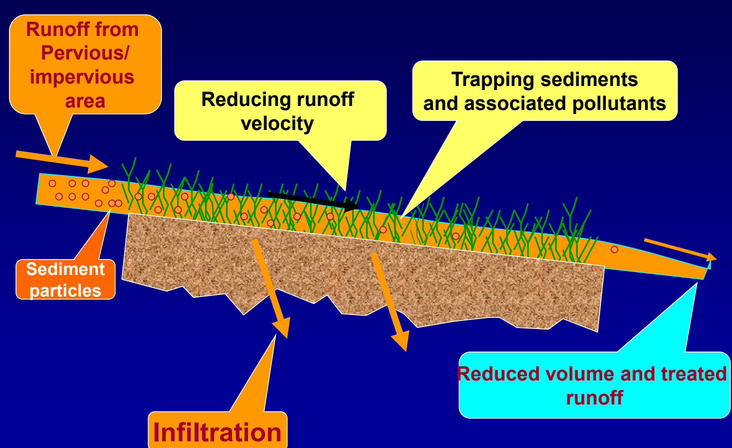
1

2

Pollutant Control in Grass Swales



3

Selected Grass Swale Research Results

- IJC (1979) found swale drained areas had up to 95% less flows and pollutant yields compared to curb and gutter.
- NURP (1983) found soluble and particulate heavy metals reduced by 50% and COD, nitrate and ammonia nitrogen reduced by about 25%.
- Pitt & McLean (1986) found about 50% reductions in pollutants and runoff volume; for small frequent rains very little runoff was observed.
- Johnson, *et al.* (2003) at the Univ. of Alabama identified hydraulic characteristics of stormwater swales under typical flows and plant bioremediation benefits in swales for heavy metal trapping (report available through WERF).
- Nara and Pitt (2005) at the Univ. of Alabama identified significant factors affecting particulate transport in grass swales and developed candidate model algorithms. Modeled procedure joins particle settling with swale hydraulics.

4

WERF Project 97-IRM-2

Innovative Metals Removal Technologies for Urban Stormwater

Conducted by the University of Alabama from 1999 to 2003

- Examined the characteristics and treatability of stormwater heavy metals.
- Conducted detailed laboratory and field tests for the control of stormwater heavy metals by media filtration and grass swales.
- Provide guidelines to enhance the design of filters and swales for metals capture from stormwater.

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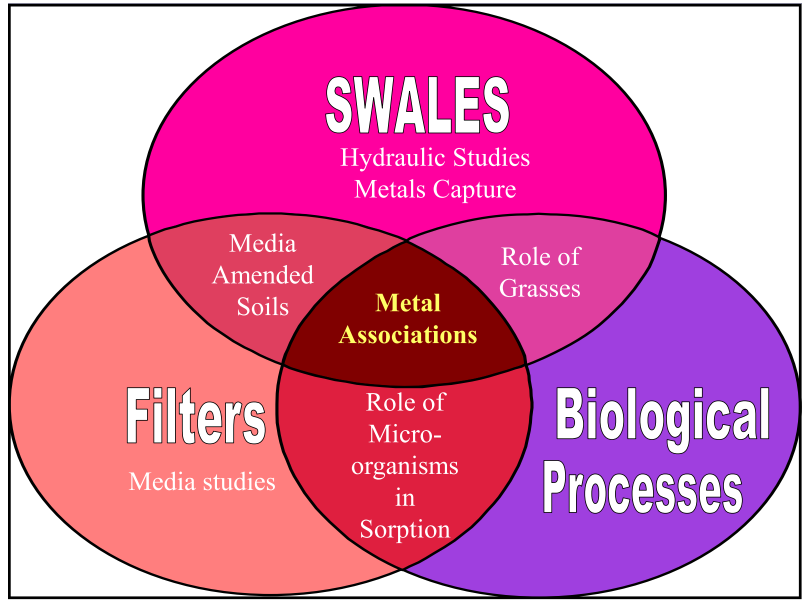
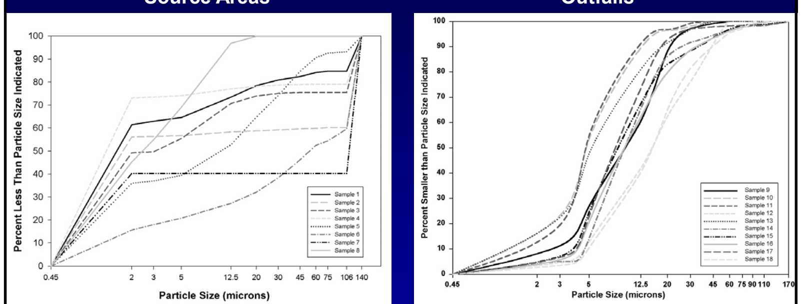


6

Association of Pollutants with Particulates in Runoff

Source Areas

Outfalls



Particle size distributions of stormwater pollutants have a great affect on pollutant control. Distributions depend on sampling location.

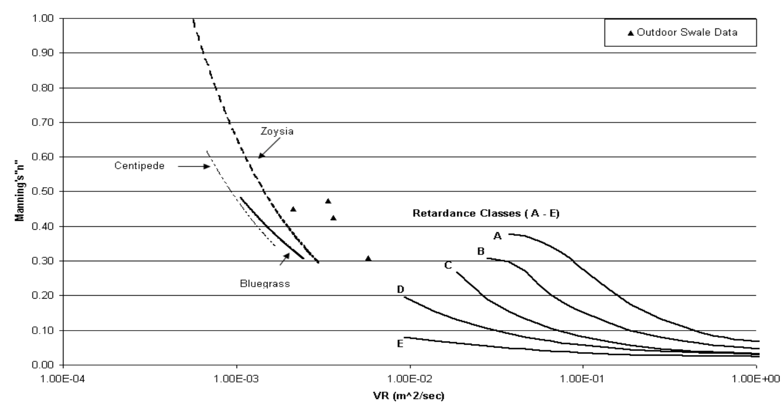
7

Grass Swale Study Research Goals

- Measure swale hydraulic characteristics (Manning's "n") for low flow conditions appropriate for stormwater quality control.
- Test hydraulic and pollutant removal performance for different flow rates, slopes, and grass types.
- Examine subsurface water quality for swale having amended soil lining.
- Develop guidelines to optimize swale design and construction for use as a stormwater control technology.

