Stormwater Treatment at Critical Source Areas

Robert Pitt
Department of Civil, Construction, and Environmental Engineering
University of Alabama, Tuscaloosa, AL

- 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 pretreatment to minimize groundwater contamination

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

Storage yards, auto junk yards, and lumber yards
along with industrial storage areas, loading docks, refueling areas, and manufacturing sites.

### Common Stormwater Controls
- Public works practices (drainage systems, street and catchbasin cleaning)
- Sedimentation
- Infiltration/biofiltration
- Critical source area controls
- Public education

### Proprietary Stormwater Controls (Hydrodynamic Devices) that use Settling for Treatment and have been Successfully Modeled in WinSLAMM

**Catchbasins and Catchbasin Cleaning**

- **Catchbasin Control Device**
- **Catchbasin Cleaning Data**
- **Select**
- **Catchbasin Cleaning Frequency**
  - **Scenario**
  - **Basin**
  - **Contamination**
  - **Flow Rate (gpm)**

**Vactor™ used to clean sewerage and inlets**

**Modified inlet to create catchbasin, Ocean County, NJ**

**Downstream Defender**

**Stormceptor**

**Vortechs**
Select bypass option in catchbasin controls to describe hydrodynamic device bypass.

Ponds and filters have been used to treat stormwater in some areas.

Bar screens and chemical addition are also used at some locations for stormwater treatment.
Pollution prevention addresses use of galvanized metals, for example.

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

INDUSTRIAL LOADING/PARKING AREA SAMPLES

Need to remove very small particles for high levels of stormwater control

Microtox Toxicity Reduction (percent)

Sieve Size (microns)

Sample “D”

Sample “F”

Sample “G”

Original Sample

Sequential Extraction (Min. 300 mL needed)

Unfiltered 250µm 4.5µm 0.45µm

UV Irradiation Chelex-100

Total Solids (100)

Metals by ICP-MS (45)

Toxicity (40)

Total phosphorus (5)

Chemical Oxygen Demand (1)

Min. Needed: 222 mL each fraction (Seven fractions; 272 mL needed for 106µm fraction)

Sample analysis strategy used to characterize stormwater treatability
High levels of pollutant reduction require the capture of very fine particulates, and likely further capture of “dissolved” pollutant fractions.

<table>
<thead>
<tr>
<th>Analyte</th>
<th>% Ionic</th>
<th>% Colloidal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Calcium</td>
<td>99.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Zinc</td>
<td>98.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Iron</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>Chromium</td>
<td>94.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Potassium</td>
<td>86.7</td>
<td>13.3</td>
</tr>
<tr>
<td>Lead</td>
<td>78.4</td>
<td>21.6</td>
</tr>
<tr>
<td>Copper</td>
<td>77.4</td>
<td>22.6</td>
</tr>
<tr>
<td>Cadmium</td>
<td>10</td>
<td>90</td>
</tr>
</tbody>
</table>

Most of the “dissolved” stormwater metals are in ionic forms and are therefore potentially amenable to sorption and ion-exchange removal processes.

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

- Alum usually had adverse toxicity effect, while ferric chloride with microsand gave best overall reductions.

**Design Modifications to Enhance Control of Toxicants in Wet Detention Ponds**

- Settling 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
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)

Pilot-scale filters examining many different media.

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

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

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

Minocqua, WI, MCTT Installation
Pilot-Scale MCTT Pollutant Control by Chamber for Selected Toxicants

<table>
<thead>
<tr>
<th></th>
<th>Main Settling Chamber</th>
<th>Peat/Sand Chamber</th>
<th>Overall Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microtox™</td>
<td>18</td>
<td>70</td>
<td>96</td>
</tr>
<tr>
<td>Lead</td>
<td>89</td>
<td>38</td>
<td>100</td>
</tr>
<tr>
<td>Zinc</td>
<td>39</td>
<td>62</td>
<td>91</td>
</tr>
<tr>
<td>Pyrene</td>
<td>100</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Bis (2-ethylhexyl) phthalate</td>
<td>99</td>
<td>-</td>
<td>99</td>
</tr>
</tbody>
</table>

