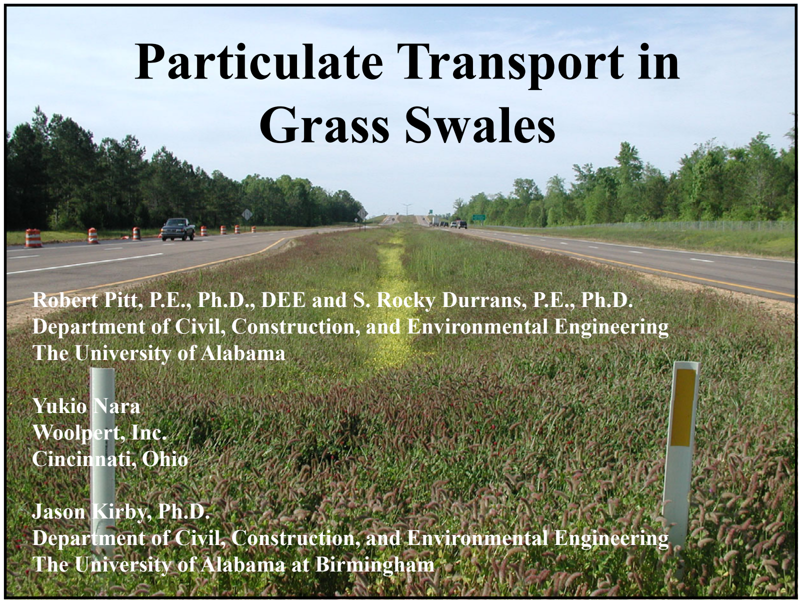

Particulate Transport in Grass Swales

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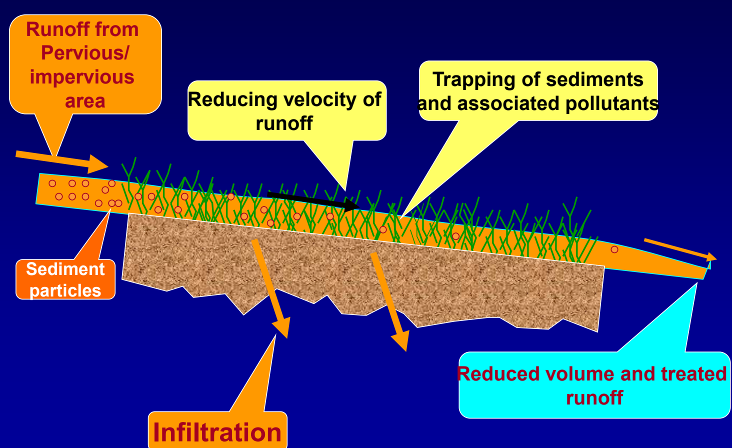
1

Selected 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 metal concentrations reduced by 50% and COD, nitrate and ammonia nitrogen reduced by about 25%.
- Pitt & McLean (1986) found about 50% reductions in pollutant yields and runoff volume in an area half drained by swales; for small frequent rains very little runoff was observed in the swale area.
- 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).
- Recent research (Nara and Pitt 2005) at the Univ. of Alabama identified significant factors affecting particulate transport in grass swales and developed suitable model algorithms. Modeled procedure joins particle settling with swale hydraulics, including infiltration benefits.

2

Particulate Removal in Shallow Flowing Grass Swales and in Grass Filters



3

Grass-Lined Swales

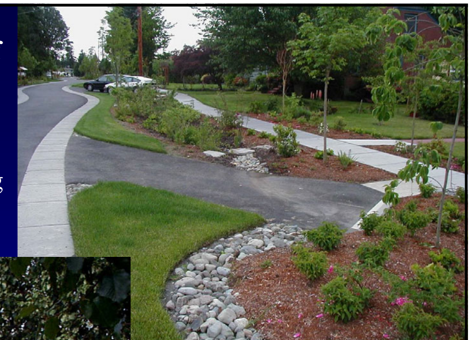
4

Large capacity grass swales and channels designed for both conveyance and water quality objectives.