8

Low Flow vs. Historical Stillwater, OK, Retardance Curves



From such graphs swale hydraulic characteristics can be predicted on the basis of flow rate, cross sectional geometry, slope, and vegetation type.
Jason Kirby 2005

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Runoff Heavy Metals Retained and Released during Indoor Swale Experiments

Metals retained, %	Cu	Cr	Pb	Zn	Cd
Zoysia	40	16	65	13	21
Centipede	39	14	57	20	28
Bluegrass	40	37	67	26	25

The removals of these metals are correlated to their associations with stormwater particulates.

Major ions released, % (these are soil constituents)

	Fe	Na	Mg	Ca	K
Zoysia	6	23	17	12	76
Centipede	45	62	87	44	125
Bluegrass	338	77	52	17	23

These are concentration changes only and do not reflect discharge loading reductions associated with concurrent infiltration. Typical mass discharge reductions for grass swales are greater than 80%.

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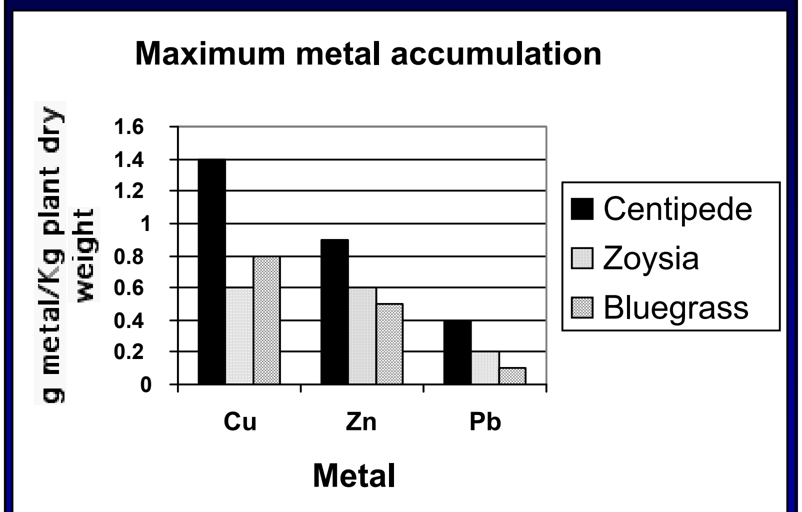
Phytoremediation



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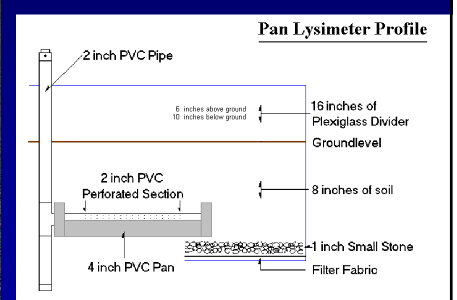
Outdoor Swale with Amended Soils and Pan Lysimeter to Collect Subsurface Flows



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Metals Removal in Swales

- Indoor swales were found to reduce heavy metal concentrations by 14 to 67% during controlled tests.
- Outdoor swales reduced metal concentrations by about 25% during actual storm events.
- Proper swale design was more important than grass species in performance.
- Overall data showed that swales can improve or deteriorate the water quality during separate storm events due to scour of previously deposited metals.

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Research Objectives of Continued Grass Swale Research at UA

(funded by the UTCA, Univ. Transportation Center for Alabama, and many unfunded student projects)

To understand the effectiveness of grass swales for trapping different sized particles

To understand the associated effects of different variables on particulate removal

To develop a predictive model for sediment movement in grass swales

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- **Initial indoor grass swale experiments**
  108 samples collected
- **Second indoor grass swale experiments**
  108 samples collected
- **Outdoor grass swale monitoring**
  69 samples collected (13 storm events)

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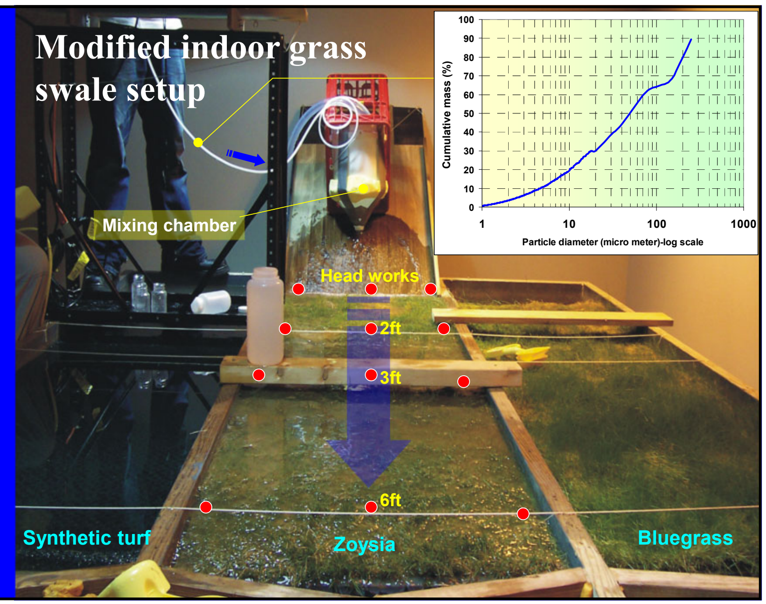

