Treatment of Stormwater Toxicants

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Outline

- Critical source area sources of stormwater toxicants
- Characteristics and treatability of stormwater toxicants
- Bench-scale to full-scale treatment schemes
- MCTT
- UpFlow filter
- Advanced media studies review
- Conclusions
- Acknowledgements

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Critical Sources of Stormwater Toxicants

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- **Critical source area controls are important components of a comprehensive stormwater management program**
- **Pollution prevention, outfall controls, better site design, etc., are usually also neede**
- **In contaminated areas, infiltration should only be used cautiously, after pre-treatment to minimize groundwater contamination**

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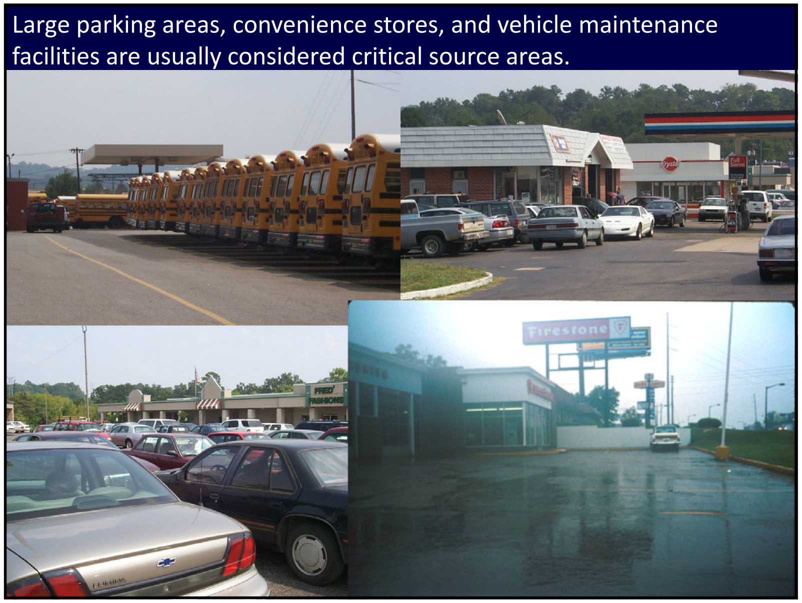
Large parking areas, convenience stores, and vehicle maintenance facilities are usually considered critical source areas.
Firestone

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Storage yards, auto junk yards, and lumber yards
Low Prices

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Runoff form landscaped areas and landscaping chemical storage and sales areas also important sources of nutrients and pesticides
FALL Prep Your LAWN
FALL FEED WINTERIZER

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along with industrial storage areas, loading docks, refueling areas, and manufacturing sites.

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Street Sampler
Concave PVC Cap, 2.54 cm Thick
Bottle Cap Attached to the Concave PVC Cap
1.59 cm hole
Coupling
0.946 liter Bottle
USGS and WI DNR

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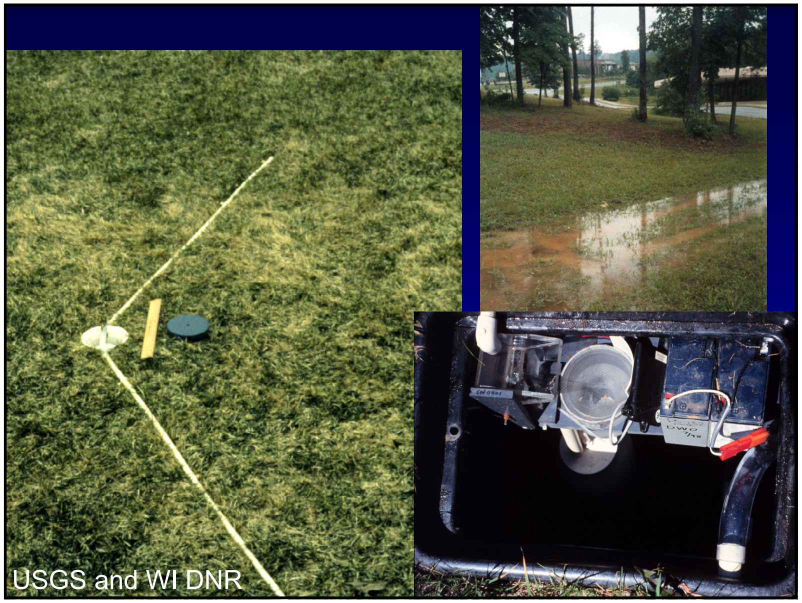

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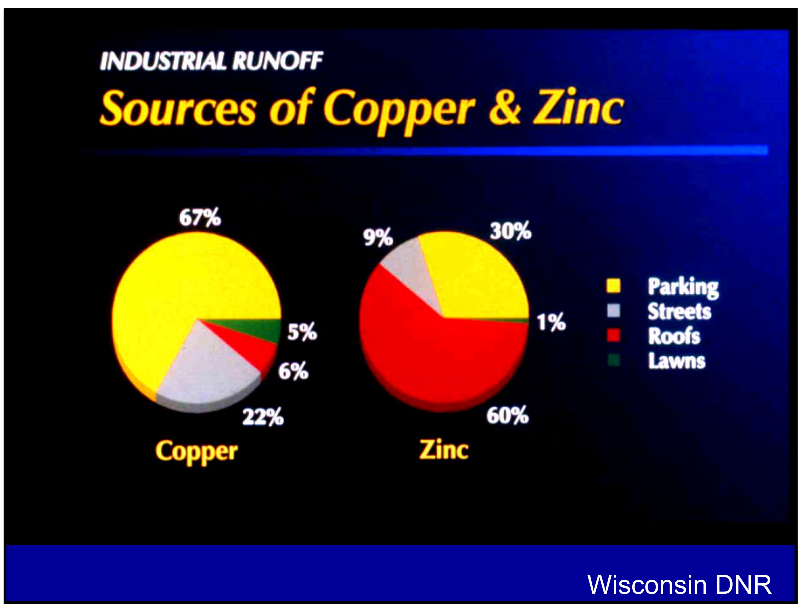

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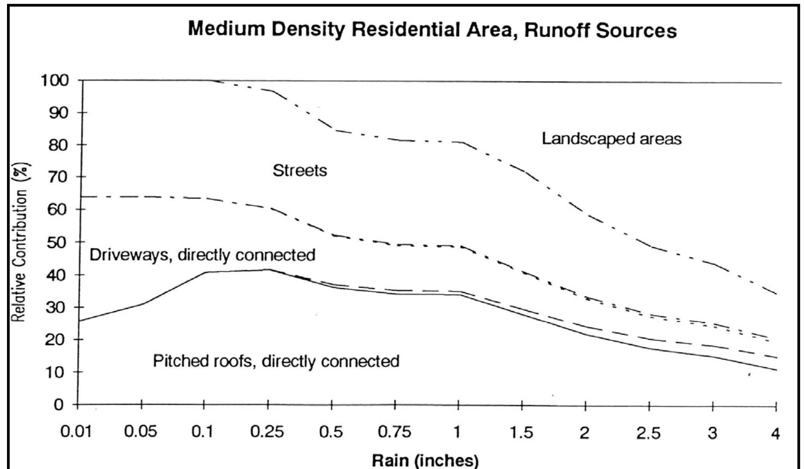

Directly connected impervious surfaces dominate flow sources during rains <0.5 inches

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

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Characteristics and Treatability of Stormwater Toxicants

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Treatability of Stormwater Toxicants and Bench-Scale Tests

- Particle size distributions
- Pollutant strengths of different sized particulates
- Sequential digestions and extractions to determine forms of metals and organics
- Bench-scale treatability tests (settling columns, aeration, photodegradation by different wavelengths, precipitation, sorption, ion exchange, etc.