5

Grass Swales Designed to Infiltrate Large Fractions of Runoff (Alabama and Washington).

Swales can be both interesting and fit site development objectives.



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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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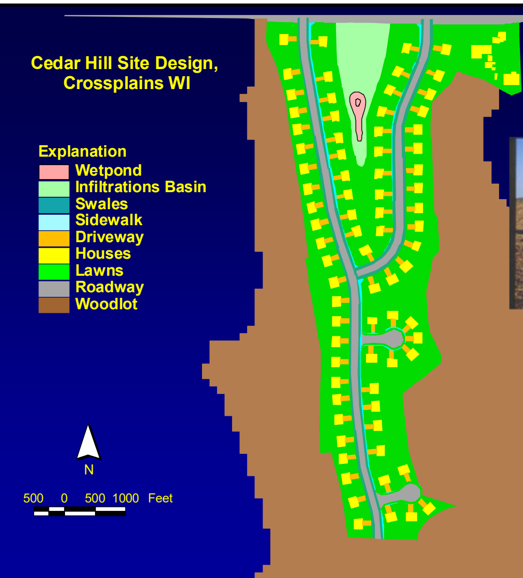
Cedar Hill Site Design, Crossplains WI



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Conventional curbs with inlets directed to site swales

9

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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Research Objectives

- To understand the effectiveness of grass swales for different sized particles
- To understand the associated effects of different variables
- To develop a predictive model in sediment transport in grass swales

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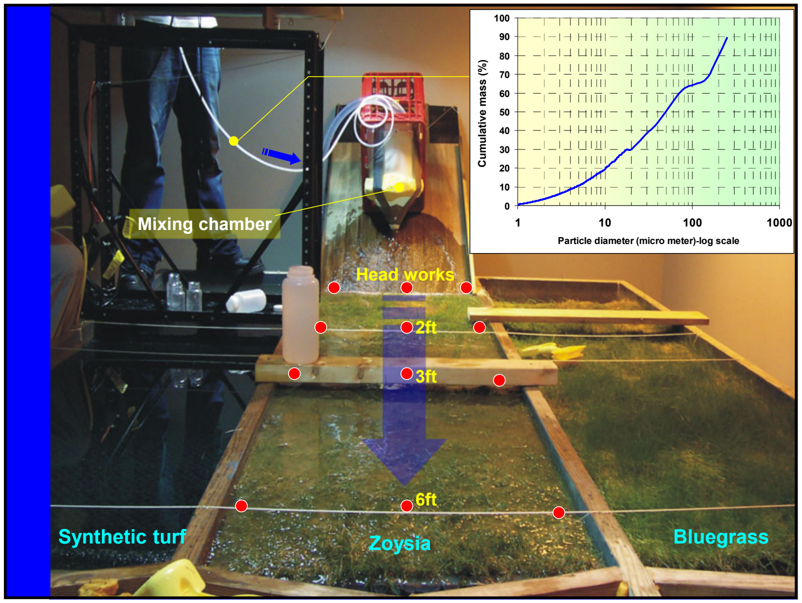
- Initial indoor grass swale experiment
  108 samples collected
- Second indoor grass swale experiment
  108 samples collected
- Outdoor grass swale monitoring
  69 samples collected (13 storm events)