Pilot-Scale Test Results for SS

<table>
<thead>
<tr>
<th></th>
<th>Inlet</th>
<th>Catch Basin</th>
<th>Settling Chamber</th>
<th>Sand-peat</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Suspended solids (mg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wisconsin Full-Scale MCTT Test Results

<table>
<thead>
<tr>
<th></th>
<th>Milwaukee (15 events)</th>
<th>Minocqua (7 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended Solids</td>
<td>98 (&lt;5 mg/L)</td>
<td>85 (10 mg/L)</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>88 (0.02 mg/L)</td>
<td>&gt;80 (&lt;0.1 mg/L)</td>
</tr>
<tr>
<td>Copper</td>
<td>90 (3 μg/L)</td>
<td>65 (15 μg/L)</td>
</tr>
<tr>
<td>Lead</td>
<td>96 (1.8 μg/L)</td>
<td>nd (&lt;3 μg/L)</td>
</tr>
<tr>
<td>Zinc</td>
<td>91 (&lt;20 μg/L)</td>
<td>90 (15 μg/L)</td>
</tr>
<tr>
<td>Benzo (b) fluoranthene</td>
<td>&gt;95 (&lt;0.1 μg/L)</td>
<td>&gt;75 &lt;0.1 μg/L</td>
</tr>
<tr>
<td>Phenanthrene</td>
<td>99 (&lt;0.05 μg/L)</td>
<td>&gt;65 (&lt;0.2 μg/L)</td>
</tr>
<tr>
<td>Pyrene</td>
<td>98 (&lt;0.05 μg/L)</td>
<td>&gt;75 (&lt;0.2 μg/L)</td>
</tr>
</tbody>
</table>
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)

Treatment Media Examined during WERF Study

• Traditional Media
  – Ion Exchange Resin
  – Granular activated carbon (GAC)
  – Sand

• Other Low Cost (disposable) media
  – Compost
  – 2 Zeolites
  – Iron Oxide Coated Sand
  – Agrofiber
  – Cotton Mill Waste
  – Peat-Sand Mix
  – Kudzu
  – Peanut Hull Pellets

• Metals Examined
  - Copper, Cadmium, Chromium, Zinc, Lead, and Iron

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

Cation Exchange Capacities for Different Media

<table>
<thead>
<tr>
<th>Media</th>
<th>CEC (meq/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat Moss</td>
<td>22</td>
</tr>
<tr>
<td>Compost</td>
<td>19</td>
</tr>
<tr>
<td>Activated Carbon</td>
<td>5.4</td>
</tr>
<tr>
<td>Zeolite</td>
<td>6.9</td>
</tr>
<tr>
<td>Cotton Waste</td>
<td>3.8</td>
</tr>
<tr>
<td>Agrofiber</td>
<td>9.4</td>
</tr>
<tr>
<td>Sand</td>
<td>3.5</td>
</tr>
</tbody>
</table>
Contaminant Losses during Anaerobic vs. Aerobic Conditions between Events

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

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

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.

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).
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 just starting.

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

15 to 20 gpm/ft² obtained for most media tested

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

EPA SBIR2 UpFlow™ Filter tests using Frankenstein 2 prototype

Support material and media
**EPA-funded SBIR2 Field Test Site Monitoring Equipment, Tuscaloosa, AL**

**Flow tests (300 gpm) for bypass capacity**

### Suspended Solids Removal Tests

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

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

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

![Performance Plot for Particle Size Distributions](image-url)
### Concentration in Particle Size Range (mg/L): 0 to 0.45 µm (TDS)

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Influent (mg/L)</th>
<th>Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 gpm/ft² or less</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13 gpm/ft² (to overflow)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20 gpm/ft²</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Concentration in Particle Size Range (mg/L): 0.45 to 3 µm

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Influent (mg/L)</th>
<th>Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 (and smaller)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10.4</td>
<td>80</td>
<td>42</td>
</tr>
<tr>
<td>20.8 (and larger)</td>
<td>80</td>
<td>62</td>
</tr>
</tbody>
</table>

