WinSLAMM Capabilities in Emerging Designs

Workshop presentation
LID Conference,
San Francisco, April 11, 2010

Robert Pitt, Ph.D., P.E., D.WRE, BCEE
Department of Civil, Construction, and Environmental Engineering
University of Alabama
Tuscaloosa, AL, USA 35487

John Voorhees, P.E., P.H. and Caroline Burger, P.E.
PV and Associates
Madison, WI

1

Outline of Presentation

- Background and history of WinSLAMM
- Stormwater control practices that can be evaluated in WinSLAMM
- Unique aspects of WinSLAMM
- Selected basic analyses
- Example evaluations of emerging stormwater designs and controls

2

1. Background & History

- Development of WinSLAMM Began in mid-1970's
  - Early EPA street cleaning projects
  - San Jose and Coyote Creek (CA)

– Primary Purpose:
  - Identify Sources of Urban Stormwater Pollutants
  - Evaluate Effectiveness of Control Practices

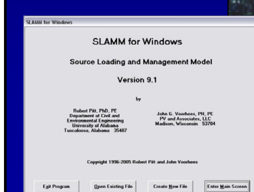
3

Background & History (cont.)

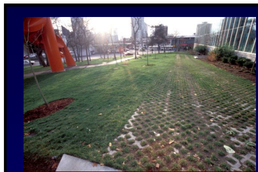
– Mid-1980's - Model used in Agency Programs:
  - Toronto Area Watershed Management Strategy
  - Wis. Dept. of Natural Resources: Priority Watershed Program

– First Windows Version Developed in 1995

– Continuously being updated based on user needs and new research (such as from Stormwater Management Authority of Jefferson County, AL, the TVA, Economic Development group, Contech Stormwater Solutions, HydroInternational, WI DOT, WI DNR, US EPA, USGS, etc.)



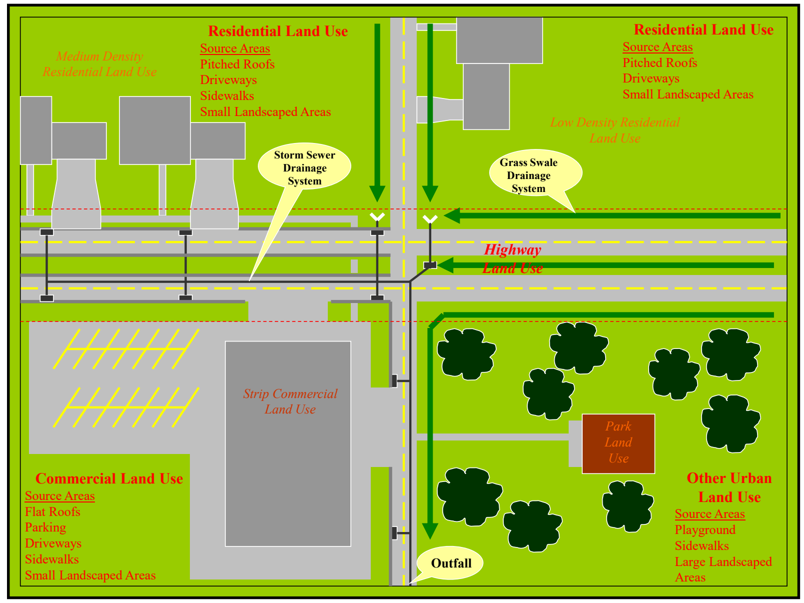
4



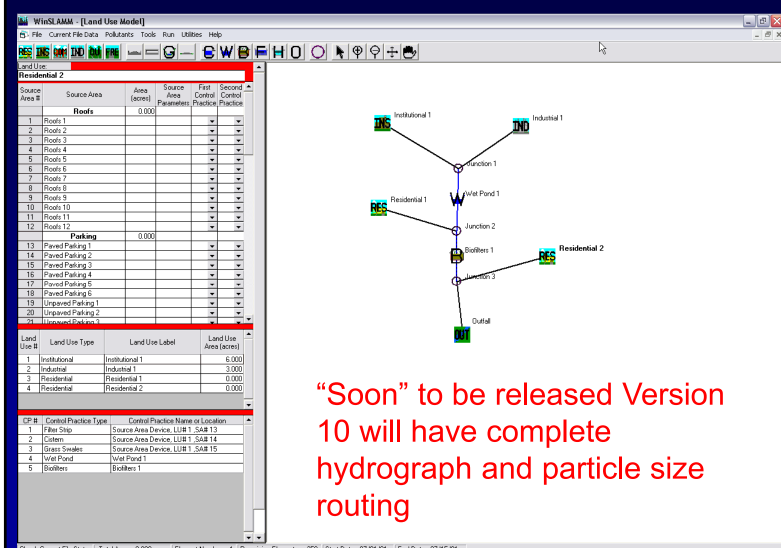
2. Control Devices Included in WinSLAMM

- Hydrodynamic devices
- Development characteristics
- Wet detention ponds
- Porous pavements
- Street cleaning
- Green/blue roofs
- Catchbasin cleaning
- Grass swales and grass filtering
- Biofiltration and bioretention
- Cisterns and stormwater use
- Media filtration/ion exchange/sorption

5



6

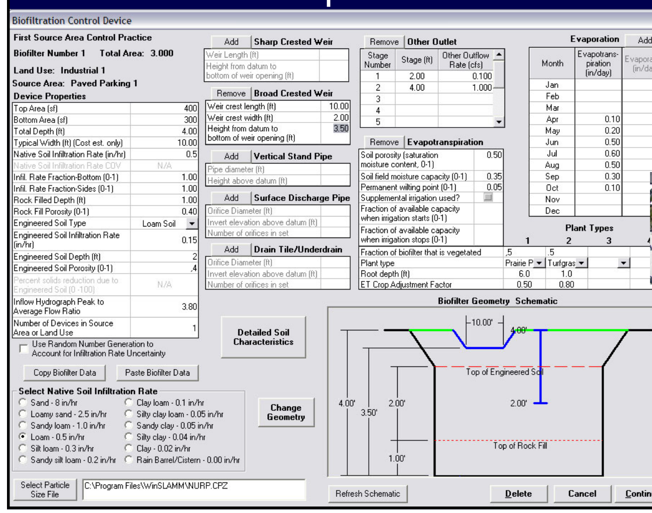


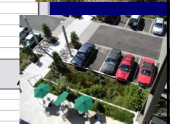
"Soon" to be released Version 10 will have complete hydrograph and particle size routing

Version 10 Draft Screen Shot

7

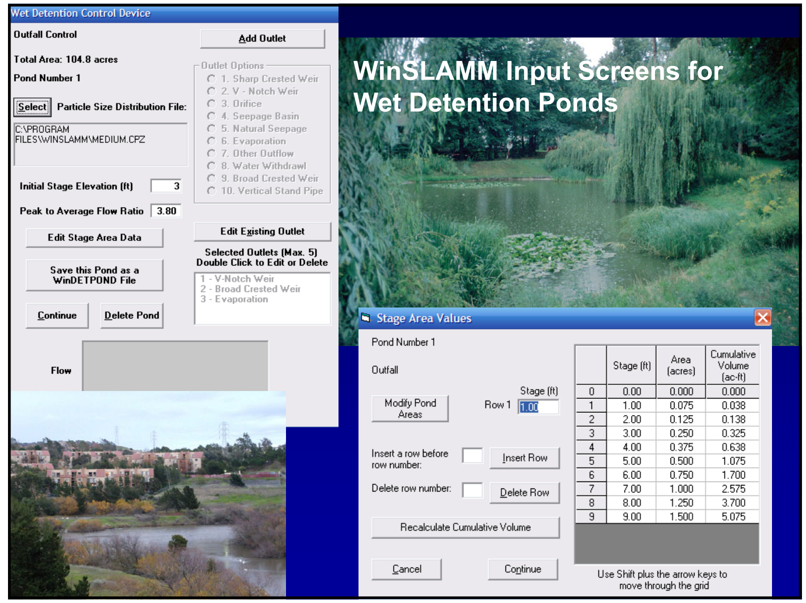
Rain Garden/Biofilter/Water Tank Input Screen





8

Grass Filter Strips Input Screen



3. Unique Aspects of WinSLAMM

- Based on field measurements and calibrations of rainfall-runoff processes, particulate transport, source area pollutant characteristics, control practice performance, etc.
- Urban processes are unique and urban stormwater models must consider these aspects (stormwater receiving water effects, hydrology of pavements, disturbed/compacted urban soils, pollutant sources, etc.)

