Background to Research Leading to Development of Upflow Filtration

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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**

2

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

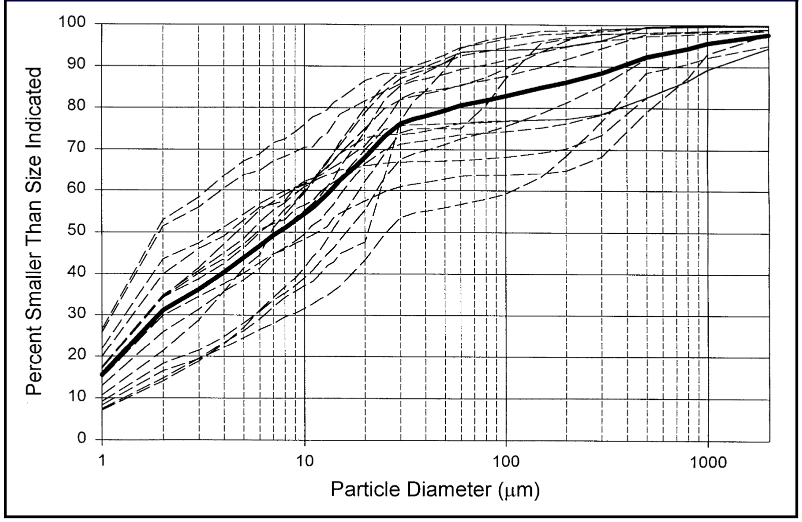
3

Storage yards, auto junk yards, and lumber yards

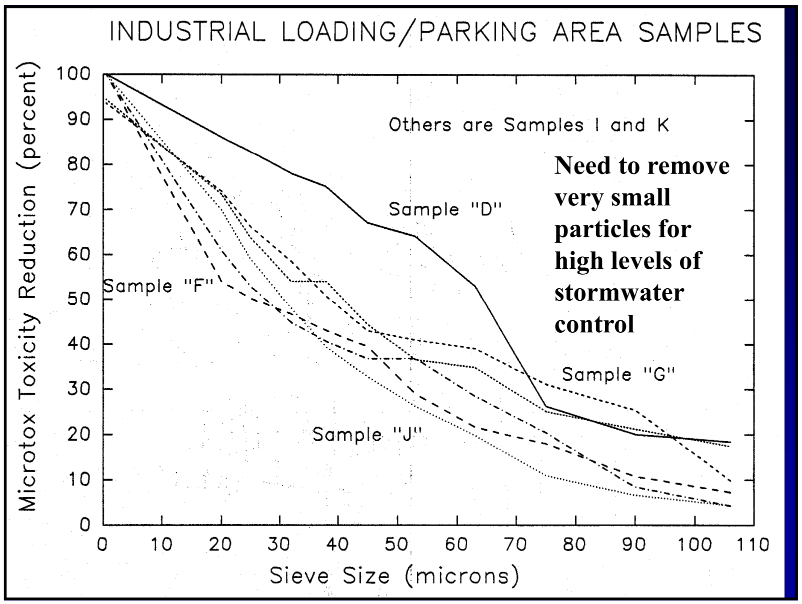
4

5

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



6



7

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.

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Development of Stormwater Control Devices using Media

- 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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Pilot-Scale Treatment Tests using Filtration, Carbon Adsorption, UV Disinfection, and Aeration

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Pilot-scale filters examining many different media.

12


Lab and pilot-scale filters and multi-chambered treatment train (MCTT)

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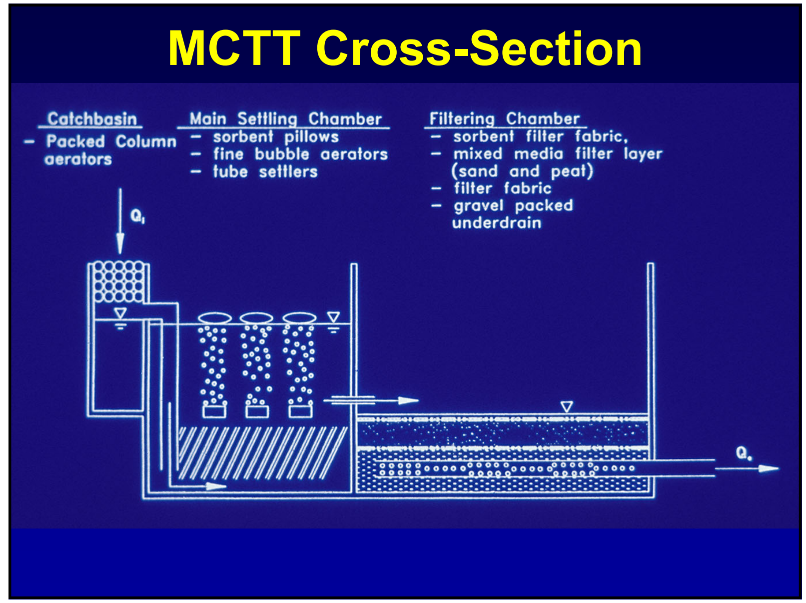
MCTT Cross-Section
Catchbasin
– Packed Column aerators
Main Settling Chamber
– sorbent pillows
– fine bubble aerators
– tube settlers
Filtering Chamber
– sorbent filter fabric,
– mixed media filter layer (sand and peat)
– filter fabric
– gravel packed underdrain

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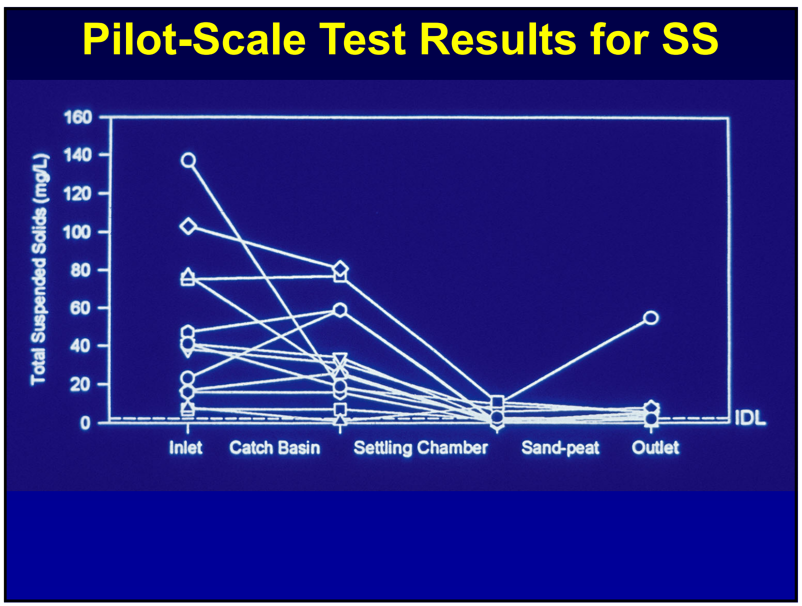
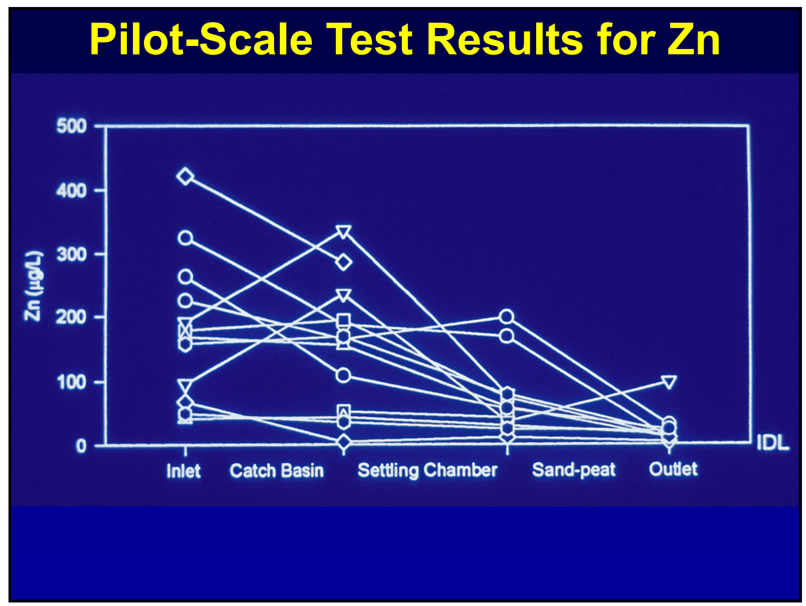

