Laboratory Studies

Usually start with lab tests, but transferability of results to field conditions is not direct, especially if tests do not use actual stormwater (wide range of particulate sizes, interfering major ions, speciation and concentration of many targeted pollutants).

Rate of uptake, time to equilibrium, effects of varying parameters on mass transfer, leaching problems with saturated media, etc.
Pilot-scale filters examining many different media.

Use actual stormwater under varying flows and loads
Full-Scale Implementation: Minocqua, WI, MCTT
Pilot-Scale MCTT Monitoring Results

High levels of zinc removal required both sedimentation and sorption/ion-exchange processes (zinc present in both particulate-bound and filterable forms)
Pilot-Scale MCTT Monitoring Results

Bis(2-ethylhexyl)phthalate was strongly associated with particulates and was therefore almost completely removed with sedimentation processes (designed to remove particulates as small as 5 µm)
Full-Scale Testing Setup in Tuscaloosa, AL

Both controlled (pumped) and actual rain performance tests
Testing Many Treatment Controls Together: Performance of Various Green Infrastructure Controls for CSO Sites at Cincinnati Demonstration Projects

- Cincinnati State Technology School
- Cincinnati Zoo
- University of Cincinnati
- Clark Montessori School
- Underground stormwater storage tank
- Large biofilter/swale/rain garden
- Paver blocks porous pavement with groundwater observation well
- Porous asphalt pavement
EPA’s Green Infrastructure Demonstration Project, Kansas City: 100 acre test watershed (“completely” controlled) and adjacent 87 acre control watershed, with both small scale and large scale flow and water quality monitoring.
More than 150 stormwater controls constructed in area in city right-of-way

About $3 Million cost of controls by city
Even with extensive and maximum retrofitting, about 40% of the area is not treated by the controls (on private property, mostly with yard drains to combined sewers).
Example micro flow and drainage area analyses for a set of stormwater controls in the test area, examining both direct runoff area to biofilters and overflows from upgradient biofilters.
1324 76th St. monitoring location, biofilter and adjacent porous concrete sidewalk
Decreasing Test Area Flows Compared to Control Area Flows During and After Construction

During and after construction

Test (pilot) total flows compared to control area total flows (ratio)
One of the Kansas City rain gardens being monitored (zero surface discharges during the three years of monitoring; this rain garden is 20% of roof drainage area)
Observed and Modeled Flows in the Test Watershed after Construction of Stormwater Controls

Observed and Modeled Total Area Runoff Quantity (ft³), with 1 in/hr native soil infiltration rates below biofilters.
Stormwater Control Performance Optimization

Media selection and performance at historical industrial site that is currently being restored to open space park land from spacecraft engine and nuclear power plant tests

- Study site is a large RCRA (Resource Conservation Recovery Act) field lab located in Southern California (Ventura Co) operated by Boeing and NASA. Very low NPDES numeric effluent limits for stormwater. Some permit limits include:
  - Cadmium: 4 µg/L
  - Copper: 14 µg/L
  - Lead: 5.2 µg/L
  - Mercury: 0.13 µg/L
  - TCDD: 2.8 X 10^{-8} µg/L

Many of the permit limits would likely be exceeded for most stormwater dischargers, including residential and open space areas.
### Chemical Behavior Parameters of Interest for Some Organics

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>$K_{ow}$ (increased association with organic matter as $K_{ow}$ increases)</th>
<th>$K_s$ (increased water solubility as $K_s$ increases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dioxin (TCDD)</td>
<td>Very high ($10^{6.8}$)</td>
<td>Low (0.1 mg/L) for monochloro isomers; Very low ($10^{-9}$ mg/L) for octachloroisomers</td>
</tr>
<tr>
<td>Perchlorate</td>
<td>Very low ($10^{-5.8}$)</td>
<td>Very high ($K_s = 2 \times 10^5$)</td>
</tr>
<tr>
<td>Dimethyl Mercury</td>
<td>High ($\sim 2 \times 10^2$)</td>
<td>High (1,000 mg/L)</td>
</tr>
<tr>
<td>Oil &amp; Grease</td>
<td>Not quantifiable but many PAHs; therefore, expected to be high</td>
<td>Not quantifiable but many are PAHs; therefore, expected to be low</td>
</tr>
</tbody>
</table>
Other Design Considerations

• Clogging
• Kinetics of pollutant removal
• Media Capacity
• Nutrient Releases from Organic Component of Media due to Changes in Porewater Chemistry
• Nutrient and Water Uptake by Biomass
• Maintenance Intervals
### Pollutant Size Associations

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Size 20 μm</th>
<th>5 μm</th>
<th>1 μm</th>
<th>0.45 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended Solids</td>
<td>76</td>
<td>81</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>Turbidity</td>
<td>43</td>
<td>55</td>
<td>92</td>
<td>96</td>
</tr>
<tr>
<td>Total-P</td>
<td>68</td>
<td>82</td>
<td>89</td>
<td>92</td>
</tr>
<tr>
<td>Nitrate</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Cadmium</td>
<td>20</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Copper</td>
<td>26</td>
<td>34</td>
<td>34</td>
<td>37</td>
</tr>
<tr>
<td>Lead</td>
<td>41</td>
<td>62</td>
<td>76</td>
<td>82</td>
</tr>
<tr>
<td>Zinc</td>
<td>64</td>
<td>70</td>
<td>70</td>
<td>72</td>
</tr>
</tbody>
</table>