12



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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 solids
  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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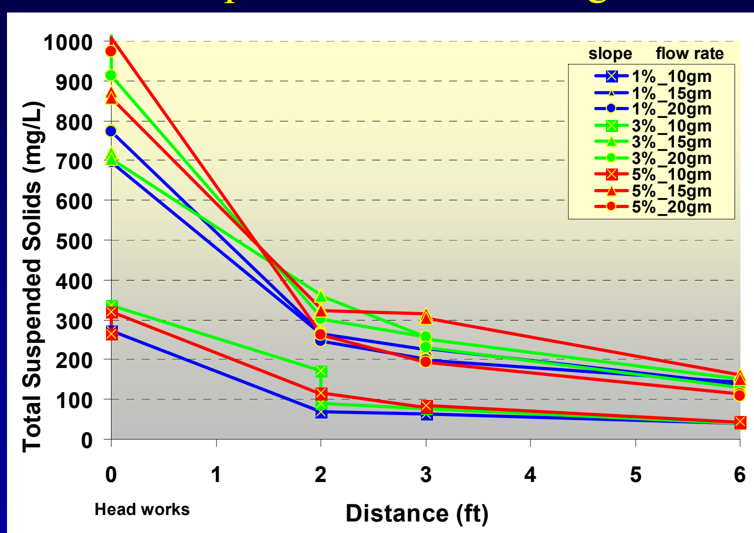
Total Suspended Solids "Bluegrass"



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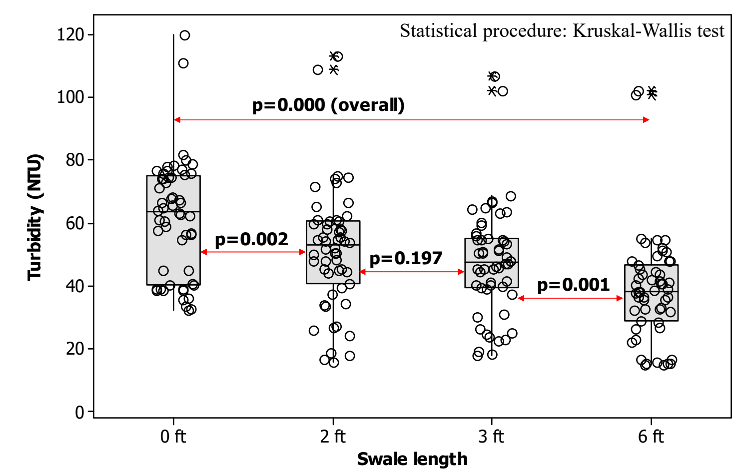
Box plots of turbidity concentrations at different swale lengths



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Significant factors and p-values at 6 ft

P-values were computed for constituent concentrations for each variable

Constituent	Variable	P-value
Total Solids	Grass type	0.000
	Slope	0.006
	Flow rate	0.000
	Grass type*Flow rate	0.023
Total Solids (<106 µm)	Grass type	0.000
	Grass type*Flow rate	0.000
	Slope*Flow rate	0.006
Total Suspended Solids	Grass type	0.000
	Slope	0.047
	Grass type*Flow rate	0.005
	Slope*Flow rate	0.013
Total Dissolved Solids	Grass type*Flow rate	0.044
Turbidity	Grass type	0.000
	Slope	0.020
	Grass type*Slope	0.001
	Grass type*Flow rate	0.000

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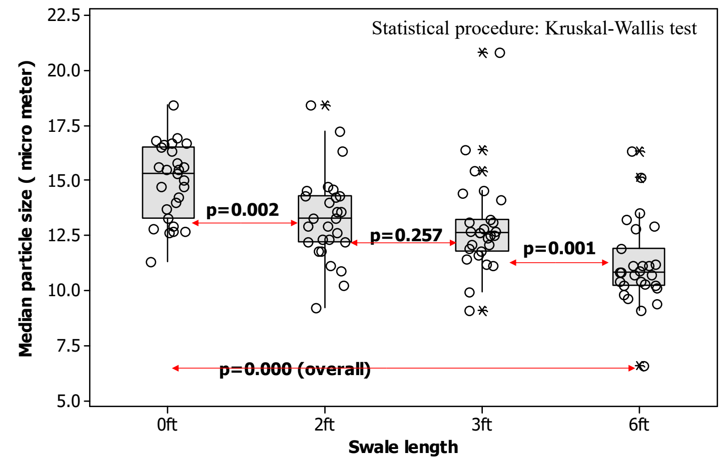
Box plots of median particle sizes at different swale lengths