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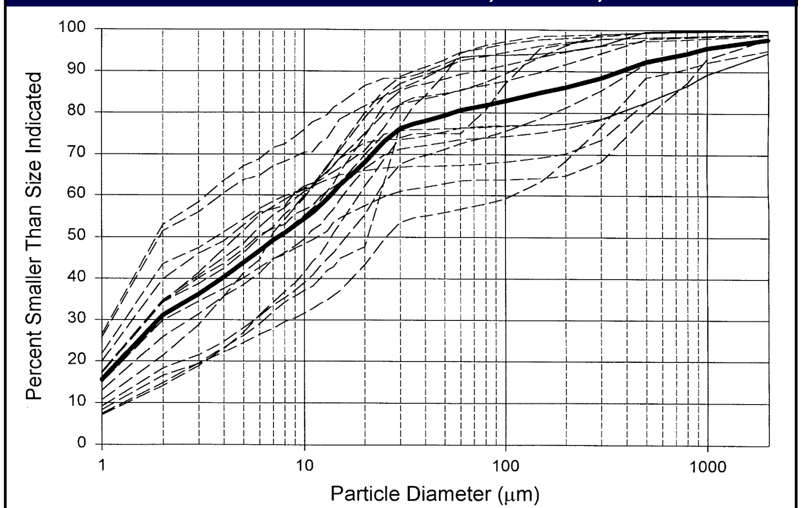
Measured Particle Sizes, Including Bed Load Component, at Monroe St. Detention Pond, Madison, WI



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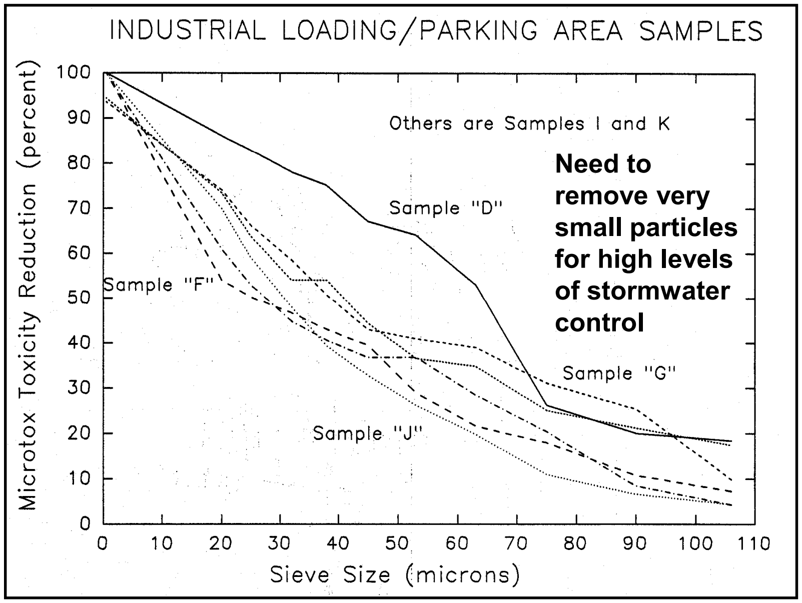

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High levels of pollutant reduction require the capture of very fine particulates, and likely further capture of "dissolved" pollutant fractions.

	Percent Pollutant Reduction after Removing all Particulates Greater than Size Shown			
	20 µm	5 µm	1 µm	0.45 µm
Total Solids	40%	43%	52%	53%
Suspended Solids	76	81	98	100
Turbidity	43	55	92	96
Total-P	68	82	89	92
Total-N	30	41	35	23
Nitrate	0	0	12	17
Phosphate	71	78	81	88
COD	48	52	52	47
Ammonia	35	46	54	58
Cadmium	20	22	22	22
Chromium	69	81	82	84
Copper	26	34	34	37
Iron	52	63	95	97
Lead	41	62	76	82
Zinc	64	70	70	72

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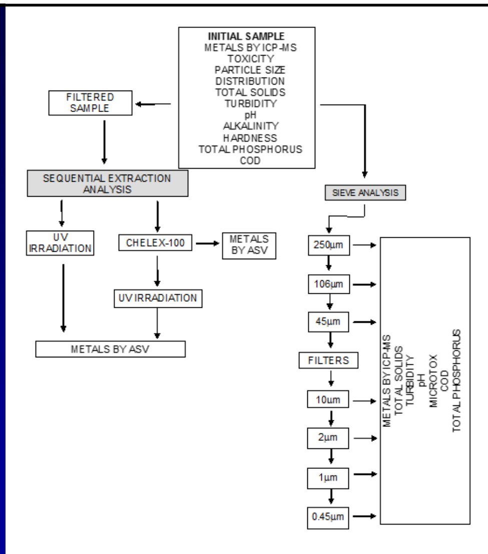
Analytical scheme used by Morquecho to determine pollutant associations with particle size, colloids, and organic complexes (samples always split using USGS/Decaport cone splitter)



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Filterable forms of the metals determine their ability to be removed using ion exchange or sorption methods (higher valence ionic forms easiest to remove, large organic-metal complexes are difficult to remove)

	Filterable metal percentage in ionic forms	Filterable metal percentage bound in organic complexes
Zinc	15	85
Copper	70	30
Cadmium	10	90
Lead	12	88

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These ratios vary for different samples and sources.

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Fugacity Modeling

- Fugacity equilibrium models (several levels available) (Mackay, *et al.* 1992) were used for predicting the phase partitioning of selected PAHs for comparison with observed partitioning.
- Equations used in the fugacity Level 1 modeling included:

Fugacity, $f = \frac{M}{\sum (V_i * Z_i)}$

Where, Z_i = fugacity capacities of air, water, sediment, SS, and fish for i =1, 2, 3, 4, and 5 respectively

$Z_1 = \frac{1}{RT}$ $\quad Z_2 = \frac{1}{H}$ $\quad Z_3 = Z_2 * P_3 * \phi_3 * \frac{K_{OC}}{1000}$ $\quad Z_4 = Z_2 * P_4 * \phi_4 * \frac{K_{OC}}{1000}$ $\quad Z_5 = Z_2 * P_5 * L * \frac{K_{OW}}{1000}$

Where, R = gas constant (8.314 J/mol K), T = absolute temperature (K), H= Henry's law constant (Pa.m3/mol), K_{OC} = Organic-water partition coefficient, K_{OW} = Octonal-water partition coefficient, P = density of phase (kg/m3), Ø= organic fraction of in the phase, L= Lipid content of fish.