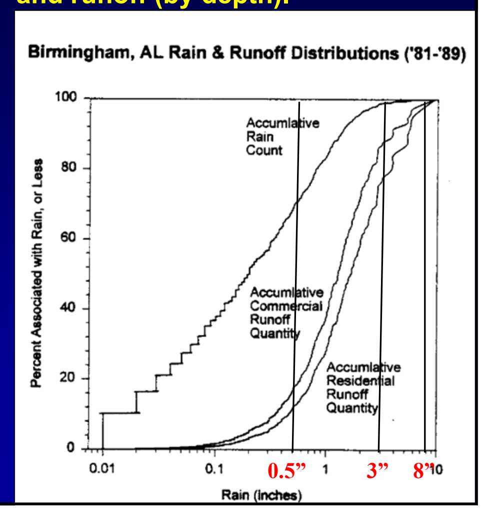
Probability distribution of Birmingham, AL, rains (by count) and runoff (by depth).

<0.5": 65% of rains (10% of runoff). Smallest storms should be captured on-site for reuse, or infiltrated.

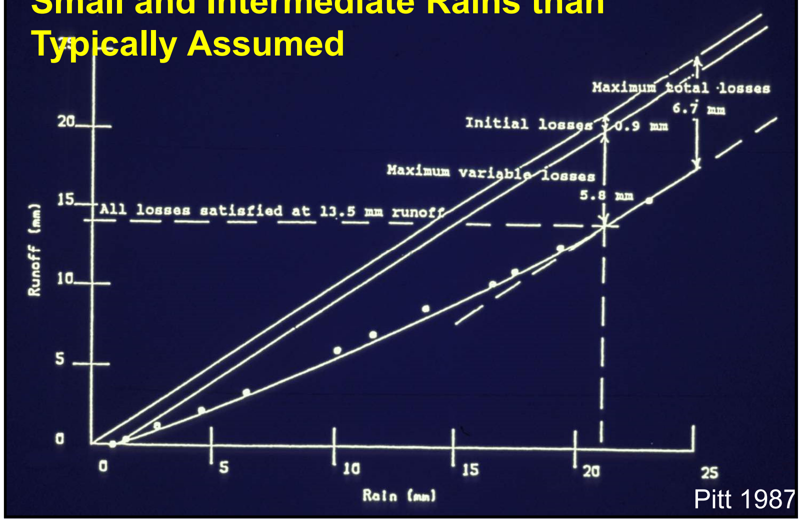
0.5 to 3": 30% of rains (75% of runoff). Infiltrate all you can, but also provide controls to treat runoff that cannot be infiltrated on site.

3 to 8": 4% of rains (13% of runoff) . Provide controls to reduce energy of large events that would otherwise affect habitat.

>8": <0.1% of rains (2% of runoff). Provide conventional flood and drainage controls.



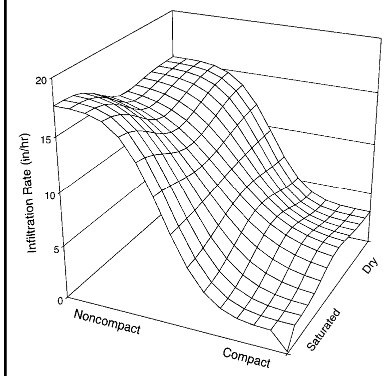
Less Runoff from Urban Streets during Small and Intermediate Rains than Typically Assumed



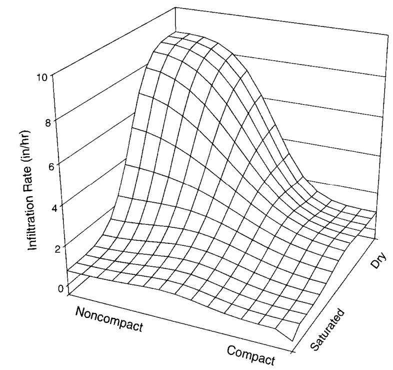
Pitt 1987

13

Disturbed Urban Soils have Unique Infiltration Rates that are Greatly Affected by Compaction



Infiltration Rates in Disturbed Sandy Urban Soils

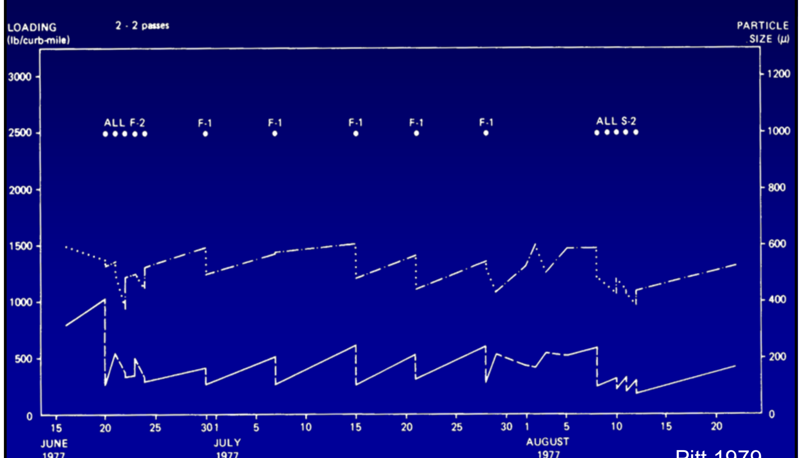


Infiltration Rates in Disturbed Clayey Urban Soils

Pitt, *et al.* 1999

14

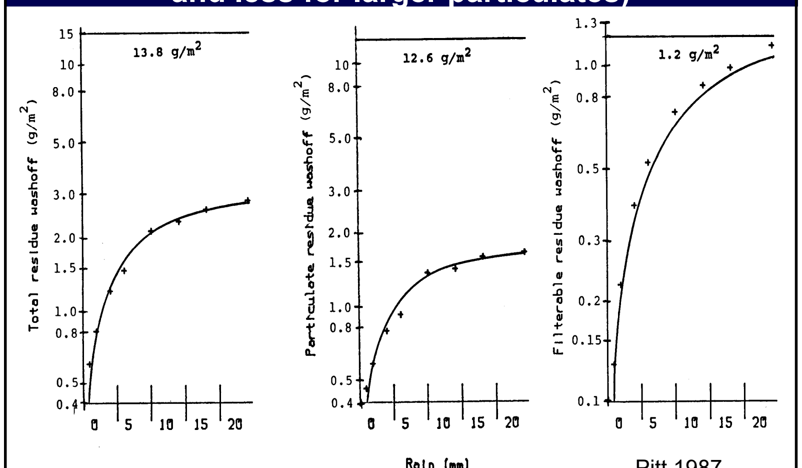
Classical Saw-tooth Pattern of Particulate Loading on Urban Streets Affected by Street Cleaning and Rains