Can have large fraction remaining even after removal down to just a few micrometers

Morquecho 2005
<table>
<thead>
<tr>
<th>Analytes on Permit</th>
<th>Treatment Technology Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_2$+NO$_3$</td>
<td>Ion-exchange or plant uptake (potential denitrification? Other problems with denitrification)</td>
</tr>
<tr>
<td>Total Zinc and Total Copper</td>
<td>Chemically-active filtration (organic media sorption/ion-exchange) after pre-settling</td>
</tr>
<tr>
<td>Total Lead</td>
<td>Physical filtration of larger particulate-associated lead after pre-settling. Chemically-active filtration (organic media sorption and potential ion-exchange)</td>
</tr>
<tr>
<td>TCDD</td>
<td>Chemically-active filtration with strong organic sorption (GAC) after pre-settling. Other organics potential elevated parent material contamination.</td>
</tr>
<tr>
<td>Total Mercury</td>
<td>Chemically-active filtration with sorption for MeHg &amp; ion-exchange for inorganic mercury and complexes.</td>
</tr>
<tr>
<td>Oil and grease</td>
<td>Chemically-active filtration with strong organic sorption component (GAC) after capture of free-floating material if concentrations are high and visible. Peat and compost also possible.</td>
</tr>
</tbody>
</table>
Media Testing Goals

– To provide information for design (e.g., optimal media components, depths, and contact times).
– To maximize the likelihood that filtration-based treatment controls will achieve performance objectives.
– To optimize design considering the large investment ($0.10 to $1.00 per lb of media and many tons needed) and to ensure long-life before clogging or break-through.

• Bench-scale lab experiments performed by Penn State – Harrisburg and the University of Alabama

Media (from left to right): GAC, Rhyolite Sand, Site Zeolite, Surface Modified Zeolite, Sphagnum Peat Moss
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 to 25 kg/m$^2$ of media surface (flow rate < 1 m/d, generally).

Tried potential maintenance options once flow rate < 5 m/d (effects of disturbing media vs. removing media from filter).

Media removal generally more effective, but must remove at least 4 – 6” because clogging solids are captured deep in the media (deeper than visible solids buildup).
Column test results: Hydraulics and Clogging

- Maintenance with scraping of the surface of the media was not very effective; the removal of several inches of media worked better, but still only for a limited time.

1. Site sand clogged first and had the lowest flow rate
2. Site zeolite was next to clog
3. Biofiltration mixed media combination performed better than current site layered media combination
Media Performance Plots for Copper, Full-Depth Long-Term Column Tests
### Cumulative Particulate Loading to Failure and Expected Years of Operation for Largest Sedimentation-Biofiltration Treatment Trains on Project Site

<table>
<thead>
<tr>
<th></th>
<th>R-SMZ</th>
<th>R-SMZ-GAC</th>
<th>R-SMZ-GAC-PM</th>
<th>Site Sand-GAC-Site Zeolite Layered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load to clogging (kg/m²)</td>
<td>7.5 - 38</td>
<td>11 - 53</td>
<td>11 - 55</td>
<td>6.5 - 33</td>
</tr>
<tr>
<td>Years to replacement</td>
<td>12 - 58</td>
<td>16 - 81</td>
<td>17 - 84</td>
<td>10 - 50</td>
</tr>
</tbody>
</table>

- Seven of the site biofilters were evaluated for maintenance problems. The biofilters were from about 1 to 10% of the drainage area and had sedimentation pre-treatment.

- All of the media combinations would likely have an operational life of at least 10 years for the constituents of greatest concern, with the exception of oil and grease for the layered media.
Batch Testing Results: Contact Time for Filtered Metals

- Minimal filtered metal removal when contact time <10 minutes (except peat which can be effective at low contact times).

- Optimal contact times removal ranged from 10 to 1,000 minutes, depending on metal and media type.
Flow Rate as a Function of Salt Loading

(soil was clay-free; these results indicate that some organic compost components are also dispersed in the presence of high salt loads leading to SAR problems; worse problem in soils or media with clays)

Kakuturu and Clark 2011
Preparing Recommended Media for Large Biofilters

1. Filling individual media bags prior to mixing
2. Loading Rhyolite sand media bags into mixer
3. Loading surface modified zeolite media bags into mixer
4. Loading granular activated carbon media bags into mixer
5. Finished mixed media loaded into final bags
6. Mixed media ready for placement into biofilters
Large Biofilter Cascading Beds Ready to Receive Media Mixtures
Conclusions

• Conclusion: Media can be tailored to address specific pollutant problems.

• Conclusion: Removal function of both water and media chemistry
  – Knowledge rich and data poor on water quality chemistry and speciation.
  – Media specs beginning to address fundamental media characteristics.

• Question: How to improve media specs to reduce variability in treated water concentrations?

• Question: Improve/develop models for predicting media effectiveness and lifespan for filtered metals removal?

• Question: And many more.......
Acknowledgements

• The Boeing Co., supported the bench-scale and full-scale media studies and Geosyntec provided site support and project management.
• The EPA, Urban Watershed Management Branch, provided support for data analyses and modeling through our current wet weather flow emerging contaminant research and prior research on stormwater treatment.
• Many students and staff at the University of Alabama and Penn State – Harrisburg assisted with the sampling and analyses.