Pilot-Scale Test Results for SS
Total Suspended Solids (mg/L)
160
140
120
100
80
60
40
20
0
IDL
Inlet
Catch Basin
Settling Chamber
Sand-peat
Outlet

15


Pilot-Scale Test Results for Zn
Zn (µg/L)
500
400
300
200
100
0
IDL
Inlet
Catch Basin
Settling Chamber
Sand-peat
Outlet

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Milwaukee, WI, Ruby Garage Public Works Maintenance Yard MCTT Site

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Minocqua, WI, MCTT Installation

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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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Water Environment Research Foundation (WERF) project on Metals Removal from Stormwater

Main Project Goals:

- Contribute to the science of metals' capture from urban runoff by filter media and grass swales.
- Provide guidelines to enhance the design of filters and swales for metals capture from urban runoff.

Media Filtration Goals:

- Characterize physical properties
- Assess & quantify ability of media to capture metals
- Rank media & select media for in-depth study
- Evaluate effect of varying conditions on rate and extent of capture
- Laboratory- and pilot-scale studies of pollutant removal
- Disposal issues of used media (using TCLP)

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Treatment Media Examined during WERF Study

- <u>Traditional Media</u>
  - Ion Exchange Resin
  - Granular activated carbon (GAC)
  - Sand
- <u>Metals Examined</u>
  - Copper, Cadmium, Chromium, Zinc, Lead, and Iron
- <u>Other Low Cost (disposable) media</u>
  - Compost
  - 2 Zeolites
  - Iron Oxide Coated Sand
  - Agrofiber
  - Cotton Mill Waste
  - Peat-Sand Mix
  - Kudzu
  - Peanut Hull Pellets

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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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Cation Exchange Capacities for Different Media

	CEC (meq/100 g)
Peat Moss	22
Compost	19
Activated Carbon	5.4
Zeolite	6.9
Cotton Waste	3.8
Agrofiber	9.4
Sand	3.5

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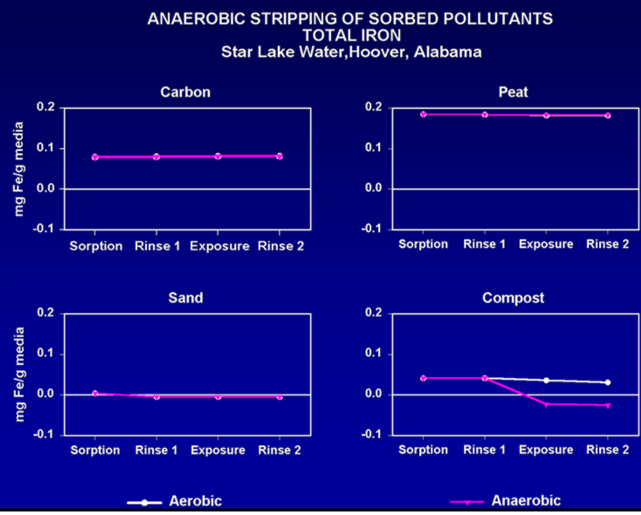
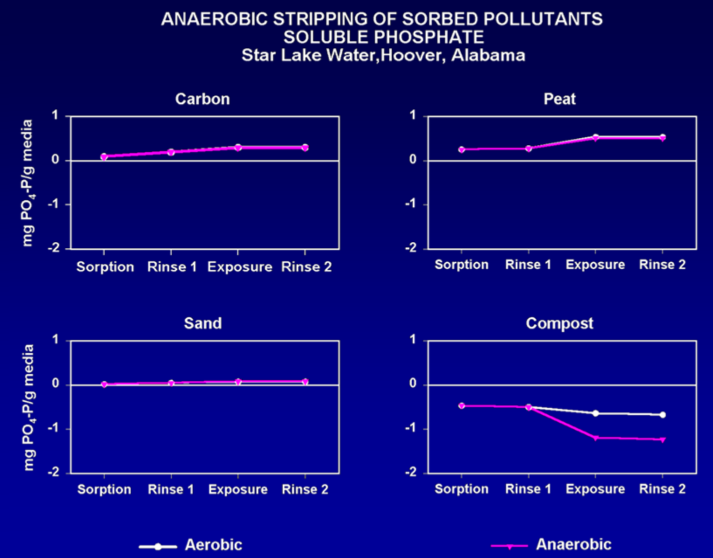
Contaminant Losses during Anaerobic vs. Aerobic Conditions between Events



25



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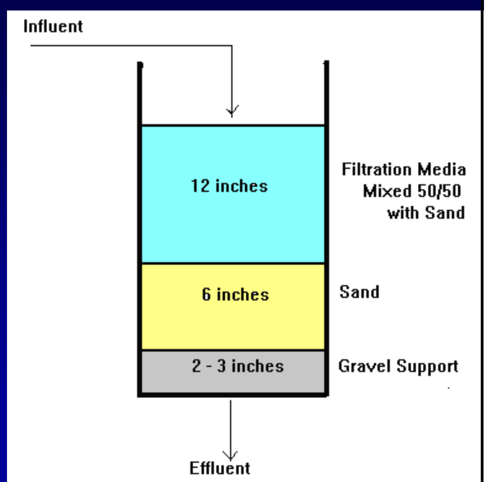
Pilot-Scale Downflow Filtration Setup

Media Investigated:

- Activated Carbon
- Zeolite
- Sand
- Lightweight Sand
- Loamy Soil
- Municipal Leaf Compost
- Peat Moss
- Kenaf Fiber
- Cotton Textile Waste



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Pilot-Scale Filtration Setup after Pre-Treatment by Stormwater Pond

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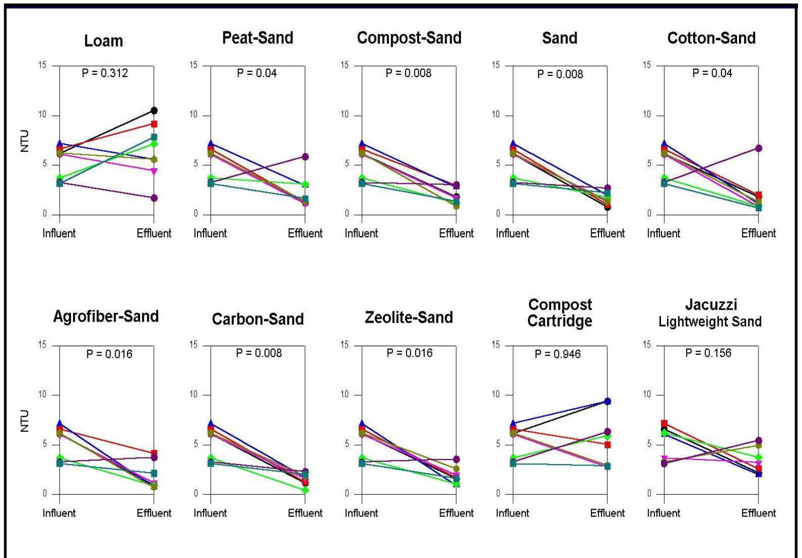

TURBIDITY, UNFILTERED: Pilot-Scale Testing, Fall 1999

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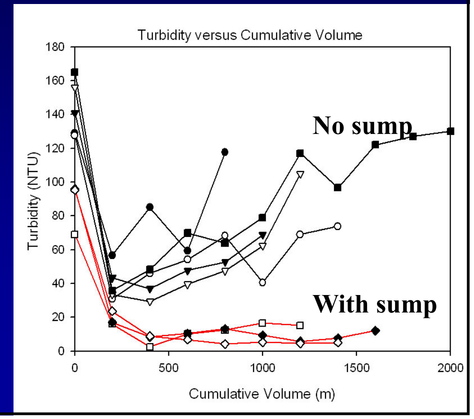
Clogging Problems Originally Addressed by Pre-Treatment. What about Upflow Filtration?

Expected Advantages:

- Reduced Clogging: Sump collects large fraction of sediment load.
- Prolonged Life: Particles trapped on the surface of the media will fall into the sump during quiescent periods.
- High Flow Rates: Since large and heavy solids will be removed by way of settling in the sump prior to encountering the filter, the filters can be operated at higher flow rates.

Upflow Filter Design with Sump



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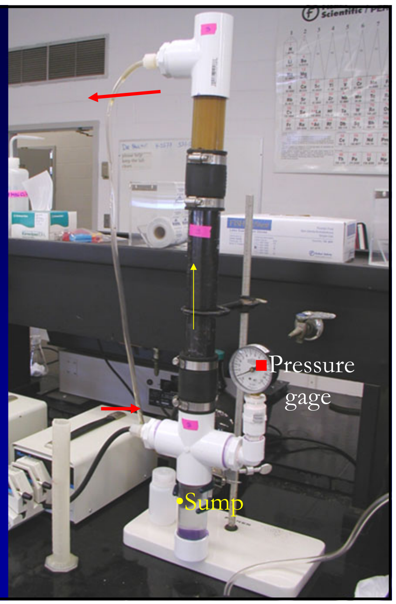
Upflow Filters for Metals Removal

- Particulate Solids: Good removal (>90%) for all media for all runs.
- Particulate Metals: Generally 80-100% removal for Pb, Zn, Cd, and Fe and 60-95% removal for Cu and Cr.
- Peat had the best removal rates for particulate bound metals. Removal rates of compost and zeolite were about the same.



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Upflow filter insert for catchbasins

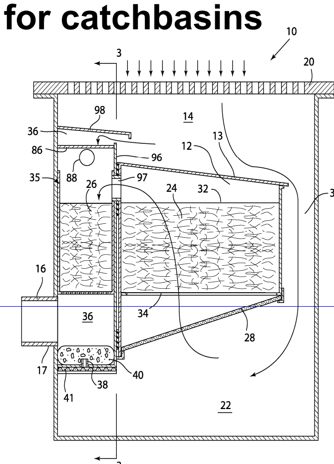

FIG. 1

Upflow Filter^{TM} patented

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

The Upflow Filter^{TM} 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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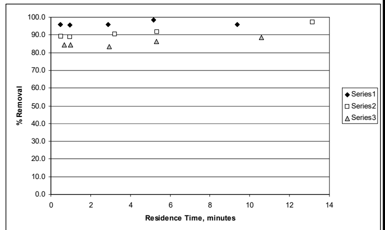
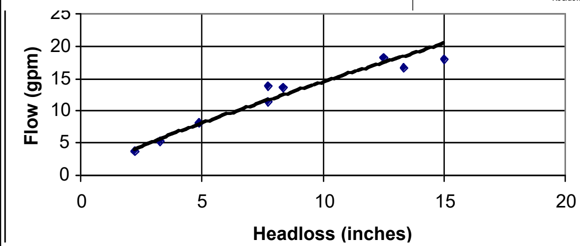
Successful flow tests using prototype unit and mixed media as part of EPA SBIR phase 1 project (controlled lab tests). Phase 2 tests recently completed (field tests), and ETV testing now starting.

80 to 90% removal of dissolved zinc using sand/peat upflow filtration





15 to 20 gpm/ft^2 obtained for most media tested

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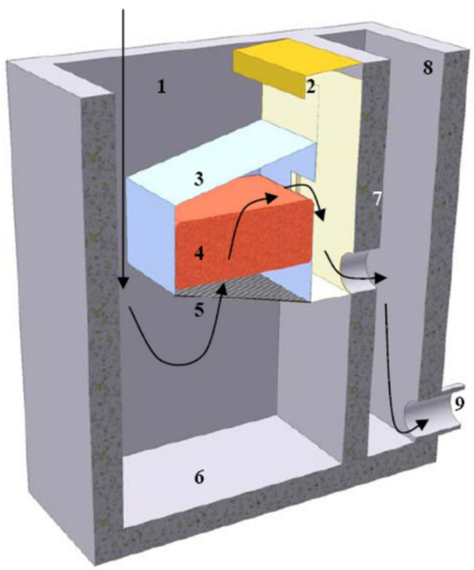
Test site drainage area, Tuscaloosa, AL (anodized aluminum roof, concrete and asphalt parking areas; total of 0.9 acres)

