Bioretention Research at the University of Maryland

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The Challenge

Figure 1.1 Water Balance at a Developed and Undeveloped Site
(Source: Schueler, 1987)
Conventional
Hydrology
Sources of Pollutants
Sources of Pollutants
Low Impact Development

- Pre-development Quantity & Quality
- Keep Stormwater On Site
- Promote Infiltration; more ET
- Filtering and other Natural Treatment Mechanisms
- Apply Green Engineering Principles to Land Development
Early Bioretention
Bioretention
Goals

- Hydrology Management
- Improvements in Water Quality
- Understand Fundamentals
- Facility Design
  - Size
  - Media
- Facility Management
Bioretention (Rain Gardens)

Hydrology: Pooling, Infiltration, & Evapotranspiration

Quality: Filtration, Adsorption, Biodegradation
Three Timescales

- **Event timescale**
  - Hydrologic management and removal of pollutants from runoff during storm event

- **Between-event timescale**
  - Degradation or incorporation of captured pollutants

- **Facility Life timescale**
  - Ecological and Biogeochemical transformations
Bioretention research & monitoring
Hydrographs

- **Post-development**
  - Higher peak,
  - Greater volume,
  - Earlier peak

- **Predevelopment**
Flows, 4/3/06 Storm Event (CP)

Effluent stopped at 4/4/06 9:12

Peak Delay
Peak Height Reduction
Discharge vs. Zero-discharge events (SS)

Rainfall depth (cm)

Event duration (hr)

Underdrain flow

No flow

60, 23
Peak Reduction Ratio, $R_{peak}$

\[ R_{peak} = \frac{q_{peak-out}}{q_{peak-in}} \]

Li, Sharkey, Hunt, & Davis, J. Hydro. Eng., accepted 2008
Performance/Design Relationships

\[ f_{24} = \frac{\text{Volume}_{24-out}}{\text{Volume}_{24-in}} \]

Li, Sharkey, Hunt, & Davis, J. Hydro. Eng., accepted 2008
Water Quality

College Park
Input
Output

Silver Spring
Input
Output
Water Quality Data (RG)

\[ EMC = \frac{M}{V} = \frac{\int_0^{tr} c(t)q(t)dt}{\int_0^{tr} q(t)dt} \]

Davis, Env. Eng. Sci. 2007
Bioretention TSS (CP & SS)

Legend
- CP
  - Influent
  - Effluent
- SS
  - Influent
  - Effluent
- BDL or no flow

TSS EMC (mg/L) vs. Exceedance Probability
Media & Suspended Solids \((O&G, Pb)\)
Bioretention
Zinc (CP & SS)

Legend
- CP
  - Influent
  - Effluent
- SS
  - Influent
  - Effluent
  - BDL or no flow

Zinc EMC (ug/L) vs. Exceedance Probability
Total Phosphorus (CP)

Legend
- Influent
- Effluent
- BDL

Phosphorus Conc. (mg/L as P) vs. Exceedance Probability

- Influent data points indicate concentrations ranging from 0.1 to 2 mg/L as P.
- Effluent data points show a trend line starting from 0.1 mg/L as P with an increasing trend towards 2 mg/L as P with increasing probability.
- BDL points are indicated with an open square symbol.

The graph shows the relationship between phosphorus concentration and exceedance probability, with a clear increase in concentration as the probability increases.
Media & Phosphorus

TP Removal Efficiency, % vs Infiltration Rate, cm/min

Hsieh & Davis J. Env. Eng. 2005
TN (CP)

Exceedance Probability vs. Nitrogen Conc. (mg/L as N)

Legend
- Influent
- Effluent
Chloride (CP)

Exceedance Probability vs. Chloride Conc. (mg/L)