Pitt 1979

15

However, very little of the particulates are actually removed during rains (more for smaller particulates and less for larger particulates)



Pitt 1987

16

Basic Program Operation

WinSLAMM Calculation Process

Calculate Runoff Volumes and Particulate Loadings for all Source Areas

↓

Apply Appropriate Source Area Treatment Practices

↓

Sum Resulting Source Area Outputs

↓

Route Totals to the Drainage System

→

Apply Appropriate Drainage System Treatment Practices

↓

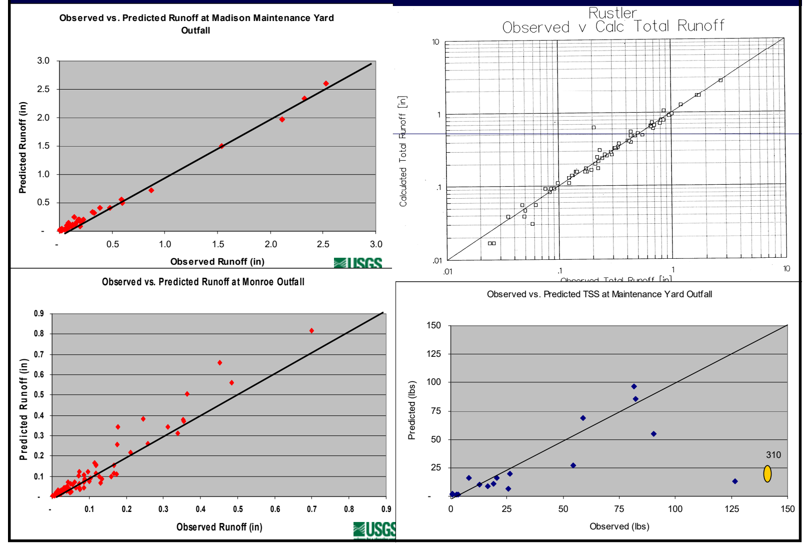
Route Totals to the Outfall

↓

Apply Appropriate Outfall Treatment Practices

17

Calculated Results Verified by Field Observations



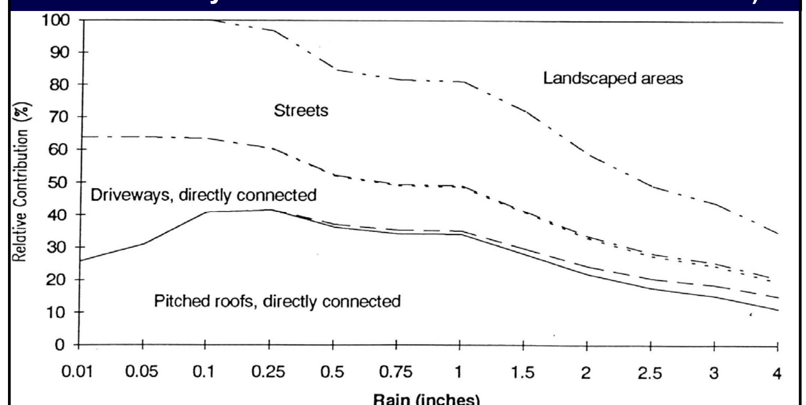
18

4. Selected Basic WinSLAMM Model Evaluations

- Sources of stormwater runoff and pollutants
- Flow rate-duration distributions for alternative development practices and controls
- Detailed evaluations of controls for regulatory compliance
- Identification of critical sources areas and outfalls for targeted controls
- Cost analyses
- Batch processing and decision analyses to compare alternatives

19

Determination of Runoff and Pollutant Sources (typical medium density residential area shown for runoff sources)

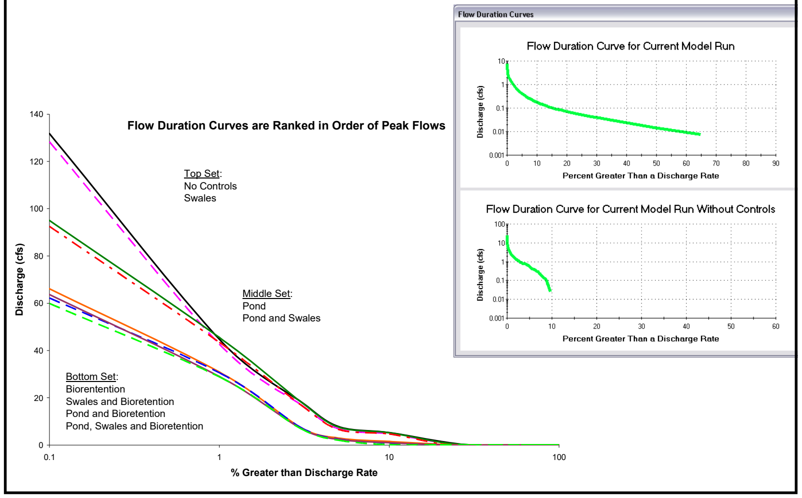


Directly connected impervious surfaces dominate flow sources during rains <0.5 inches

Disturbed urban soils can become very important runoff source areas during larger rains

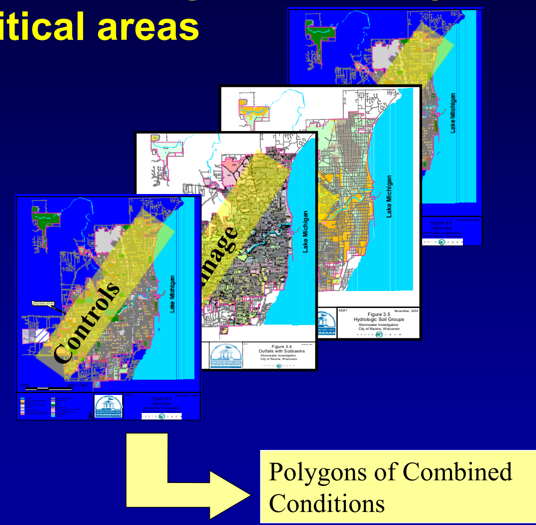
20

Runoff Flow Rate-Duration Analyses for Alternatives



21

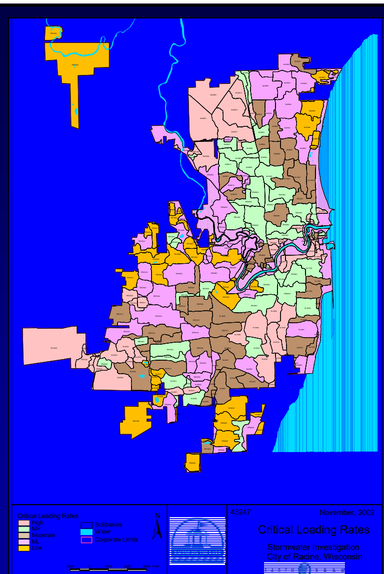
Example large-scale analysis to identify critical areas



22

Racine GIS Example

To identify "Critical" Subbasins



23

Life-Cycle Cost Analyses

Control Practice Cost Data

Street Cleaning | Tab 9 | Tab 10 | Tab 11
Upflow Filter | Hydrodynamic Device | Porous Pavement | Grass Swales
Summary Data | **Detention Pond** | Biofilter | Catchbasin