### Concentration in Particle Size Range (mg/L): 3 to 12 µm

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Influent (mg/L)</th>
<th>Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (and smaller)</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>20.1</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>40.2 (and larger)</td>
<td>80</td>
<td>67</td>
</tr>
</tbody>
</table>

### Concentration in Particle Size Range (mg/L): 12 to 30 µm

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Influent (mg/L)</th>
<th>Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 (and smaller)</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>4.2</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>10.6</td>
<td>80</td>
<td>42</td>
</tr>
<tr>
<td>21.2 (and larger)</td>
<td>80</td>
<td>68</td>
</tr>
</tbody>
</table>

### Concentration in Particle Size Range (mg/L): 30 to 60 µm

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Influent (mg/L)</th>
<th>Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 (and smaller)</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>12.2</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>30.4</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>60.8 (and larger)</td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

### Concentration in Particle Size Range (mg/L): 60 to 120 µm

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Influent (mg/L)</th>
<th>Effluent (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4 (and smaller)</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>8.9</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>22.2</td>
<td>98</td>
<td>97</td>
</tr>
<tr>
<td>44.4 (and larger)</td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

### Probability Plot of Concentration for Particle Range 0-0.45 um

- Normal
- Mean: 0.011
- StDev: 18.07

### Probability Plot of Concentration for Particle Range 0.45-3 um

- Normal
- Mean: 0.011
- StDev: 18.07

### Probability Plot of Concentration for Particle Range 3-12 um

- Normal
- Mean: 0.011
- StDev: 18.07

### Probability Plot of Concentration for Particle Range 12-30 um

- Normal
- Mean: 0.011
- StDev: 18.07

### Probability Plot of Concentration for Particle Range 30-60 um

- Normal
- Mean: 0.011
- StDev: 18.07

### Probability Plot of Concentration for Particle Range >240 um

- Normal
- Mean: 0.011
- StDev: 18.07
70 to 90% SS reductions for influent concentrations >90 mg/L

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

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

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.
Hydraulic Characterization

Assembling Upflow Filter modules for lab tests

Hydro International, Ltd.

Initial CFD Model Results

High flow tests

Operation during normal and bypass conditions

Draindown between events

ETV test setup at Penn State - Harrisburg
Conclusions

• The MCTT provided substantial reductions in stormwater toxicants (both in particulate and filtered phases) and suspended solids.

• The main settling chamber provided substantial reductions in total and dissolved toxicity, lead, zinc, certain organic toxicants, SS, COD, turbidity, and color.

• The sand-peat chamber also provided additional filterable toxicant reductions.

• The catchbasin/ grit chamber is an important element in reducing maintenance problems by trapping bulk material.

Conclusions (cont.)

• 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.

Conclusions (cont.)

• 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.

Conclusions (continued)

<table>
<thead>
<tr>
<th>Constituent and units</th>
<th>Reported irreducible concentrations (conventional high-level stormwater treatment)</th>
<th>Effluent concentrations with treatment train using sedimentation along with sorption/ion exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate solids (mg/L)</td>
<td>10 to 45</td>
<td>&lt;5 to 10</td>
</tr>
<tr>
<td>Phosphorus (mg/L)</td>
<td>0.2 to 0.3</td>
<td>0.02 to 0.1</td>
</tr>
<tr>
<td>TKN (mg/L)</td>
<td>0.9 to 1.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Cadmium (µg/L)</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>Copper (µg/L)</td>
<td>15</td>
<td>3 to 15</td>
</tr>
<tr>
<td>Lead (µg/L)</td>
<td>12</td>
<td>3 to 15</td>
</tr>
<tr>
<td>Zinc (µg/L)</td>
<td>37</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>
References


Acknowledgements

WERF Project 97-IRM-2
Project Manager: Jeff Moeller

U.S. EPA Small Business Innovative Research Program (SBIR1 and SBIR2 plus ETV testing)
Project Officer: Richard Field

Many graduate students at the University of Alabama and Penn State-Harrisburg

Industrial Partners (US Infrastructure and Hydro International)