Advanced 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

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Sources of Stormwater Toxicants

- Source area monitoring to characterize pollutant concentrations from different source areas in different land uses for different rains
- Model calibration (WinSLAMM) and use to calculate source contributions for different development scenarios and rain characteristics (and to model the benefits of different control options)

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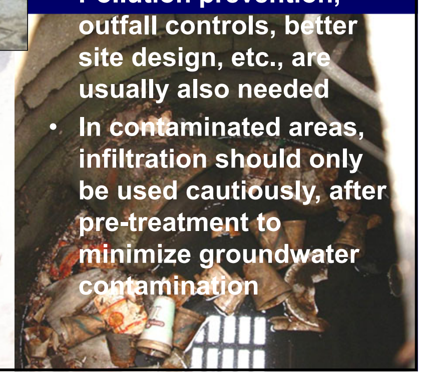

- Critical source area controls are important components of a comprehensive stormwater management program
- Pollution prevention, outfall controls, better site design, etc., are usually also needed
- In contaminated areas, infiltration should only be used cautiously, after pre-treatment to minimize groundwater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

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

5


Low Prices
$1 50
Storage yards, auto junk yards, and lumber yards

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7


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

8


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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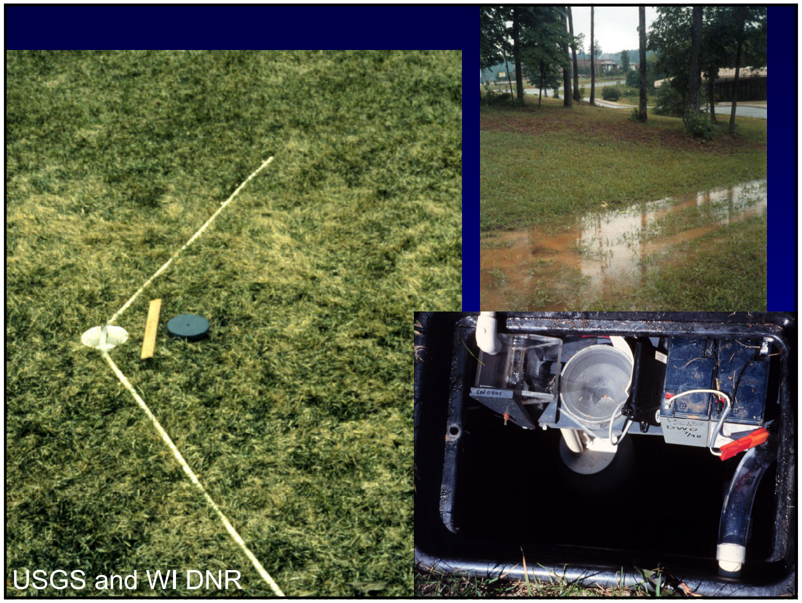

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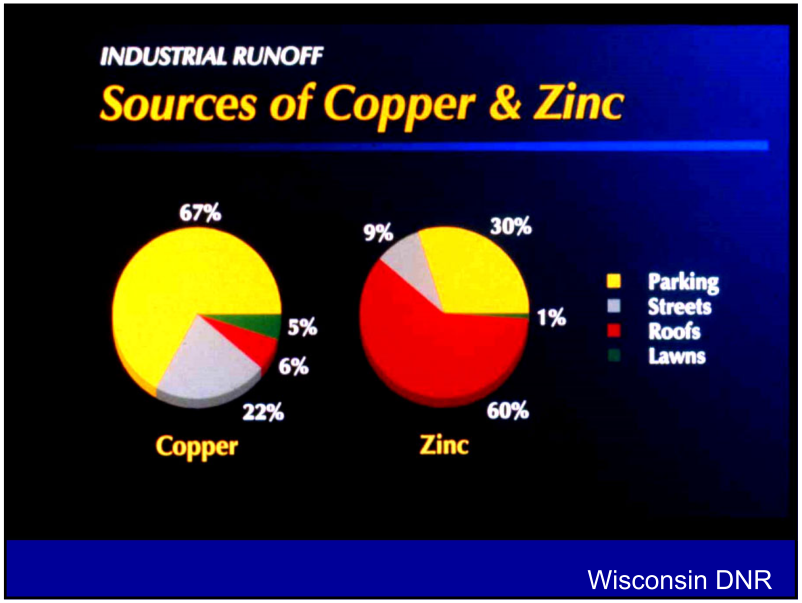

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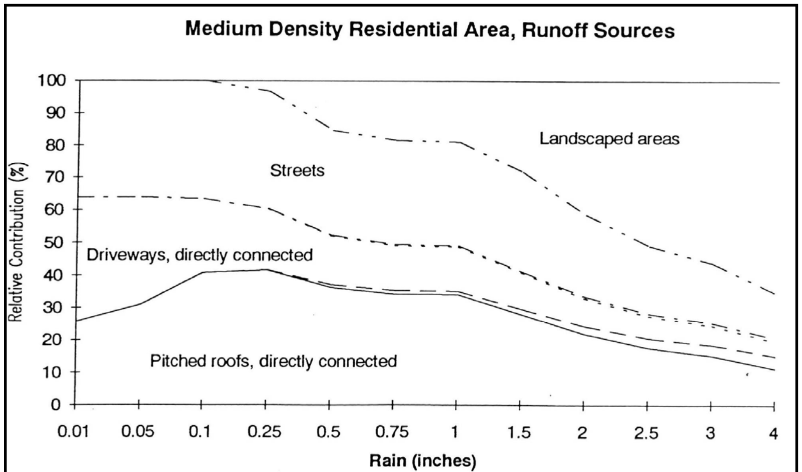

