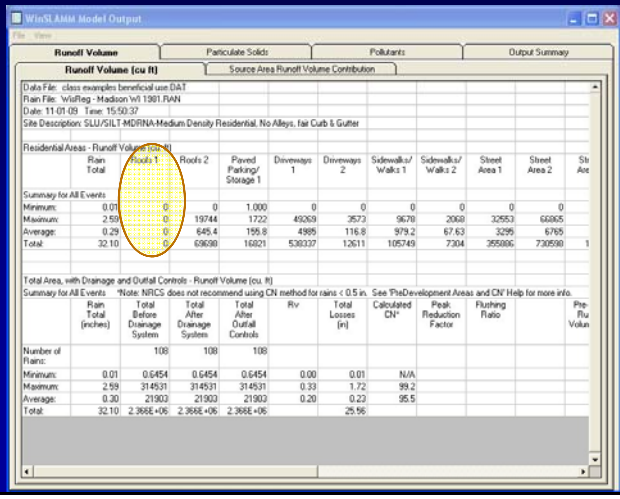
Land Use: Residential
Source Area: Roofs 1
Biofiltration Device Number 1
Outlet Number 2

Month	Water Use Rate (gal/day)
January	113.00
February	243.00
March	126.00
April	175.00
May	149.00
June	248.00
July	428.00
August	479.00
September	211.00
October	71.00
November	71.00
December	71.00

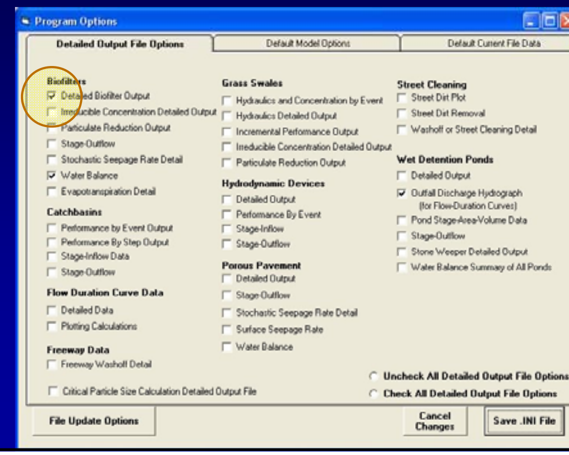
Cancel Continue Delete

These are the monthly calculated water use rates, based on household population and water use for toilet flushing, and the monthly average deficits between the ET and rainfall. Again, additional irrigation is possible if enhanced infiltration is desired.

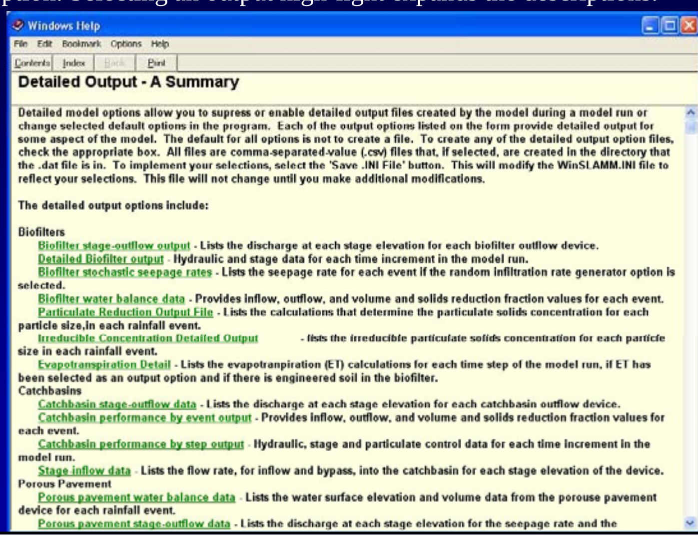
The cisterns at the homes associated with the directly connected roofs (roof 1 category) were able to use all of the roof runoff for toilet flushing and irrigation in this example.