(•) Use Pre-Determined Costs

Costs in Thousands of Dollars

Water Volume (1000 cf)	Low Capital Cost	Med. Capital Cost	High Capital Cost	O&M Cost
30.0	13.0	27.0	41.0	1.30
40.0	14.0	29.0	43.0	1.31
50.0	15.0	31.0	48.0	1.38
60.0	16.5	34.0	51.0	1.45
70.0	18.0	37.0	55.0	1.52
80.0	19.5	41.0	60.0	1.60
90.0	21.0	44.0	63.0	1.70
100.0	23.0	47.0	70.0	1.80
200.0	41.0	83.0	125.0	2.60
300.0	62.0	120.0	175.0	3.60
400.0	84.0	160.0	230.0	4.40
500.0	102.0	200.0	285.0	5.20
600.0	119.0	230.0	330.0	6.10
700.0	136.0	260.0	385.0	6.90
800.0	152.0	295.0	430.0	7.50
900.0	170.0	320.0	480.0	8.10
1000.0	185.0	340.0	520.0	9.00

2005 Costs - Birmingham, AL

UNITS: $ per 1000 cubic feet

( ) Use User Defined Costs

Item	Unit	$/Unit	Quan.	Cost
Cut/Fill	CY			

LF : Linear Feet CY : Cubic Yards

SY : Square Yards LS : Lump Sum

Assumptions

Exit

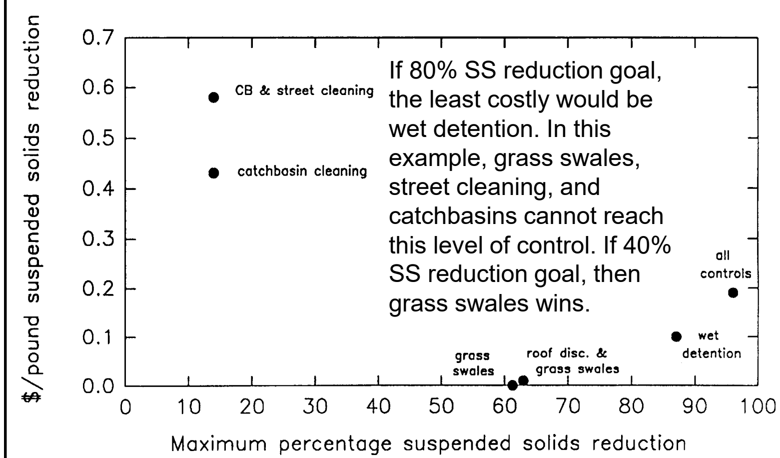
24

WinSLAMM can calculate life-cycle costs and compare different control programs to obtain unit removal costs with the batch processor:

File Name	Runoff Volume (cf)	Partic. Solids Yield (lbs)	Sub Basin Capital Cost	Sub Basin Land Cost	Sub Basin Maint. Cost	Sub Basin Total Annual Cost	Sub Basin Total Present Value Cost	% Part. Solids Reduc.	Cost per lb Sediment Reduced
Cost Example - Base Case No Controls	5246545	37413	0	0	0	0	0	0%	n/a
Cost Example - G	3136146	22341	119109	0	9100	18658	232515	40%	$ 1.24
Cost Example - P 20 percent	4425257	30761	681686	0	3422	58122	724332	18%	$ 8.74
Cost Example - P 50 percent	3193328	20784	1704215	0	8555	145306	1810829	44%	$ 8.74

25

These life-cycle costs can be easily plotted to identify the most cost-effective control options:



26

Batch Processor used for Combinations of Controls for Decision Analyses that Consider Many Attributes

Stormwater Treatment Option	Annual Total SW Treat. Cost ($/yr)	Annual Addit. Drain. System Cost ($/yr)	Total Annual Cost ($/yr)	Land Needs for SW mgt (acres)	Runoff Volume (cf/yr)	Part. Solids Yield (lbs/yr)	Reduc in SS Yield (%)
Base, No Controls	0	64,230	64,230	0	5,600,000	71,375	n/a
Option 1 Pond	19,134	64,230	83,364	4.5	5,507,000	10,192	86
Option 2 Reg. Swale	3,158	26,850	30,008	0	2,926,000	32,231	55
Option 3 Site Biofilter	32,330	37,380	69,710	0	2,705,000	68,890	1
Option 4 Small pond	10,209	64,230	74,439	2.3	5,557,000	19,552	73
Option 5 Pond and reg. swale	22,292	26,850	49,142	4.5	2,844,000	4,133	94
Option 6 Pond, swale, biofilter	54,622	0	54,622	4.5	1,203,000	2,183	97
Option 7 Small pond and swale	13,367	26,850	40,217	2.3	2,887,000	6,937	90
Option 8 Small pond, swale and biofilter	45,698	0	45,698	2.3	1,253,000	4,125	94

27

Additional Batch Processor Data (cont.)

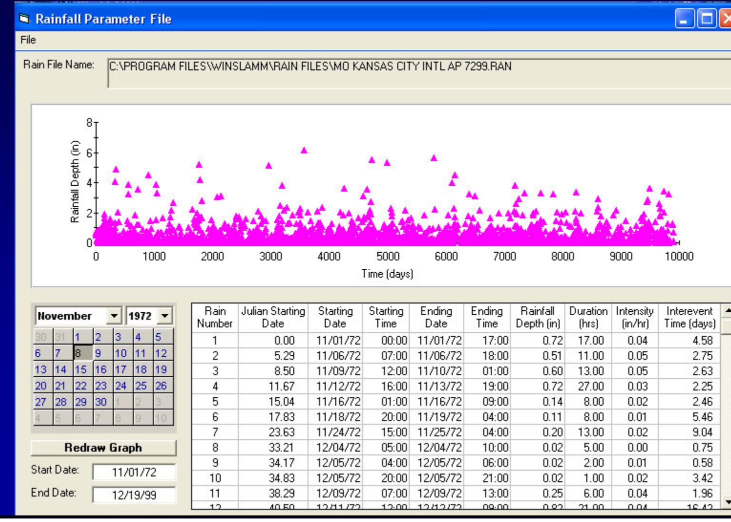
Stormwater Treatment Option	Part. Phos Yield (lbs/yr)	Volum. Runoff Coeff. (Rv) (est. bio. cond.)	% of time flow >1 cfs	% of time flow >10 cfs	SS conc. (mg/L)	Part. P conc. (mg/L)	Zn conc. (µg/L)
Base, No Controls	174	0.29 (poor)	4.5	0.3	204	0.50	359
Option 1 Pond	25	0.29 (poor)	4	0.05	30	0.073	128
Option 2 Reg. Swale	79	0.15 (fair)	2	0.1	178	0.43	390
Option 3 Site Biofilter	172	0.14 (fair)	2	0.2	408	1.0	696
Option 4 Small pond	41	0.29 (poor)	4	0.2	48	0.12	151
Option 5 Pond and reg. swale	10	0.15 (fair)	2	0	23	0.057	203
Option 6 Pond, swale, biofilter	5.5	0.06 (good)	0.5	0	29	0.073	386
Option 7 Small pond and swale	17	0.15 (fair)	2	0.05	39	0.095	220
Option 8 Small pond, swale and biofilter	10	0.07 (good)	0.8	0	53	0.13	390

28

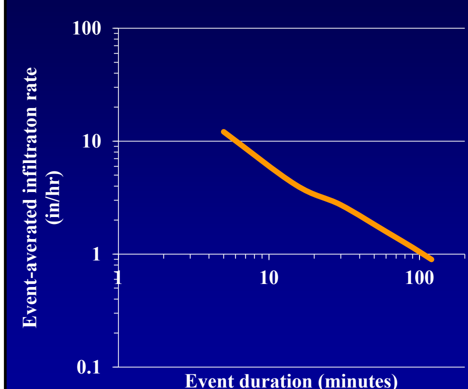
5. Example Evaluations of New Stormwater Controls