34

1. Filtration Chamber
2. Bypass with Floatables Baffle
3. Media Housing
4. Filtration Media
5. Angled Screen
6. Sump
7. Baffle Wall
8. Effluent Chamber
9. Outlet Pipe
10. Weep Tubes (not pictured)



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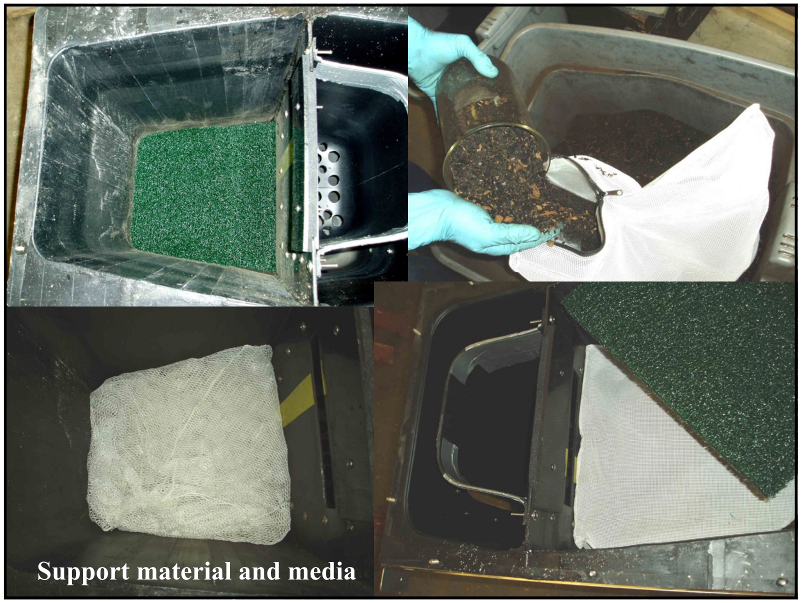
EPA SBIR2 UpFlow™ Filter tests using Frankenstein 2 prototype

36


Support material and media

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EPA-funded SBIR2 Field Test Site
Monitoring Equipment, Tuscaloosa, AL

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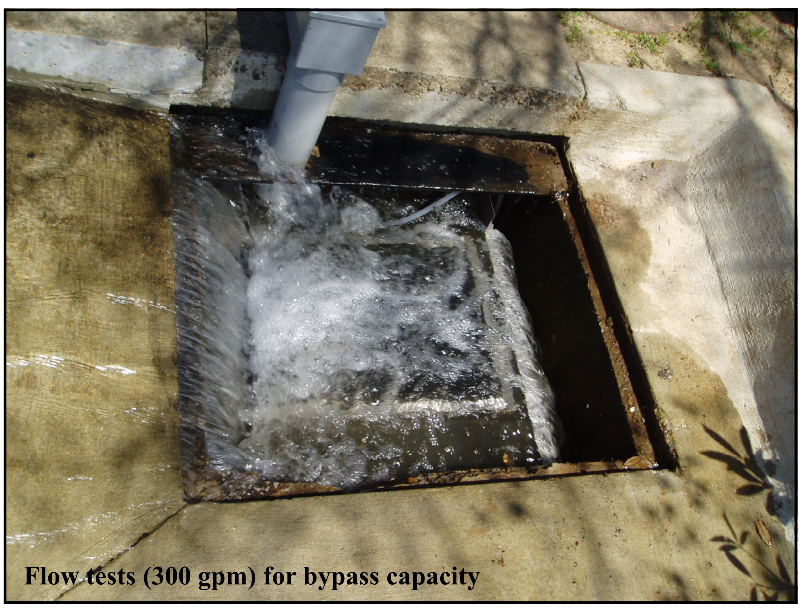
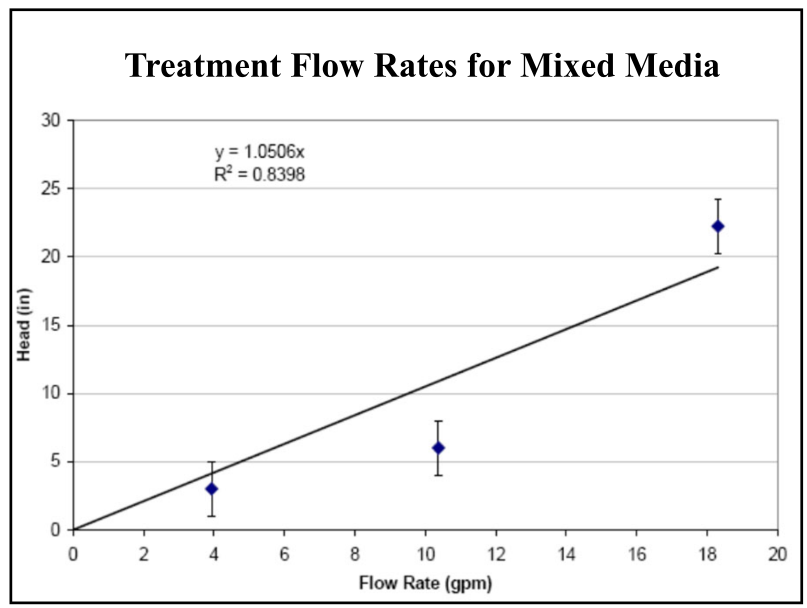
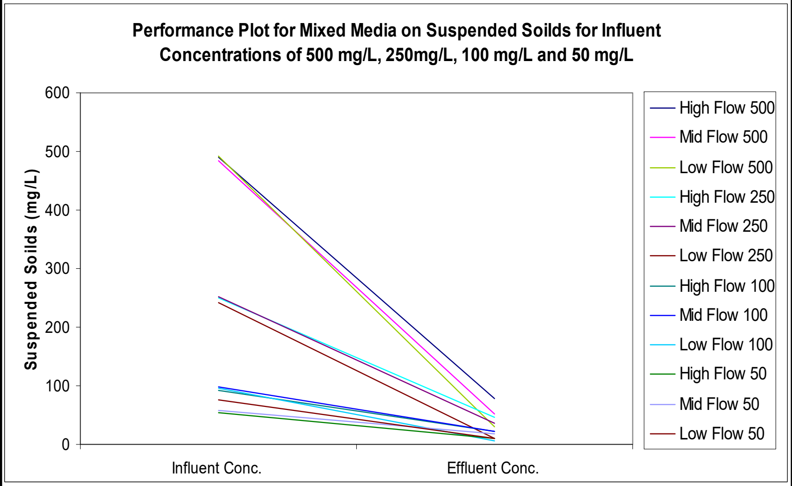

Flow tests (300 gpm) for bypass capacity

39


Treatment Flow Rates for Mixed Media
y = 1.0506x
R^2 = 0.8398
Head (in)
Flow Rate (gpm)
0
5
10
15
20
25
30
0
2
4
6
8
10
12
14
16
18
20