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Variables and analytical methods

- **Study of variables**
  1) Grass types
  2) Slopes
  3) Flow rates
  4) Swale lengths

- **Analytical methods**
  1) Total particulates
  2) Turbidity
  3) Total Suspended Solids
  4) Total Dissolved Solids
  5) Particle Size Distribution by Coulter Counter (Beckman® Multi-Sizer III)

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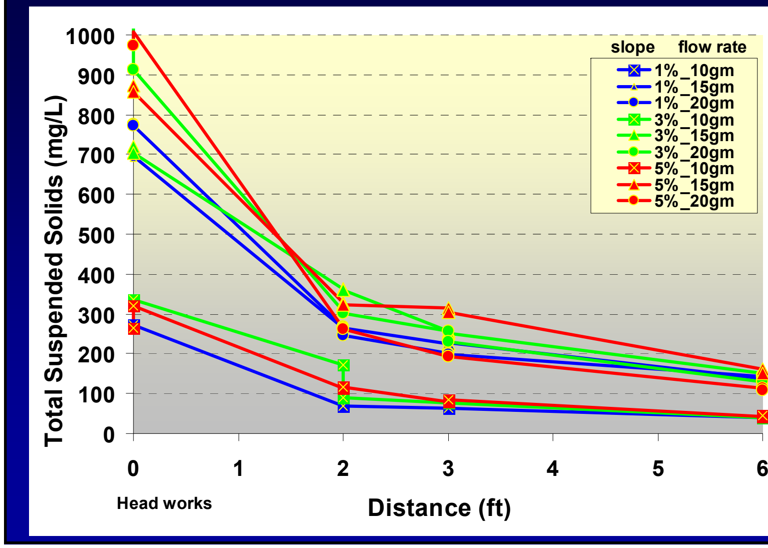
Total Suspended Solids "Bluegrass"



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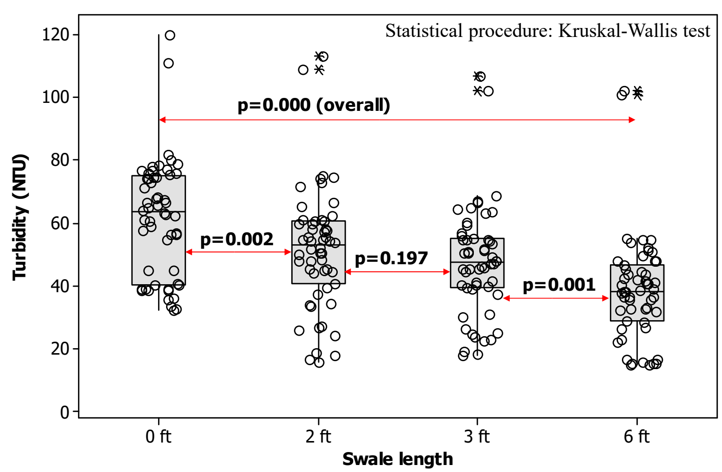
Box plots of turbidity concentrations at different swale lengths



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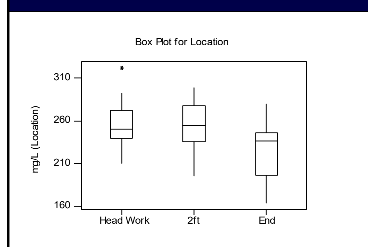
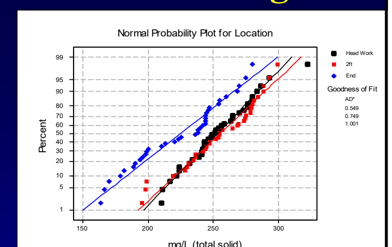
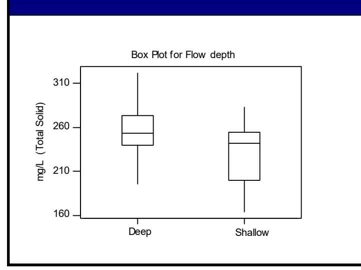
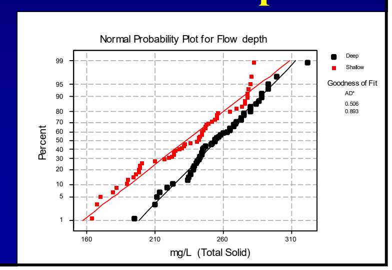
Solids Removal in Swales: Flow Length





Solids Removal in Swales: Flow Depth





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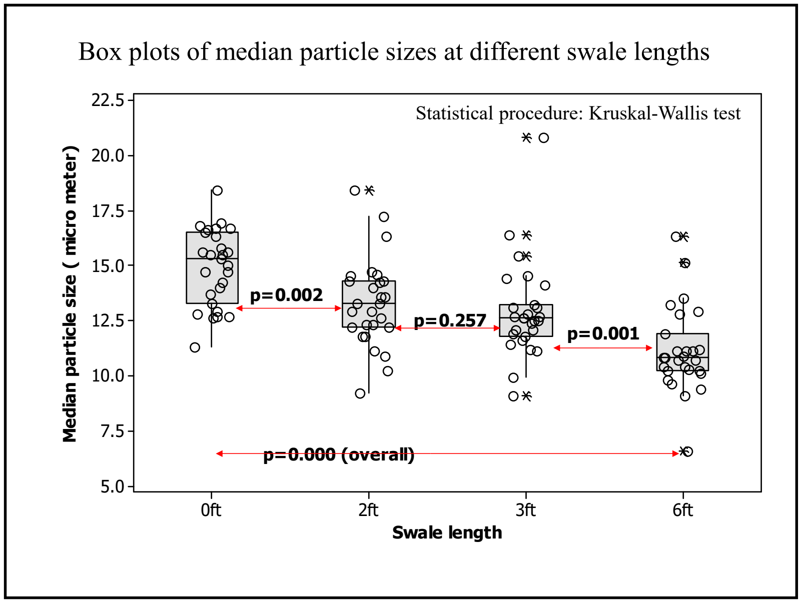