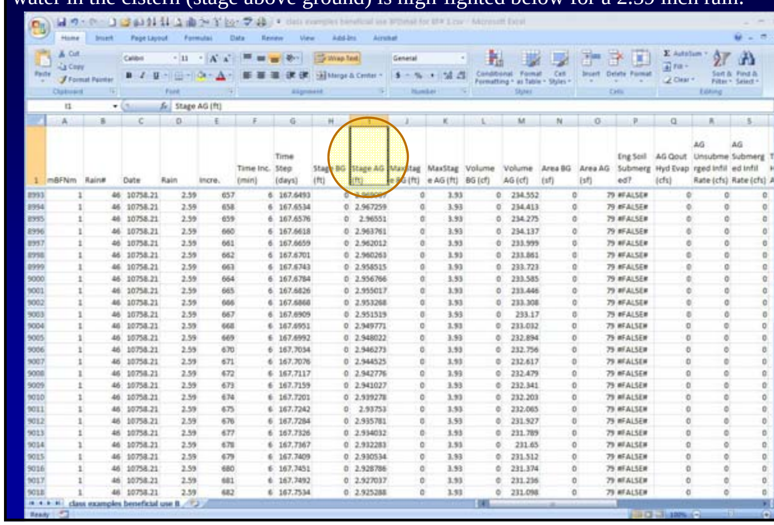
In WinSLAMM, there are many additional detailed output options that can be accessed with the program options menu. The detailed biofilter output allows one to see how much water is in the cistern at any time, amongst much other information:



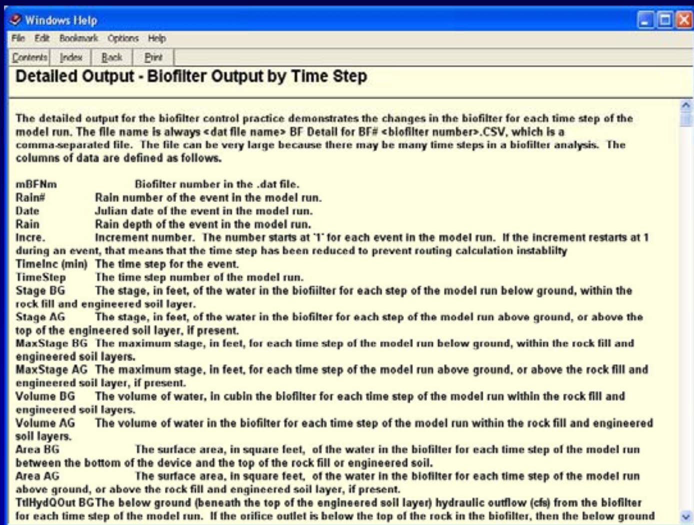
The help files describe the information provided in each output option. Selecting an output high-light expands the descriptions.



The following is an example of the detailed biofilter output, showing the details for each time step in the calculations (every 6 minutes in this example). The depth of the water in the cistern (stage above ground) is high-lighted below for a 2.59 inch rain:



The context-sensitive help files explain each column header:


Windows Help

File Edit Bookmark Options Help

Contents Index Back Print

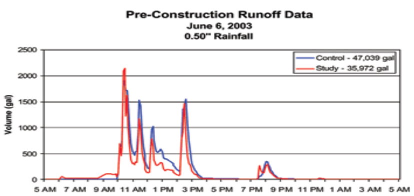
Detailed Output - Biofilter Output by Time Step

The detailed output for the biofilter control practice demonstrates the changes in the biofilter for each time step of the model run. The file name is always <dat file name> BF Detail for BF# <biofilter number>.CSV, which is a comma-separated file. The file can be very large because there may be many time steps in a biofilter analysis. The columns of data are defined as follows.