Directly connected impervious surfaces dominate flow sources during rains <0.5 inches
Disturbed urban soils can become very important runoff source areas during larger rains

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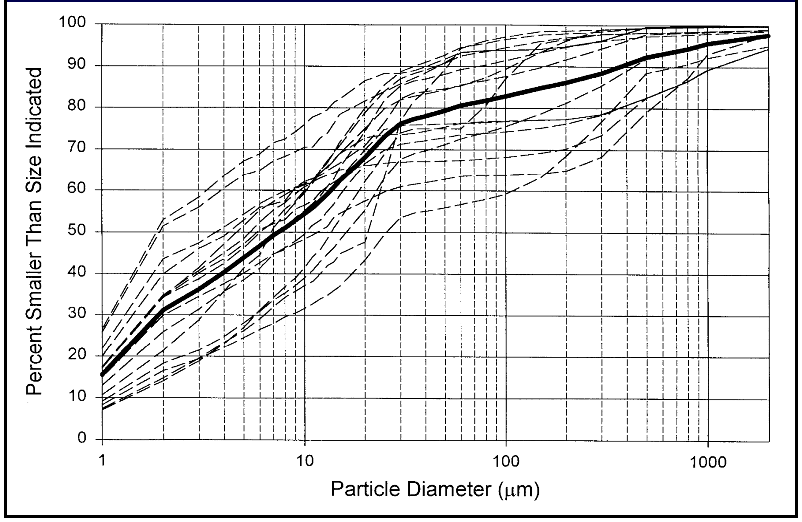
Measured Particle Sizes, Including Bed Load Component, at Monroe St. Detention Pond, Madison, WI



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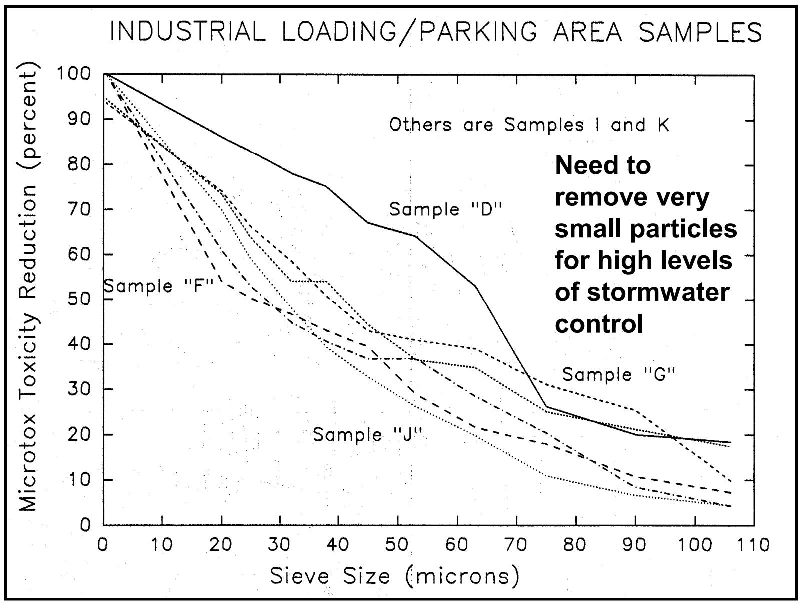

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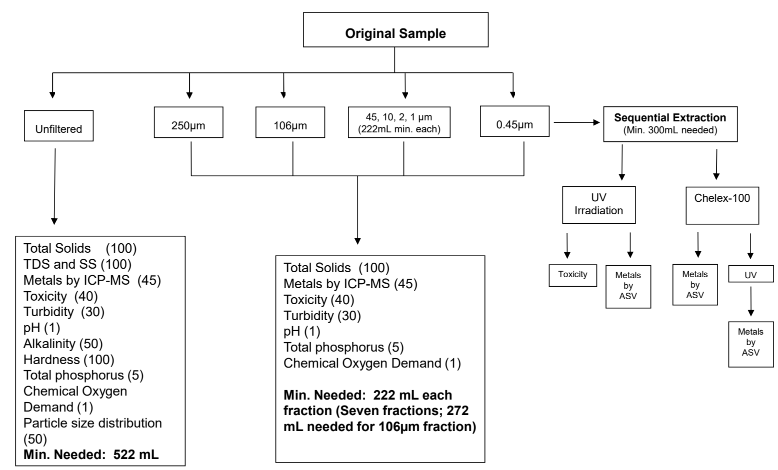

Sample analysis strategy used to characterize stormwater treatability

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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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Filtered Sample Ionic and Colloidal Associations

Analyte	% Ionic	% Colloidal
Magnesium	100	0
Calcium	99.1	0.9
Zinc	98.7	1.3
Iron	97	3
Chromium	94.5	5.5
Potassium	86.7	13.3
Lead	78.4	21.6
Copper	77.4	22.6
Cadmium	10	90

Most of the "dissolved" stormwater metals are in ionic forms and are therefore potentially amenable to sorption and ion-exchange removal processes, but there are some exceptions.

