Modeling the Performance of Advanced Stormwater Management Options and the Use of Decision Analysis in Selecting the Most Appropriate Set of Controls

Robert Pitt, Department of Civil, Construction, and Environmental Engineering, the University of Alabama, Tuscaloosa, AL

John Voorhees, AECOM, Madison, WI

Shirley Clark, School of Science, Engineering and Technology, Penn State Harrisburg, Middletown, PA

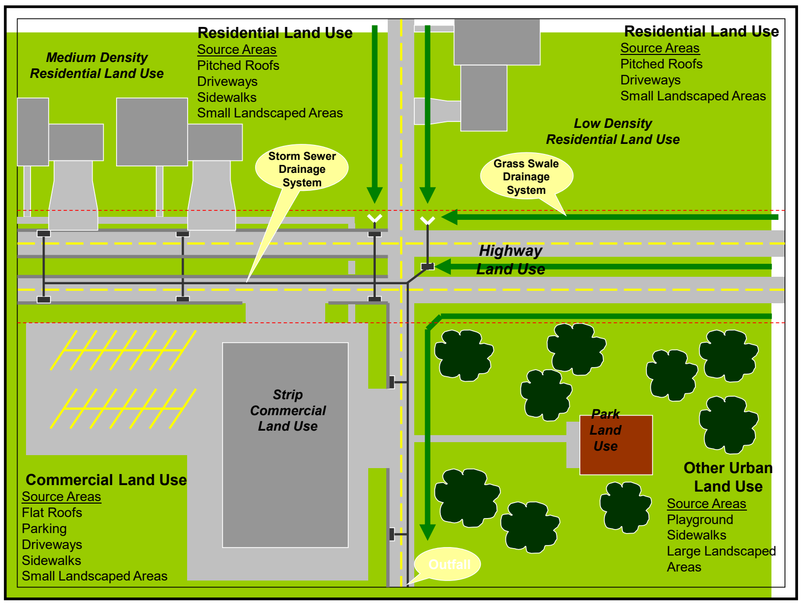
1

Basic WinSLAMM Program Structure

Runoff Volume Generation

- Generate Runoff from the **Source Areas**
- Sum the **Source Area** Runoff for each **Land Use**
- Route Runoff from the **Land Use** Areas Through the **Drainage System**
  - Curb and Gutter
  - Undeveloped Roadside
  - Grass Swales
- Route the Runoff from the **Drainage System** to the **Outfall** discharging to the Receiving Water

2



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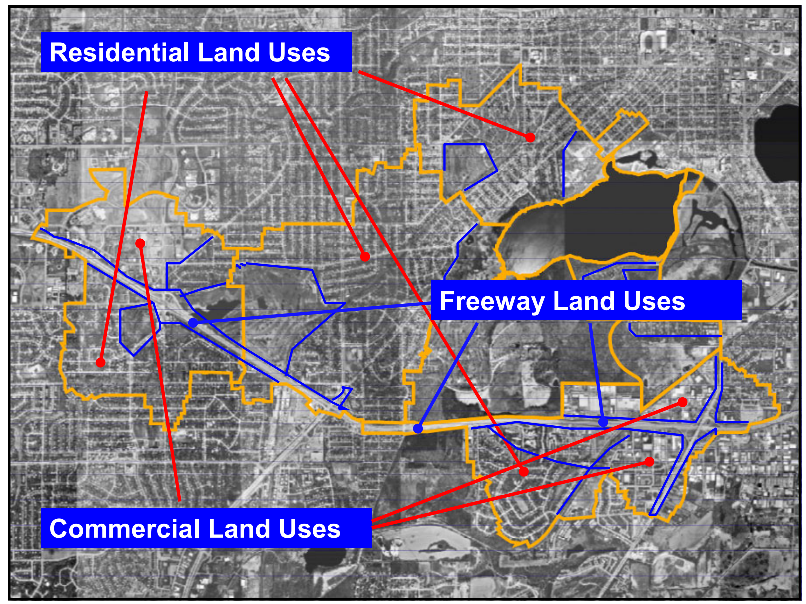
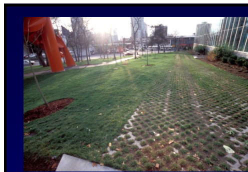


4

Project Strategy and Modeling

- In a typical project, WinSLAMM is used to quantify benefits for different applications of many stormwater controls using long-term continuous simulations. It is also used to examine capital and maintenance costs, along with quantify the maintenance schedules needed for the different alternatives. Decision analyses, considering many project objectives, is also supported by WinSLAMM.

