Urban Stormwater Runoff Phosphorus Loading & BMP Treatment Capabilities

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Overview

- Phosphorus Basics
- Urban Loadings
- BMP Capabilities
- Sorption Applications
- Things to Avoid
Phosphorus

- Essential nutrient for life
- Cyclic between land & water
- Limiting nutrient in fresh water
- Found in Stormwater:
  - Particulate-bound phosphorus
  - Dissolved phosphorus (DP)
Problem:

- Excess Phosphorus in fresh water causes **Eutrophication** (over enrichment):
  - Algal blooms
    - Micro-toxins ... *Toxic Cyanobacteria*
  - Hypoxia --- depletion of Dissolved Oxygen
    - Fish kills
    - Invasive species
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- Algal blooms
- Microtoxins
- Toxic Cyanobacteria
- Hypoxia (depletion of dissolved oxygen)
- Fish kills
- Invasive species

POSTED: Based on counts of the cyanobacteria (blue-green algae), MDPH thresholds for recreational waters have been exceeded.

- Water which looks like the pictures above may contain algae capable of producing toxins that can be dangerous to humans and pets.
- People and pets should avoid contact in areas of algae concentration
- Do not swallow water and rinse off after contact

For further information call:
MA Department of Public Health at 617-624-5757
Additional Issues from Phosphorus Loading:

- Taste and odor problems with drinking water
  - Increased drinking water treatment costs
  - Disinfection byproducts
- Water clarity
- Fish & aquatic community
- Recreational quality
- Property values

Lake Champlain, AUG 2008
Canadian Experimental Lakes Area # 226:

- Curtain divided lake
- Carbon & Nitrogen added to both sides
- Phosphorus added to lower half

ELA, Fisheries and Oceans Canada
Qingdao, Eastern China`s Shandong province
July, 2008
Typical Urban Stormwater Phosphorus Sources

- Fertilizers
- Waste Water (CSO / Septic)
- Animal Waste
- Development ... Sediment Loss & exposure
- Airborne Fallout: Dust, Pollen, Fossil Fuels
- Vegetation / Leaves
- Detergents
- Hydrocarbons & Lubricants
Total Phosphorus
Stormwater Loading by Land Use

Pounds / Acre / Year

Commercial | Industry | High Density Residential | Highways | Parking Lot | Shopping Center | Med. Density Residential | Parks | Low Density Residential

EPA Stormwater BMP Design Guide, 2004
Phosphorus Load with Increasing % Imperviousness

Center for Watershed Protection - Schueler and Caraco 2001
Total Phosphorus Load with Increasing % Tree Canopy

- Linear regression
- $R^2 = 0.94$

**Graph:**
- X-axis: % Tree Canopy
- Y-axis: Total Phosphorus (mg/L)
- Data points for Harper and Monroe

USGS Water-Resources Investigations Report 99–4021
Stormwater
Total Phosphorus (TP) Partitioning

1. Particulate-Bound (PB) Phosphorus

2. Dissolved Phosphorus (DP)
   - less than 0.45-micron
     - Soluble Reactive Phosphorus (SRP) / Bio-available
     - “QUICK SUGAR” for Algal Blooms
## Stormwater Runoff

### Phosphorus Partitioning by Land Use

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Open Space</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ave. TP EMC (mg/L)</strong></td>
<td>0.41</td>
<td>0.34</td>
<td>0.45</td>
<td>0.59</td>
</tr>
<tr>
<td><strong>Ave. DP EMC (mg/L)</strong></td>
<td>0.20</td>
<td>0.18</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>% PB</strong></td>
<td>51 %</td>
<td>47 %</td>
<td>64 %</td>
<td>73 %</td>
</tr>
<tr>
<td><strong>% DP</strong></td>
<td>49 %</td>
<td>53 %</td>
<td>36 %</td>
<td>27 %</td>
</tr>
</tbody>
</table>

TP = Particulate-bound phosphorus & Dissolved Phosphorus  
DP = Dissolved Phosphorus  
PB = Particulate-bound Phosphorus  

New York State DEC, 2008
Total Phosphorus (TP) Removal

BMP Efficiencies

Center for Watershed Protection, National Pollutant Performance Removal Database version3, Sept. 2007
Typical Urban Stormwater BMPs designed to captures 80% TSS:

- Particulate-bound Phosphorus (PB)
- Dissolved Phosphorus (DP)

50% TP --- Associated with TSS (sediment)
50% TP --- Dissolved (< 0.45-microns)

80% TSS capture X 50% (particulate-bound phosphorus) = 40% (TP) Removal
Natural factors impacting Phosphorus Fate in Stormwater Runoff & BMPs

- Water chemistry conditions
  - pH
  - Alkalinity
  - Temperature
  - Redox potential
  - Particle charge
  - Concentration
- Time / maintenance frequency
Phosphorus Fate

