Determining which iron minerals in iron-enhanced sand filters remove phosphorous from stormwater runoff

A Progress Report

Drs. Beth A. Fisher, Joshua M. Feinberg, John Gulliver
<table>
<thead>
<tr>
<th>Iron minerals expected in recycled industrial waste</th>
<th>Estimated capacity to bind phosphorous</th>
<th>Detectable &amp; quantifiable by magnetic methods &lt; 100 ppm</th>
<th>Detectable by X-ray diffraction &lt; 100 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrihydrite, disordered</td>
<td>High affinity for P binding</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Goethite, FeO•OH</td>
<td>Common in environment, binding w/P unknown</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Magnetite, Fe₃O₄</td>
<td>Correlates w/heavy metals, binding w/P unknown</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Metallic Iron, Fe</td>
<td>Unstable in environment, binding w/P unknown</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Hematite, Fe₂O₃</td>
<td>Low P adsorbability</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Siderite, FeCO₃</td>
<td>Low P adsorbability</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Iron-enhanced sand filters: research and development status</td>
<td>Known</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Hydraulic conductivity range</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of water flow through filter</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filter longevity: Physical sediment clogging</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filter longevity: Chemical capacity to hold phosphorous</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Quantity of total iron for long-term effectiveness in filtering</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Specific iron minerals that effectively bind with phosphorous</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Overall goal
Determine which specific minerals are most effective at removing phosphorus in iron-enhanced sand filters and the environmental conditions that affect phosphorous removal.

Sites
We are examining 4 iron-enhanced sand filter systems:

- North Lion Park, Crystal
- Olson Middle School, Minneapolis
- Champlain
- Williams Street Pond, Saint Paul

Strategy
We will be (1) characterizing the iron mineralogy, and (2) monitoring the chemical environment of the filter systems.
Characterizing the iron mineralogy

Methods
X-ray Diffraction
Electron microscopy (SEM and Microprobe)
X-ray Fluorescence
Magnetism
Wet Chemistry
Beth Fisher’s New Monitoring Stations

Built from scratch a series of sensor stations to monitor in real time the environmental conditions at our sites.

These stations are created using open-source technology and code and monitor the following parameters:

• Temperature in the filter media and adjacent open water
• Water level in the iron enhanced sand filter (IESF)
• Conductivity in and our of the IESF
• Redox conditions at various depths within the filter.
• Dissolved oxygen within the filter.

Beth is only supported 20% time on this project.
Iron-enhanced sand filter media

Solar powered open-source logger station on cellular data network +$4/month cellular service $253

Pre-filtration water sensors

Overflow to storm sewer

Post-filtration water sensors

Filter media drain to outlet

Perimeter drain to outlet

Iron-enhanced sand filter media

Filter media sensors:
- Dissolved Oxygen $665
- Moisture $180
- Redox (4 depths) $300

Total sensors for each retention pond type iron-phosphorous trap system $3,995

Water sensors:
- Dissolved Oxygen $665
- Turbidity $520
- Conductivity $180
- Water level sonar (above water on post or logger station) $120

Figure of filtration pond modified from Minnesota Stormwater Manual, Minnesota Pollution Control Agency.
Sensor Networks: Cost vs. Coverage

- Campbell Scientific data-loggers & radios

CR1000 Measurement & Control Datalogger: $1400
AM16/32B 16 or 32 Channel Relay Multiplexer: $500
RF430 spread spectrum radio: $600

Total = $2500
Sensor Networks: Cost vs. Coverage

• Open-source data-loggers & radios

- EnviroDIY Mayfly Microprocessor & Datalogger $60
- Accessories (vary depending on need) $30-90
- Solar Panel $10-35
- Cell Phone or Radio Modules $30-60

Total = $140-$220
Open-Source DataLogger & Sensor Station

Decagon CTD
Campbell Turbidity
Mineral Characterization at North Lion Park Site

Initial measurements show that this filter contains a complicated assemblage of:

- Metallic iron
- Magnetite
- Ilmenite
- Goethite
- Hematite

The repeated wetting and drying of the filter is likely associated with the formation of magnetite.

Oxidation of the metallic iron produces coatings of hematite and goethite.
North Lion Park Monitoring

Precipitation in Brooklyn Center

Daily Precipitation in Inches

Days in June
North Lion Park Monitoring

- [https://data.envirodiy.org/sites/NLP01/](https://data.envirodiy.org/sites/NLP01/)
- Conductivity & temp in pond and media
- Dissolved oxygen & temp in pond and media
- Soil moisture
- Water level above media

- [https://data.envirodiy.org/sites/NLP02/](https://data.envirodiy.org/sites/NLP02/)
- Redox at three depths in media
Olson Middle School, MPLS, MN

Sand + Biochar

Sand + Iron
Mineral Characterization at Olson Middle School Site

Initial measurements show that this filter contains a simpler assemblage of:

- Metallic iron
- Goethite
- Hematite

Fewer wetting and drying cycles of the filter have meant that magnetite is rarely formed.

Oxidation of the metallic iron produces coatings of hematite and goethite.
Mineral Characterization at Champlain Site

Initial measurements show that this filter contains a complicated assemblage of:

- Metallic iron
- Magnetite
- Goethite
- Hematite
- Siderite - iron carbonate
- Vivianite - iron phosphate

Constant flooding of the site has given rise to a combination of oxidized and reduced iron minerals.

Oxidation of the metallic iron produces coatings of hematite and goethite.
Champlain Pond Monitoring

- Logging to SD card
- Conductivity & temp in pond and media
- Dissolved oxygen & temp in pond and media
- Soil moisture
- Water level above media

- https://data.envirodiy.org/sites/CMP02/
- Redox at three depths in media
Williams Street Pond, St. Paul
Mineral Characterization at Williams Street Pond Site

Initial measurements show that this filter contains a assemblage of:

Metallic iron
A trace of Magnetite
Goethite
Hematite

For a site that works so well, it is strange that there is not more magnetite.

Oxidation of the metallic iron produces coatings of hematite and goethite.
Williams Street Pond Monitoring Plan

Sensors ordered:

- Conductivity & temp in pond and media
- Dissolved oxygen & temp in pond and media
- Redox at three depths in media
- Water level (already monitored)

Groundwater intrusion?

- Piezometer in IESF media with water level
- Temperature profile in media
Future Work

• More iron mineralogy at existing sites

• Electron microscopy on filter media for existing sites

• Sampling and iron mineralogy to capture seasonal variation

• Analyze samples from established sites with known success rates (e.g. Maplewood sites)
Intangible Outcomes from this Project

Training and Development of a new Scientist

• Beth Fisher has created a cheaper means for monitoring the conditions inside these filters than what is currently available.
  
  • These stations provide more data or equivalent or better quality than commercially available stations.

• She’s learned a whole new range of analytical skills

• She’s spoken with and formed professional connections to a wide range of consultants, watershed, and agency reps working on IESFs.

• She’s only been working the equivalent of 1 day a week.
Thank you!

Please contact us at:

Josh Feinberg, feinberg@umn.edu
Beth Fisher, fisherba@umn.edu