	Infiltration Trenches/Basins	Biofiltration	Rain Gardens	Cisterns/Rain Barrels	Wet Detention Pond	Grass Swale	Street Cleaning	Catchbasins	Hydrodynamic Devices	Porous Pavement	Drainage Disconnection
Roofs	X	X	X	X	X				X		X
Paved Parking/Storage	X	X	X	X	X				X	X	X
Unpaved Parking/Storage	X	X	X	X	X				X		X
Playgrounds	X	X	X	X	X				X	X	X
Driveways	X	X	X	X						X	X
Sidewalks/Walks	X	X	X	X						X	X
Streets/Alleys	X	X	X	X			X		X		
Undeveloped Areas	X	X	X	X	X				X		
Small Landscaped Areas	X	X	X	X	X				X		
Other Pervious Areas	X	X	X	X	X				X		
Other Impervious Areas	X	X	X	X	X				X	X	X
Freeway Lanes/Shoulders	X	X	X	X	X				X		
Large Turf Areas	X	X	X	X	X				X		
Large Landscaped Areas	X	X	X	X	X				X		
Land Use Area	X	X	X	X							
Drainage System	X	X	X	X		X		X			
Outfall	X	X	X	X	X						



Control Devices Included in WinSLAMM

- Hydrodynamic Devices
- Development Characteristics
- Wet Detention Ponds
- Porous Pavement
- Street Cleaning
- Catchbasin Cleaning
- Grass Swales and Grass Filtering
- Biofiltration and Bioretention
- Cisterns and Stormwater Use
- Media Filtration/ion exchange/sorption

- **WinSLAMM evaluates many stormwater controls (affecting source areas, drainage systems, and outfalls) together, for a long series of rains.**
- **WinSLAMM describes a drainage area in sufficient detail for water quality investigations, including disturbed urban soils and small and intermediate rain processes.**
- **WinSLAMM also applies stochastic analysis procedures to more accurately represent actual uncertainty in model input parameters in order to better predict the actual range of outfall conditions.**

Stormwater Infiltration Controls in Urban Areas

- Bioretention areas
- Rain gardens
- Porous pavement
- Grass swales
- Infiltration basins
- Infiltration trenches
- Disconnections of paved areas and roofs from the drainage system
- Also consider evapotranspiration and stormwater beneficial uses

Portland, OR, site having green roof, porous pavement, and biofiltration


Rain Garden Designed for Complete Infiltration of Roof Runoff

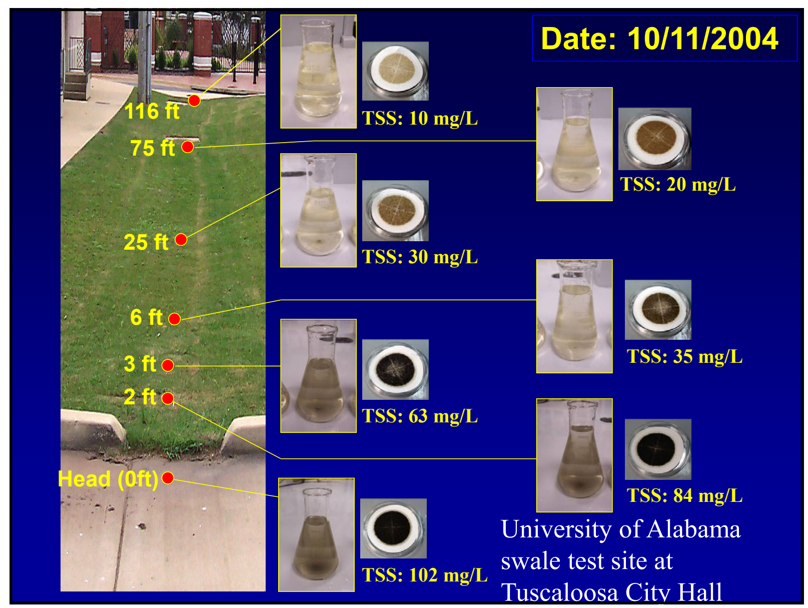
9


Recent Bioretention Retrofit Projects in Commercial and Residential Areas in Madison, WI

10


Grass Swales with conventional curbs and inlets (WI, MS, AL)
Also incorporate grass filtering before infiltration

11


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

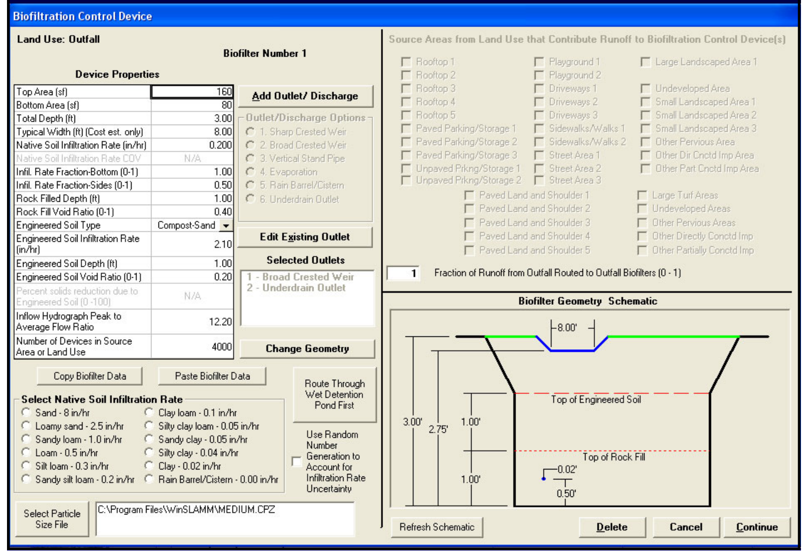
12

Porous paver blocks have been used in many locations to reduce runoff to combined systems, reducing overflow frequency and volumes (Sweden, Germany, and WI).