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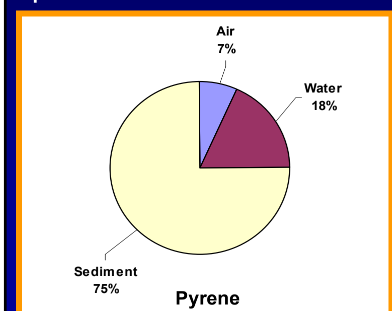
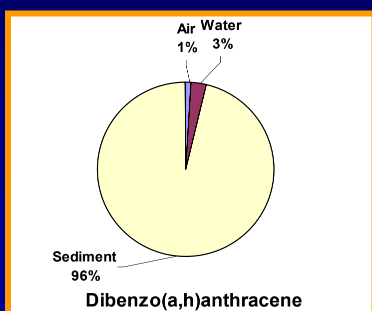
Fates of Stormwater PAHs

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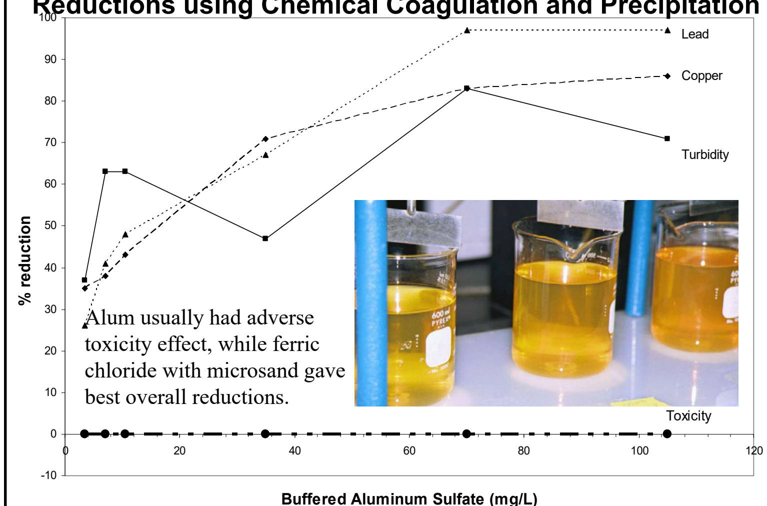
Example Stormwater Turbidity, Lead and Copper Reductions using Chemical Coagulation and Precipitation



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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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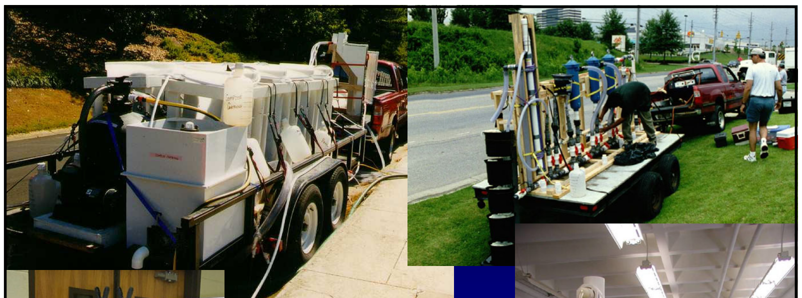

Some laboratory and field pilot-scale test setups (EPA and WERF-supported research at Univ. of Alabama). Critical that tests use actual stormwater, not artificial mixtures.

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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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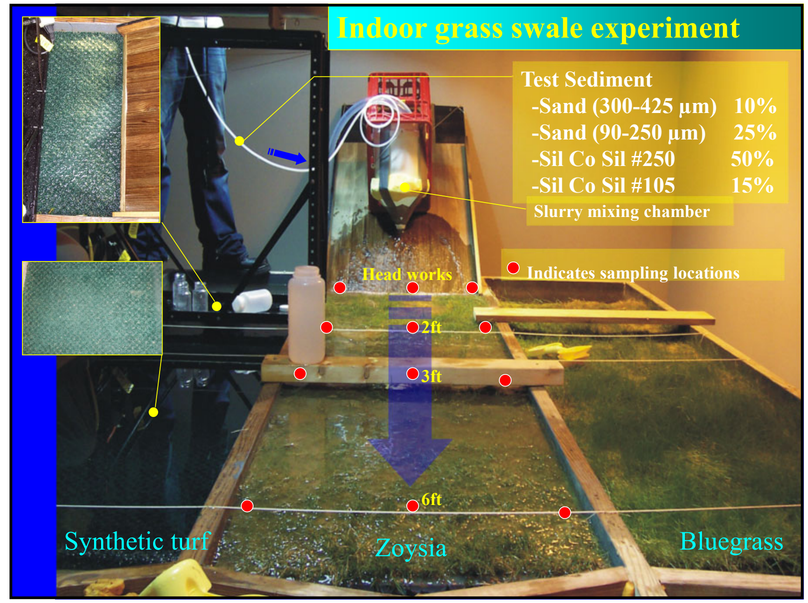