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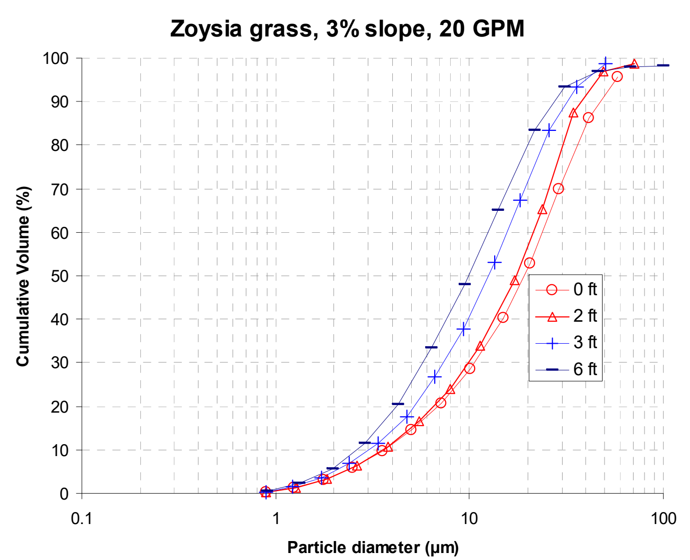

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Modeling Particulate Transport in Grass Swales and Grass Filters

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Concept:

"Settling frequency"

= traveling time / settling duration

the larger the settling frequency, the more times the particle will bounce along the flow path (with an increased probability of being permanently captured). Larger particles have a greater settling frequency than small particles for the same flow conditions:

Traveling time = Swale length / flow velocity

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

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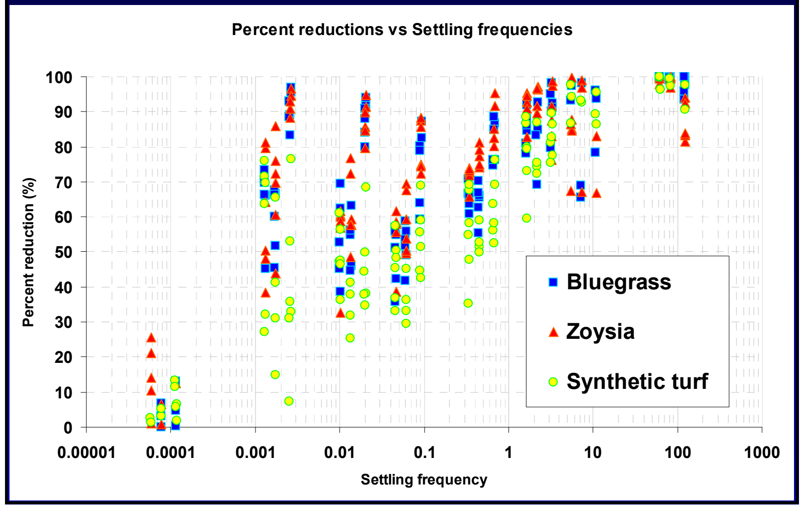
Different grass types



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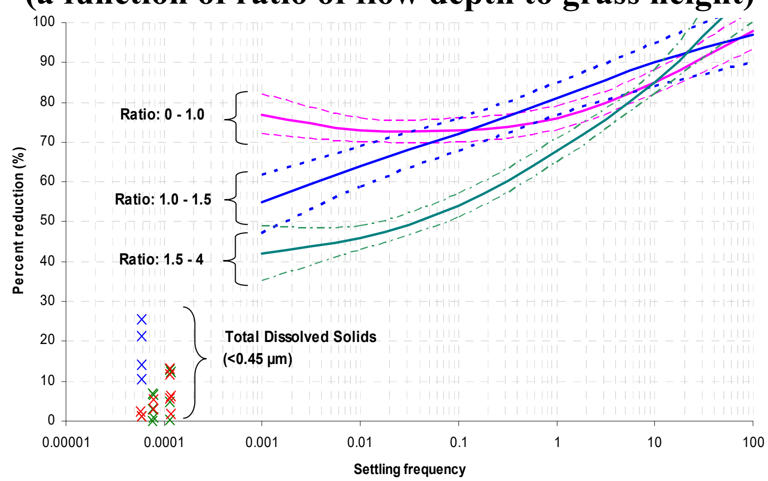
Settling Frequency vs. Particulate Capture (a function of ratio of flow depth to grass height)