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

13

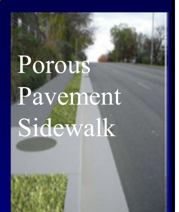
Basic Biofiltration Input Screen in WinSLAMM

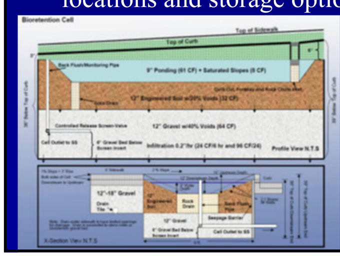


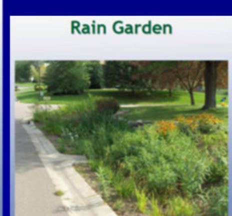
14

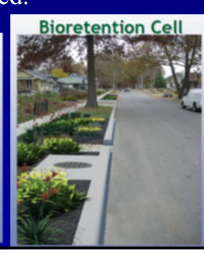
Current Kansas City Project using Green Infrastructure to reduce CSOs

- Conventional CSO evaluations were conducted using XP_SWMM in order to identify the design storm for the demonstration area that will comply with the discharge permits.
- XP_SWMM was also used by KCMO Water Services Department, Overflow Control Program, to examine different biofiltration and porous pavement locations and storage options in the test watershed.









15

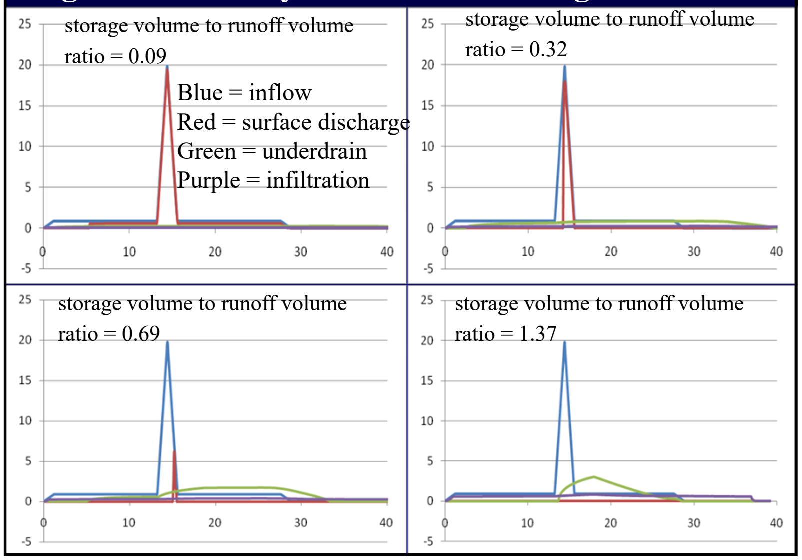
Interactions of Controls being Evaluated in Kansas City

The 8 x 20 ft. curb-cut biofilters are modeled as a cascading swale system where the site runoff is filtered and allowed to infiltrate. If the runoff volume, or inflow rate, is greater than the capacity of the biofilters, the excessive water is discharged into the combined sewer.

When evaluated together, cisterns capture the roof runoff first, but the excess water is discharged to the curb-cut biofilters for infiltration. Continuous simulations drain the devices between events, depending on the intervent conditions and water demand.

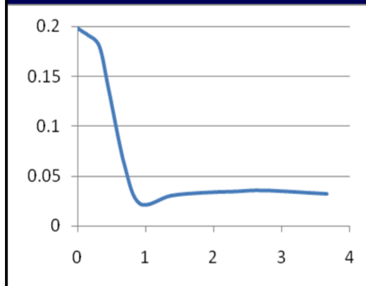
16

Single Event Analysis of 1.4 inch Design Storm “D”

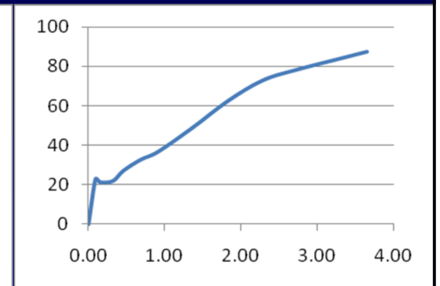


17

Single Event (Design Storm) WinSLAMM Evaluations (1.4 inch storm “D”)



1.4 inch storm D peak discharge rate (cfs/acre) vs. storage volume to runoff volume ratio