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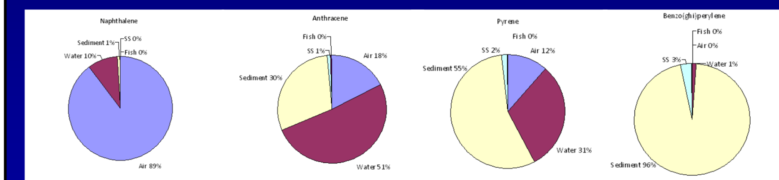
Fugacity Modeling

- Model predications indicated that high molecular weight PAHs are predominately partitioned with sediments, while low molecular weight PAHs are predominant in the air and water phases. Most of the 13 PAHs investigated during this study were HMW PAHs and therefore more associated with particulates.
- HMW PAHs indicate pyrogenic (combustion) sources.
- LMW PAHs indicate petrogenic (oil) sources.



Molecular Weight: 128 | Molecular Weight: 178 | Molecular Weight: 202 | Molecular Weight: 276

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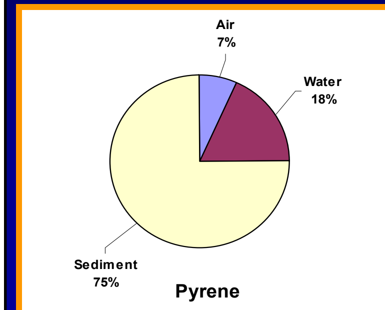
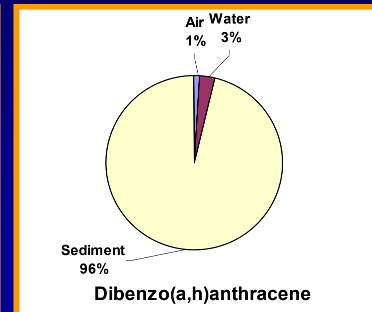
Fates of Stormwater PAHs

- Most of the PAHs partition into the sediment and water phases, with sediment being the dominant phase
- High organic content of particulate matter increases particulate-bound fraction of most PAHs





Examples of fugacity partitioning calculation results, verified by field investigations

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Observed PAH Associations with Stormwater Particulates (MCTT Treatability Tasks)

PAH	% Association	
	Water	Particulate Matter
Naphthalene	22	78
Fluorene	3	97
Phenanthrene	2	99
Anthracene	8	92
Fluoranthene	29	71
Pyrene	19	81
Benzo(a)anthracene	3	99
Chrysene	1	99
Benzo(b)fluoranthene	1	99
Benzo(k)fluoranthene	2	98
Benzo(ghi)perylene	1	99
Benzo(a) pyrene	1	99

The fugacity modeling generally under-predicted the particulate bound fractions, but was very useful in identifying significant factors affecting the partitioning.

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Settling and Scour of Stormwater Particulates

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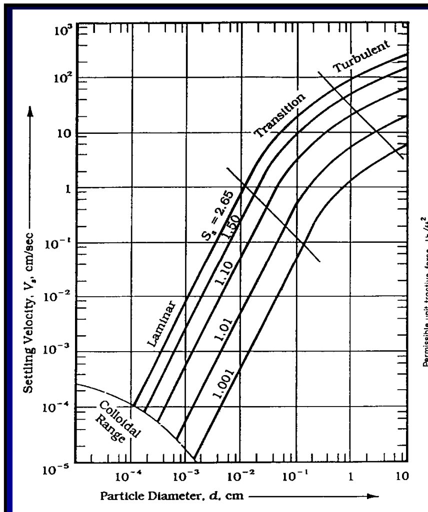
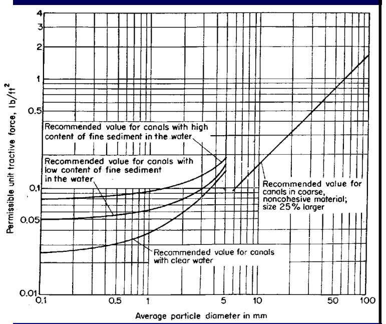


Traditional methods can be used to calculate settleability of stormwater particulates and scour of previously settled material.



Settling velocity of discrete particulates as a function of size and specific gravity (Reynolds and Richards 1996)

Erodibility of previously settled material based on size and shear stresses (Chow 1959)

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Specific Gravity and Volatile Solids of Sediment Collected from Stormwater Treatment Device

Sieve size range (um)	Average Specific Gravity (g/cc)	Average Volatile Solids (%)
Large organic matter (mostly sticks and leaves)	0.84	81.2
>2800	0.66	70.9
1400 - 2800	1.15	57.8
710-1400	1.43	42.7
355-710	2.56	26.1
180-355	2.76	19.4
75-180	2.97	20.6
45-75	3.30	25.7
<45 (Pan)	3.46	26.0

Specific gravity decreases as the volatile solids content increases; larger particle sizes have lower specific gravity and greater volatile solids as they contain larger amounts of light-weight organic debris for these industrial area stormwater sediment samples. Their settling rates are still large due to their large sizes. 30

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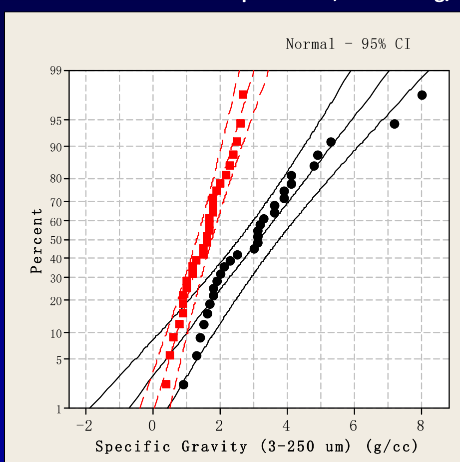
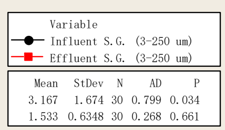
Changes in Specific Gravity with Sedimentation Treatment at an Industrial Site

Influent: 5th to 95th percentile, 1.3 to 6 g/cc (median: 3.2 g/cc)
Effluent: 5th to 95th percentile, 0.5 to 2.3 g/cc (median: 1.5 g/cc)





Preferential removal of higher specific gravity materials results in a shift to lower overall specific gravity of particulates in effluent water (and greater migration distance in receiving water after discharge).