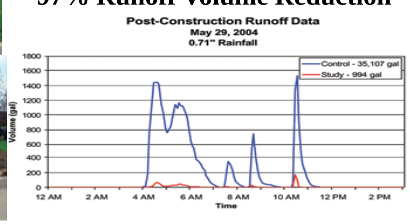
mBFNm Biofilter number in the .dat file.
Rain# Rain number of the event in the model run.
Date Julian date of the event in the model run.
Rain Rain depth of the event in the model run.
Incre. Increment number. The number starts at '1' for each event in the model run. If the increment restarts at 1 during an event, that means that the time step has been reduced to prevent routing calculation instablilty
TimeInc (min) The time step for the event.
TimeStep The time step number of the model run.
Stage BG The stage, in feet, of the water in the biofiilter for each step of the model run below ground, within the rock fill and engineered soil layer.
Stage AG The stage, in feet, of the water in the biofilter for each step of the model run above ground, or above the top of the engineered soil layer, if present.
MaxStage BG The maximum stage, in feet, for each time step of the model run below ground, within the rock fill and engineered soil layers.
MaxStage AG The maximum stage, in feet, for each time step of the model run above ground, or above the rock fill and engineered soil layer, if present.
Volume BG The volume of water, in cubin the biofilter for each time step of the model run within the rock fill and engineered soil layers.
Volume AG The volume of water in the biofilter for each time step of the model run within the rock fill and engineered soil layers.
Area BG The surface area, in square feet, of the water in the biofilter for each time step of the model run between the bottom of the device and the top of the rock fill or engineered soil.
Area AG The surface area, in square feet, of the water in the biofilter for each time step of the model run above ground, or above the rock fill and engineered soil layer, if present.
TtlHydQOut BG The below ground (beneath the top of the engineered soil layer) hydraulic outflow (cfs) from the biofilter for each time step of the model run. If the orifice outlet is below the top of the rock in the biofilter, then the below ground

Rain Garden Designed for Complete Infiltration of Roof Runoff

Burnsville, Minnesota, Rainwater Gardens



97% Runoff Volume Reduction



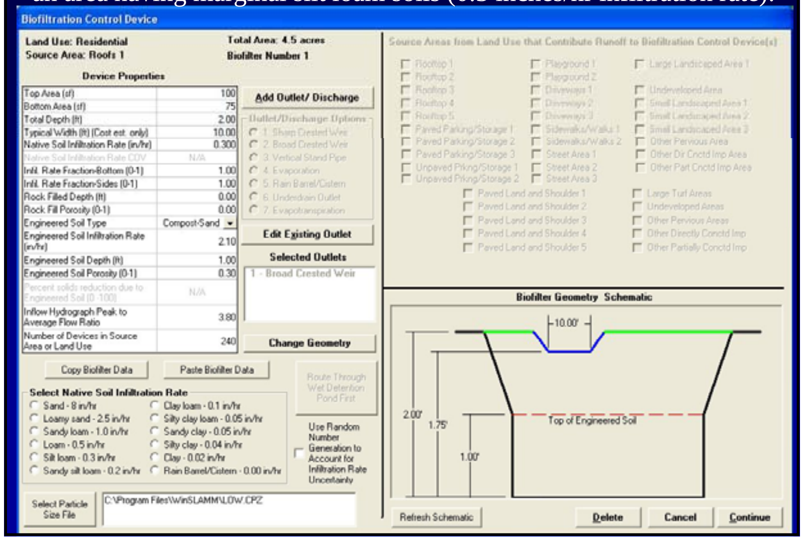
An example of the dramatic runoff volume reductions possible through the use of conservation design principles (17 rain gardens, at about $3,000 each, at 14 homes in one neighborhood)

***Land and Water*, Sept/Oct. 2004**

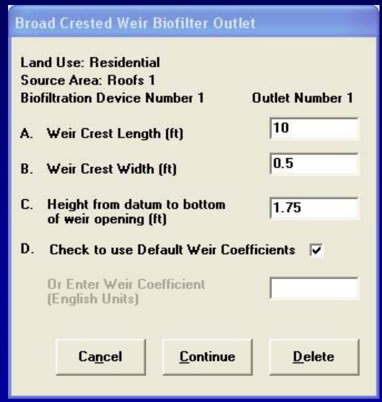
Rain Garden Modeling

- Rain gardens are also modeled using the biofilter option.
- Rain gardens are usually very simple devices, constructed by excavating a 1 to 3 feet deep hole near the downspout of a building. The depth and area for the rain garden is usually determined by landscaping considerations, but should also be based on the soil infiltration rate and the roof area.
- The excavated hole is then partially back-filled with an amended soil. Native soils are not usually recommended due to the likely presence of clays. Most states now recommend a mixture of sand and an organic amendment. The excavated soil can be used to build up the downslope edge of the area to provide additional storage.
- Surface storage is also needed above the amended soil; a depression of at least several inches for a small rain garden to about a foot for a larger device is needed.
- Rain gardens are also usually planted with deep-rooted native plants to help enhance infiltration.