1.4 inch storm D volume reduction (%) vs. storage volume to runoff volume ratio

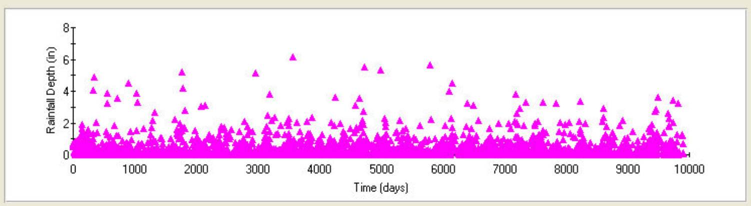
18

Kansas City 1972 to 1999 Rain Series

Rainfall Parameter File

File

Rain File Name: C:\PROGRAM FILES\WINSLAMM\RAIN FILES\MO KANSAS CITY INTL AP 7299.RAN



November 1972

Redraw Graph

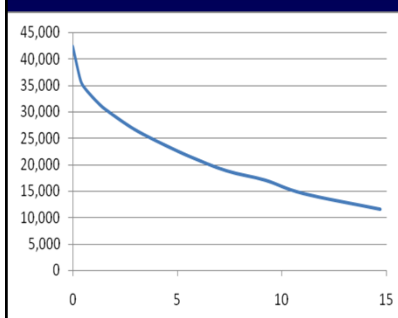
Start Date: 11/01/72

End Date: 12/19/99

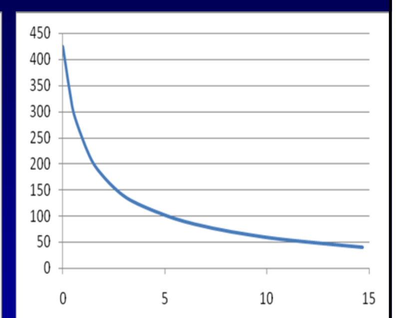
Rain Number	Julian Starting Date	Starting Date	Starting Time	Ending Date	Ending Time	Rainfall Depth (in)	Duration (hrs)	Intensity (in/hr)	Interevent Time (days)
1	0.00	11/01/72	00:00	11/01/72	17:00	0.72	17.00	0.04	4.58
2	5.29	11/06/72	07:00	11/06/72	18:00	0.51	11.00	0.05	2.75
3	8.50	11/09/72	12:00	11/10/72	01:00	0.60	13.00	0.05	2.63
4	11.67	11/12/72	16:00	11/13/72	19:00	0.72	27.00	0.03	2.25
5	15.04	11/16/72	01:00	11/16/72	09:00	0.14	8.00	0.02	2.46
6	17.83	11/18/72	20:00	11/19/72	04:00	0.11	8.00	0.01	5.46
7	23.63	11/24/72	15:00	11/25/72	04:00	0.20	13.00	0.02	9.04
8	33.21	12/04/72	05:00	12/04/72	10:00	0.02	5.00	0.00	0.75
9	34.17	12/05/72	04:00	12/05/72	06:00	0.02	2.00	0.01	0.58
10	34.83	12/05/72	20:00	12/05/72	21:00	0.02	1.00	0.02	3.42
11	38.29	12/09/72	07:00	12/09/72	13:00	0.25	6.00	0.04	1.96

19

Long-Term Continuous WinSLAMM Simulations (28 years)



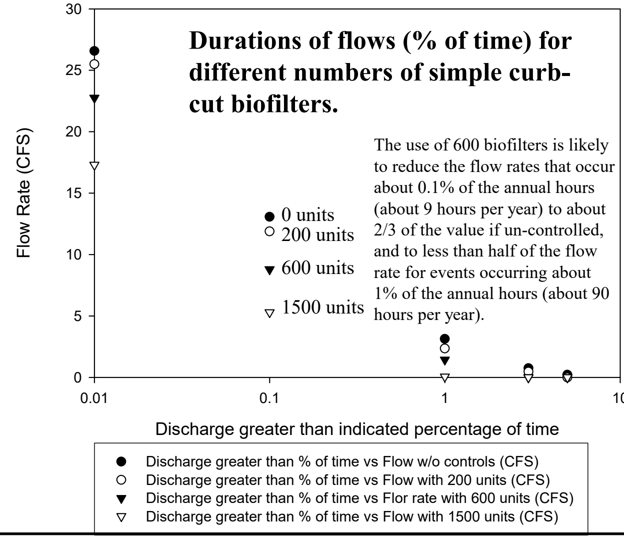
Total runoff (ft^3/acre/year) vs. % of area as biofiltration devices



Annual total particulate solids yield (lbs/ac/year) vs. % of area as biofiltration devices