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Modeling Sediment Transport

1) First order decay (for sensitivity analyses)

$$\mathbf{Ln(C_{out} / C_{in}) = -kt}$$

C_{out} = Sediment concentration at sampling locations
C_{in} = Initial sediment concentration at the headwork
k = First order kinetic constant
t = Distance from the headwork

2) "Settling frequency" (for design)

= traveling time / settling duration

Traveling time = Swale length / flow velocity

Settling duration = flow depth / settling velocity (Stoke's Law)

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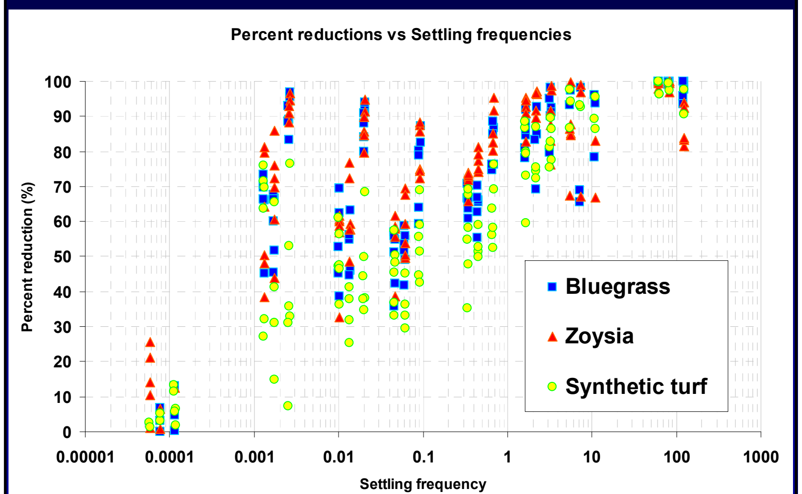
Different grass types



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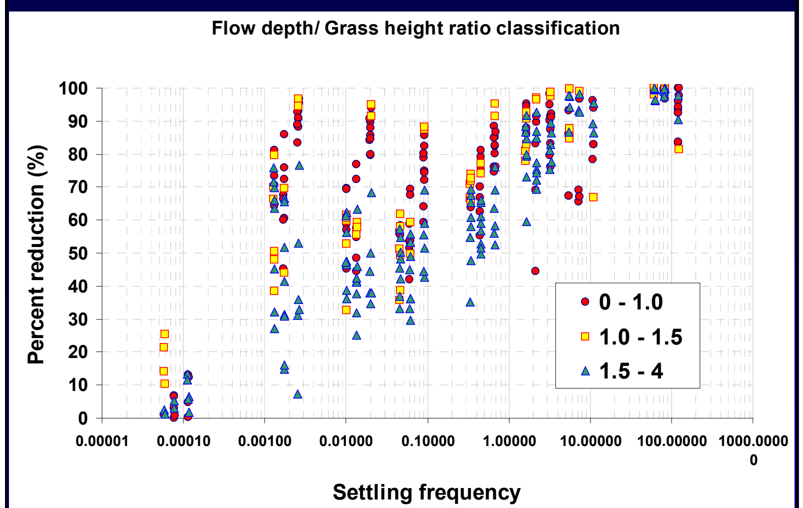
Different flow depth/grass height ratios



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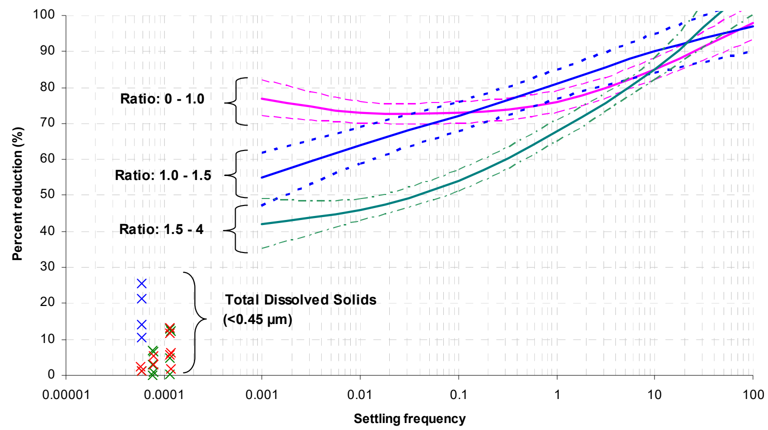
Modeling Equations

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 $Y = 2.382 * [\log(X)]^2 + 15.47 * \log(X) + 67.46$



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Model Verification at Full-Sized Swale

- To verify the predictive model, plots of percent reduction and settling frequency were created using data obtained from outdoor swale observations.
- Data between 3 ft and 25 ft were used (based on TSS results)
- Negative and low percent reductions occurred when the initial concentrations were at or below the irreducible values (20mg/L for TSS). These events were therefore not used in developing the following statistical models.