- Example of “green infrastructure” controls in a combined sewer area (modeling of roof runoff control alternatives) in areas having marginal soils
- Example of storage-treatment balancing for stormwater media filters

Continuous Simulations using Kansas City 1972 to 1999 Rain Series to Evaluate Roof Runoff Controls in Combined Sewer Area

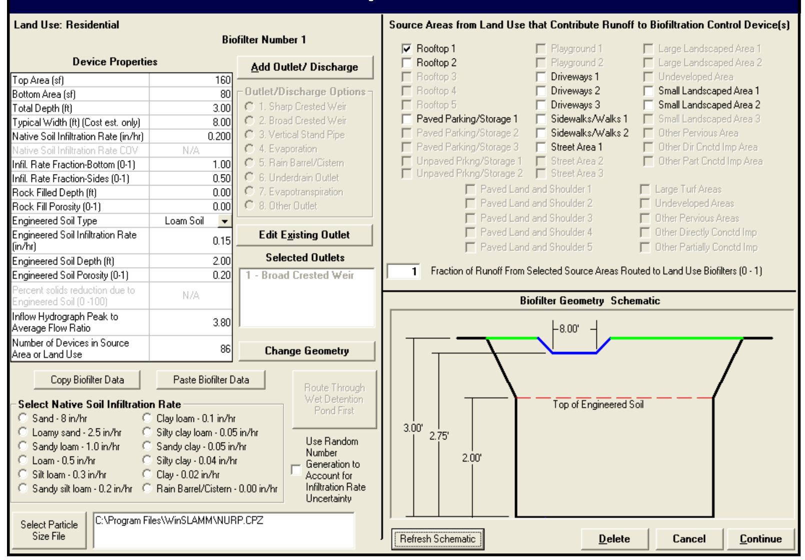


Varying-duration Site Infiltration Rates

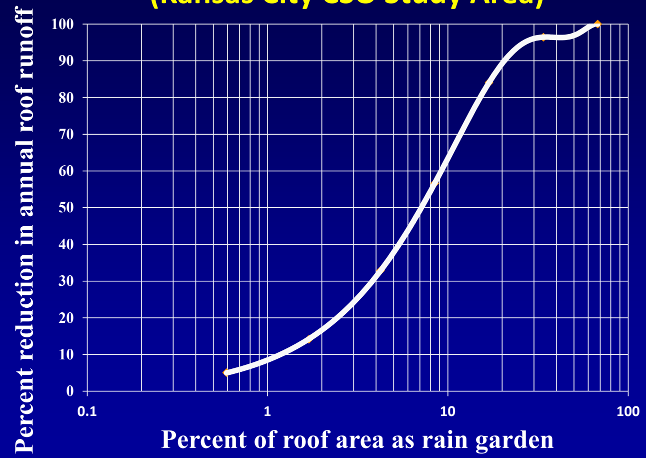


This plot shows the time-averaged infiltration rates based on the individual incremental values. The surface infiltration rates are less than 1 in/hr for rains about 2 hrs long and longer. Additional site measurements and deep soil profiles have indicated that infiltration rates are quite low for most of the area.

Basic Rain Garden Input Screen in WinSLAMM

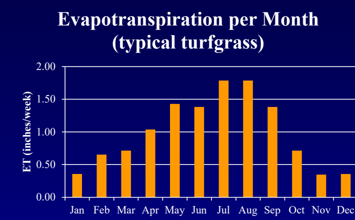


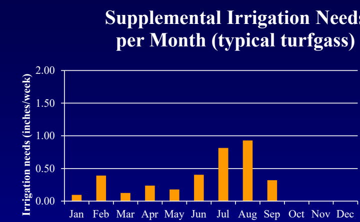
Reductions in Annual Flow Quantity from Directly Connected Roofs with the use of Rain Gardens (Kansas City CSO Study Area)

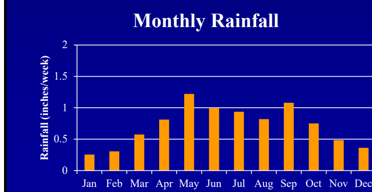


33

Water Harvesting Potential of Roof Runoff







Irrigation needs for the landscaped areas surrounding the homes were calculated by subtracting long-term monthly rainfall from the regional evapotranspiration demands for turf grass.

34

Household water use (gallons/day/house) from rain barrels or water tanks for outside irrigation to meet ET requirements:

January	42	July	357
February	172	August	408
March	55	September	140
April	104	October	0
May	78	November	0
June	177	December	0

35

Water Use Calculations in WinSLAMM

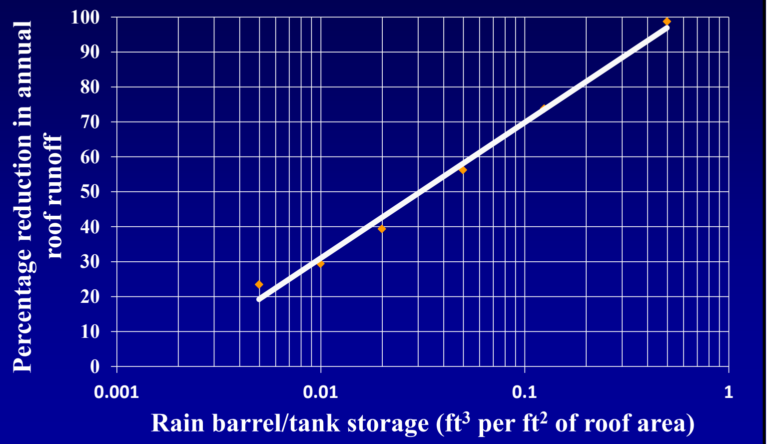
WinSLAMM conducts a continuous water mass balance for every storm in the study period.

For rain barrels/tanks, the model fills the tanks during rains (up to the maximum amount of runoff from the roofs, or to the maximum available volume of the tank).

Between rains, the tank is drained according to the water demand rate. If the tank is almost full from a recent rain (and not enough time was available to use all of the water in the tank), excess water from the event would be discharged to the ground or rain gardens after the tank fills.

36

Reductions in Annual Flow Quantity from Directly Connected Roofs with the use of Rain Barrels and Water Tanks (Kansas City CSO Study Area)



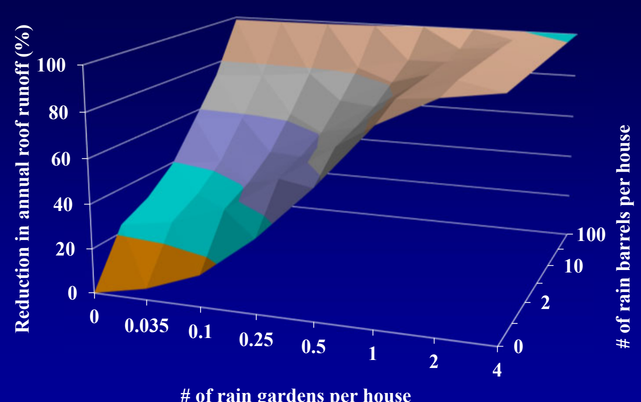
37

0.125 ft of storage is needed for use of 75% of the total annual runoff from these roofs for irrigation. With 945 ft² roofs, the total storage is therefore 118 ft³, which would require 25 typical rain barrels, way too many! However, a relatively small water tank (5 ft D and 6 ft H) can be used instead.