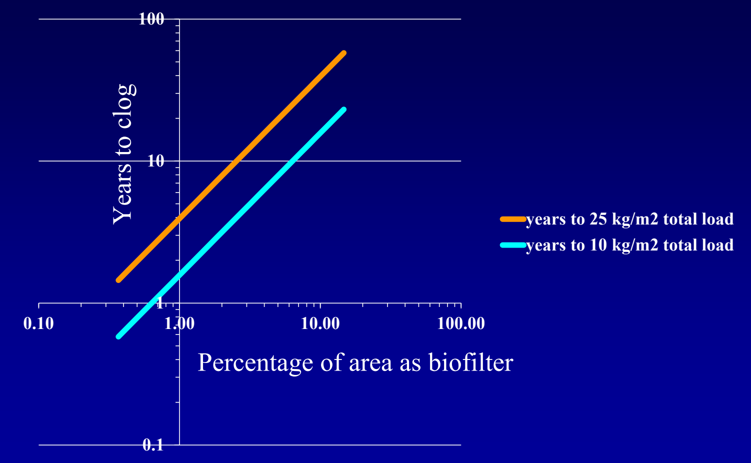
20

Long-Term Continuous Simulations of Flow Durations



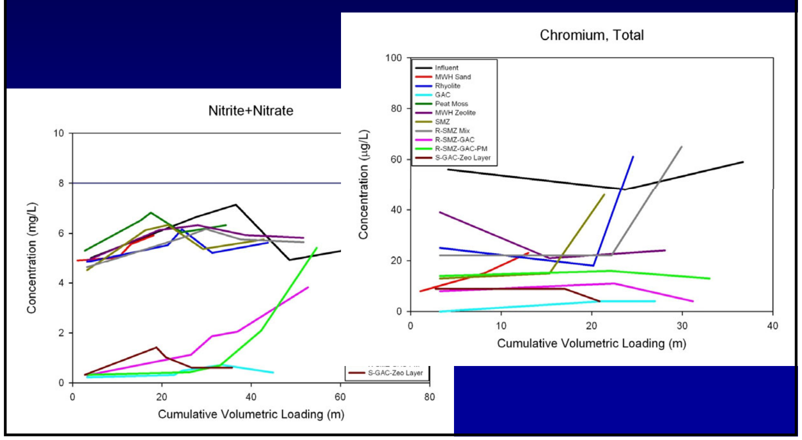
21

Years to clog as a function of biofilter size



22

Current Evaluations of Amendment Materials and Filtration Media that can be used for Treatment before Infiltration



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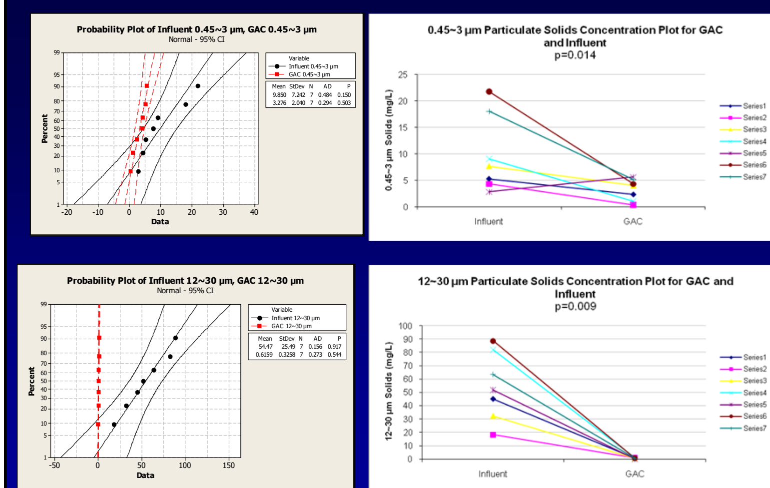
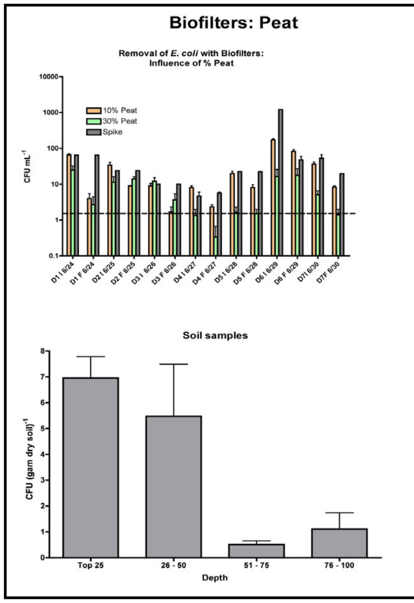


Treatment media can be very effective for a wide range of particle sizes

24



Bacteria Retention in Biofiltration Soil/Peat Media Mixtures

- Need at least 30% peat for most effective *E. coli* reductions
- Bacteria captured in top several inches of soil
- Continued tests to evaluate other organic amendments and longer testing periods

25

Cistern Calculations in WinSLAMM

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

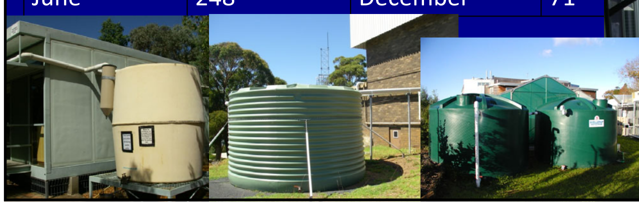
For the water tank cisterns, the model fills the tanks during rains (up to the maximum amount of runoff from the roofs, or to the maximum available volume of the tank).

Between rains, the tank is drained according to the current water demands. If the tank is almost full from a recent rain (and not enough time was available to drain the tank), excess water from the event would be discharged to down-gradient controls or to the drainage system after the tank fills.