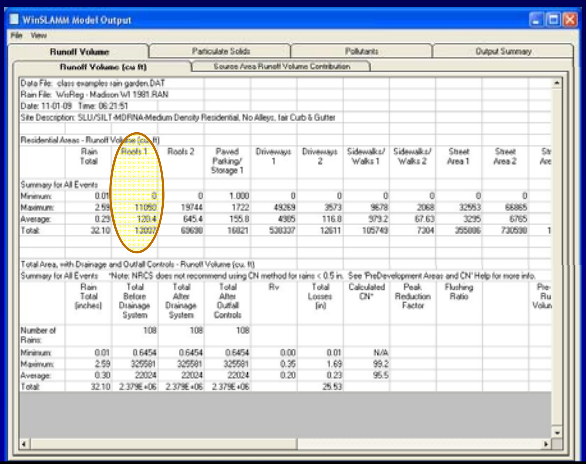
Input screen for a simple rain garden (2 per house in this example) in an area having marginal silt loam soils (0.3 inches/hr infiltration rate):



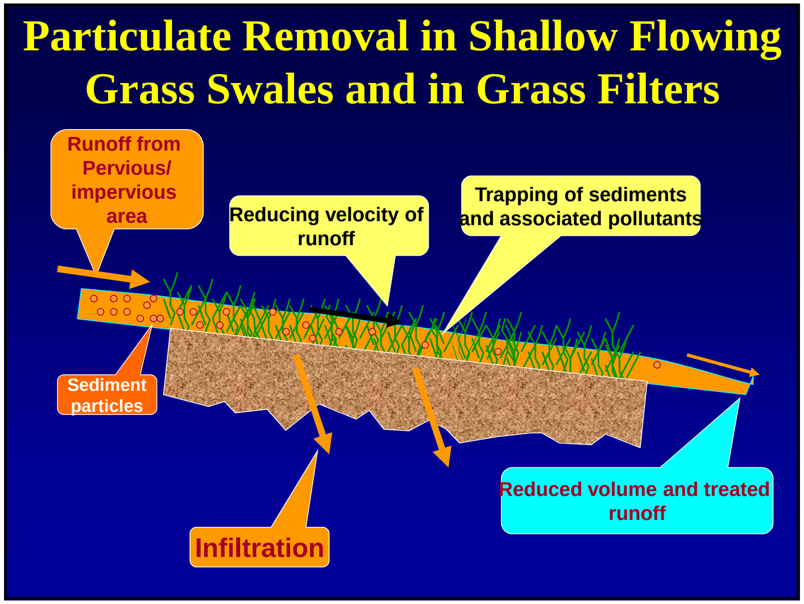
The required broad-crested weir is just the downslope overflow, the only other water discharge is infiltration into the native soil. With marginal soils, greater surface storage is needed:

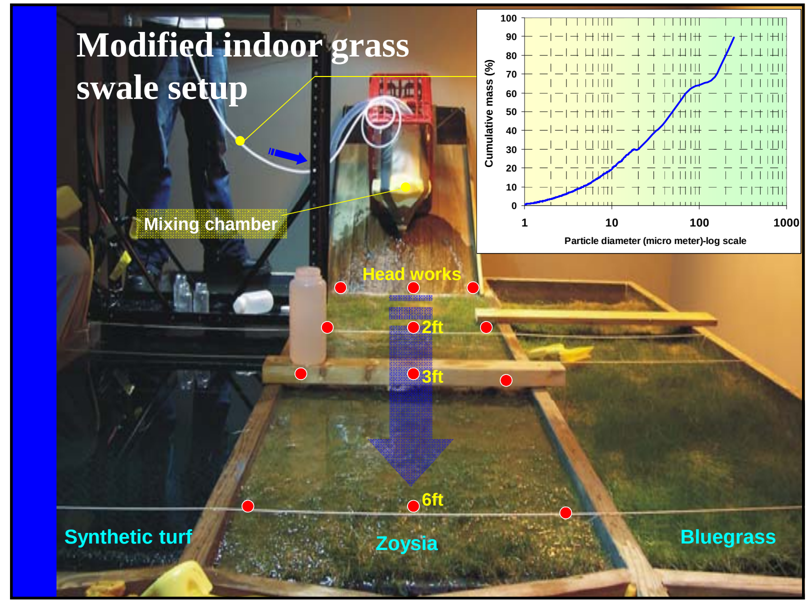


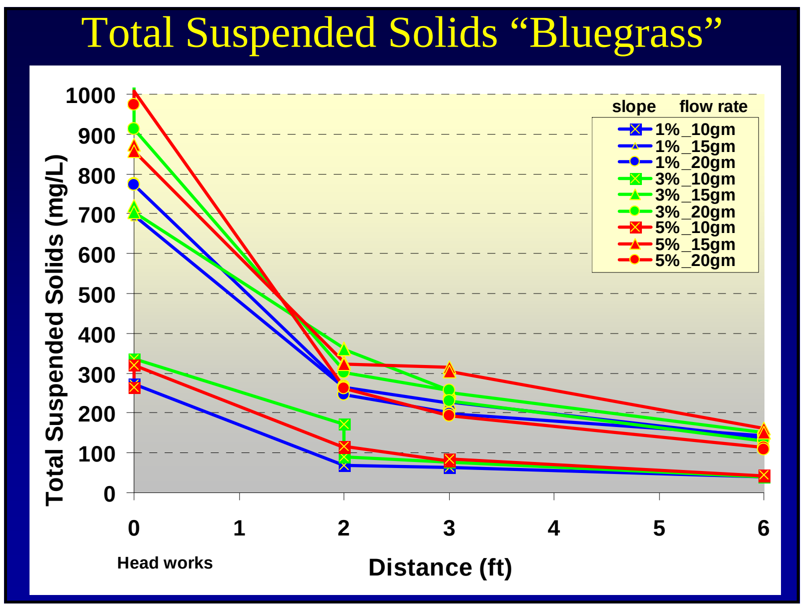
Reduced runoff occurs from the roof areas having rain gardens. In this example, overflows occurred several times a year during the largest storms (under the "view" drop down menu, select output option 1 to see results for each rain individually). Only 13,000 ft^3 was discharged from these roofs during this period, compared to over 120,000 ft^3 with no controls. This could be reduced further, if desired, by using larger, or more, rain gardens, and re-analyzed using the model.

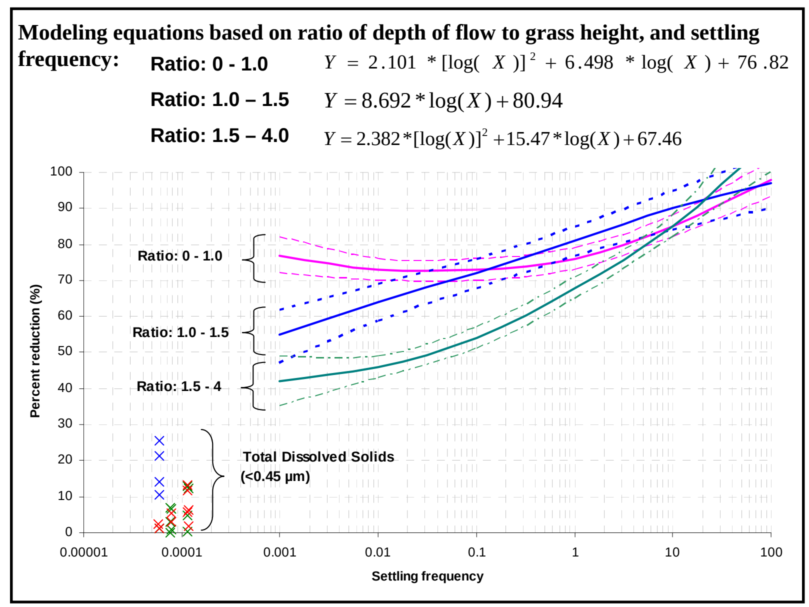


Grass-Lined Swales


Particulate Removal in Shallow Flowing Grass Swales and in Grass Filters
Runoff from Pervious/ impervious area
Reducing velocity of runoff
Trapping of sediments and associated pollutants
Sediment particles
Infiltration
Reduced volume and treated runoff