40



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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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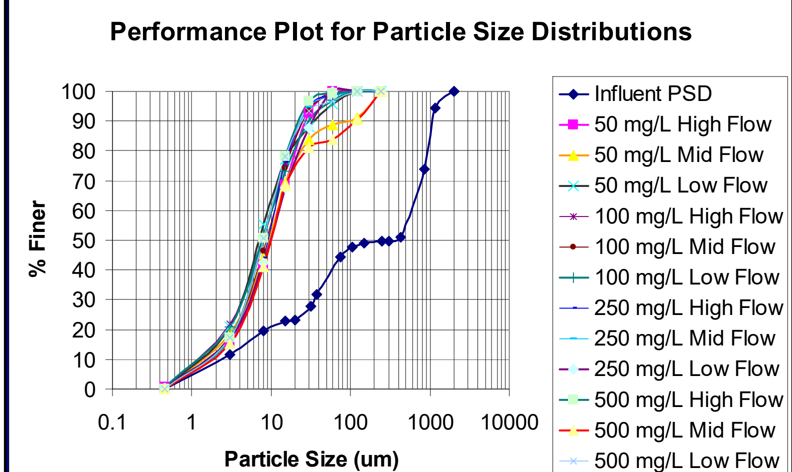
Upflow Filter Mixed Media Tests (Mn-coated Zeolite, Bone Char, Peat Moss)



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% Reductions

concentration in particle size range (mg/L):	350 m/day (or less)	760 m/day	1200 m/day (to overflow)
0 to 0.45 µm (TDS)			
69 (and smaller)	0	0	0
70	0	0	0
80	0	0	0
93 (and larger)	0	0	0
0.45 to 3 µm			
2.1 (and smaller)	0	0	0
4.2	0	0	0
10.4	80	42	26
20.8 (and larger)	80	62	34
60 to 120 µm			
4.4 (and smaller)	95	95	95
8.9	97	97	97
22.2	98	97	97
44.4 (and larger)	98	98	98

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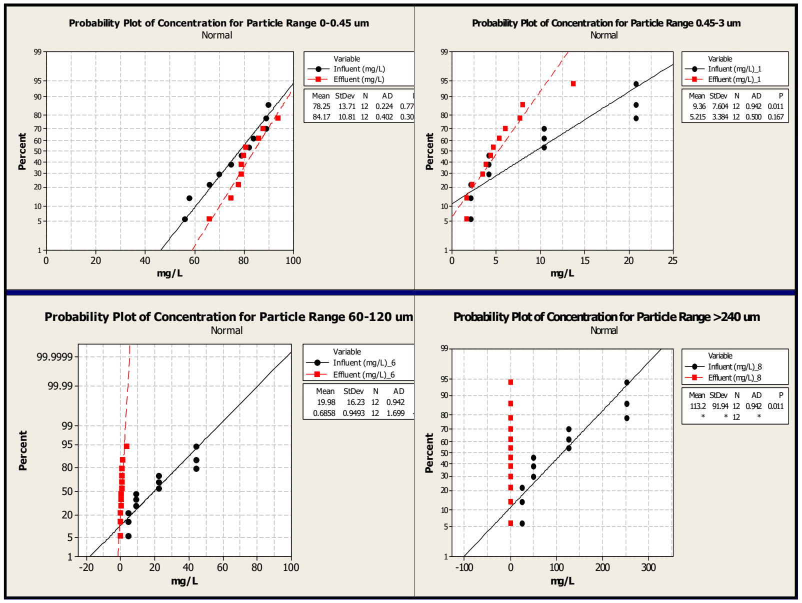
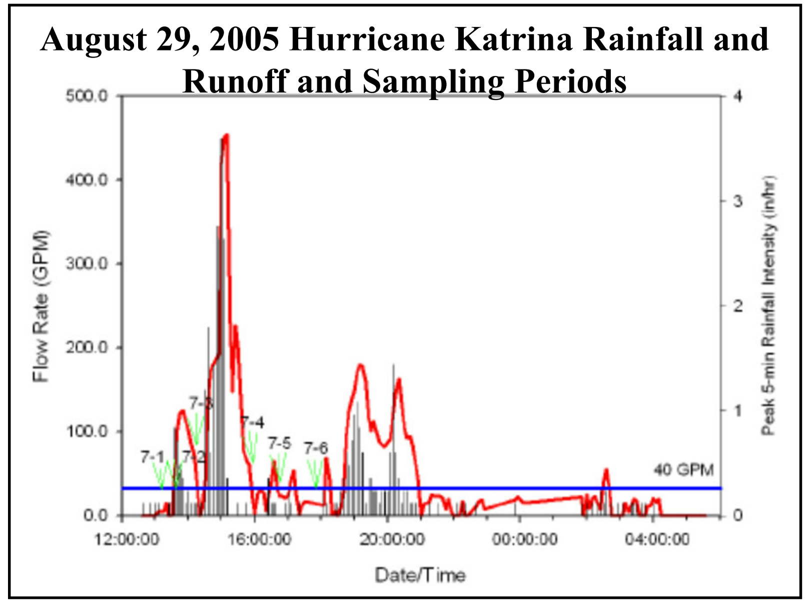
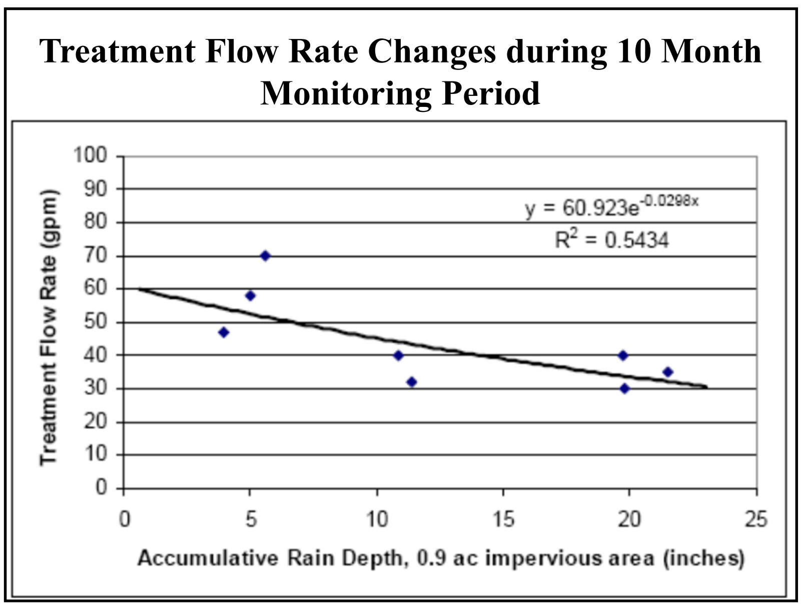

Probability Plot of Concentration for Particle Range 0-0.45 um
Normal
Probability Plot of Concentration for Particle Range 0.45-3 um
Normal
Probability Plot of Concentration for Particle Range 60-120 um
Normal
Probability Plot of Concentration for Particle Range >240 um
Normal
Percent
mg/L
Variable
Influent (mg/L)
Effluent (mg/L)