26

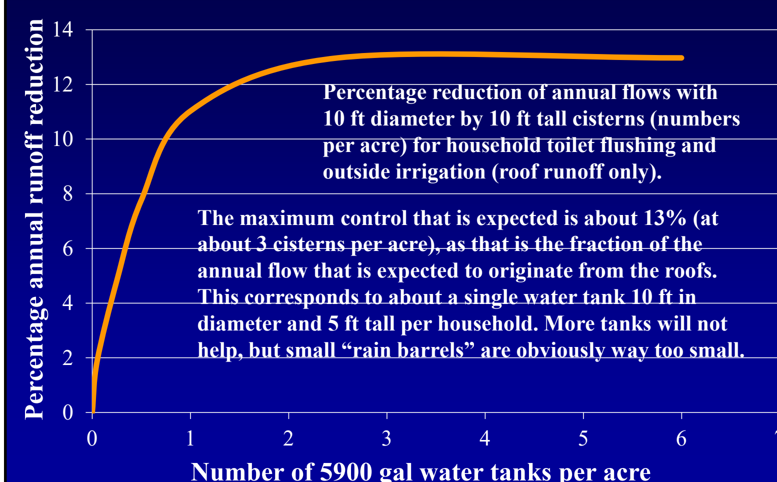
The water tank cisterns modeled were about 10 ft in diameter and 10 ft tall. The expected per household water use (gallons/day) from cisterns for toilet flushing and outside irrigation (ET deficit only) for the KC study area is:

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



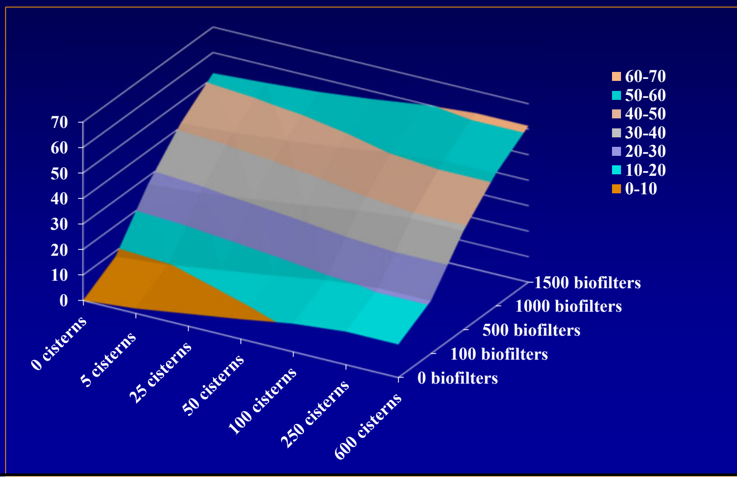

27

Number of water tanks and annual flow volume reductions



28

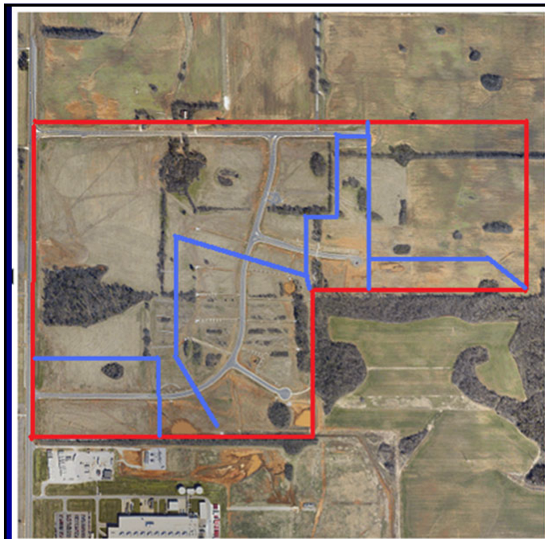
Simultaneous use of cisterns and biofilters in a 100 acre site (% annual flow discharge reductions)



29

North Huntsville Industrial Park showing conservation design elements

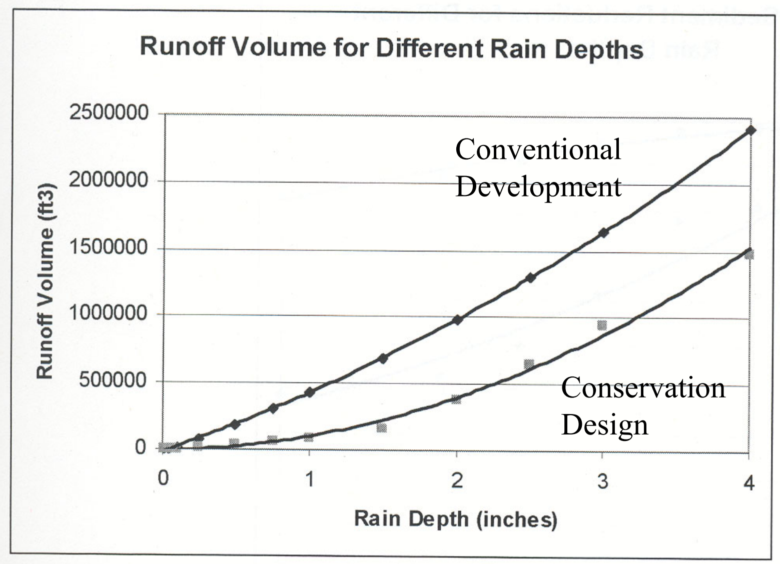
30



Aerial Photo of Site under Construction (Google Earth)

- On-site bioretention swales
- Level spreaders
- Large regional swales
- Wet detention ponds
- Critical source area controls
- Pollution prevention (no Zn!)
- Buffers around sinkholes