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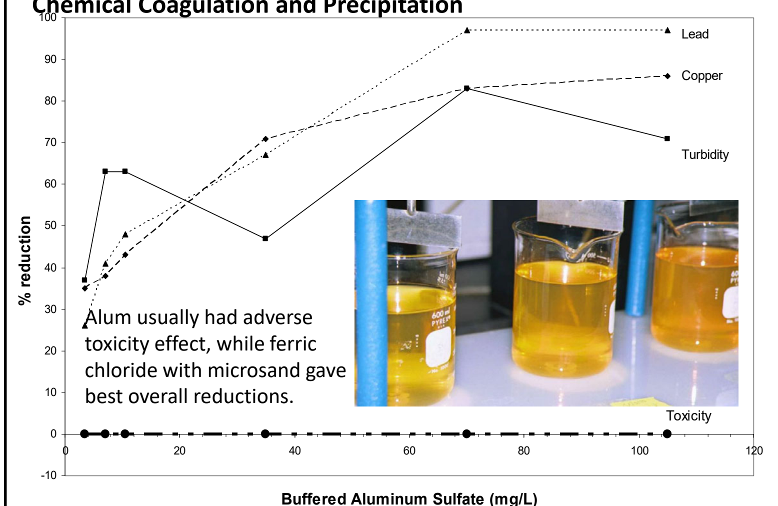
Example Stormwater Turbidity, Lead and Copper Reductions using Chemical Coagulation and Precipitation



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Bench-scale to Full-scale Treatment Schemes

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Design Modifications to Enhance Control of Toxicants in Stormwater Controls and Pilot-Scale Tests

- Capture of fine particulates
- Photo-degradation (enhanced vertical circulation, but not complete mixing that can scour sediments)
- Aeration
- Floatation (subsurface discharges) to increase trapping of floating litter

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Development of Stormwater Control Devices

- Multiple treatment processes can be incorporated into stormwater treatment units sized for various applications.
  - Gross solids and floatables control (screening)
  - Capture of fine solids (settling or filtration)
  - Control of targeted dissolved pollutants (sorption/ion exchange)

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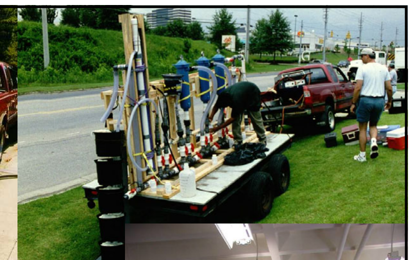

Some laboratory and field pilot-scale test setups (EPA and WERF-supported research at Univ. of Alabama). Critical that tests use actual stormwater, not artificial mixtures.

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Development and Testing of
Treatment Methods

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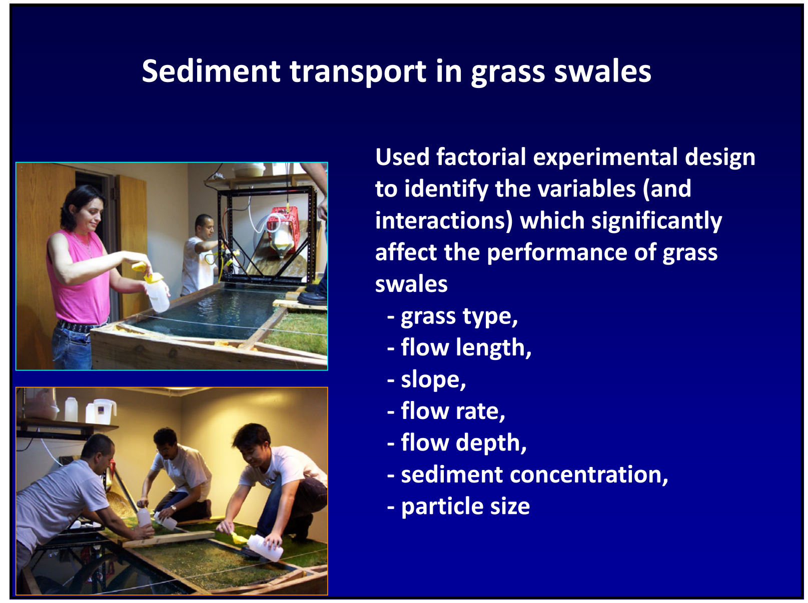
Sediment transport in grass swales
Used factorial experimental design to identify the variables (and interactions) which significantly affect the performance of grass swales
- grass type,
- flow length,
- slope,
- flow rate,
- flow depth,
- sediment concentration,
- particle size

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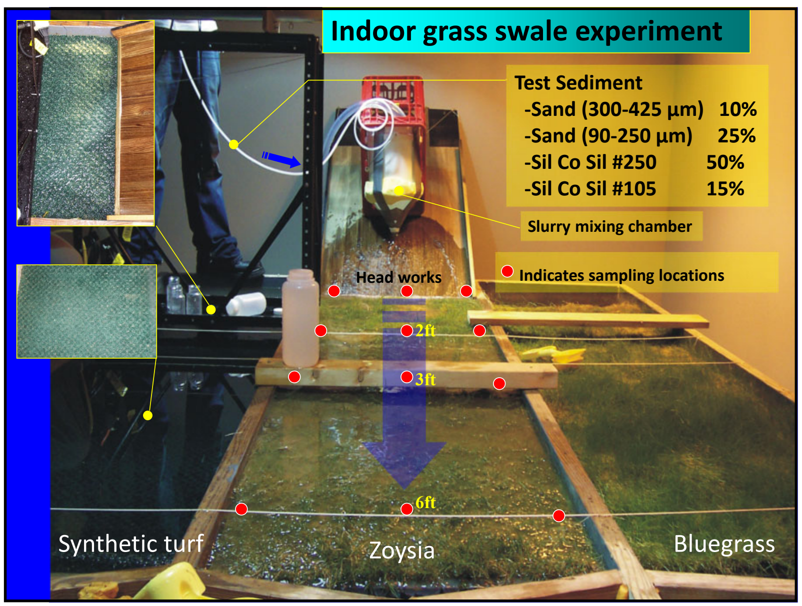
Indoor grass swale experiment
Test Sediment
-Sand (300-425 µm) 10%
-Sand (90-250 µm) 25%
-Sil Co Sil #250 50%
-Sil Co Sil #105 15%
Slurry mixing chamber
Head works
Indicates sampling locations
2ft
3ft
6ft
Synthetic turf
Zoysia
Bluegrass

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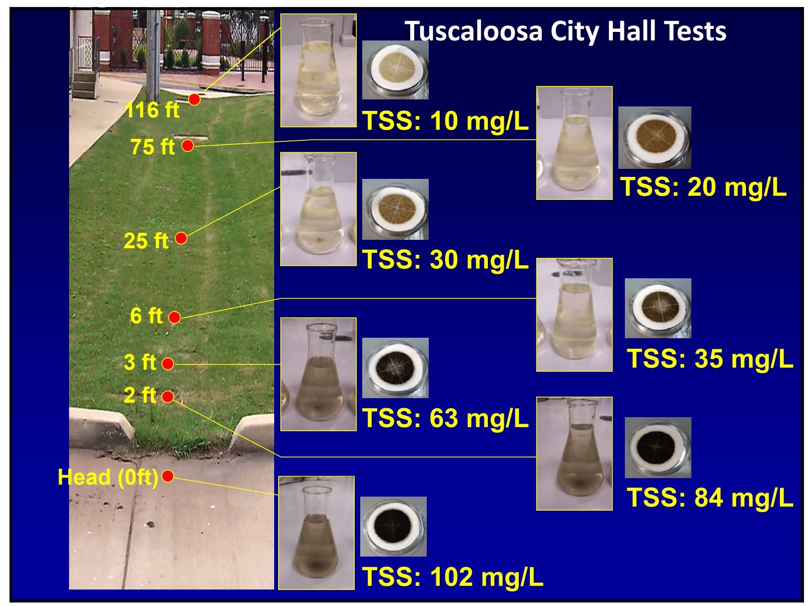
Tuscaloosa City Hall Tests
116 ft
75 ft
25 ft
6 ft
3 ft
2 ft
Head (0ft)
TSS: 10 mg/L
TSS: 20 mg/L
TSS: 30 mg/L
TSS: 35 mg/L
TSS: 63 mg/L
TSS: 84 mg/L
TSS: 102 mg/L