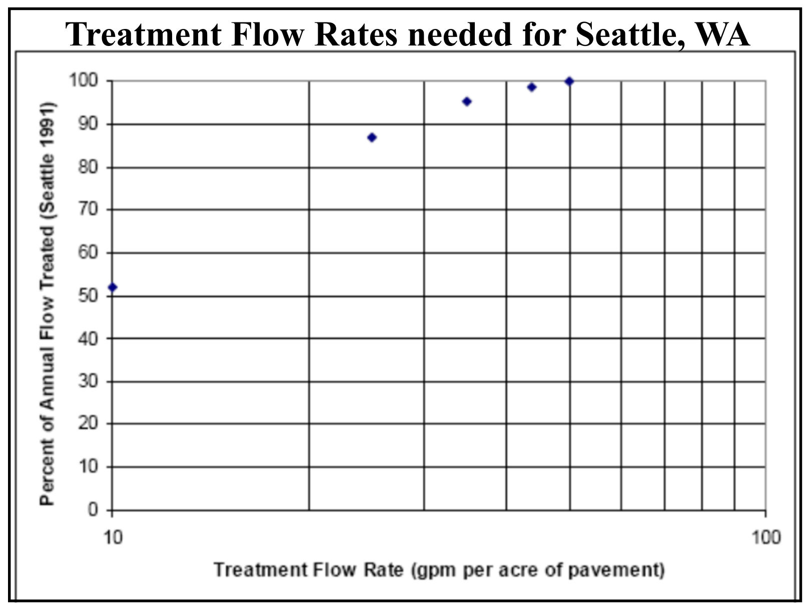
45


August 29, 2005 Hurricane Katrina Rainfall and Runoff and Sampling Periods
Flow Rate (GPM)
Peak 5-min Rainfall Intensity (in/hr)
500.0
400.0
300.0
200.0
100.0
0.0
12:00:00
16:00:00
20:00:00
00:00:00
04:00:00
Date/Time
40 GPM
7-1
7-2
7-3
7-4
7-5
7-6

46

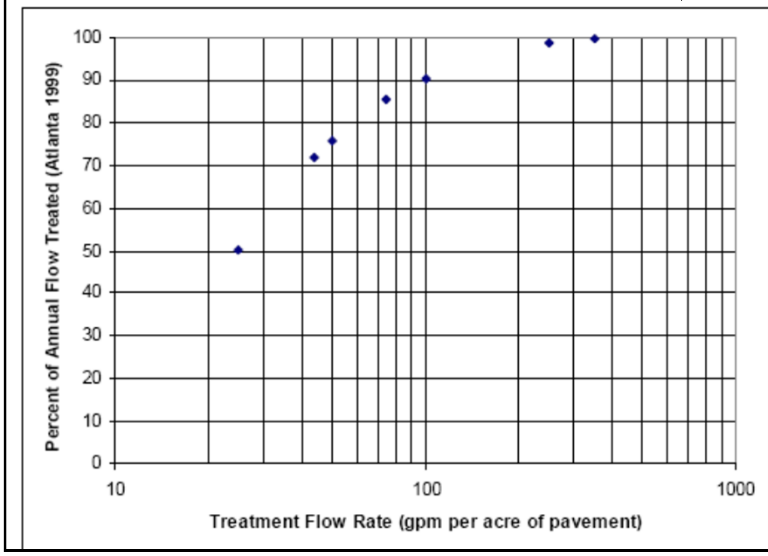

Treatment Flow Rate Changes during 10 Month Monitoring Period
Treatment Flow Rate (gpm)
Accumulative Rain Depth, 0.9 ac impervious area (inches)
y = 60.923e^-0.0298x
R^2 = 0.5434

47


Treatment Flow Rates needed for Seattle, WA
Percent of Annual Flow Treated (Seattle 1991)
Treatment Flow Rate (gpm per acre of pavement)
10
100

48

Treatment Flow Rates needed for Atlanta, GA



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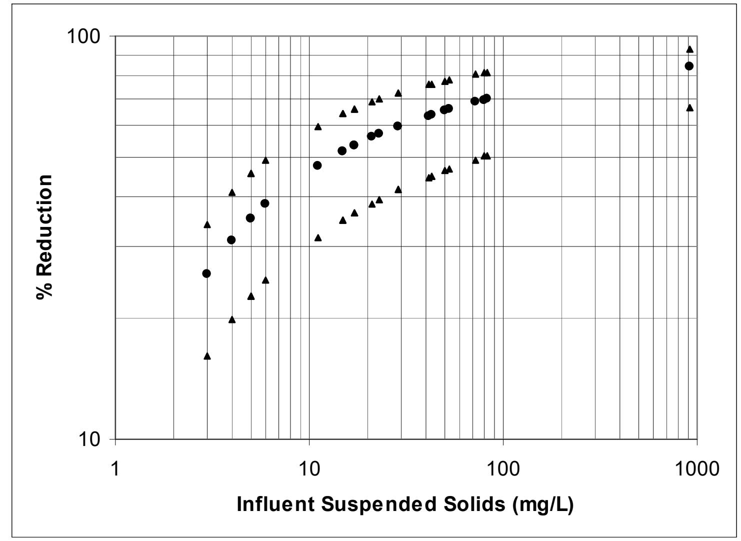
70 to 90% SS reductions for influent concentrations >80 mg/L



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Effluent SS <100 mg/L whenever influent is <500 mg/L

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Particulate Solids Removal by Particle Size, during Monitoring Period (UpFlow Filter, with Sump)

Particle size range (µm)	SS influent mass (kg)	SS effluent mass (kg)	SS removed (kg)	% reduction
0.45-3	9.3	2.8	6.6	70
3-12	18.7	6.4	12.3	66
12-30	22.4	7.7	14.7	66
30-60	26.7	6.8	19.9	74
60-120	4.6	1.8	2.9	61
120-250	19.8	4.3	15.5	78
250-425	11.5	0.0	11.5	100
425-850	17.1	0.0	17.1	100
850-2,000	10.5	0.0	10.5	100
2,000-4,750	4.8	0.0	4.8	100
>4,750	3.5	0.0	3.5	100
sum	148.9	29.8	119.2	80

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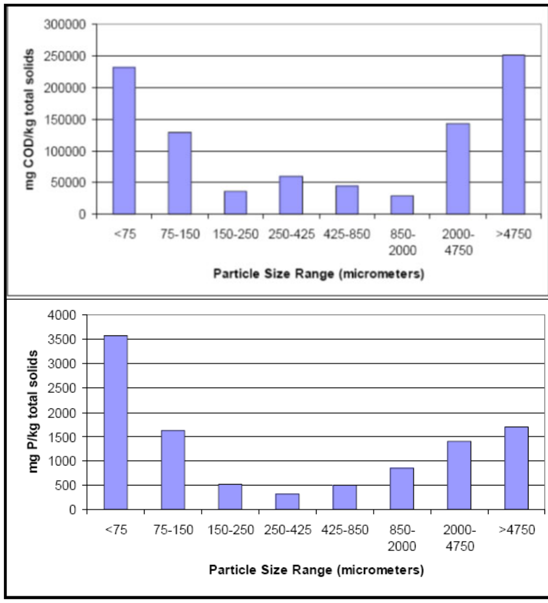