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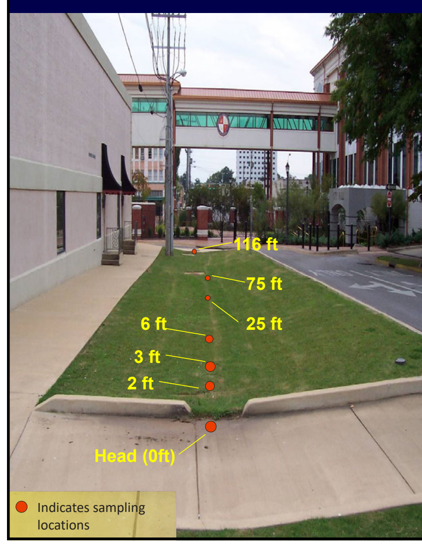
Outdoor Grass Swale Observations



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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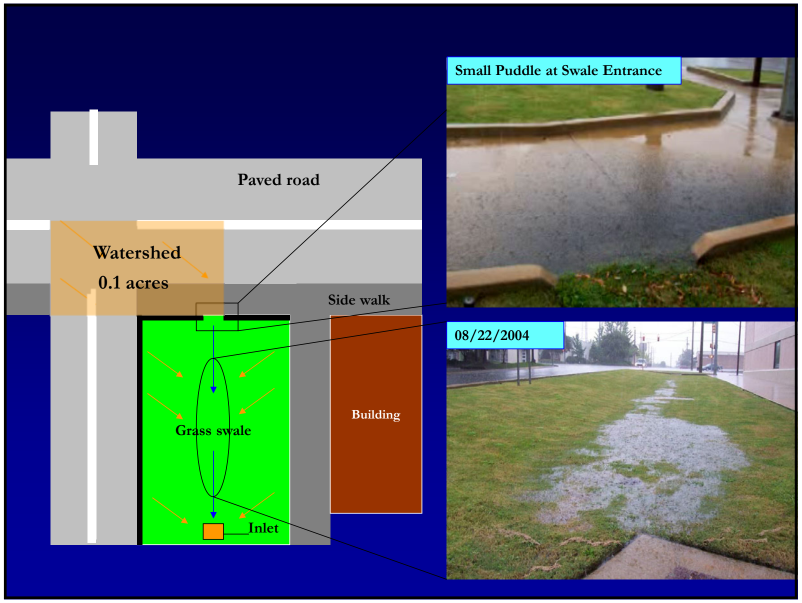
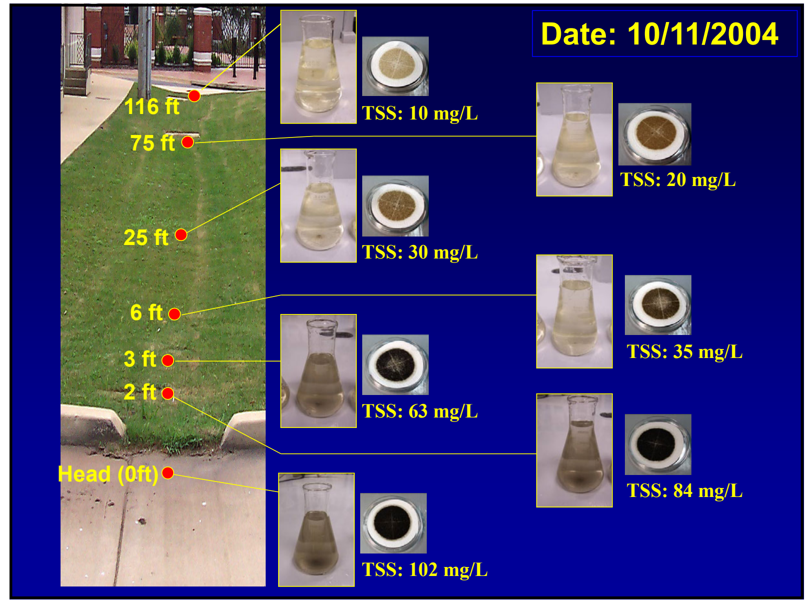