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Laboratory Media Studies

- Rate and Extent of Metals Capture
  - Capacities (partitioning)
  - Kinetics (rate of uptake)
- Effect of pH & pH changes due to media, particle size, interfering ions, etc
- Packed bed filter studies
- Physical properties and surface area determinations

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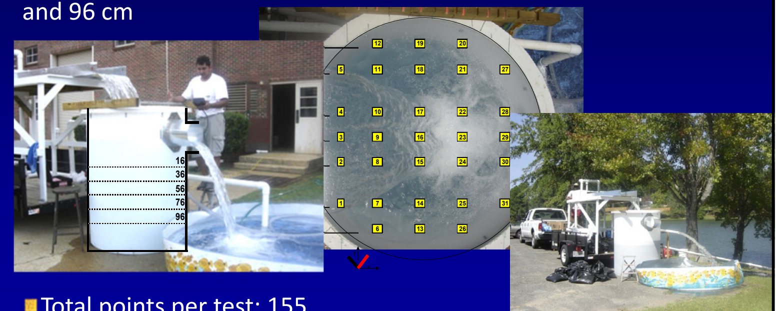
Scour of Captured Sediment in Storm Drain Catchbasin Inlets

- Three flow rates: 10, 5, and 2.5 LPS (160, 80, and 40 GPM)
- Velocity measurements (Vx, Vy, and Vz)
- Five overlying water depths above the sediment: 16, 36, 56, 76, and 96 cm



- Total points per test: 155
- 30 instantaneous velocity measurements at each point

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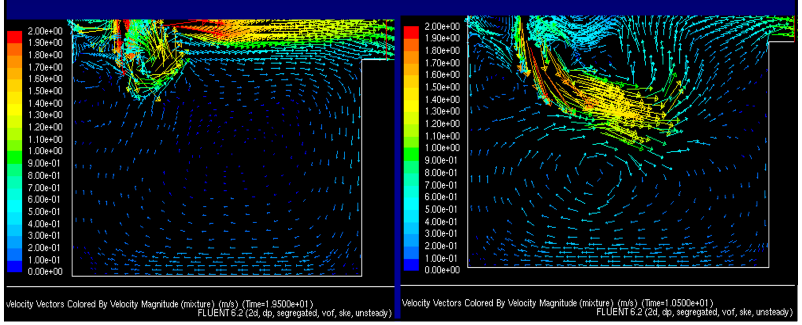
CFD Modeling to Calculate Scour/Design Variations

- Used CFD (Fluent 6.2 and Flow 3D) to determine scour from stormwater controls; results being used to expand WinSLAMM analyses after verification with full-scale physical model
- This is an example of the effects of the way that water enters a sump on the depth of the water jet and resulting scour



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Multi-Chamber Treatment Train (MCTT) and UpFlow Filter

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Development and Testing of Full-Scale Controls Targeting Stormwater Toxicants

- The Multi Chamber Treatment Train (MCTT)
- Up-Flow filter
- Advanced media tests for soil amendments and bioretention

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Multi Chamber Treatment Tank (MCTT)

- Developed under support of the US EPA to provide treatment before stormwater infiltration
- In the public domain, not commercialized
- Targets organic and metallic toxicants
- Very high levels of control through multiple treatment unit processes
- Relatively slow treatment flow rate
- An underground treatment device

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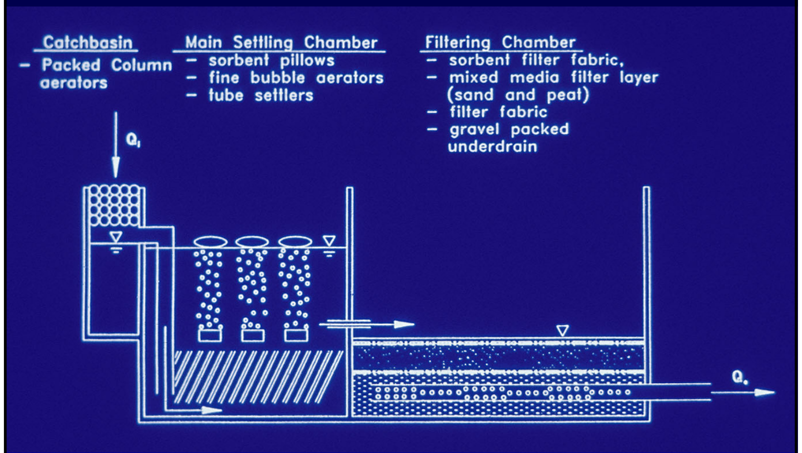
MCTT Cross-Section



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Example MCTT Main Settling Chamber Sizes

- (all 48 hours holding times, except as noted)

City	Annual Rain Depth (in)	Runoff Capacity (in) for 70% Toxicant Control	Runoff Capacity (in) for 90% Toxicant Control
Phoenix, AZ	7	0.25 (24 hours)	0.35
Los Angeles, CA	15	0.30	0.45
Madison, WI	31	0.32	0.52
Buffalo, NY	38	0.35	0.50
Seattle, WA	39	0.25	0.40
Portland, ME	44	0.42	0.72
Birmingham, AL	55	0.37	0.53
New Orleans, LA	60	0.80	0.92

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Milwaukee, WI, Ruby Garage Public Works Yard MCTT

- The Milwaukee MCTT is at a public works yard and serves about 0.1 ha (0.25 acre) of pavement.
- This MCTT was designed to withstand very heavy vehicles driving over the unit.
- The estimated cost was $54,000 (including a $16,000 engineering cost), but the actual total capital cost was $72,000. The high cost was due to uncertainties associated with construction of an unknown device by the contractors and because it was a retro-fit installation.

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Milwaukee, WI, Ruby Garage Maintenance Yard Drainage Area

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Milwaukee, WI, Ruby Garage Maintenance Yard MCTT Installation

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Milwaukee, WI, Ruby Garage Inlet Chamber

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Milwaukee, WI, Ruby Garage Main Settling Chamber

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Minocqua, WI, MCTT Test Area

- The Minocqua MCTT test site is a 1 ha (2.5 acre) newly paved parking lot for a state park and commercial area.
- The installed capital cost of this MCTT was about $95,000.
- 3.0 m X 4.6 m (10 ft X 15 ft) box culverts used for the main settling chamber (13 m, or 42 ft long) and the filtering chamber (7.3 m, or 24 ft long).
- These costs are about equal to the costs of installation of porous pavement (about $40,000 per acre of pavement).