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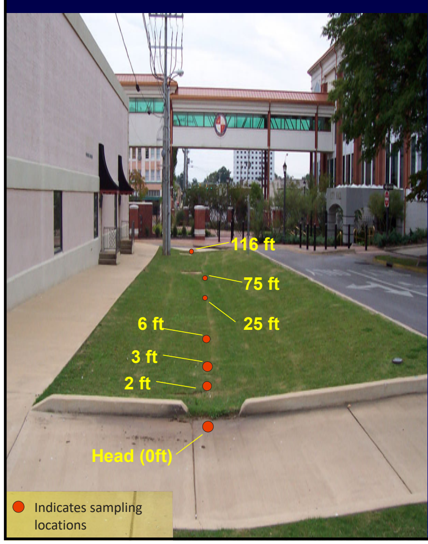
Outdoor Grass Swale Observations



Description of the test site

Length of swale: 116 ft

Type of grass: Zoysia

Approx. watershed area: 4200 ft^2 = 0.1 acres

Events: 13 storm events from 8/22 to 12/08/04

Soil texture: compacted loamy sand

Infiltration rate: < 1 in/hr

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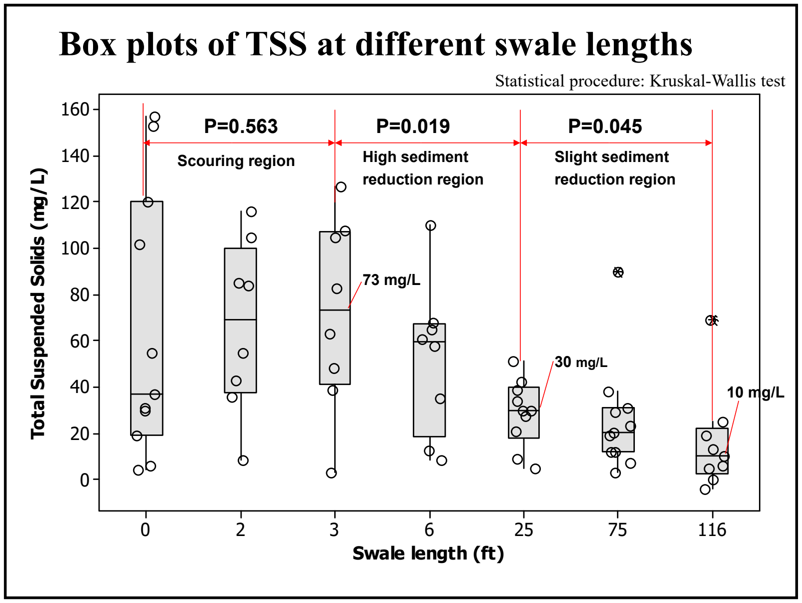
Box plots of TSS at different swale lengths
Statistical procedure: Kruskal-Wallis test
P=0.563
Scouring region
P=0.019
High sediment reduction region
P=0.045
Slight sediment reduction region
73 mg/L
30 mg/L
10 mg/L
Total Suspended Solids (mg/L)
Swale length (ft)
0 2 3 6 25 75 116

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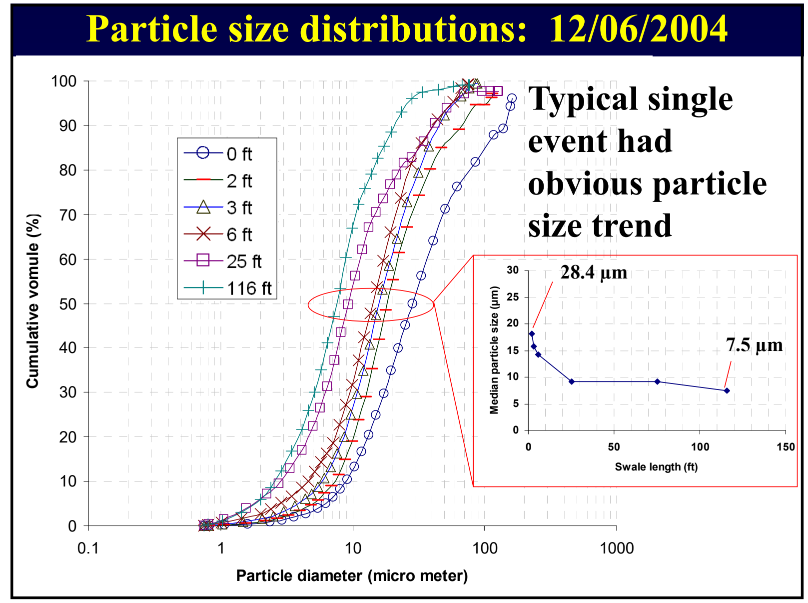
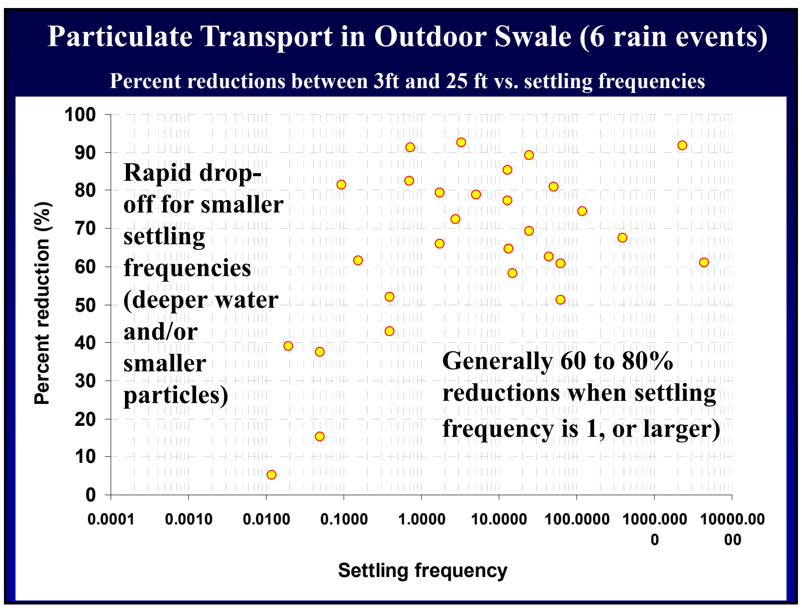

