Southeastern Wisconsin

Regional Planning Commission

Innovative Technology for Removing Dissolved Phosphorus: Iron-Enhanced Sand Filters

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Clean Rivers, Clean Lake

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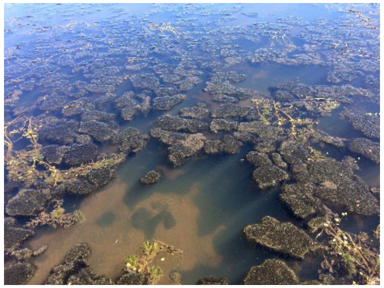
Outline

1. Phosphorus as a problem
2. Treating dissolved phosphorus
3. How iron-enhanced sand filters work
4. Filter design and configurations
5. Maintenance
6. Costs
7. Where to go for more information

Phosphorus as a Problem

- High phosphorus concentrations are a problem in many waterbodies in Southeastern Wisconsin
  - Excess phosphorus can lead to excess growth of algae and plants



Algal mats on Lake Comus

Algae covering plants in Lake Comus

Filamentous Algae on Delavan Lake

- Portions or the entirety of 92 waterbodies in SEWRPC's seven-county regions are listed as impaired due to phosphorus on the draft 2022 303(d) list
- An additional five waterbodies are listed for phosphorus in the portions of the Milwaukee River watershed that are in Fond du Lac and Sheboygan Counties

Phosphorus as a Problem

- Total phosphorus consists of two components
  - Particulate phosphorus—phosphorus that is incorporated into or adsorbed onto particles (i.e., suspended solids)
  - Dissolved phosphorus—phosphorus that is in solution in the water
  - The practical difference is that particulate phosphorus will be captured by a filter, while dissolved phosphorus will pass through

Water sample containing both particulate and dissolved phosphorus

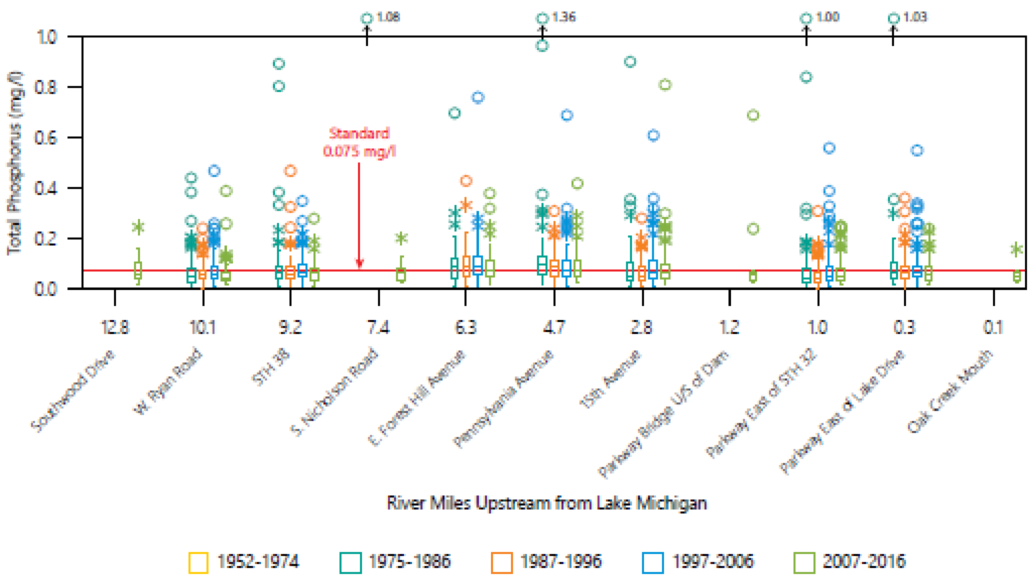
Water sample containing only dissolved phosphorus

Filters with sediment containing particulate phosphorus

Phosphorus as a Problem

- Example: Oak Creek watershed

Figure 4.104
Concentrations of Total Phosphorus at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