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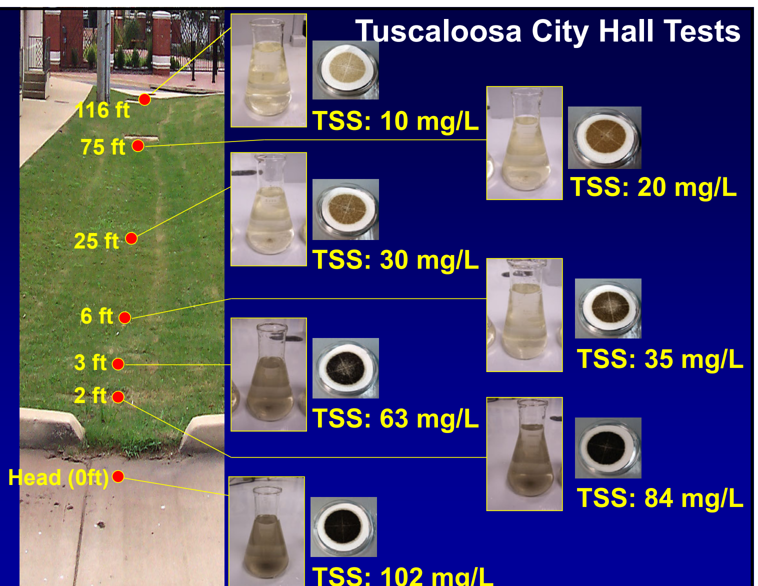
Tuscaloosa City Hall Tests



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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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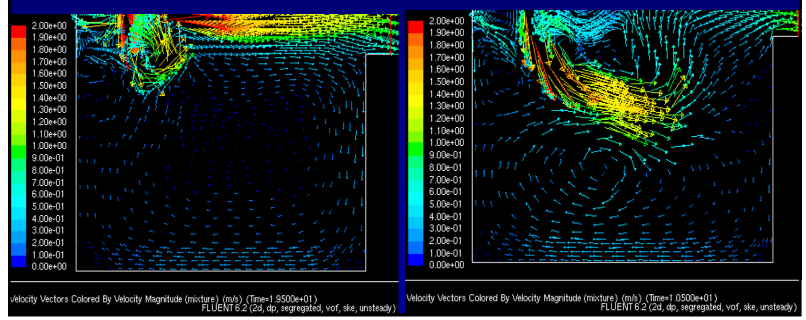
CFD Modeling to Calculate Scour/Design Variations

- 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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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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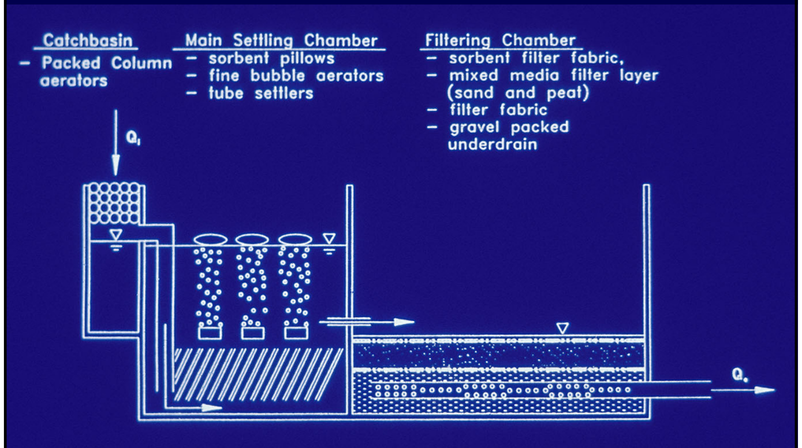
MCTT Cross-Section



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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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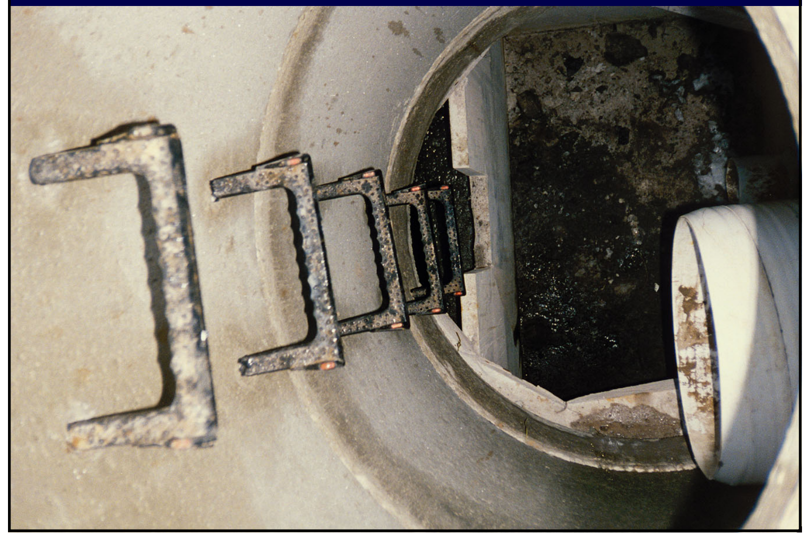
Minocqua, WI, MCTT Inlet Chamber