COD and phosphorus concentrations as a function of particle size

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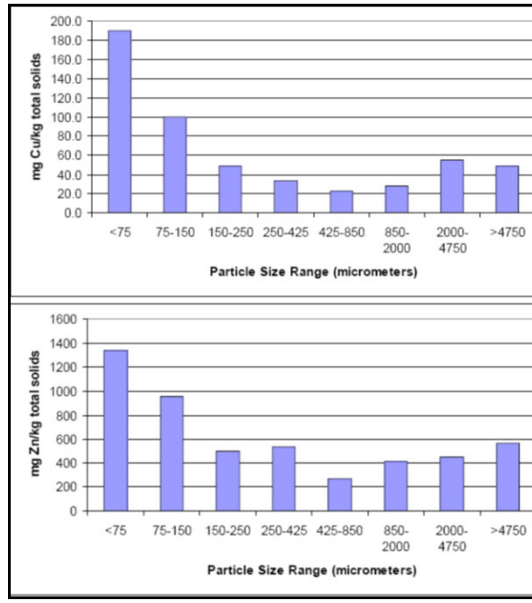
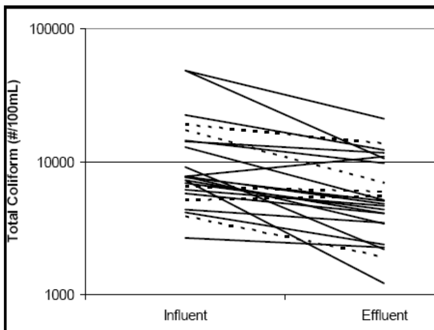
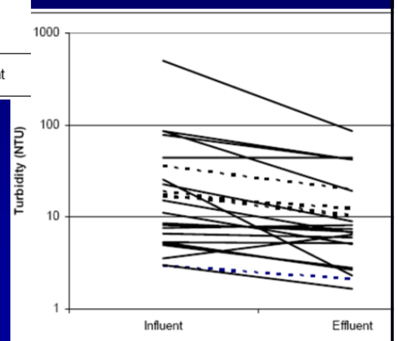


Copper and zinc concentrations as a function of particle size

54





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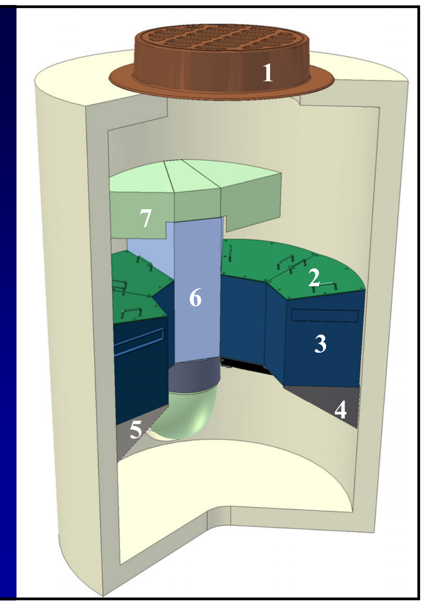
UpFlow Filter™

Components:

1. Access Port
2. Filter Module Cap
3. Filter Module
4. Module Support
5. Coarse Screen
6. Outlet Module
7. Floatables Baffle/Bypass

Hydro International, Ltd.



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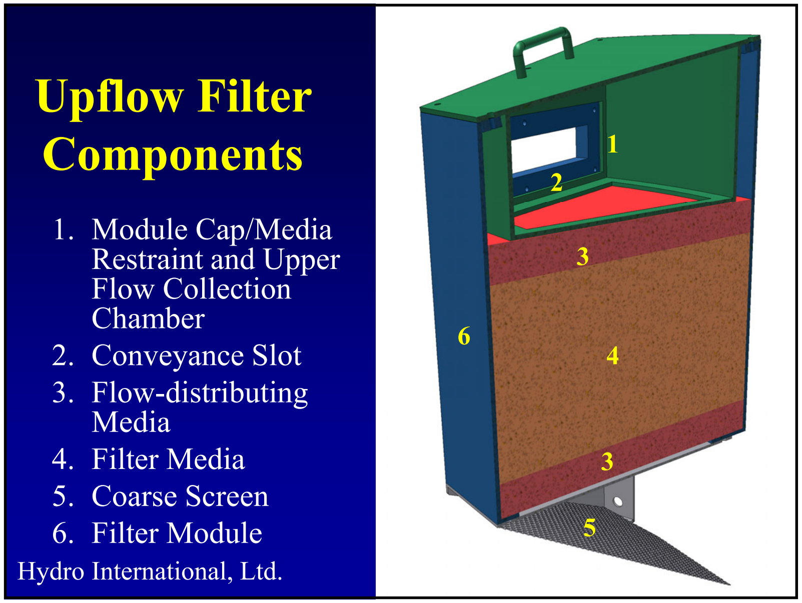
Upflow Filter Components
1. Module Cap/Media Restraint and Upper Flow Collection Chamber
2. Conveyance Slot
3. Flow-distributing Media
4. Filter Media
5. Coarse Screen
6. Filter Module
Hydro International, Ltd.
1
2
3
6
4
3
5

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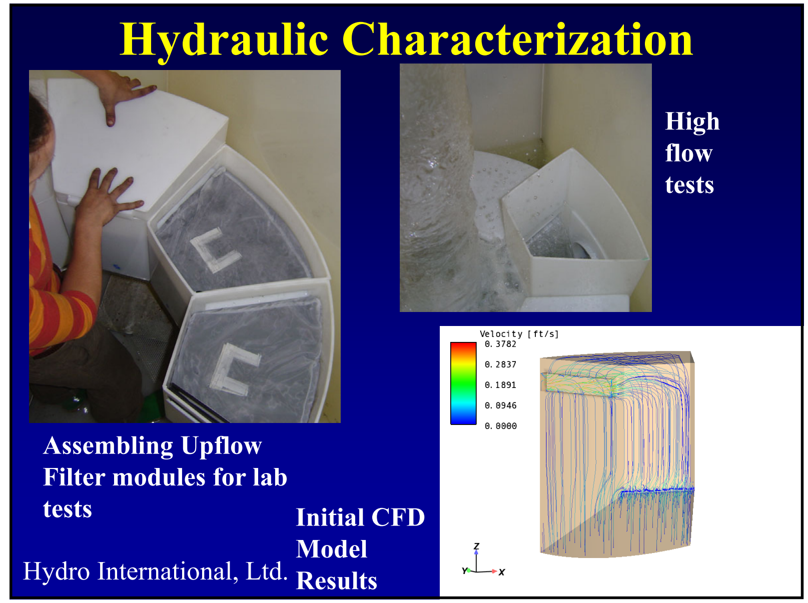
Hydraulic Characterization
High flow tests
Assembling Upflow Filter modules for lab tests
Velocity [ft/s]
0.3782
0.2837
0.1891
0.0946
0.0000
Initial CFD Model Results
Hydro International, Ltd.