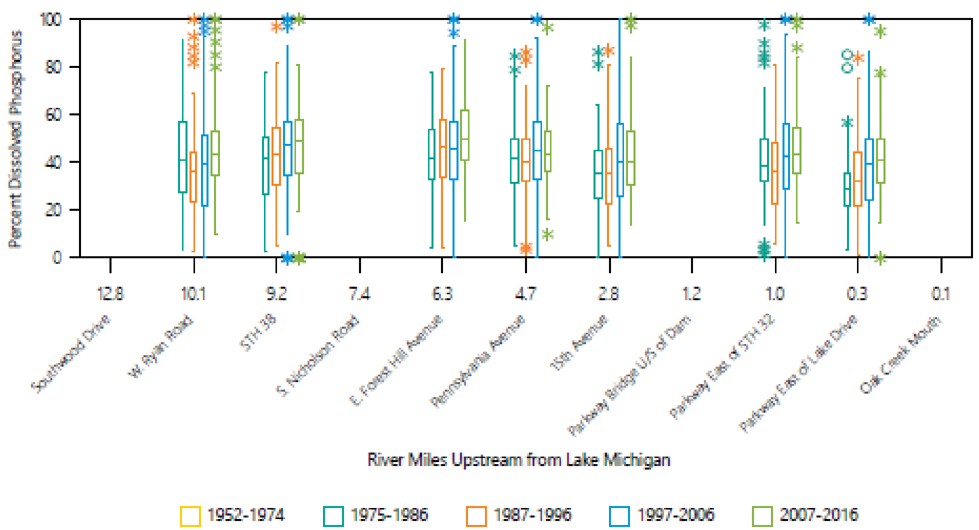
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

- 37 percent of 833 samples collected between 2007 and 2016 had total phosphorus concentrations above the standard of 0.075 milligrams per liter

Phosphorus as a Problem

- Dissolved phosphorus makes up a substantial portion of total phosphorus—45 percent in Oak Creek
- The fraction of total phosphorus consisting of dissolved phosphorus is increasing in Oak Creek

Figure 4.106
Percentage of Total Phosphorus Consisting of Dissolved Phosphorus at Sites Along the Mainstem of Oak Creek: 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

Phosphorus as a Problem

- Many stormwater best management practices (BMPs) treat phosphorus through settling or filtering of particles
- These capture particulate phosphorus but can pass dissolved phosphorus to receiving waters
- On average, about 44 percent of the phosphorus in stormwater is dissolved phosphorus
- Milwaukee River Basin TMDL calls for average MS4 phosphorus reductions of 61 percent (range 14-88 percent)

Treating Dissolved Phosphorus

- There is a need for a technology that will remove dissolved phosphorus from stormwater
- Ideal characteristics for this include
  - Should be usable as an amendment to existing BMPs
  - Should be relatively inexpensive
  - Should be safe to place and easy to handle
  - Should not be fine-grained and clog filters
  - Should not dissolve and pass through filters
  - Should not have adverse chemical effects
  - Should not leach undesirable materials into water

Treating Dissolved Phosphorus

- One approach would be processes that turn dissolved phosphorus to solid-phase forms that could be treated by conventional stormwater management practices

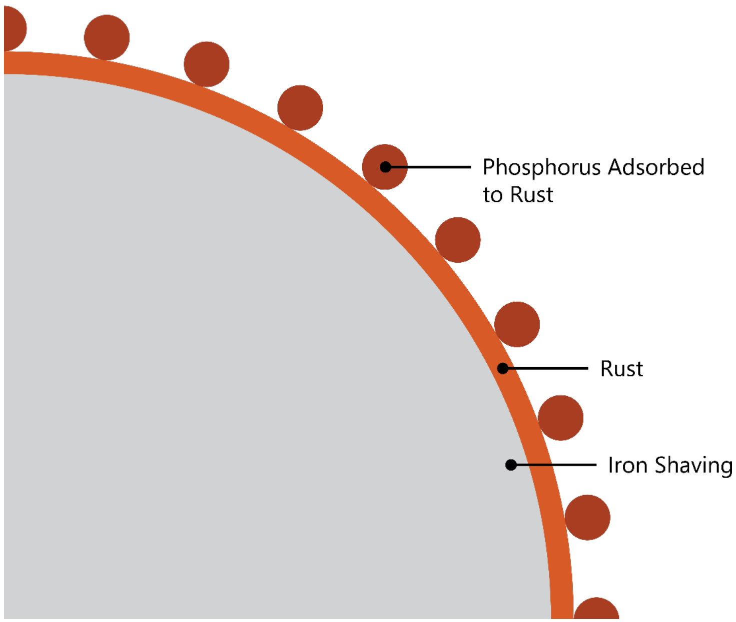
- Metallic iron meets these characteristics