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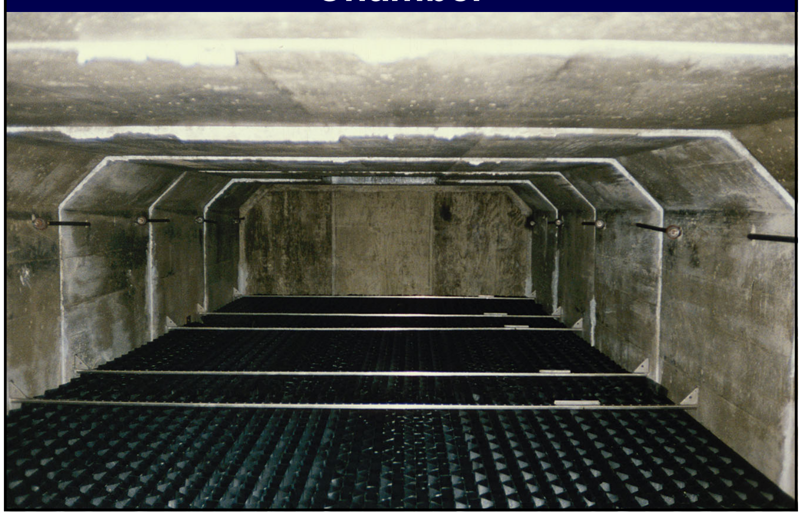
Minocqua, WI, MCTT Sedimentation Chamber



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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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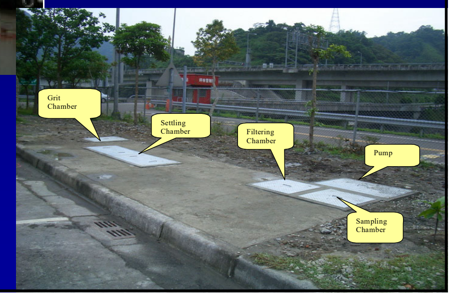
MCTT Installation, Above Ground View, Taipei County, Taiwan



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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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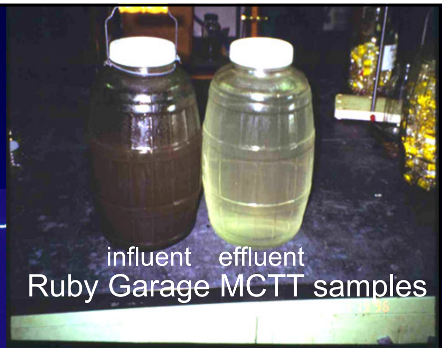
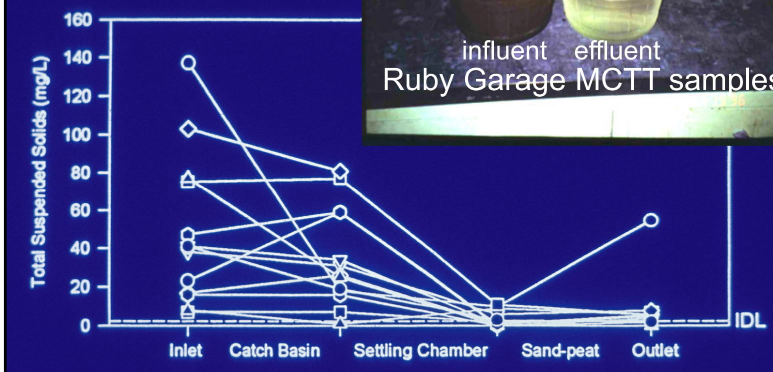
Pilot-Scale MCTT Test Results





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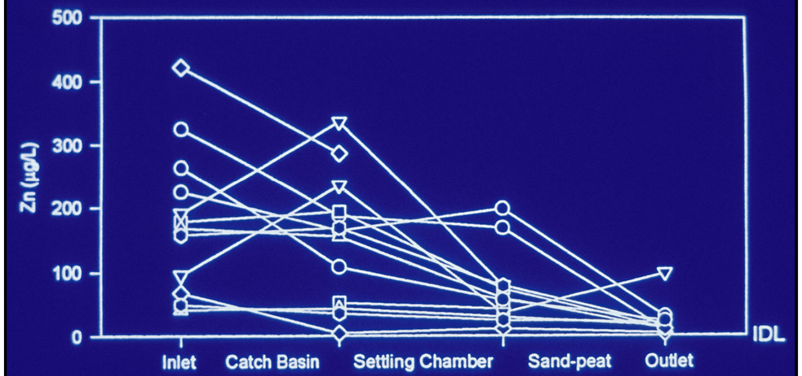
Pilot-Scale Test Results



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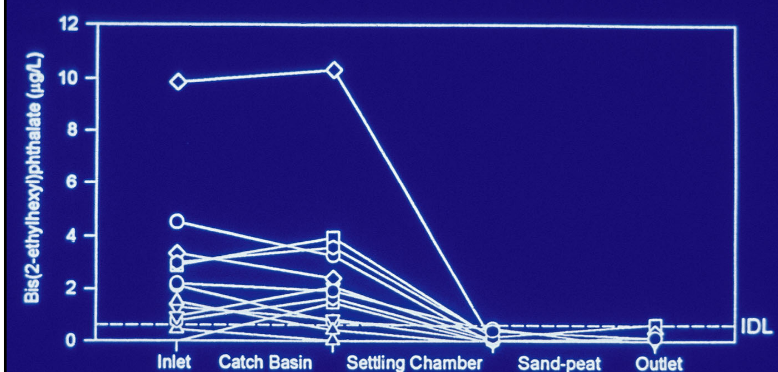
Pilot-Scale Test Results