- Phosphorus speciation will shift
  - Sediments release Phosphorus
    - Particulate-bound (PB) shifts into Dissolved Phosphorus (DP)

- Examples
  - Impact of acid rain (pH of 7.0 versus 5.0)
  - Runoff detained versus diluted (pH & time)
  - Anaerobic activity / decaying organics
<table>
<thead>
<tr>
<th>Primary Unit Process / Removal Mechanism</th>
<th>Total Phosphorus (TP)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Particulate-bound Phosphorus (PB)</td>
<td>Dissolved Phosphorus (DP)</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Filtration</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>Biological Uptake</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>*assuming vegetative harvesting</td>
<td></td>
<td>*assuming vegetative harvesting</td>
</tr>
<tr>
<td>Sorption</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Sorption

- Combination of complex physiochemical interactions;
  - Adsorption - surface attachment
  - Absorption - internal attachment (sponge)
  - Ion Exchange - displacement of ions (Ca, Mg, Na)

Sorption Capacity --- mg/g

Ion Exchange Capacity --- meq/100g
Ways to increase TP removal & reduce performance variance?

1. **↑ TSS Removal**
   (particulate-bound P Removal)
   - Increase volume treated

2. **Prevent Phosphorus Speciation Shift**
   - Increase maintenance frequency

3. **Amend BMPs to Capture DP**
   - Sorption
Quantifying Sorption Capability for Dissolved Pollutant Removal

- **Isotherm** – How much can it hold?
- **Kinetics** – How fast can it go in?
- **Breakthrough** – How much before it is full? (maintenance)
- **Desorption** – Retaining DP … is the bond strong enough?
### Dissolved Phosphorus (DP) Sorption Performance

(T. Wu et al, Stormwater Phosphorus Adsorption on Oxide Coated Media, WEFTEC, 2008)

<table>
<thead>
<tr>
<th>Media Type</th>
<th>Isotherm $K_f$ (mg/g)</th>
<th>Kinetics $q_e$ (mg/g)</th>
<th>Breakthrough Exhaustion (BVs)</th>
<th>Desorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-oxide Pumice</td>
<td>0.40</td>
<td>1.19</td>
<td>1,800 - 2,700</td>
<td>No</td>
</tr>
<tr>
<td>Al-oxide Waste Aggregate</td>
<td>1.3</td>
<td>0.51</td>
<td>1,450 - 3,600</td>
<td>No</td>
</tr>
<tr>
<td>Mod. Activated Alumina</td>
<td>5.7</td>
<td>0.40</td>
<td>&lt; 1</td>
<td>No</td>
</tr>
<tr>
<td>Zeolite / Perlite / Carbon (ZPG)</td>
<td>0.05</td>
<td>None</td>
<td>5</td>
<td>Yes</td>
</tr>
<tr>
<td>Perlite</td>
<td>0.002</td>
<td>1.37</td>
<td>&lt; 10</td>
<td>No</td>
</tr>
<tr>
<td>Recycled Tire</td>
<td>0.003</td>
<td>None</td>
<td>&lt; 45</td>
<td>Yes</td>
</tr>
<tr>
<td>Expanded Shale</td>
<td>0.14</td>
<td>0.98</td>
<td>9 - 50</td>
<td>Yes</td>
</tr>
<tr>
<td>Bioretention Soil</td>
<td>0.18</td>
<td>4.67</td>
<td>50</td>
<td>No</td>
</tr>
<tr>
<td>Concrete Sand</td>
<td>&lt; 0.01</td>
<td>&lt; 0.001</td>
<td>&lt; 5</td>
<td>No</td>
</tr>
</tbody>
</table>

Very Finely Graded Medias (< 0.5 mm) with low hydraulic conductivity
Amended Sand Filters & Filtration Trenches

Applications

Use Sorption based Media or Material

- displace part of Sand bed
Amended Low Impact Development
Bioretention & Rain gardens

Use Sorption based Media or Material
- Layer under mulch
- Part of under drain
Amended Pervious Pavements

- Interlocking Pavers
- Pervious Pavements

Applications

- In Joints
- Bedding Course
- Polishing System

Under Drain PVC
Things to Avoid with “Sorption” Materials

- Limit use of materials prone to desorption
  - Organics / Compost / Soils
    - P-index is an indicator
  - Evaluate Material
    - Expanded Shale, Recycled Tires, ZPG

- Prevent leaching of other Toxics
  - pH, Heavy Metals
    - Slag, Iron-based materials, other waste by-products
Summary

To address Eutrophication & Enhanced Phosphorus Requirements......

- Look beyond Total Phosphorus (TP) & account for Dissolved Phosphorus (DP)

- **Amend** BMPs to be “Best Management Practices” and address DP removal
Questions?
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