Particle size distributions: 12/06/2004
Typical single event had obvious particle size trend
0 ft
2 ft
3 ft
6 ft
25 ft
116 ft
Cumulative vomule (%)
Particle diameter (micro meter)
28.4 µm
7.5 µm
Median particle size (µm)
Swale length (ft)

30


Particulate Transport in Outdoor Swale (6 rain events)
Percent reductions between 3ft and 25 ft vs. settling frequencies
Rapid drop-off for smaller settling frequencies (deeper water and/or smaller particles)
Generally 60 to 80% reductions when settling frequency is 1, or larger)
Percent reduction (%)
Settling frequency

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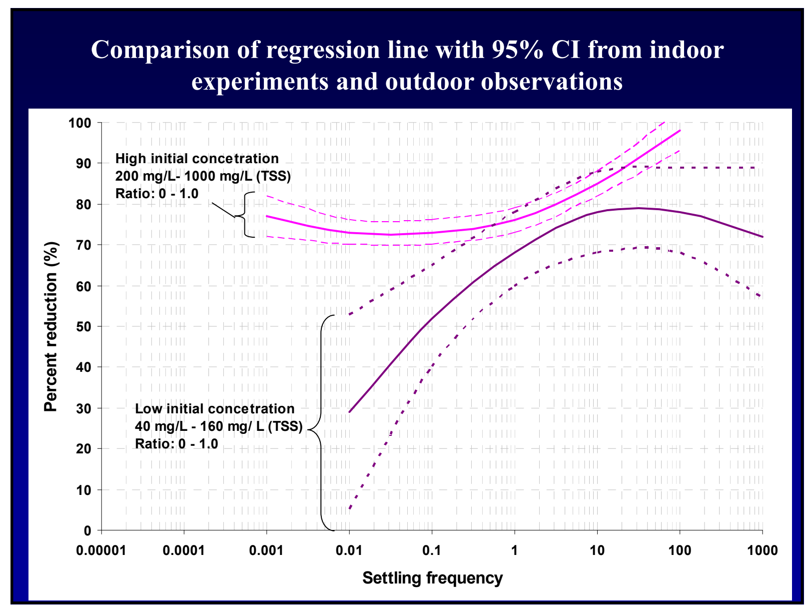
Comparison of regression line with 95% CI from indoor experiments and outdoor observations
High initial concetration
200 mg/L- 1000 mg/L (TSS)
Ratio: 0 - 1.0
Low initial concetration
40 mg/L - 160 mg/ L (TSS)
Ratio: 0 - 1.0
Percent reduction (%)
Settling frequency

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- **Outdoor swale observations**
  - * Significant reductions were observed in TSS and turbidity.
  - * Three distinct swale regions:
    1) 0 ft – 3 ft: Scouring region (equilibrium concentrations)
    2) 3 ft – 25 ft: High sediment reduction region
    3) 25 ft – 116 ft: Slight sediment reduction region (relatively constant concentrations)

- **Model verifications**
  - * Initial sediment concentrations were found to be an important variable in sediment transport in grass swales.
  - * The predictive model for low TSS concentrations was only available for <1 (flow depth / grass height) ratio conditions.

33

Elements of Conservation Design for Cedar Hills Development

(near Madison, WI, project conducted by Roger Bannerman, WI DNR and USGS)

- Grass Swales
- Wet Detention Pond
- Infiltration Basin/Wetland
- Reduced Street Width

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35

Conventional curbs with inlets directed to site swales

36

Reductions in Runoff Volume for Cedar Hills (calculated using WinSLAMM and verified by site monitoring)

Type of Control	Runoff Volume, inches	Expected Change (being monitored)
Pre-development	1.3	
No Controls	6.7	515% increase
Swales + Pond/wetland + Infiltration Basin	1.5	78% decrease, compared to no controls 15% increase over pre-development

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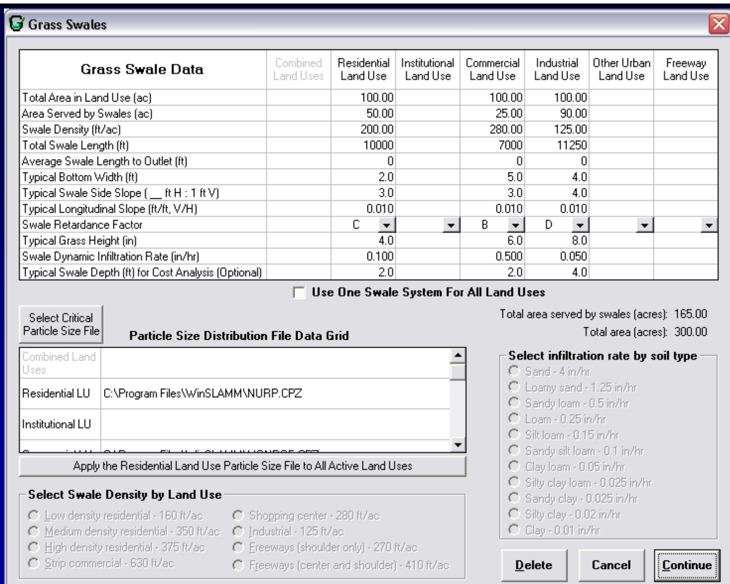
Five Components to Modeling Grass Swales