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Minocqua, WI, MCTT Installation

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Minocqua, WI, MCTT Inlet Chamber

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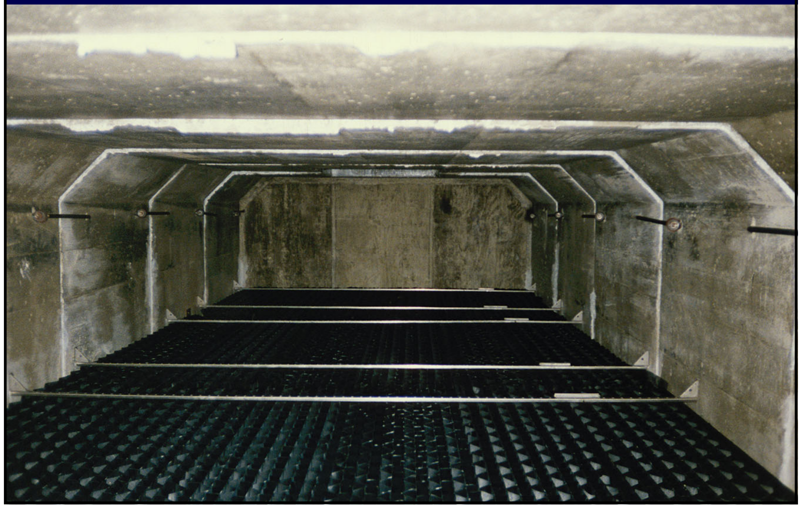
Minocqua, WI, MCTT Sedimentation Chamber



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Minocqua, WI, MCTT Filter Chamber

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Caltrans MCTT Test Installations

Part of the Caltrans stormwater monitoring project in Los Angeles County, CA. Both drainage areas are 100% impervious. The MCTTs comprise about 1.3 to 1.5 % of the drainage areas.

	Drainage Area, ha (acres)	Sedimentation Basin Area, m^2 (ft^2)	Filter Basin Area, m^2 (ft^2)
Via Verde	0.44 (1.1)	35.5 (380)	17.4 (190)
Lakewood	0.76 (1.9)	61.2 (660)	32.9 (350)

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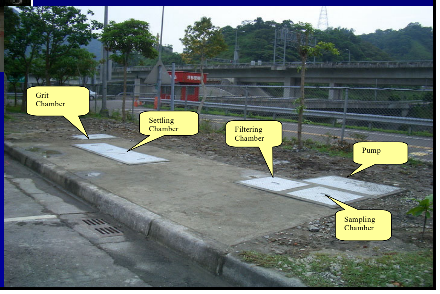
MCTT Installation, Above Ground View, Taipei County, Taiwan



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Maintenance of MCTT Units

- Major maintenance items for MCTTs include removal of sediment from the sedimentation basin when the accumulation exceeds 150 mm (6 in.) and removing and replacing the filter media about every 3 years.
- After two wet seasons, the total accumulated sediment depth at the Caltrans installations was less than 25 mm (1 in.), indicating that sediment removal may not be needed for about 10 years.

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Median Observed Percentage Changes in Constituent Concentrations

Constituent	Main Settling Chamber	Sand/Peat Chamber	Overall Device
Toxicants			
Microtox™ (uf)	18	70	96
Microtox™ (f)	64	43	98
lead	89	38	100
zinc	39	62	91
N-nitroso-di-N-propylamine	82	100	100
hexachlorobutadiene	72	83	34
pyrene	100	n/a	100
bis (2-ethylhexyl) phthalate	99	-190	99

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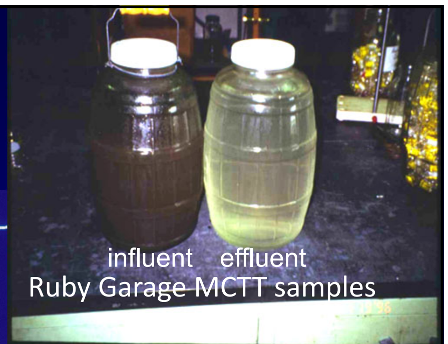
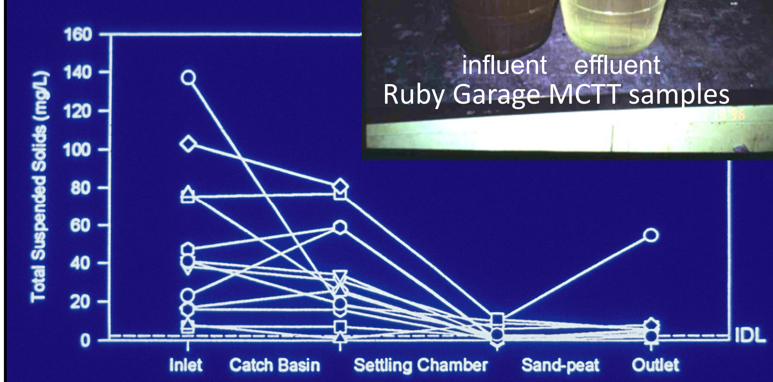
Pilot-Scale MCTT Test Results





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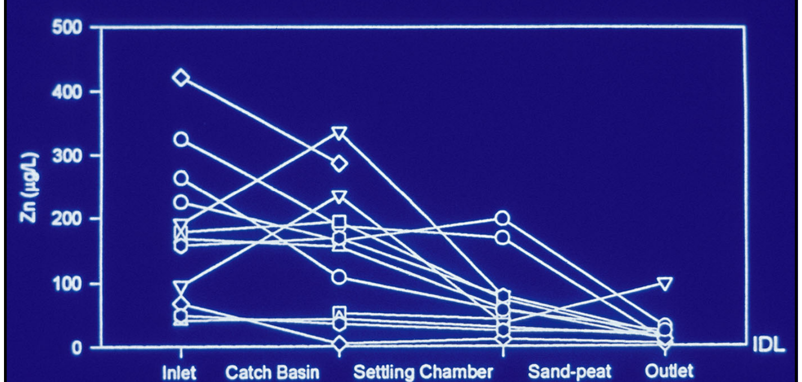
Pilot-Scale Test Results



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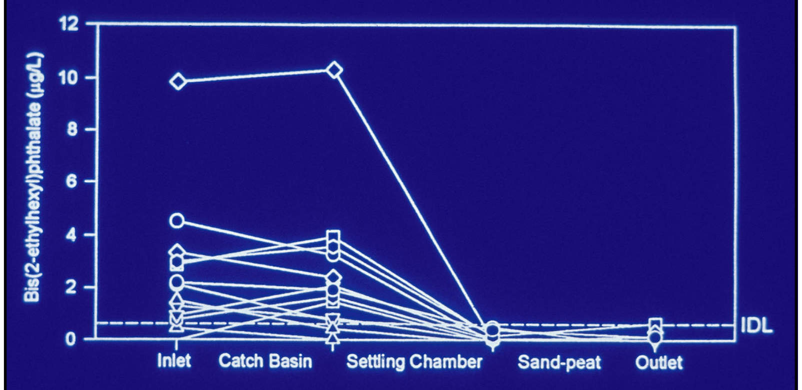
Pilot-Scale Test Results



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Wisconsin Full-Scale MCTT Test Results

(median % reductions and median effluent quality)	Milwaukee (15 events)	Minocqua (7 events)
Suspended Solids	>98 (<5 mg/L)	85 (10 mg/L)
Phosphorus	88 (0.02 mg/L)	>80 (<0.1 mg/L)
Copper	90 (3 µg/L)	65 (15 µg/L)
Lead	96 (1.8 µg/L)	nd (<3 µg/L)
Zinc	>91 (<20 µg/L)	90 (15 µg/L)
Benzo (b) fluoranthene	>95 (<0.1 µg/L)	>75 <0.1 µg/L)
Phenanthrene	>99 (<0.05 µg/L)	>65 (<0.2 µg/L)
Pyrene	>98 (<0.05 µg/L)	>75 (<0.2 µg/L)

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UpFlow Filter

- High level treatment at high treatment flow rates
- Retrofit at standard inlet locations
- Minimum clogging
- Multiple and complimentary treatment unit processes
- Developed as part of the US EPA Small Business Innovative Research program and commercialized by HydroInternational

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	Flow Rate Needed for Different Levels of Annual Flow Treatment (gpm/acre pavement)		
Location	**50%**	**70%**	**90%**
Seattle, WA	10	18	30
Portland, ME	18	30	53
Milwaukee, WI	20	35	65
Phoenix, AZ	20	35	90
Atlanta, GA	25	40	100

The UpFlow filter has a treatment flow rate of about 20 gpm per filter module, or about 120 gpm for a unit with six modules.