Small Puddle at Swale Entrance
Paved road
Watershed
0.1 acres
Side walk
08/22/2004
Grass swale
Building
Inlet

25


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

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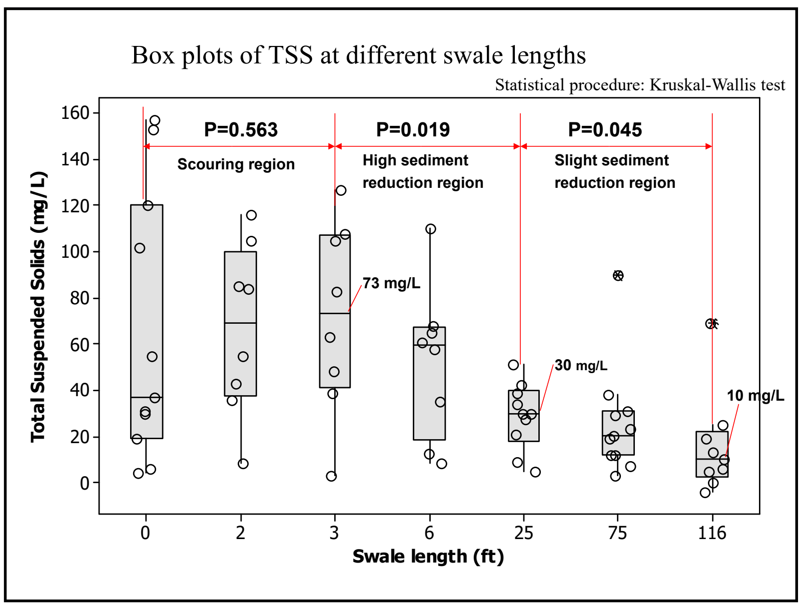
Box plots of TSS at different swale lengths
Statistical procedure: Kruskal-Wallis test
P=0.563
Scouring region
P=0.019
High sediment reduction region
P=0.045
Slight sediment reduction region
73 mg/L
30 mg/L
10 mg/L
Total Suspended Solids (mg/L)
Swale length (ft)

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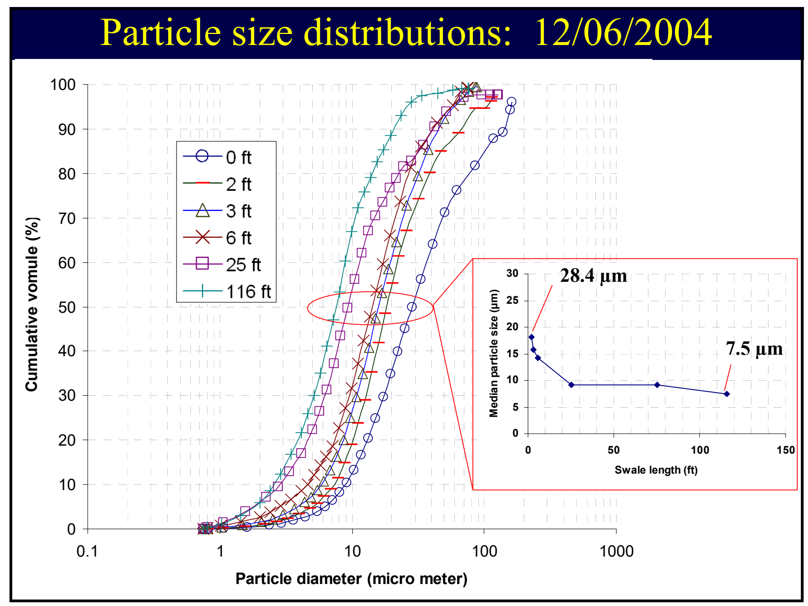
Particle size distributions: 12/06/2004
Cumulative vomule (%)
0 ft
2 ft
3 ft
6 ft
25 ft
116 ft
28.4 µm
7.5 µm
Median particle size (µm)
Swale length (ft)
Particle diameter (micro meter)