Legend
- Influent
- Effluent
## Pollutant Mass Loads

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>CP Load (kg/ha-yr)</th>
<th>CP Discharge (kg/ha-yr)</th>
<th>SS Load (kg/ha-yr)</th>
<th>SS Discharge (kg/ha-yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>674</td>
<td>27</td>
<td>233</td>
<td>2</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.93</td>
<td>0.074</td>
<td>0.23</td>
<td>0.002</td>
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<tr>
<td>Copper</td>
<td>0.23</td>
<td>0.079</td>
<td>0.13</td>
<td>0.005</td>
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<tr>
<td>Lead</td>
<td>0.017</td>
<td>&lt;0.017</td>
<td>0.017</td>
<td>&lt;0.017</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.086</td>
<td>0.035</td>
<td>0.017</td>
<td>&lt;0.017</td>
</tr>
<tr>
<td>TN</td>
<td>15</td>
<td>15</td>
<td>10</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Nitrate</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>TP</td>
<td>1</td>
<td>1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Chloride</td>
<td>60</td>
<td>154</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>TOC</td>
<td>48</td>
<td>55</td>
<td>39</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
Bioretention PAH (CP)

**PAH concentration (µg/L)**

- Naphthalene
- Acenaphthylene
- Fluorene
- Phenanthrene
- Anthracene
- Fluoranthe
- Pyrene
- Benzo(a)anthracene
- Chrysene
- Benzo(b+k)fluoranthene
- Indeno(1,2,3-cd)pyrene
- Dibenz(a,h)anthracene
- Benzo(g,h,i)perylene

**PAHs in dissolved phase**

- CPI
- CPO

w/ UMBC
**Bacterial Transport**

The graph shows the transport of B6914 C/C₀ under different conditions. The x-axis represents time in hours, ranging from 0 to 6. The y-axis represents the concentration ratio B6914 C/C₀, ranging from 0 to 1.

- **Red squares** represent Coarse IOCS.
- **Black squares** represent Coarse sand.
- **Green diamonds** represent Fine IOCS.
- **Brown diamonds** represent Fine sand.
- **Gray crosses** represent conventional media.

The graph illustrates the differences in transport efficiency across various media types and conditions.
Bacteria-columns

Removal efficiency for B6914

Under UV light
Nitrate

- Critical Bay Pollutant
- Tough

Runoff

Bioretention Soil/Media

Biological Denitrification Zone

$\text{NO}_3^- \Rightarrow \text{N}_2$

Three Timescales

- **Event timescale**
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  - Degradation or incorporation of captured pollutants

- **Facility Life timescale**
  - Ecological and Biogeochemical transformations
Motor Oil

Bench Reactor

After 0 day

17 days

Biotic

18 days

Inhibited

Hong et al. Water Environ. Res. 2006
Survival of Trapped E. coli

Drainage time (days)

- Conventional bioretention media
- Fine IOCS
Bacteria Survival

**Drainage time (days)**

- **N/No** vs. **Time (days)**
  - **E. Coli**
  - **Protozoa**

**Total protozoa (MPN)**

- **Time (days)**
Three Timescales

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Suspended Solids Deposition

➢ A three-layer model

Incoming Suspension

Mass balance:
\[ q \frac{\partial C}{\partial Z} + \rho \frac{\partial \sigma}{\partial t} = 0 \]

Solids deposition
\[ \frac{\partial C}{\partial Z} = -\lambda C \]

Hydraulic conductivity:
\[ \frac{K_0}{K_b} = (1 + \gamma \sigma)^2 \]

\[ K_a = K_0 \]

Li & Davis, J. Env. Eng. 2008
TSS Accumulation

- TSS do not penetrate below 5-20 cm in the media
- Clay-size components exert controlling effect on clogging
- Intermittent flow conditions allow more particulate capture than continuous flow
- Periodic surface media replacement can be used to recover hydraulic conductivity.