rain barrel/tank storage per house (ft³)	percentage reduction in annual roof runoff	# of 35 gallon rain barrels	tank height size required if 5 ft D (ft)	tank height size required if 10 ft D (ft)
0	0	0	0	0
4.7	20	1	0.24	0.060
9.4	31	2	0.45	0.12
19	43	4	0.96	0.24
47	58	10	2.4	0.60
118	75	25	6.0	1.5
470	98	100	24	6.0

38

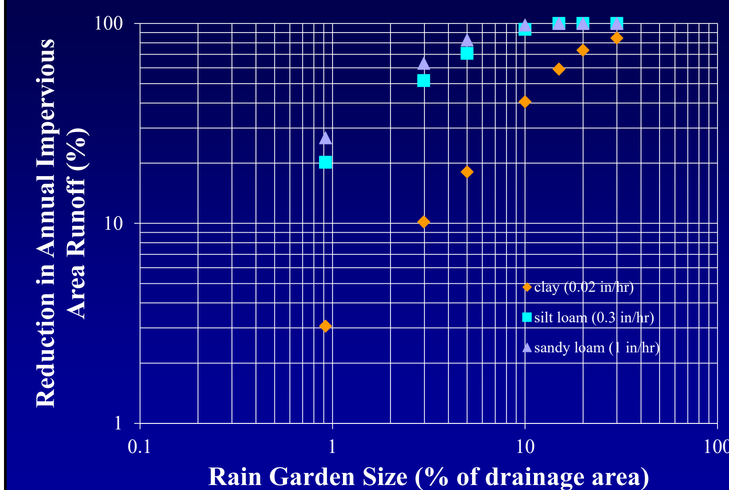
Interaction Benefits of Rain Barrels and Rain Gardens in the Kansas City CSO Study Area



Two 35 gal. rain barrels plus one 160 ft² rain garden per house can reduce the total annual runoff quantity from directly connected roofs by about 90%

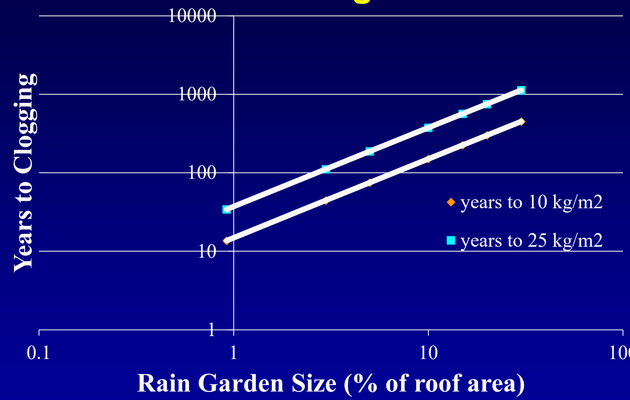
39

Annual Runoff Reductions from Paved Areas or Roofs for Different Sized Rain Gardens for Various Soils



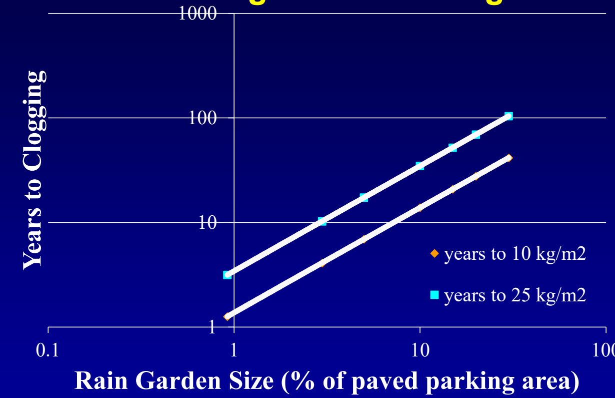
40

Clogging Potential for Different Sized Rain Gardens Receiving Roof Runoff



Clogging not likely a problem with rain gardens from roofs

Clogging Potential for Different Sized Rain Gardens Receiving Paved Parking Area Runoff



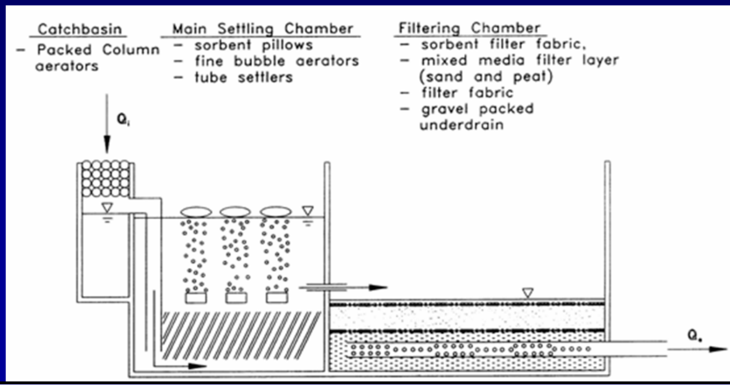
Rain gardens should be at least 10% of the paved drainage area, or receive significant pre-treatment (such as with long grass filters or swales, or media filters) to prevent premature clogging.

Storage-Treatment Tradeoffs for Stormwater Media Filters

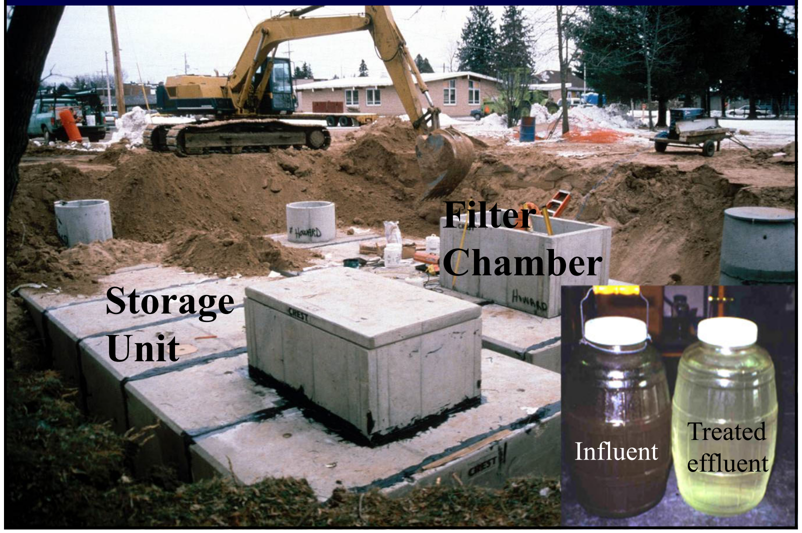
- The performance of a stormwater treatment filter is dependent on the amount of the annual runoff that is treated and by the level of treatment provided.
- Most filters usually have a maximum treatment flow rate that can be utilized per filter unit to obtain the stated treatment level of the treated water.
- The use of storage can moderate the high flows, decreasing the amount of stormwater that is bypassed without treatment.
- The sizing of this adjacent storage needs to be done in conjunction with a continuous model that can evaluate many storage-treatment combinations.

The typical approach to treat large flows is to use a large number of filter units.

The Multi-Chambered Treatment Train (MCTT) was developed by Pitt (1999) for the EPA to provide pre-treatment of stormwater from critical source areas before infiltration. In order to handle a wide range of flows and to provide excellent treatment, storage (provided in the main settling chamber) before the filtration unit was considered a critical unit process.