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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 Filtration

- 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

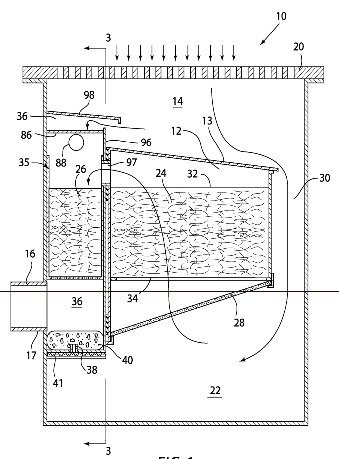

FIG. 1

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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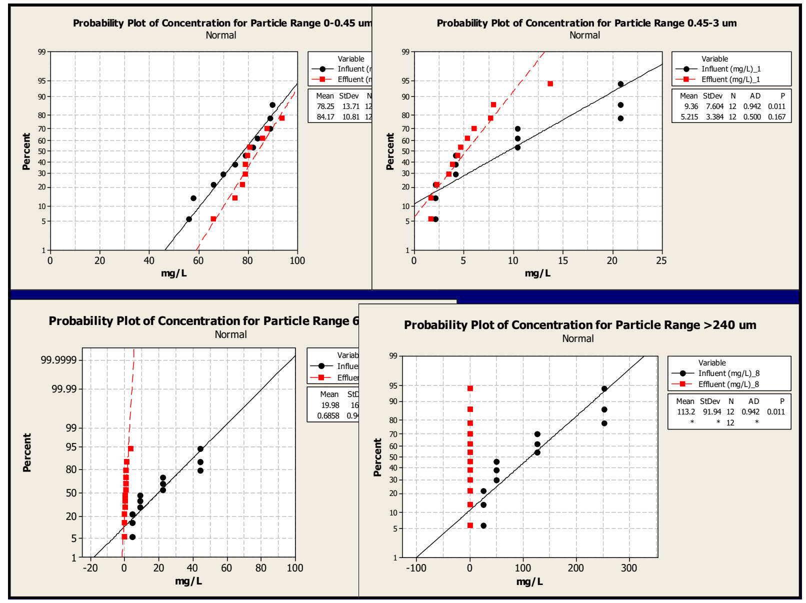

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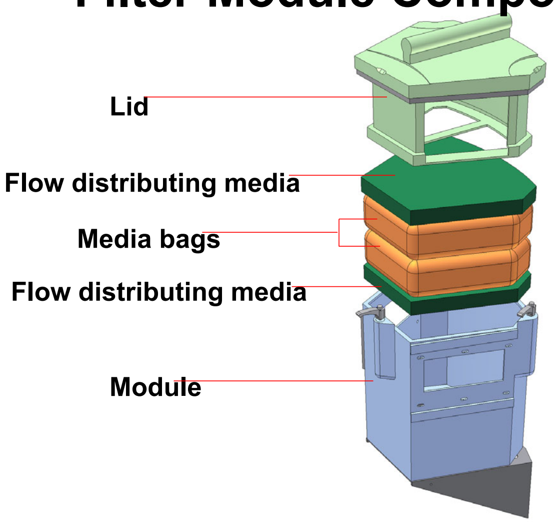
Filter Module Components



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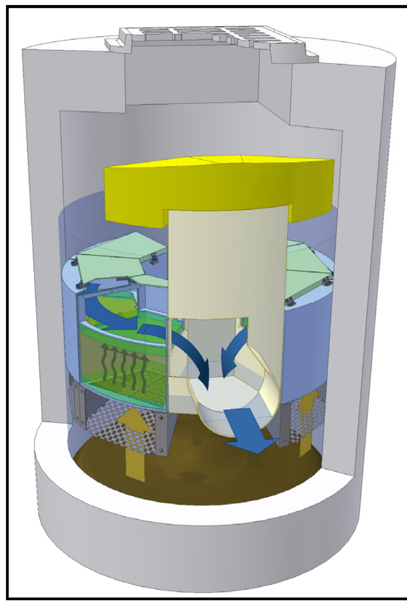
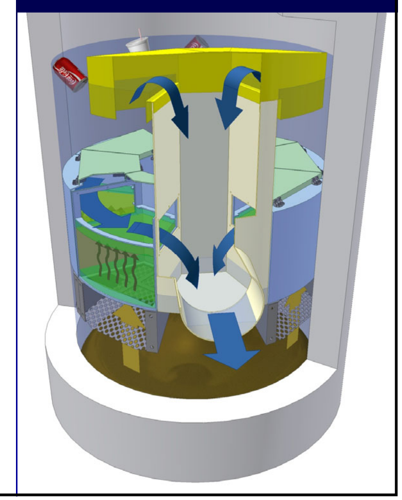