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Upflow filter insert for catchbasins

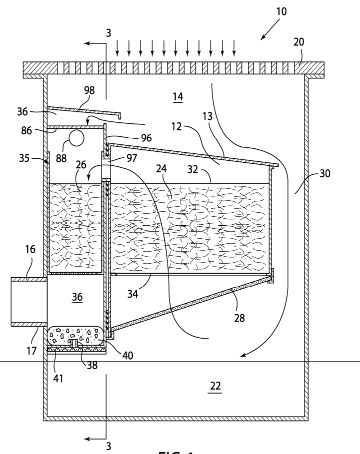

FIG. 1

Upflow Filter™ patented

Main features of the MCTT can be used in smaller units.

The Upflow Filter™ uses sedimentation (22), gross solids and floatables screening (28), moderate to fine solids capture (34 and 24), and sorption/ion exchange of targeted pollutants (24 and 26).

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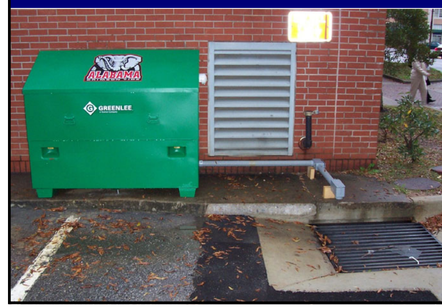
Pilot-Scale Field Monitoring

- Data collected through extensive field testing by the University of Alabama
- No chemical exhaustion of media after 12 months of field testing
- Greater than 70% removal of particulate metals & nutrients and fine SSC in filter and another 10% capture of SSC in the sump
- SSC removal down to 1 micron particles



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Suspended Solids Removal Tests

Media (each bag)	Flow (gpm)	Influent SS Conc. (mg/L)	Average Effluent SS Conc. (mg/L)	% SS reduc.
Zeo+ Zeo	High (21)	480	75	84
Zeo+ Zeo	Mid (10)	482	36	92
Zeo+ Zeo	Low (6.3)	461	16	97
Mix + Mix	High (27)	487	75	85
Mix + Mix	Mid (15)	483	42	91
Mix + Mix	Low (5.8)	482	20	96

Zeo: Manganese-coated zeolite
Mix: 45% Mn-Z, 45% bone char, 10% peat moss

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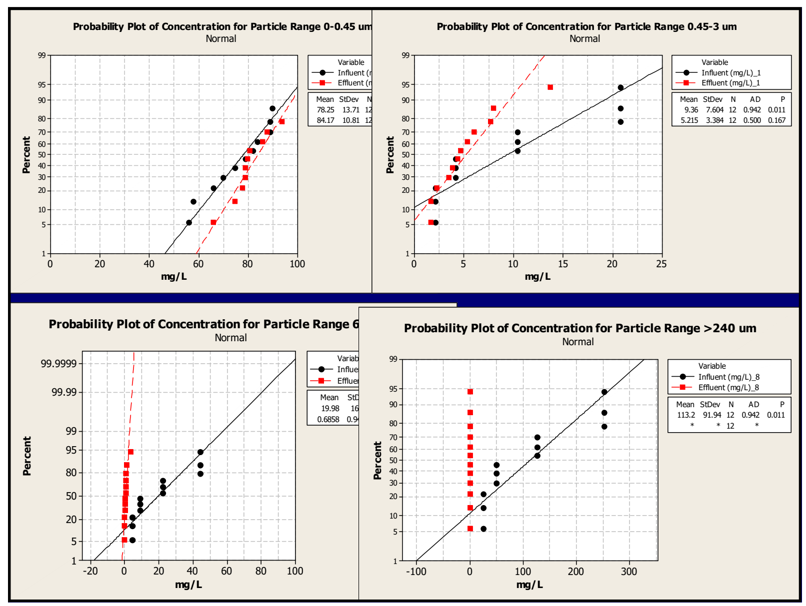

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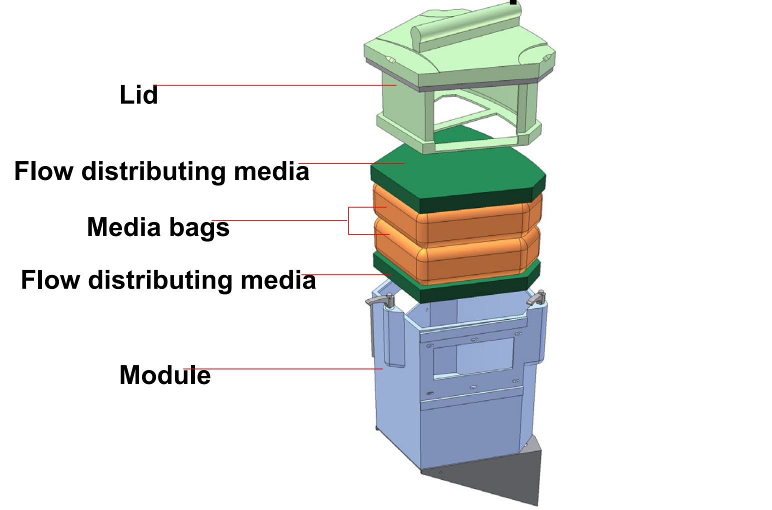
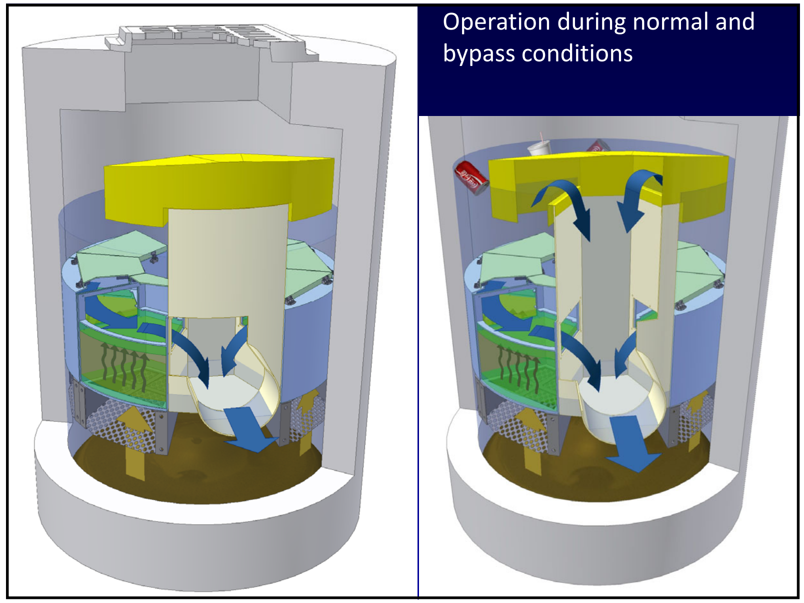
Filter Module Components



