Phosphorus Treatment - Advanced Removal Mechanisms and Amended Design for Stormwater BMPs

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Overview

- Phosphorus Basics
- NPS Loads
- Stormwater BMP performance
- Advanced Phosphorus Removal Mechanism
- Amended BMP Designs
- Things to Avoid
Phosphorus Basics

- Essential nutrient for life
- Cyclic between land & water
- Limiting nutrient in fresh water
Canadian Experimental Lakes Area # 226:

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

Fisheries and Oceans Canada - 1973
Millions of Years
Lake Erie - Oct. 2010
Problem:

- Excess Phosphorus in fresh water causes *Eutrophication* (over enrichment):
  - Algal blooms
    - Micro-toxins … *Cyanobacteria*
  - Hypoxia
    - Fish kills
    - Invasive species
Additional Issues:

- Taste & odor problems
- Fish & aquatic community
- Recreational quality
- Property values

**Caution:**

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
NPS Phosphorus Sources

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

- Commercial: 1.5 pounds/acre/year
- Industry: 1.0 pounds/acre/year
- High Density Residential: 0.75 pounds/acre/year
- Highways: 0.5 pounds/acre/year
- Shopping Center: 0.25 pounds/acre/year
- Med. Density Residential: 0.1 pounds/acre/year

EPA Stormwater BMP Design Guide, 2004
Imperviousness Cover & Phosphorus Load

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

USGS Water-Resources Investigations Report 99–4021
Phosphorus Load with Increasing % Tree Canopy

![Graph showing the relationship between Total Phosphorus (mg/L) and % Tree Canopy. The graph includes data points from Harper and Monroe. The linear regression line has an R² value of 0.94.](image)

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

1. Particulate-Bound (PB) Phosphorus

2. Dissolved Phosphorus (DP)
   - Bio-available
   - “QUICK SUGAR” for Algal Blooms
## 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>% PB</td>
<td>51 %</td>
<td>47 %</td>
<td>64 %</td>
<td>73 %</td>
</tr>
<tr>
<td>% DP</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

National Stormwater Quality Database  
New York State DEC, 2008
Phosphorus in Stormwater

What should you capture?

PHOSPHORUS

from Breault and others, 2005

<table>
<thead>
<tr>
<th>PARTICLE SIZE (MICRONS, µm)</th>
<th>CONCENTRATION, PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel &gt;2000</td>
<td>0.06</td>
</tr>
<tr>
<td>Coarse sand 2000-250</td>
<td>0.04</td>
</tr>
<tr>
<td>Fine sand 250-125</td>
<td>0.06</td>
</tr>
<tr>
<td>Very fine sand 125-63</td>
<td>0.18</td>
</tr>
<tr>
<td>Silt and clay &lt;63</td>
<td>0.18</td>
</tr>
</tbody>
</table>
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
Range of Total Phosphorus (TP)

% Removal per BMP Type

Center for Watershed Protection,
National Pollutant Performance Removal Database version 3, Sept. 2007
Factors impacting Phosphorus Fate & Transport

- Water chemistry conditions
  - pH
  - Alkalinity
  - Temperature
  - Redox potential
  - Particle charge
  - Concentration

- Time / Maintenance frequency
Phosphorus Fate

- Phosphorus speciation will shift

Some Examples

- Impact of runoff pH of 7.0 vs 5.0
- Detention (pH & time)
- Anaerobic activity / decaying organics
## Stormwater TP Removal Mechanisms & Generalized Capability

<table>
<thead>
<tr>
<th>Unit Process / Removal Mechanism</th>
<th>Total Phosphorus (TP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sedimentation</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Filtration</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Biological Uptake</strong></td>
<td>Limited</td>
</tr>
<tr>
<td></td>
<td>*assuming vegetative harvesting</td>
</tr>
<tr>
<td><strong>Sorption</strong></td>
<td>No</td>
</tr>
</tbody>
</table>
Sorption

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

- Sorption Capacity --- mg/g

Compared to soils ...

- Ion Exchange Capacity --- meq/100g
Ways to increase TP removal & reduce variation

1. **TSS Removal**
   (particulate-bound P Removal)

2. **Design / Implement systems to**;
   A. Capture SILT-sized particles
      (63-microns)
   B. Prevent RESUSPENSION
Ways to increase TP removal & reduce variation

3. Prevent Phosphorus Speciation Shift
   - Maintenance?

4. Amend & Design BMPs to Capture DP
   - Incorporate Sorption Materials to polish

5. Treat more $WQ_v (> 90\%)$
Phosphorus in Stormwater

- Particulate bound
- Dissolved Phosphorus

Sediment particle
Quantifying Sorption Capability for Dissolved Pollutant Removal

- Isotherm –
  - Best Case Maximum capacity it can hold?

- Kinetics –
  - How fast can it be sorbed?

- 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 (0.5 mm to 10 mm)</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>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>Very Finely Graded Medias (&lt; 0.5 mm) with low hydraulic conductivity</td>
<td></td>
<td></td>
<td></td>
<td></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>
Amended
Low Impact Development
Bioretention & Rain gardens

Use Sorption based Media or Material
- Layer under mulch or
- Part of under drain or
- Polishing Cell
Amended Surface Filters (sand filters / bioretention)

Applications

- Use Sorption based Media or Material
  - displace part of Sand bed
Amended Pervious Pavements

- Interlocking Permeable Pavers

Applications
Sorbative MEDIA
As MEDIA layer or bed in:
- Joints
- Bedding Course
- Polishing Filter

Under Drain PVC
Things to Avoid with “Sorption” Materials

- Monitor the use of materials prone to desorption
  - Organics / Compost / Soils
  - Evaluate Material

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

- Urban Runoff can be a significant Phosphorus contributor
- Impaired water bodies should use BMPs to treat **Dissolved Phosphorus (DP)**
- BMPs “Best Management Practices” can easily be amended to address DP removal
Questions?

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