Operation during normal and bypass conditions



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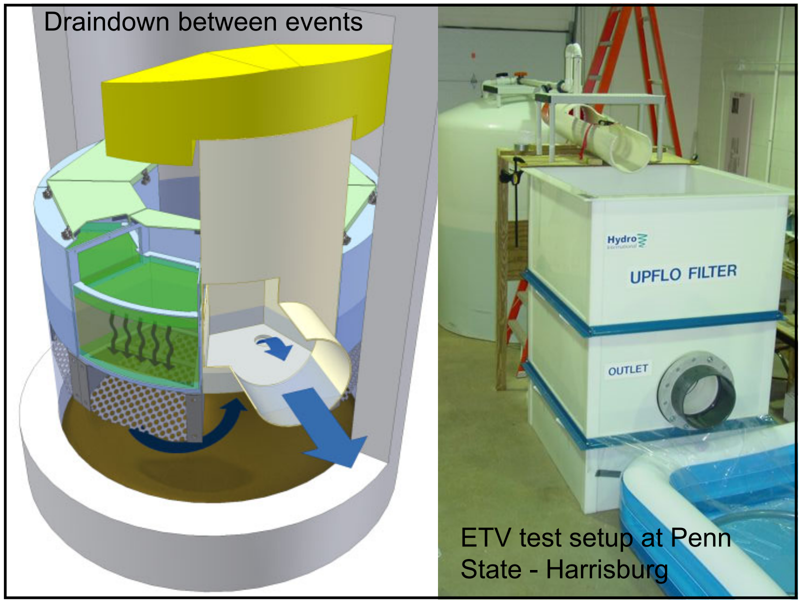

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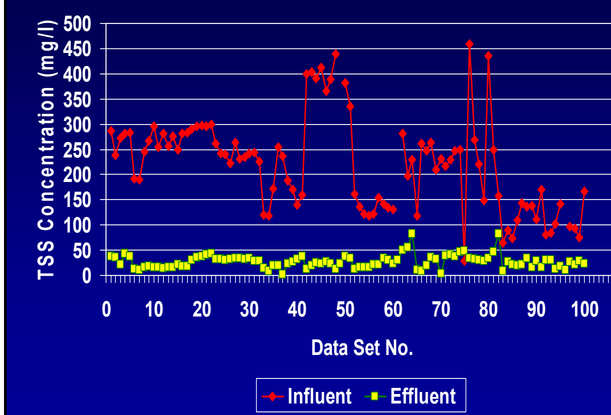
Pre-commercialization Test Data



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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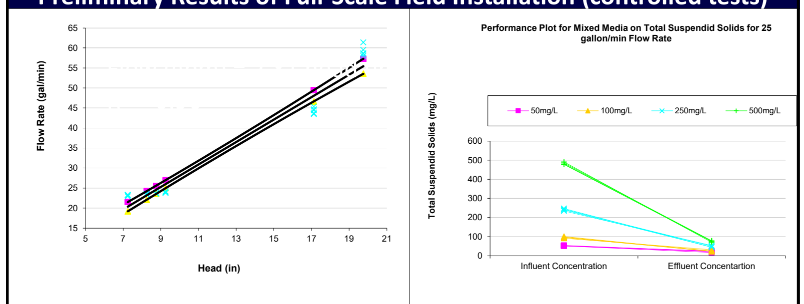
Preliminary Results of Full-Scale Field Installation (controlled tests)



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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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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Recent 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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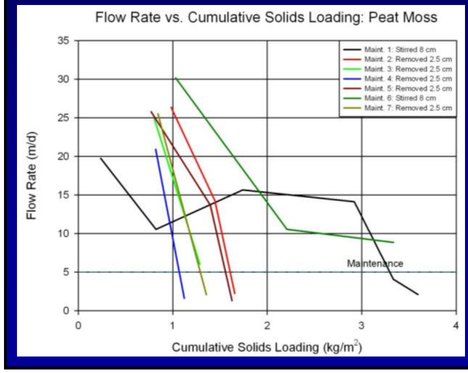
Long-Term Column Tests: Maintenance

- Infiltration rates typically decrease over a device's life due to solids capture on the surface of and in the media.
- Most media typically fail when the total solids loading is about 10 – 25 kg/m^2 of media surface (flow rate < 1 m/d, generally).



Removal of several inches of media from the surface only provided temporary and relatively small relief. After about 2 or 3 removals, it did little good. Pretreatment (such as by sedimentation as in the MCTT and UpFlow filter) is critical to ensure long run times before clogging.

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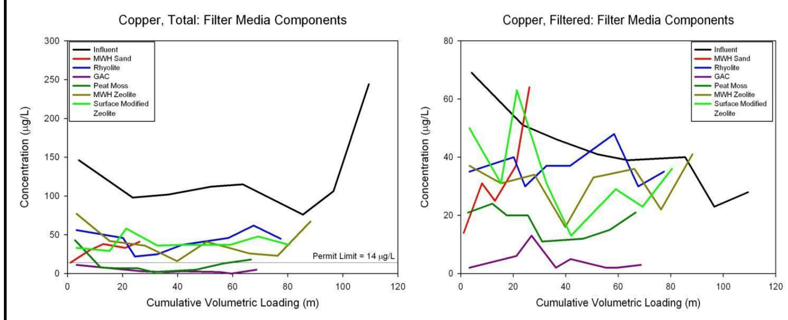
Long-Term Column Tests: Removal as a Function of Pollutant Form



Excellent removals of particulate associated pollutants, but removal of dissolved/colloidal components vary greatly by media.