31



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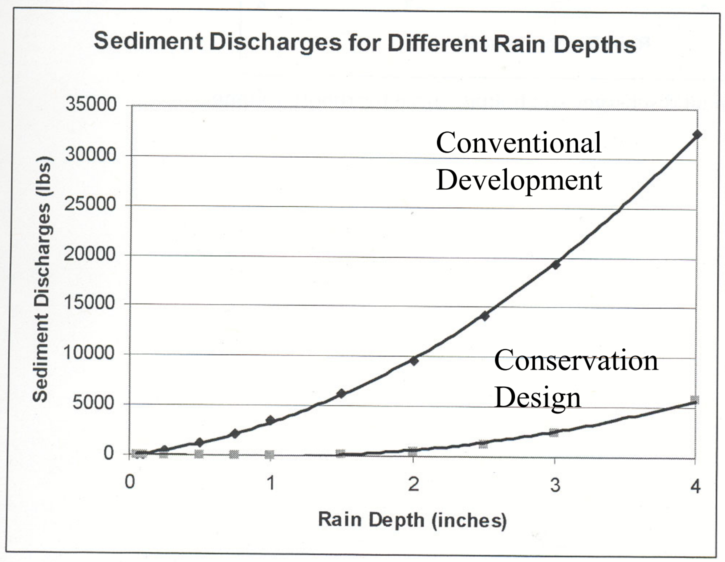
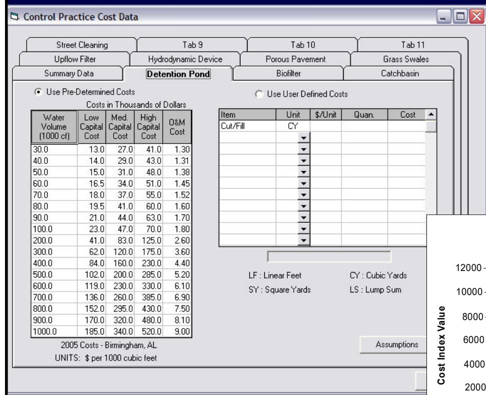


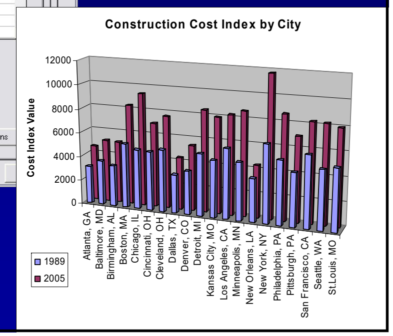
33

WinSLAMM Economic Analyses



Many different US cities currently included in economic model

Basic WinSLAMM economic analyses input screen



34

The economic analyses in WinSLAMM can be used to automatically calculate the capital, maintenance and operation, and financing costs for the stormwater control programs being examined.

This information can be used with the model batch processor to develop cost-benefit curves for the different control options.

Besides the unit cost rates that are already available, it is possible to enter more specific local cost data, based on site costs.

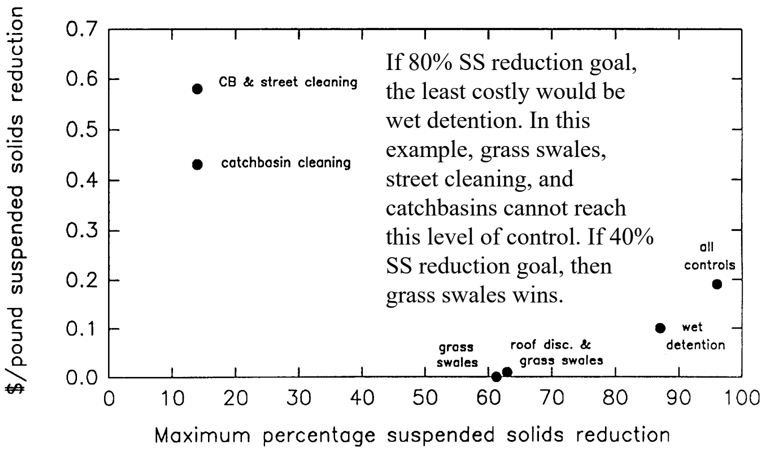
35

Decision Analysis

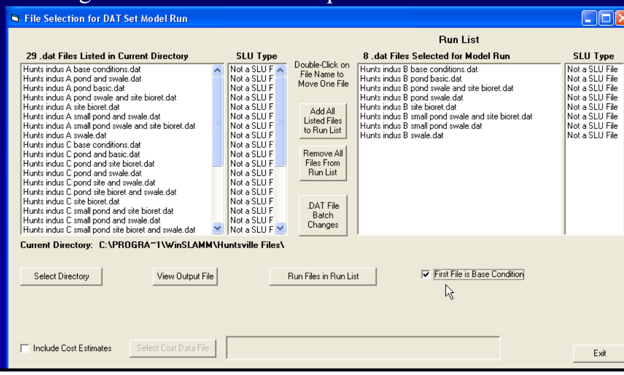
- With so much data available, and so many options that can be analyzed, how does one select the "best" stormwater control program?
- The least costly that meets the objective?