73



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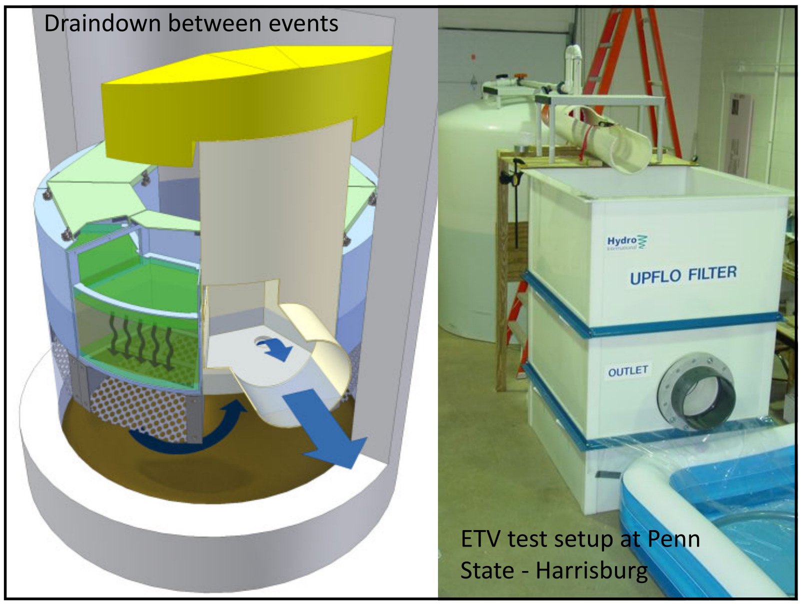

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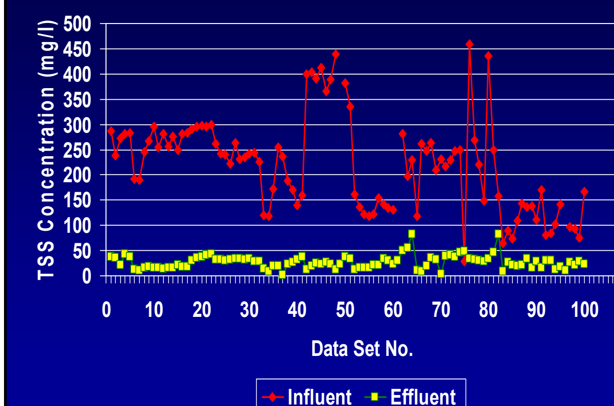
Preliminary Test Data



Data Set No:	Media
1 - 41	CPZ
42 -49	Perlite
50 -61	Sand & Perlite
62 - 71	Mycelex
72 - 81	CPS
82 - 107	CPZ (ETV Phase 1)

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Full-Scale Setup in Tuscaloosa, AL

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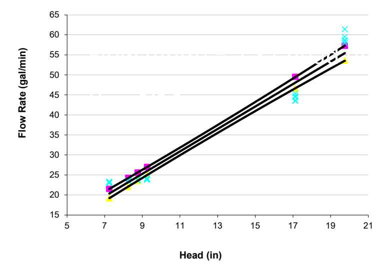
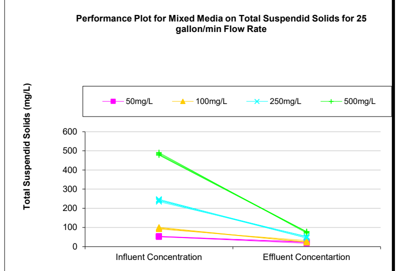
Results of Full-Scale Field Installation (controlled tests)





25 gallon/min Flow Rate and 100 mg/L Conc.

Particle Size (µm)	Influent Conc. (mg/L)	Effluent Conc. (mg/L)	Reduction (%)
< 0.45	220	160	27
0.45 to 3	5.2	1.1	78
3 to 12	19	11	38
12 to 30	26	8.3	68
30 to 120	16	1.3	92
120 to 1180	28	0.18	99
> 1180	5.7	0	100
sum >0.45 µm	99	21.9	78

25 gallon/min Flow Rate and 500 mg/L Conc.

Particle Size (µm)	Influent Conc. (mg/L)	Effluent Conc. (mg/L)	Reduction (%)
< 0.45	240	120	49
0.45 to 3	26	3.2	88
3 to 12	92	32	65
12 to 30	130	28	79
30 to 120	81	3.9	95
120 to 1180	142	0.55	100
> 1180	30	0	100
sum >0.45 µm	500	67.7	86

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Advanced Media Studies Review

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Evaluation of Media for Soil Amending and Biofiltration

- Different media can be used to target different categories of contaminants
- Fine particulate removal is the most critical as most stormwater toxicants are associated with the solids
- However, significant portions can be associated with the filterable phases and media mixtures can be optimized

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Tests on media filtration

- Batch kinetic tests to estimate expected capacity and uptake rate
- Full-depth, long-term column tests to measure removal and maintenance
- Vary-depth column tests to measure effects of contact time on removal
- Aerobic and anaerobic exposure tests to examine interevent leaching of previously captured materials

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Media Tested

Media	Description
Granular Activated Carbon (GAC)	VCC 8X30 Virgin Coconut Shell Activated Carbon (Baker Corp.); 29 lbs/ft^3 (1.8 to 2.1 g/cm^3); $0.98/lb
Rhyolite Sand	D1 biofilter media sand (Rhyolite Topdressing Sand) from Golf Sand, Inc., North Las Vegas, NV;75 in/hr infiltration rate; particle density 2.38 g/cm^3; bulk density 1.28 g/cm^3; 98.6% sand, 1.1% silt, 0.3% clay; 45.4% greater than 0.25 mm; 44.6% between 0.18 and 0.25 mm.
Site Zeolite	Z-200 Modified Zeolite (Baker Corp.); $1.36/lb
Surface Modified Zeolite	14-40 Saint Cloud Zeolite with 325 µm Modified Zeolite at 3% Vol:Vol
Sphagnum Peat Moss	Purchased from nursery in Elizabethtown, PA
Site Sand	Fine textured silica sand

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Conclusions

Constituent and units	Typically reported irreducible concentrations (conventional high-level stormwater treatment)	Effluent concentrations possible with treatment train using sedimentation along with sorption/ion exchange
Particulate solids (mg/L)	10 to 45	<5 to 10
Phosphorus (mg/L)	0.2 to 0.3	0.02 to 0.1
TKN (mg/L)	0.9 to 1.3	0.8
Cadmium (µg/L)	3	0.1
Copper (µg/L)	15	3 to 15
Lead (µg/L)	12	3 to 15
Zinc (µg/L)	37	<20
PAHs (µg/L)	10 to 100	<1 to 5

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