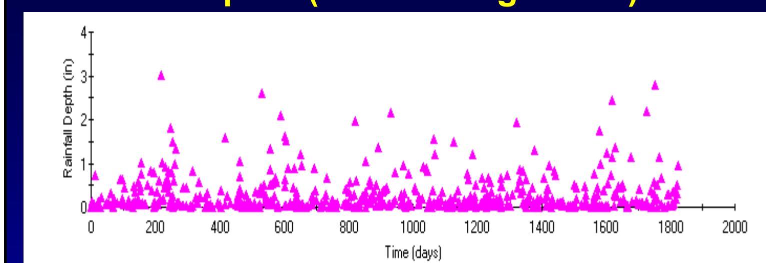
Minocqua, WI, MCTT Installation



Knowledge of Site Hydrology is Critical in the Design of Stormwater Treatment Systems

- Continuous simulations allow evaluations to consider highly varying flow rates and antecedent conditions.
- Critical flow characteristics vary for different regions and for different development characteristics.
- This example is for commercial paved areas, common locations for stormwater filters.
- A typical five year period used by the state of Wisconsin for stormwater quality evaluations was used in the evaluations.

Five year plot of Madison, WI total rain depths (1980 through 1985)



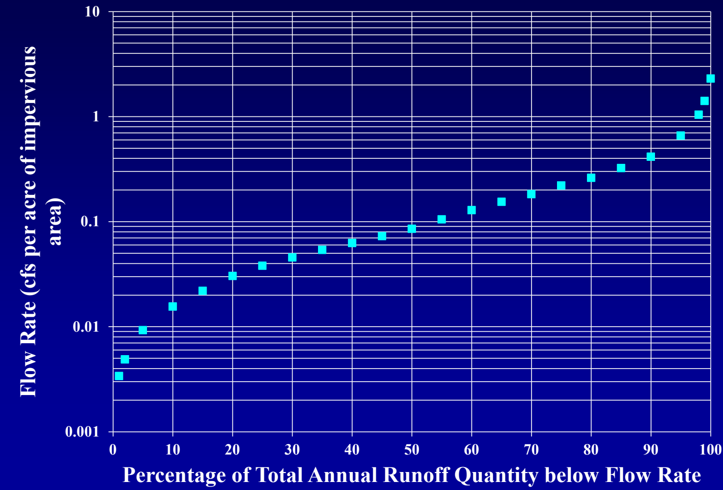
This period was selected by the WI DNR and the USGS to be representative of typical long-term conditions, and not to contain any unusually large rains. The largest rains in this period were about three inches in depth. A treatment system designed to treat 100% of the resultant flows from these events may bypass some limited flows every several years, depending on the frequency of very large drainage-class storm events.

Flow Rate Distribution Calculations

- WinSLAMM was used to calculate cumulative flow rate distribution plots for all events in the 5-year study period. These flows were calculated on 6-minute increments, then exported to Excel, sorted and summed to prepare the fraction of time associated with any flow rate, or less.
- Another plot was created showing how adjacent storage and controlled releases could reduce these flows.

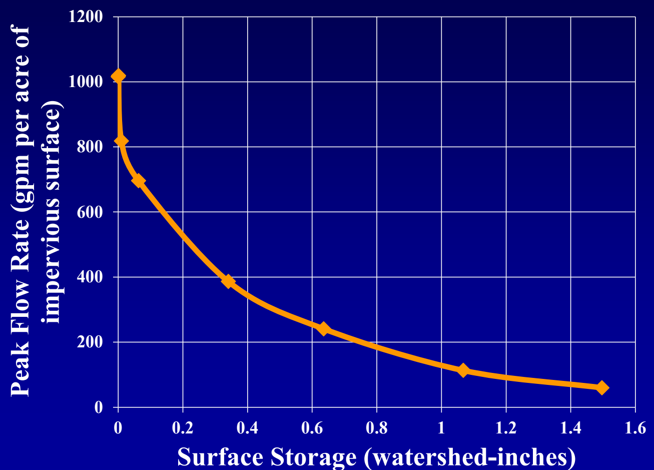
49

Annual Cumulative Flow Rate Distributions (Madison, WI, 1980 through 1985 rains)



50

Effects of Storage on Peak Flow Rates (Madison, WI)



51

Treatment Flow Rates and Fraction of Total Flow Treated

- The 6-minute calculated flows were used to determine treatment flow rate effects.
- A number of treatment flow rates were subtracted from all of the calculated site runoff rate values. The excessive flows not treated for each flow increment were then summed and compared to the total flow quantity. These excessive flow sums for each treatment flow rate were then plotted to indicated how much of the total period flow would be treated, if different treatment flow rates were available.

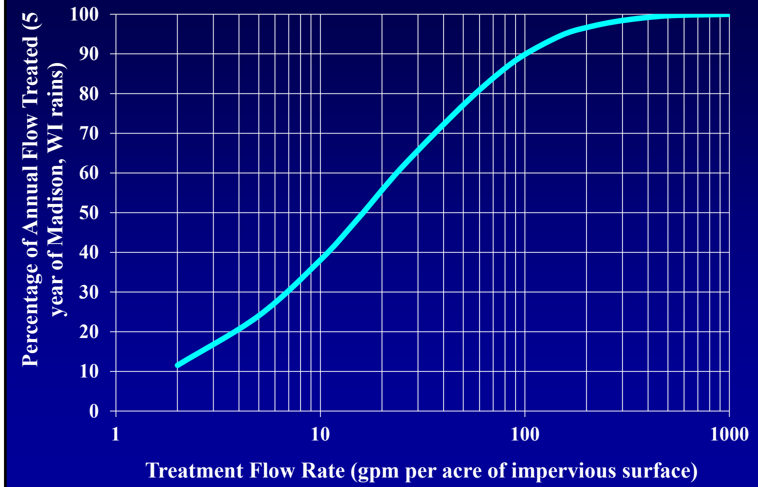
52

Treatment Flow Rates and Fraction of Total Flow Treated (cont.)

- This was repeated using the adjusted 6-minute flow rate distributions associated with different storage volumes. These results were also plotted to indicate the benefits of storage and treatment flow rates on the amount of the total flow able to be treated.

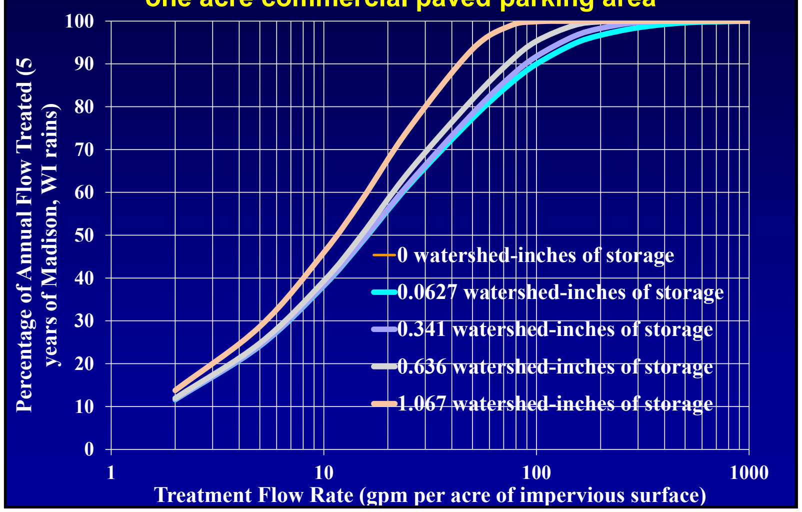
53

Percentage of Annual Flows Treated for Different Treatment Flow Rates (no storage)



54

Effects of treatment flow rate and storage on percentage of annual flow treated, 1980 through 1985 Madison, WI rains and one acre commercial paved parking area



55

- As an example, about 45 gpm per acre of impervious area can provide 90% treatment of the total period flows, if about 1.1 inches of storage was available.
- Very little benefit is available for storage amounts up to about 0.34 inches.