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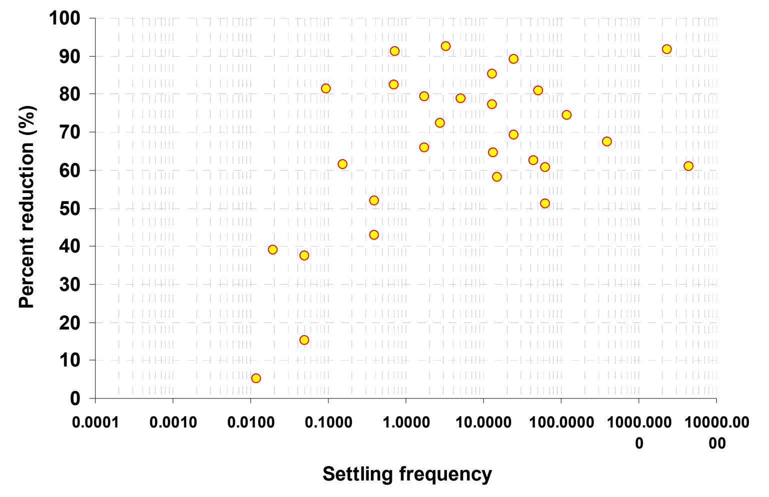
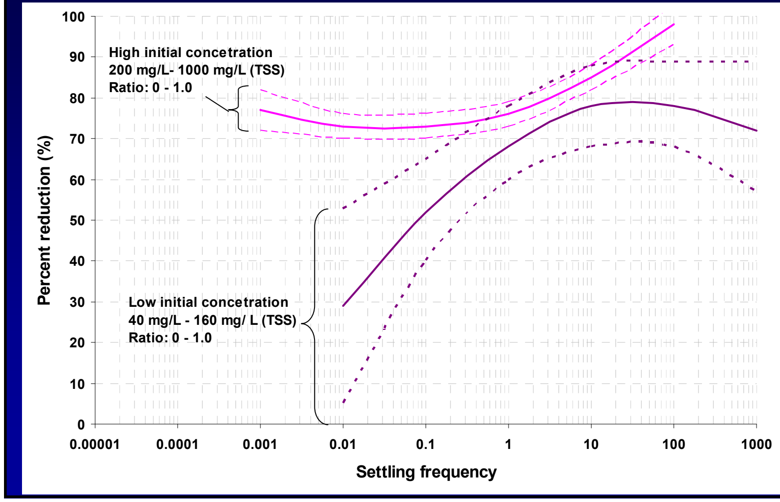
Particulate Transport in Outdoor Swale (6 rain events)

Percent reductions between 3ft and 25 ft vs. settling frequencies



Comparison of regression line with 95% CI from indoor experiments and outdoor observations



Example: Sediment Capture in Grass Swale

- the discharge rate is 29 ft^3/sec (0.80 m^3/sec) and the particulate solids influent concentration is 250 mg/L
- the channel bottom width is 5 ft (1.5 m) wide, with 3 (H) to 1 (V) side slopes
- the calculated normal depth is 0.7 ft (210 mm, 21 cm) and the velocity is calculated to be 5.8 ft/sec (1.8 m/sec) after mature vegetation is established
- the swale length for this area is 1,250 ft (378 m)

Water is assumed to enter the swale at the midpoint location, resulting in an effective treatment swale length of 625 ft (189 m). With a water velocity of 5.8 ft/sec (1.8 m/sec), the average travel time is 189 m/1.8 m/sec = 105 sec (1.8 m) for this length.