- Swale Density
- Swale Infiltration Rate
- Swale Geometry
- Grass Characteristics
- Runoff Particle Size Distribution and Flow Hydrograph

38



Grass Swales

Grass Swale Data	Combined Land Uses	Residential Land Use	Institutional Land Use	Commercial Land Use	Industrial Land Use	Other Urban Land Use	Freeway Land Use
Total Area in Land Use (ac)		100.00		100.00	100.00		
Area Served by Swales (ac)		50.00		25.00	90.00		
Swale Density (ft/ac)		200.00		280.00	125.00		
Total Swale Length (ft)		10000		7000	11250		
Average Swale Length to Outlet (ft)		0		0	0		
Typical Bottom Width (ft)		2.0		5.0	4.0		
Typical Swale Side Slope (__ ft H : 1 ft V)		3.0		3.0	4.0		
Typical Longitudinal Slope (ft/ft, V/H)		0.010		0.010	0.010		
Swale Retardance Factor		C		B	D		
Typical Grass Height (in)		4.0		6.0	8.0		
Swale Dynamic Infiltration Rate (in/hr)		0.100		0.500	0.050		
Typical Swale Depth (ft) for Cost Analysis (Optional)		2.0		2.0	4.0		

Use One Swale System For All Land Uses

Select Critical Particle Size File

Particle Size Distribution File Data Grid

Total area served by swales (acres): 165.00

Total area (acres): 300.00

Combined Land Uses	
Residential LU	C:\Program Files\WinSLAMM\NURP.CPZ
Institutional LU	

Apply the Residential Land Use Particle Size File to All Active Land Uses

Select Swale Density by Land Use
- Low density residential - 160 ft/ac
- Medium density residential - 350 ft/ac
- High density residential - 375 ft/ac
- Strip commercial - 630 ft/ac
- Shopping center - 280 ft/ac
- Industrial - 125 ft/ac
- Freeways (shoulder only) - 270 ft/ac
- Freeways (center and shoulder) - 410 ft/ac

Select infiltration rate by soil type
- Sand - 4 in/hr
- Loamy sand - 1.25 in/hr
- Sandy loam - 0.5 in/hr
- Loam - 0.25 in/hr
- Silt loam - 0.15 in/hr
- Sandy silt loam - 0.1 in/hr
- Clay loam - 0.05 in/hr
- Silty clay loam - 0.025 in/hr
- Sandy clay - 0.025 in/hr
- Silty clay - 0.02 in/hr
- Clay - 0.01 in/hr

Delete Cancel Continue

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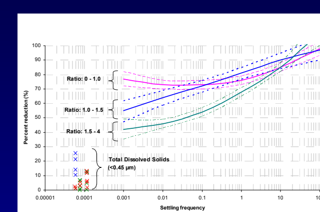
Particulate Removal Calculations

For each time step -
- Calculate flow velocity, settling velocity and flow depth
- Determine flow depth to grass height, for particulate reduction for each particle size increment using Nara & Pitt reference
- Check particle size group limits
  - Not exceed irreducible concentration value
  - No filtering for particles less than 50 microns



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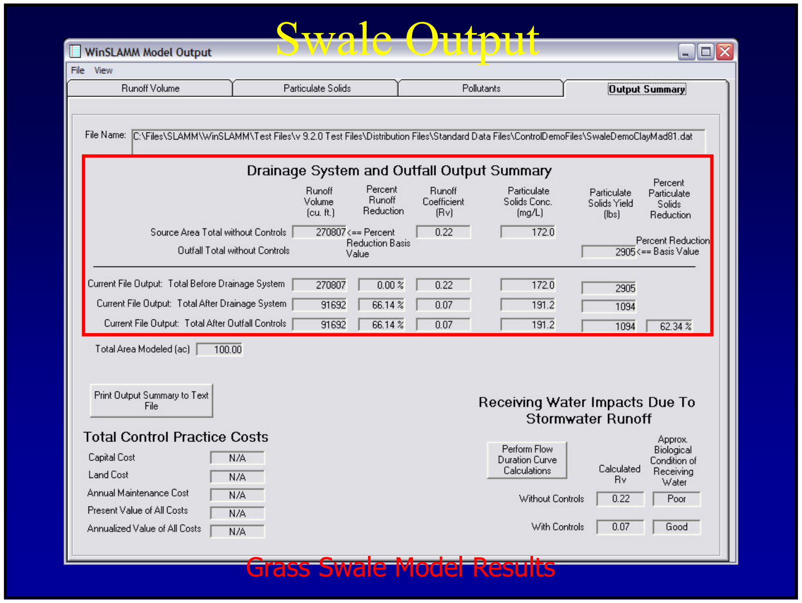
Swale Output
WinSLAMM Model Output
Drainage System and Outfall Output Summary
Receiving Water Impacts Due To Stormwater Runoff
Total Control Practice Costs
Grass Swale Model Results