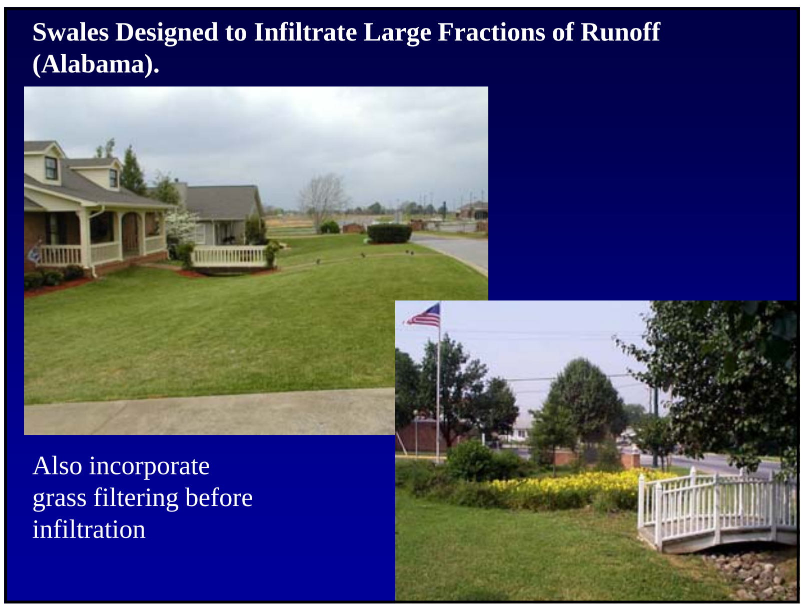

Modified indoor grass swale setup
Mixing chamber
Head works
2ft
3ft
6ft
Synthetic turf
Zoysia
Bluegrass
Cumulative mass (%)
Particle diameter (micro meter)-log scale


Total Suspended Solids "Bluegrass"
Total Suspended Solids (mg/L)
slope flow rate
1%_10gm
1%_15gm
1%_20gm
3%_10gm
3%_15gm
3%_20gm
5%_10gm
5%_15gm
5%_20gm
Head works
Distance (ft)


Modeling equations based on ratio of depth of flow to grass height, and settling frequency:
Ratio: 0 - 1.0 Y = 2.101 * [log(X)]^2 + 6.498 * log(X) + 76.82
Ratio: 1.0 – 1.5 Y = 8.692 * log(X) + 80.94
Ratio: 1.5 – 4.0 Y = 2.382 * [log(X)]^2 + 15.47 * log(X) + 67.46
Ratio: 0 - 1.0
Ratio: 1.0 - 1.5
Ratio: 1.5 - 4
Total Dissolved Solids (<0.45 μm)
Percent reduction (%)
Settling frequency


Date: 10/11/2004
116 ft
75 ft
25 ft
6 ft
3 ft
2 ft
Head (0ft)
TSS: 10 mg/L
TSS: 20 mg/L
TSS: 30 mg/L
TSS: 35 mg/L
TSS: 63 mg/L
TSS: 84 mg/L
TSS: 102 mg/L
University of Alabama
swale test site at
Tuscaloosa City Hall