Li & Davis, J. Env. Engg. (2008)
Metals Accumulation - Pb

Navy Yard

Dimensionless TSS or Normalized Captured Pb Deposit

Li & Davis, Env. Sci. Technol. In press
Depth and Distance - Lead

Depth (cm)

Pb total (mg/kg)

Original BSM
- Solid = Organic
- Empty = BSM

Depth and Distance - Lead

Depth (cm)

Pb total (mg/kg)

Original BSM
- Solid = Organic
- Empty = BSM
<table>
<thead>
<tr>
<th>Metal</th>
<th>Soil retention</th>
<th>Plant uptake</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>4.3%</td>
<td>1.1%</td>
<td>94.6%</td>
</tr>
<tr>
<td>Zn</td>
<td>5.5%</td>
<td>1.9%</td>
<td>92.6%</td>
</tr>
<tr>
<td>Cu</td>
<td>9.5%</td>
<td>1.4%</td>
<td>89.1%</td>
</tr>
<tr>
<td>Cd</td>
<td>3.1%</td>
<td>1.2%</td>
<td>95.7%</td>
</tr>
</tbody>
</table>

*Sun & Davis, Chemosphere, 2007*
Accumulation - PAH

PAH Concentration (µg/g dry)

Top Crust (1-2 mm)
Top Loose Gravel
  In 0 to 10 cm
  In 10 to 20 cm
  In 20 to 30 cm
  In 30 to 41 cm
  In 41 to 51 cm
  Mid 0 to 10 cm
  Mid 10 to 20 cm
  Mid 20 to 30 cm
  Mid 30 to 41 cm
What we know so far…

- Excellent Management of Hydrology
  - Peak Reduction
  - Volume Reduction
  - Peak Delay
    - Evapotranspiration
    - Infiltration
- Media Volume: Area & Depth
  Apparently Control

*(Hydrologic Management)*
What we know so far...

- Excellent Removal of Several Pollutants Independent of Media
  - Suspended Solids
  - Oil and Grease (Physical Capture)
  - Metals: Lead, Zinc, Copper, Cadmium
  - Bacteria
- High Infiltration Media can be Employed
  - Err on side of greater infiltration
- Depth of Facility not Important here
What we know so far...

- Phosphorus, Ammonia, Organic N Removal Complex
  - Adsorption
  - Transport with Suspended Solids
  - Preferential Flow Pathways
- Depth and Media Characteristics Important *(Chemical Processes)*
- Chloride may be a problem
What we know so far…

- Modifications for Sustainable Removal of Pollutants
- Encourage Biodegradation Processes
  - Denitrification Zone
  - Capture and Biodegradation of Oil & Grease
  - Biological Predation
- Exploitation for vegetation in uptake, degradation, and removal of pollutants.
Implementation Challenges

- Lack of Performance Information
- Lack of Understanding
- Space
- Utilities
- Regulatory Hurdles
- Inertia
- Contractor Inexperienced
- Specification Details
- Ownership of pollutants?
- Long term???
Co-Workers

- **Students**
  - Mohammad Shokuhian
  - Houng Li
  - Himanshu Sharma
  - Eunyoung Hong
  - Ameya Pradhan
  - Xueli Sun
  - Rebecca Stack

- **Others**
  - Roman Hsieh
  - Lan Zhang
  - Hunho Kim
  - Kelly Flint
  - Christie Minami
  - Philip Jones
  - Eric Seagren
  - Brian Needelman
  - Upal Ghosh & Katie DiBlasi
  - Bill Hunt & Lucas Sharkey
  - Jeff Karns
  - Neil Weinstein
  - Rufus Chaney
Research Sponsors

www.ence.umd.edu/~apdavis/Bioret.htm
Beyond...
The Proper Metrics for Success?

- How do we measure the environmental impact of land development and proposed solutions?
The Nitrogen Dilemma

- **Nitrogen** is the limiting pollutant for the Chesapeake Bay
- Ag lands discharge a high \( N \) load
- Developed lands generally discharge a low \( N \) load
- Save the Bay! Convert all farm land to houses!
TN (SS)