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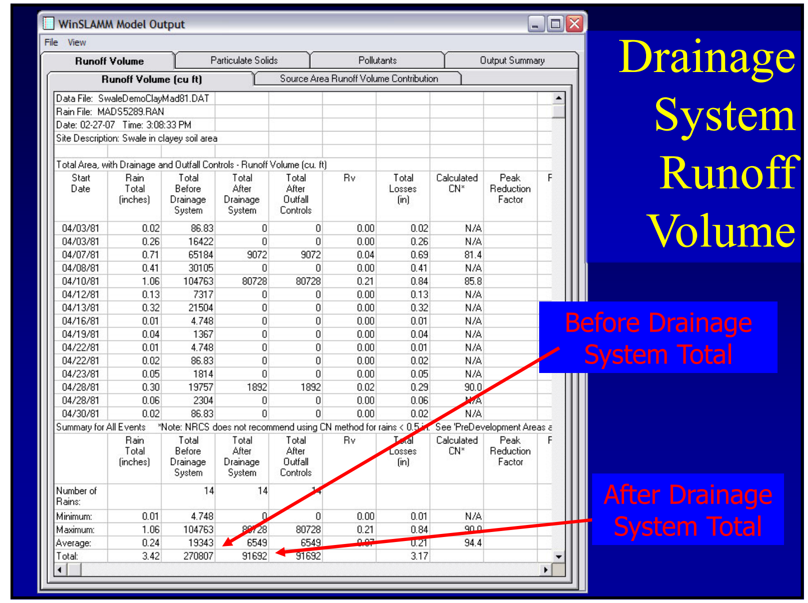
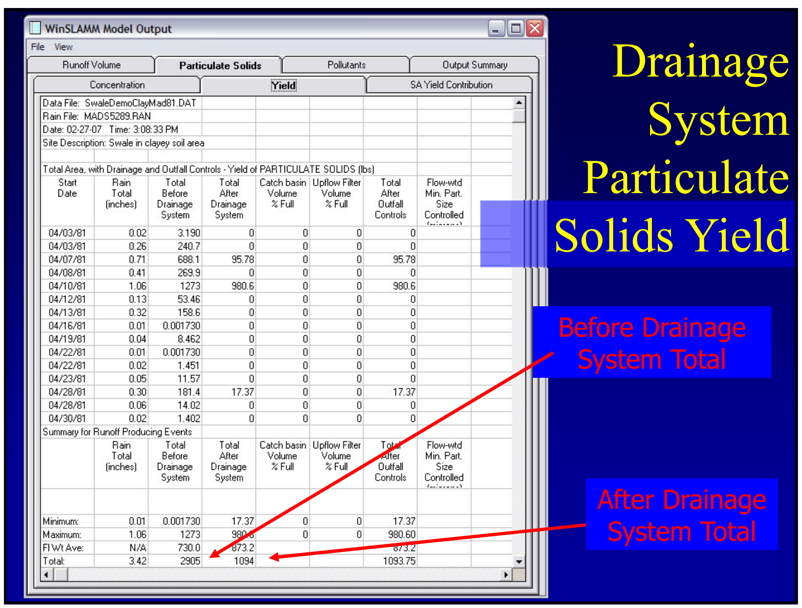
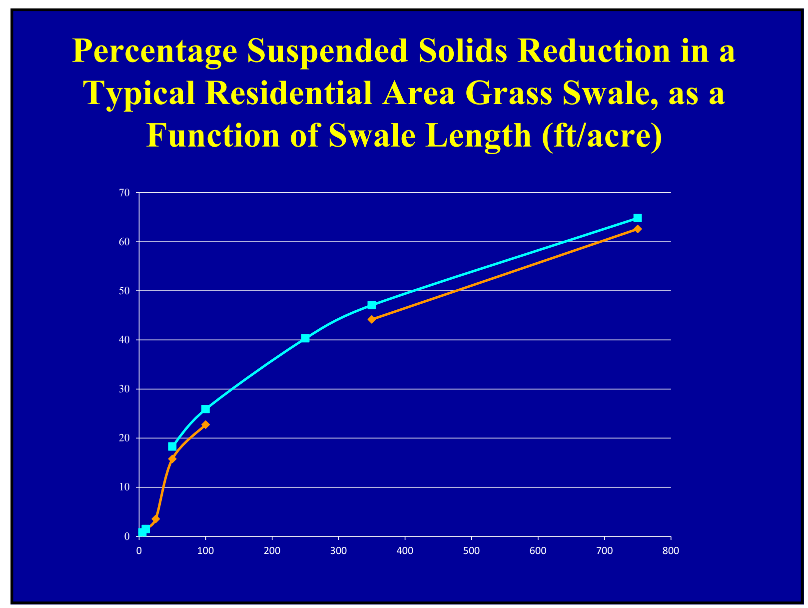

Drainage System Runoff Volume
WinSLAMM Model Output
Before Drainage System Total
After Drainage System Total

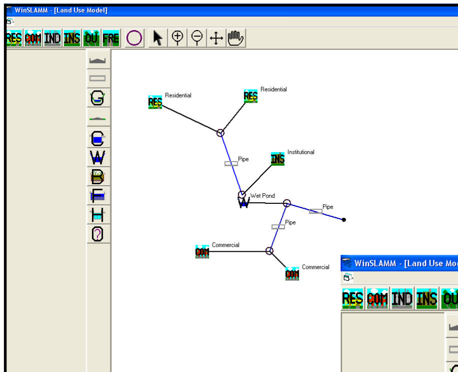
42


Drainage System Particulate Solids Yield
WinSLAMM Model Output
Before Drainage System Total
After Drainage System Total

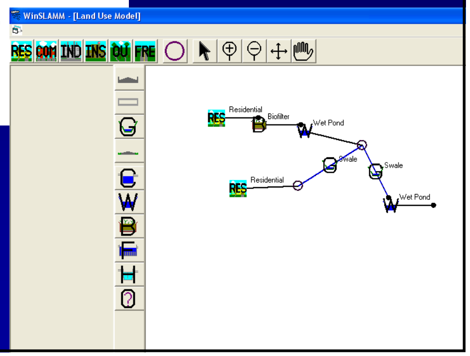
43


Percentage Suspended Solids Reduction in a Typical Residential Area Grass Swale, as a Function of Swale Length (ft/acre)
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800

44



Preliminary Examples of Drag and Drop Land Use Scale WinSLAMM Interface



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