36

Possible, if only have one numeric standard:



A multi-attribute decision analysis procedure can be used to examine many conflicting objectives. One example is by Keeney and Raiffa (*Decision Analysis with Multiple Conflicting Objectives*). This method uses utility curves to describe the benefits of varying levels of control and tradeoff coefficients that compare the different objectives. The first step is to determine the outcomes for several alternative stormwater control programs using the WinSLAMM batch processor:



This is an example WinSLAMM batch processor output, showing many features (including costs, performance, habitat effects, etc.) for eight alternative programs:

.dat Set Run Output

Print Exit

File Number	File Name	Catchment Area (ac)	Number of Years in Model Run	Runoff Volume (cf)	Rv	Biological Condition
1	Hunts indus B base conditions	61.2	0.994	4613738	0.389	Poor
2	Hunts indus B pond basic	61.2	0.994	4461735	0.376	Poor
3	Hunts indus B pond swale and site bioret	61.2	0.994	145318.4	0.012	Good
4	Hunts indus B pond swale	61.2	0.994	921676.3	0.078	Good
5	Hunts indus B site bioret	61.2	0.994	1519309	0.128	Good
6	Hunts indus B small pond swale and site bioret	61.2	0.994	214237.3	0.018	Good
7	Hunts indus B small pond swale	61.2	0.994	1037077	0.087	Good
8	Hunts indus B swale	61.2	0.994	1139064	0.096	Good

Runoff Volume Percent Reduction	Particulate Solids Yield (lbs)	Particulate Solids Yield Percent Reduction	Particulate Solids Concentration (mg/L)	Sub Basin Capital Cost	Sub Basin Land Cost	Sub Basin Maintenance Cost	Sub Basin Total Annualized Cost	Sub Basin Total Present Value Cost	Cost per cubic foot Runoff Volume Reduced ($/cf)	Cost per pound Particulate Solids Reduced ($/lb)
N/A	28605.4	N/A	99.39343	0	0	0	0	0	N/A	N/A
3.29	3887.083	86.41	13.96634	146647	27300	4144	18102	225593	0.12	0.73
96.85	158.1661	99.45	17.44839	454663	37199	25755	65223	812828	0.01	2.28
80.02	997.9495	96.51	17.35772	187284	27300	5630	22849	284750	0.01	0.82
67.07	26270.7	8.16	277.1968	279570	9899	20387	43615	543538	0.01	18.57
95.36	459.3605	98.39	34.3733	397317	23549	24354	58125	724365	0.01	2.05
77.52	1855.217	93.51	28.67783	105557	13650	3704	13270	165368	0.00	0.49
75.31	9335.764	67.36	131.3907	40637	0	1486	4747	59157	0.00	0.24

Example ranges of attributes, and trade-offs:

Attribute	Range of attribute value for acceptable options	Trade-offs between remaining attributes
Total annual cost ($/year)	$40,217 to 83,364	0.20
Land needs (acres)	2.3 to 4.5 acres	0.08
Rv	0.06 to 0.29	0.30
% of time flow >1 cfs	0.5 to 4 %	0.05
% of time flow >10 cfs	0 to 0.05 %	0.18
Particulate solids yield (lbs/y)	2,183 to 10,192 lbs/y	0.07
Part. Phosphorus yield (lbs/y)	5.5 to 25 lbs/y	0.12
		Sum = 1.0

Utility curves are also developed for each attribute

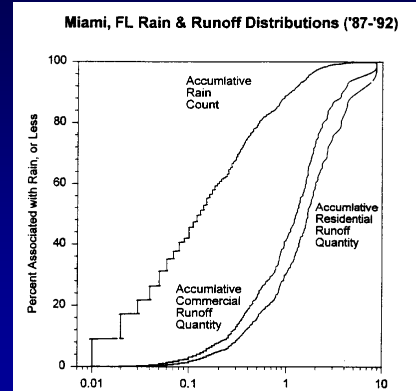
Calculation of Factors for Each Option (utility for modeled outcome times tradeoff); Sum of Factors, and Overall Rank

Stormwater Control Option	Rv utility	Rv factor	Mod flow utility	Mod flow factor	High flow utility	High flow factor	Sum of factors	Over-all Rank
Tradeoff Value	**0.30**		**0.05**		**0.18**			
Option 1 Pond	0.25	0.075	0.25	0.0125	0.75	0.135	0.2225	5
Option 5 Pond and reg. swale	0.75	0.225	0.75	0.0375	1.0	0.18	0.7455	4
Option 6 Pond, reg. swale and biofilter	1.0	0.30	1.0	0.05	1.0	0.18	0.8540	2
Option 7 Small pond and reg. swale	0.75	0.225	0.75	0.0375	0.75	0.135	0.7555	3
Option 8 Small pond, reg. swale and biofilter	1.0	0.30	1.0	0.05	1.0	0.18	0.9290	1

41

Combinations of Controls Needed to Meet Many Stormwater Management Objectives

- Smallest storms should be captured on-site for use, or infiltrated
- Design controls to treat runoff that cannot be infiltrated on site
- Provide controls to reduce energy of large events that would otherwise affect habitat
- Provide conventional flood and drainage controls



Pitt, *et al.* (2000)

42