56

Storage-Treatment Examples

- The following examples examine several treatment objectives and show how interactions of storage and treatment can be used to select the most cost-effective combination.
- Typical filter and storage costs are shown on the following tables and are used in conjunction with the previous performance curves to determine the costs of the different treatment and storage options.

57

Example Filter Costs

	Cost for Filters	Total Treatment Flow Rate (gpm)	Total Storage in Basic Unit (ft^3)
small vault and 3 filter cartridges	$14,500	22.5	72
plus another 3 filter cartridges (total of 6)	$19,000	45	72
large vault with 9 filter cartridges	$33,500	67.5	360
plus another 3 filter cartridges (total of 12)	$38,000	90	360
plus another 3 filter cartridges (total of 15)	$42,500	112.5	360

58

Example Storage Volumes and Costs

Total Storage Volume (ft^3)	Number of Each Type of Storage Tank (200 ft^3/1,000 ft^3/6,000 ft^3)	Total Cost for Storage
200	1/0/0	$5,000
400	2/0/0	10,000
1,000	0/1/0	15,000
2,000	0/2/0	30,000
6,000	0/0/1	40,000
12,000	0/0/2	80,000

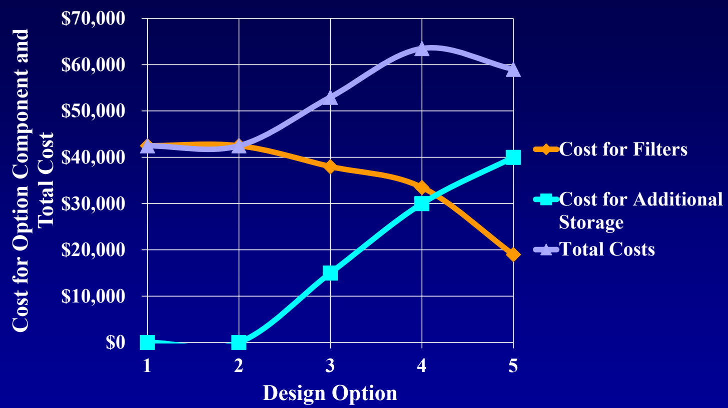
59

Example Cost and Performance Scenarios

- The following plots examine a series of different combinations of storage and filtration capacity. Each example uses a different set of conditions that are able to meet the performance objectives.
- For each option, a combination of filters and storage volume was determined to meet the performance objective. The costs for each of these components are plotted separately for each option, along with the total costs for both components. The least cost option that can meet the performance objective is then easily identified.

60

1) Goal is to treat 90% of the annual runoff



The most cost-effective solution is to use the basic filter only option with 15 filter cartridges (total cost of $42,500) for the acre of impervious area, without any additional storage.

61

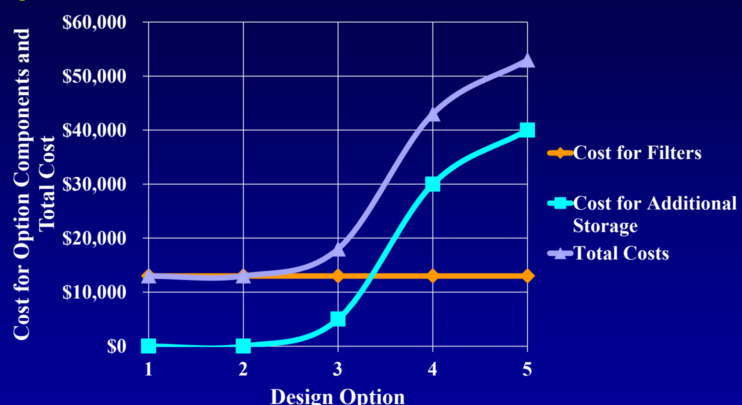
2) Goal is to treat the total annual runoff at 40, 60, or 80% SSC reduction levels in order to meet TMDL requirements.

It is assumed that the filter unit can reduce the SSC at the 85% level under all flow conditions considered. The treatment flow options therefore vary for each level of control desired:

Control Option	Fraction of Total Annual Flow that Must be Treated, Assuming Constant 85% Reductions by the Filters
40% SSC Load Reductions	48%
60% SSC Load Reductions	71%
80% SSC Load Reductions	95%

62

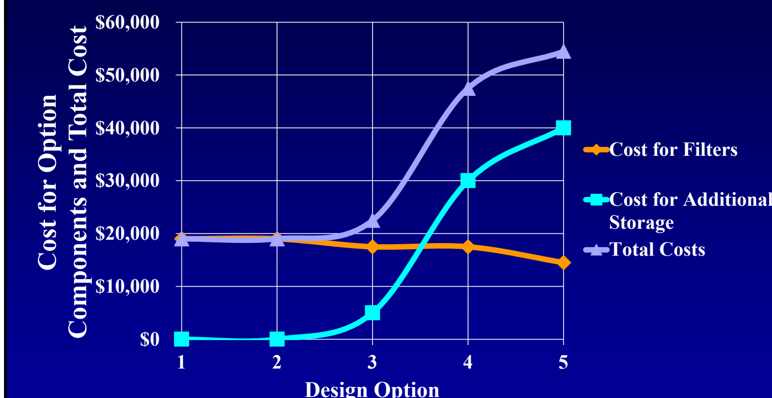
Costs for different storage-treatment options for 40% SSC load reductions



Only the smallest vault with two cartridges is needed. No additional storage is needed. The expected cost is about $13,000 per acre of impervious acre.

63

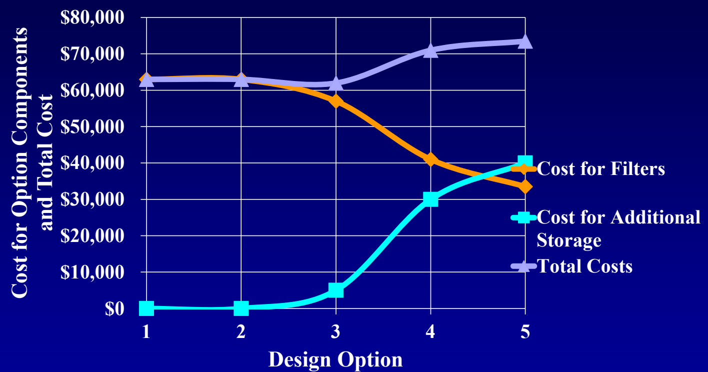
Costs for different storage-treatment options for 60% SSC load reductions



Only the smallest vault with 5 filter cartridges is needed to provide the least cost option, with no additional storage. The expected total cost is about $19,000 per acre of impervious acre.

64

Costs for different storage-treatment options for 80% SSC load reductions



An intermediate control option is slightly more cost-effective. This option uses the large vault with 15 filter cartridges, plus the small vault with 3 more cartridges, at about $62,000 per impervious acre.

Conclusions

- WinSLAMM considers specialized urban hydrology and pollutant transport processes that consider the unique features of urban surfaces and soils.
- These are especially critical when considering water quality evaluations that are heavily influenced by smaller and intermediate-sized runoff events.
- Field measurements are needed for calibration and verification for all stormwater models, and are the basis for most of the processes included in WinSLAMM.
- WinSLAMM considers a wide range of historical and newly emerging stormwater control practices, and routes flows, particulates, and pollutants considering interactions of these controls and site conditions.

Additional WinSLAMM Information

- Supporting materials, documentation, and ordering information ($300 for a site license) available at: http://www.winslamm.com/
- Upcoming training sessions through the University of Wisconsin, Engineering Professional Development (Madison, WI, April 19 and 20, 2010; Baltimore, MD, May 25 and 26, 2010).