- Primary Cu removal mechanism is physical straining/removal of particulate-associated copper.
- Cu removal by GAC and then peat may be related to organic complexation of copper in influent water or complexation with the organic content of the media.
- Poorer removal of Cu by zeolites and sands (typically associated with CEC mechanisms).

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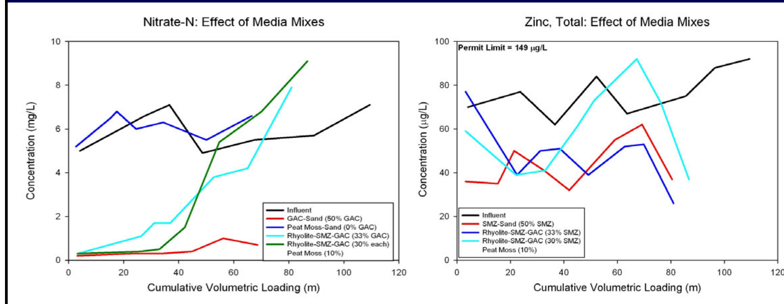
Long-Term Column Tests: Effect of Mixes on Pollutant Removal and Breakthrough



Nitrate removal excellent in GAC. Breakthrough occurs more rapidly as the fraction of GAC in the media mix decreases.

Similar trends noted for SMZ for zinc, although not as pronounced. Effects seen later in media life, rather than during initial sample collection when washout is occurring from other components in the media mixture.

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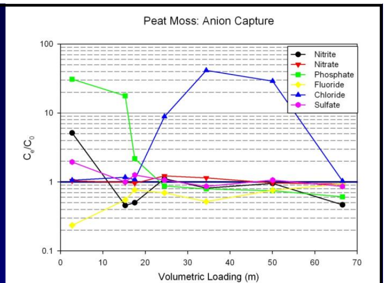
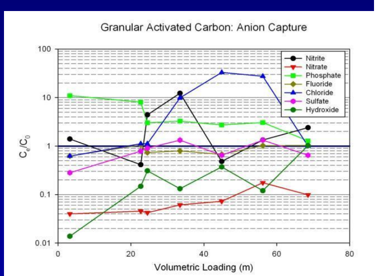
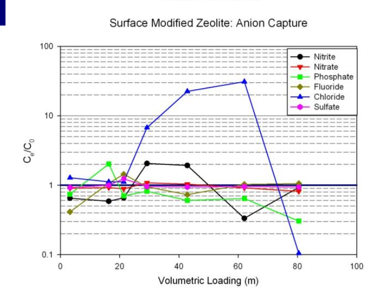
Ion-Exchanging Media: Trade-Offs between Pollutant Removals and Releases







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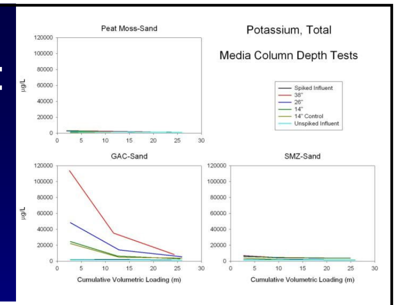
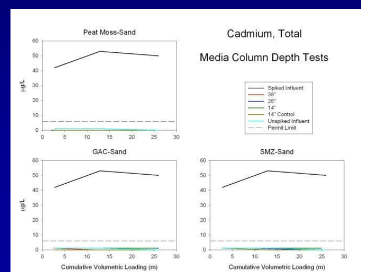
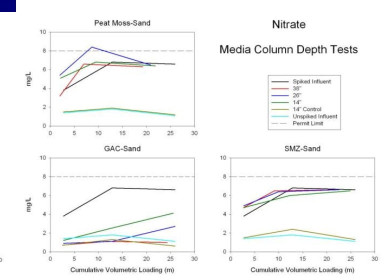
Media Depth Tests: Contact Time vs. Pollutant Removal







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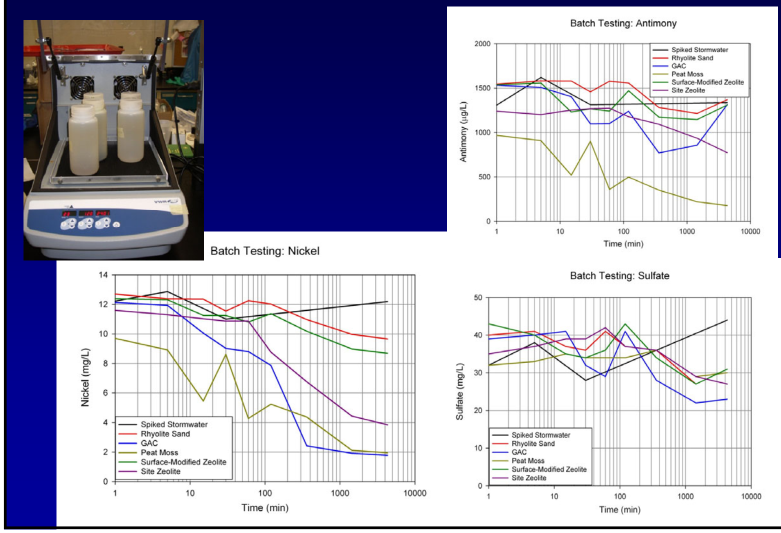
Batch Testing to Optimize Contact Time



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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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