The mature grass is about 3 inches (75 mm) in height, so the flow depth to grass height ratio is 210 mm/75 mm = 2.8. The suspended solids concentration is determined to be 250 mg/L and the particle size distribution of the water entering the swale is typical.

Particle Size Range	Approx. % of Particulate Solids in Range	Particulate Concentration in Size Range
0.45 to 2 µm	0.5	1.3
2 to 5 µm	2.7	6.8
5 to 10 µm	9.2	23.0
10 to 30 µm	40.4	101.0
30 to 60 µm	21.8	54.4
60 to 106 µm	10.6	26.5
106 to 425 µm	14.8	37.0
Total:	100.0	250 mg/L

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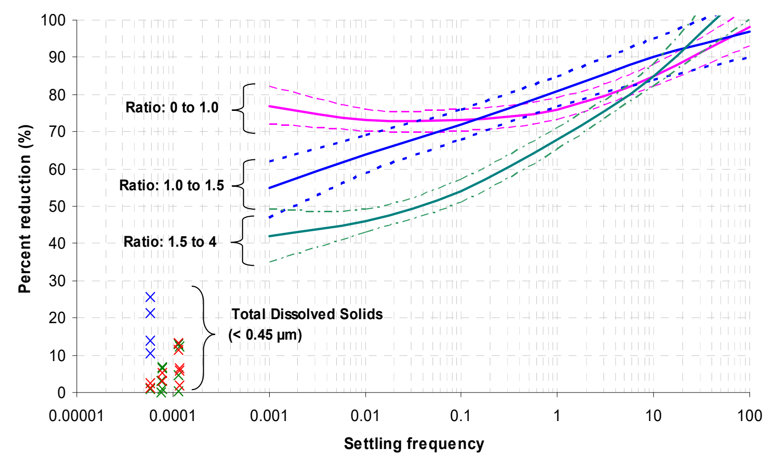

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Particle Size Range	Approx. Settling Rate (cm/sec)	Settling Time for 21 cm Flow Depth (sec)	Settling Frequency for Swale (105 sec travel time)	Percent Reduction in Size Range (median)
0.45 to 2 µm	1.52×10^{-4}	138,000	0.00076	42
2 to 5 µm	1.10×10^{-3}	19,000	0.0055	44
5 to 10 µm	5.05×10^{-3}	4,160	0.025	48
10 to 30 µm	3.59×10^{-2}	585	0.18	57
30 to 60 µm	0.182	115	0.91	68
60 to 106 µm	0.619	33.9	3.1	74
106 to 425 µm	6.22	3.38	31	96

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Particle Size Range (µm)	Influent Particulate Conc. in Size Range	Irreducible Conc. for Size Range (mg/L)	Particulate Conc. for Size Range after Swale (mg/L)	Final Resultant Conc. for Size Range (mg/L)
0.45 to 2	1.3	7	0.8	1.3
2 to 5	6.8	5	3.8	5
5 to 10	23.0	5	12.0	12.0
10 to 30	101.0	10	43.4	43.4
30 to 60	54.4	5	17.4	17.4
60 to 106	26.5	5	6.9	6.9
106 to 425	37.0	10	1.5	10

An overall 62% reduction in suspended solids concentration was achieved for this example (250 mg/L influent and 96 mg/L effluent).

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Conclusions

- Grass swales and grass filters can be an important component in conservation design.
- Grass swales can be designed to provide suitable storm drainage benefits and water quality benefits.
- Particulate trapping by "filtering" and sedimentation only occurs for relatively shallow flows, and is therefore most important for smaller events in swales. Infiltration (and associated pollutant trapping) may be more important for larger events. Monitoring results have confirmed excellent pollutant yield reductions in swales.
- Grass swales must be carefully designed to ensure adequate channel stability.