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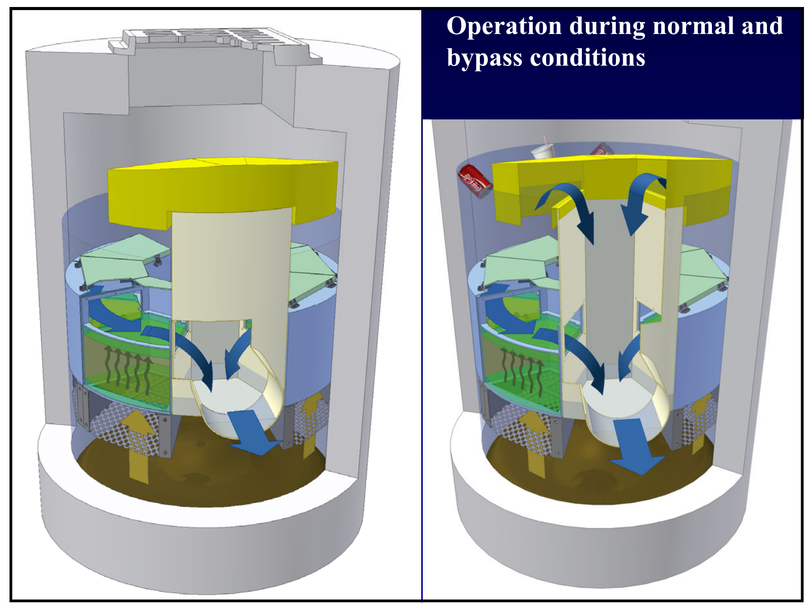
Operation during normal and bypass conditions

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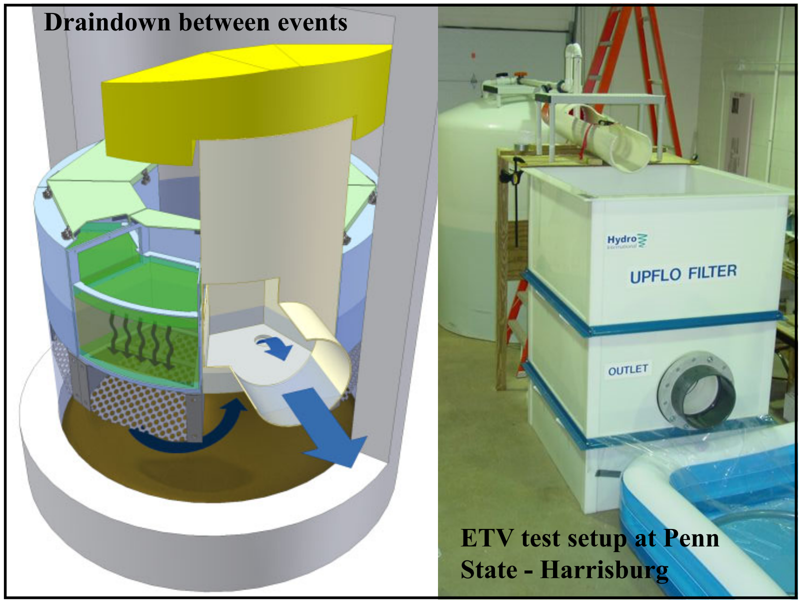

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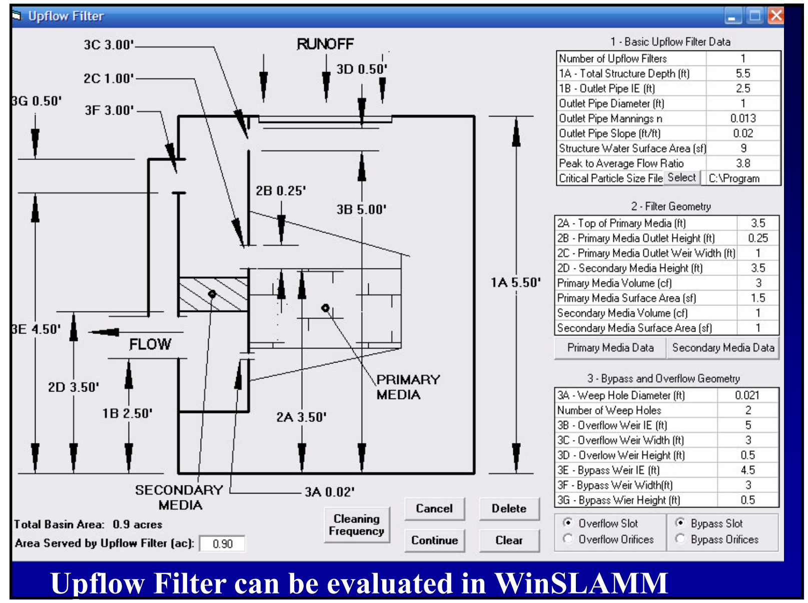

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Conclusions

- The bench-scale treatability tests conducted during the development of the MCTT showed that a treatment train was needed to provide redundancy because of frequent variability in sample treatability storm to storm, even for a single sampling site.
- Possible to develop other stormwater controls that provide treatment train approach.
- Upflow filtration with a sump and interevent drainage provided the best combination of pre-treatment options and high flow capacity, along with sustained high contaminant removal rates.

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Conclusions (continued)

Constituent and units	Reported irreducible concentrations (conventional high-level stormwater treatment)	Effluent concentrations 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

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Selected References

- Barrett, M. *Performance Summary Report for the Multi-Chambered Treatment Trains*. Prepared for the California Department of Transportation. May 2001.
- Clark, S., R. Pitt, and R. Raghavan. *SBIR Phase 1 report for Upflow Filtration Treatment of Stormwater*. U.S. EPA. Publication pending 2003.
- Corsi, S.R., S.R. Greb, R.T. Bannerman, and R.E. Pitt. *Evaluation of the Multi-Chambered Treatment Train, a Retrofit Water Quality Management Practice*. U.S. Geological Survey. Open-File Report 99-270. Middleton, Wisconsin. 24 pgs. 1999.
- Johnson, P., R. Pitt, S. Clark, M. Urritta, and R. Durrans. *Innovative Metal Removal for Stormwater Treatment*. Water Environment Research Foundation. Publication pending 2003.
- Pitt, R., B. Robertson, P. Barron, A. Ayyoubi, and S. Clark. *Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT)*. U.S. Environmental Protection Agency, Wet Weather Flow Management Program, National Risk Management Research Laboratory. EPA/600/R-99/017. Cincinnati, Ohio. 505 pgs. March 1999.

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