Conventional curbs with inlets directed to site swales

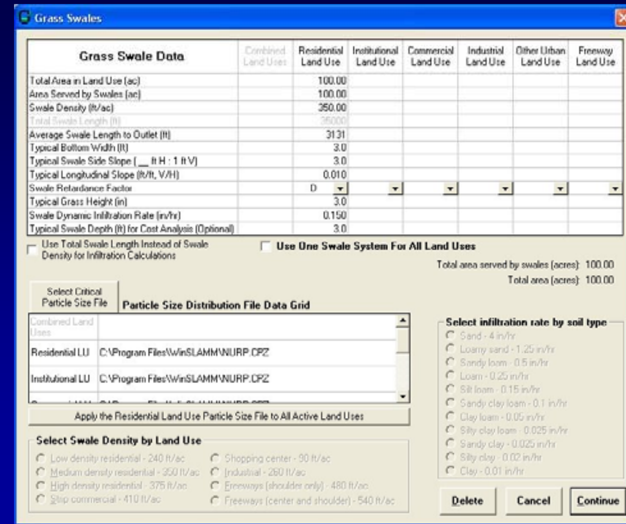

Swales Designed to Infiltrate Large Fractions of Runoff
(Alabama).
Also incorporate
grass filtering before
infiltration


Swale Problems
Blocked
with Fill
Shallow
Groundwater
Erosive
Channel
Under-
Sized

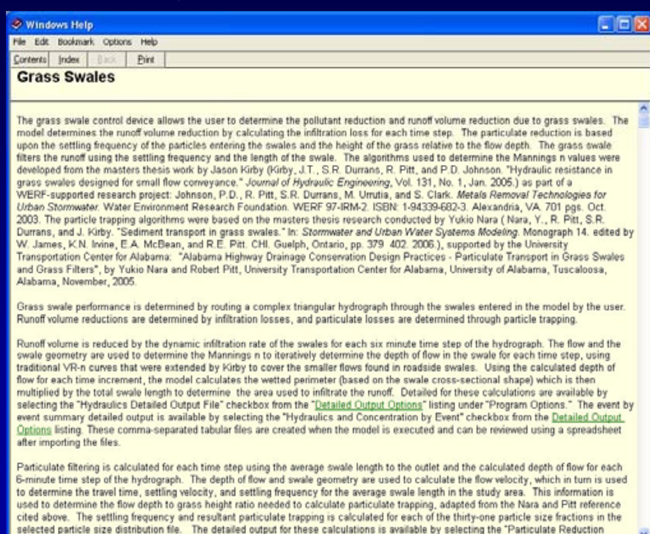
Modeling Grass Swales

- The main input screen for grass swales is under the "land use" drop down menu under the "catchbasin or drainage control" option, and then select "drainage control."
- In this example, the swale density is selected based on the land use. The total length of the swales is automatically calculated, along with the average swale length to the outfall (based on the total service area).
- The swale bottom width, side slope, and longitudinal slope are entered based on the area to be served. Residential areas usually have relatively narrow swale widths, while industrial areas have larger widths. These dimensions are determined in concert with the drainage design requirements for the area.
- The swale grass retardance factor is from USDA research and is usually D for urban areas. The grass height is a function of maintenance, but 3 inches may be suitable.
- The swale dynamic infiltration rate is about half of the normal infiltration rate for most swales, but is equal to the soil infiltration rate for relatively flat swales. See the help files for more information.

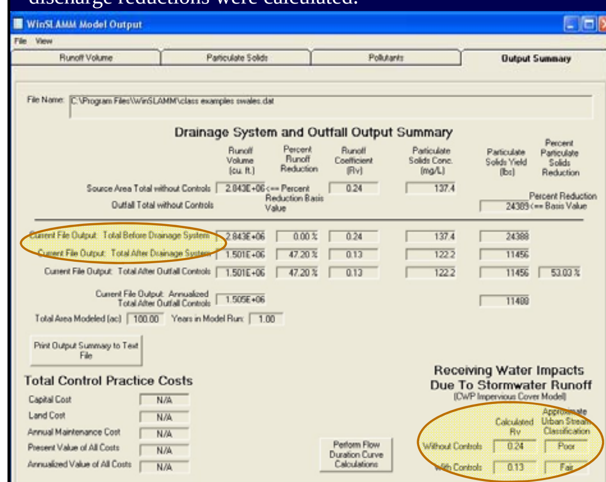
Main grass swale input screen:



Context-sensitive grass swale help file:

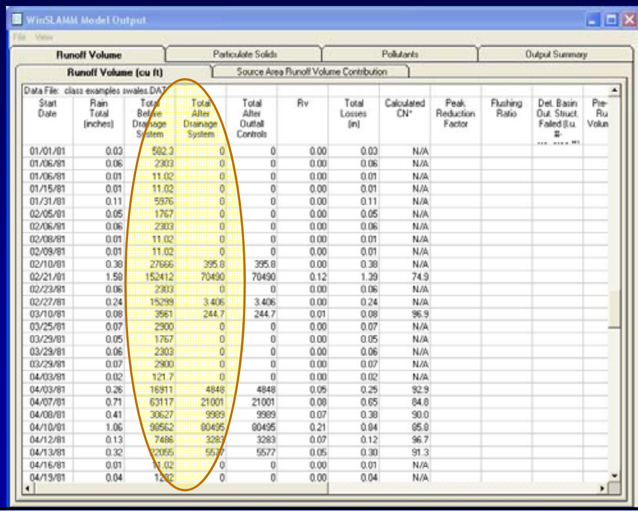


Output summary after grass swale analysis. The difference between the "total before drainage system" and "total after drainage system" shows the effects of the swales. In this example, about 47% runoff volume and 53% particulate solid discharge reductions were calculated:



In addition, the calculated urban receiving water classification (based on the Center for Watershed Protection's *Impervious Cover Model*) may improve from poor to fair, if the complete watershed was similarly developed, compared to development without controls.

The runoff volume detailed output also shows the benefits of the swale. This is the expanded output showing the effects for each individual rain, available by selecting the full output option 1 under the "view" drop down menu.



Start Date	Rain Total (inches)	Total Before Drainage System	Total After Drainage System	Total After Outfall Controls	Rv	Total Losses (in)	Calculated CN*	Peak Reduction Factor	Flushing Ratio	Det. Basin Out. Struct. Failed
01/01/81	0.03	582.3	0	0	0.00	0.03	N/A			
01/06/81	0.06	2303	0	0	0.00	0.06	N/A			
01/06/81	0.01	11.02	0	0	0.00	0.01	N/A			
01/15/81	0.01	11.02	0	0	0.00	0.01	N/A			
01/31/81	0.11	5976	0	0	0.00	0.11	N/A			
02/05/81	0.05	1767	0	0	0.00	0.05	N/A			
02/06/81	0.06	2303	0	0	0.00	0.06	N/A			
02/08/81	0.01	11.02	0	0	0.00	0.01	N/A			
02/09/81	0.01	11.02	0	0	0.00	0.01	N/A			
02/10/81	0.38	27666	395.8	395.8	0.00	0.38	N/A			
02/21/81	1.50	152412	70490	70490	0.12	1.39	74.9			
02/23/81	0.06	2303	0	0	0.00	0.06	N/A			
02/27/81	0.24	15299	3.406	3.406	0.00	0.24	N/A			
03/10/81	0.08	3561	244.7	244.7	0.01	0.08	96.9			
03/25/81	0.07	2900	0	0	0.00	0.07	N/A			
03/29/81	0.05	1767	0	0	0.00	0.05	N/A			
03/29/81	0.06	2303	0	0	0.00	0.06	N/A			
03/29/81	0.07	2900	0	0	0.00	0.07	N/A			
04/03/81	0.02	121.7	0	0	0.00	0.02	N/A			
04/03/81	0.26	16911	4848	4848	0.05	0.25	92.9			
04/07/81	0.71	63117	21001	21001	0.08	0.65	84.8			
04/08/81	0.41	30627	9989	9989	0.07	0.38	90.0			
04/10/81	1.06	99562	80495	80495	0.21	0.84	85.8			
04/12/81	0.13	7486	3283	3283	0.07	0.12	96.7			
04/13/81	0.32	22055	5577	5577	0.05	0.30	91.3			
04/16/81	0.01	11.02	0	0	0.00	0.01	N/A			
04/19/81	0.04	1202	0	0	0.00	0.04	N/A			