How Iron-Enhanced Sand Filters Work

- Iron shavings form rust on their surfaces

How Iron-Enhanced Sand Filters Work

- Dissolved phosphorus chemically binds to the surface of the rust

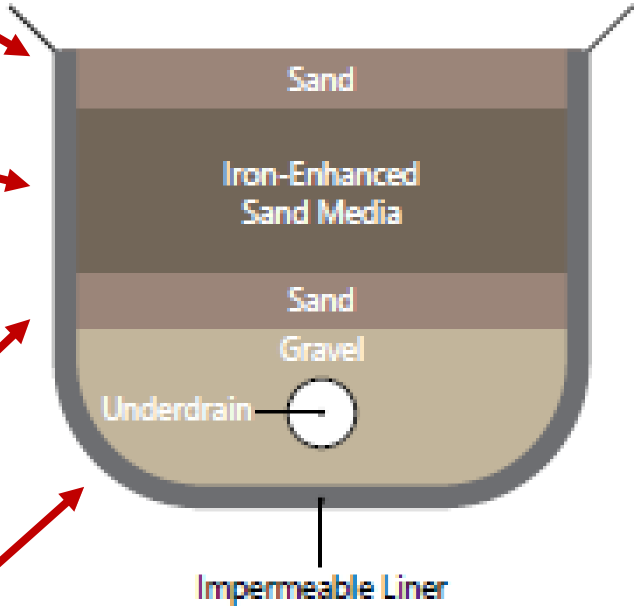


- While the rust surface can fill up, new rust will form as long as
  - Metallic iron is present
  - Conditions remain oxidizing—this means that media can dry out and air can reach it
  - pH in the water and filter are within typical ranges for stormwater

Iron-Enhanced Sand Filter Design

- 2-5 inches ASTM C33 sand
- 18 inches of media
  - ASTM C22 sand with 5-8 percent (by weight) iron shavings
  - Iron shavings should have a similar size profile as the sand
  - Mixed thoroughly
- 6 inches ASTM C33 sand
- Pea gravel with underdrain

General Design of Iron-Enhanced Sand Filters



Note: drawing is not to scale.

Source: University of Minnesota Saint Anthony Falls Laboratory and SEWRPC

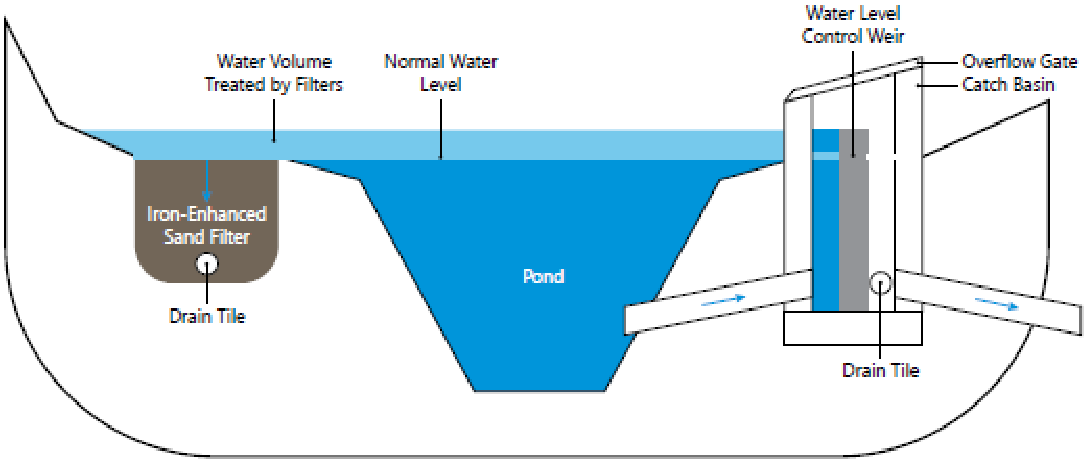
Configuration 1: Stand-alone IESF

- Example: Wright County Soil and Conservation District, Minnesota
  - This treated runoff from 18 acres of farmland
  - Monitored during 31 rainfall events over two years
  - Reduced the mass load of dissolved phosphorus by an average of 64 percent
  - Reductions for individual events ranged between 9 and 87 percent

(Capital Region Water District 2017)

Configuration 2: Pond Perimeter IESF

Figure 6.2
General Design of Iron-Enhanced Sand Filter Stormwater Trenches



Note: drawing is not to scale.

Source: University of Minnesota Saint Anthony Falls Laboratory and SEWRPC

- IESF installed as a trench next to a retention pond
- Filter trench surface is higher than the pond surface but lower than the control weir → creates a treatment volume
- As the pond fills, stormwater flows onto the trench and through the filter into an underdrain that connects to the outlet structure

Configuration 2: Pond Perimeter IESF

- Performance – Prior Lake, Minnesota
  - After installation removed 26 percent of dissolved phosphorus mass load (28 events),
  - Following removal of decomposing plants from surface of filter, removed 43 percent of dissolved phosphorus mass load
  - Most phosphorus load reductions occurred during larger runoff events with relatively high dissolved concentrations and mass loads

University of Minnesota Saint Anthony Falls Laboratory (Erickson, Weiss, and Gulliver 2015)

Configuration 2: Pond Perimeter IESF

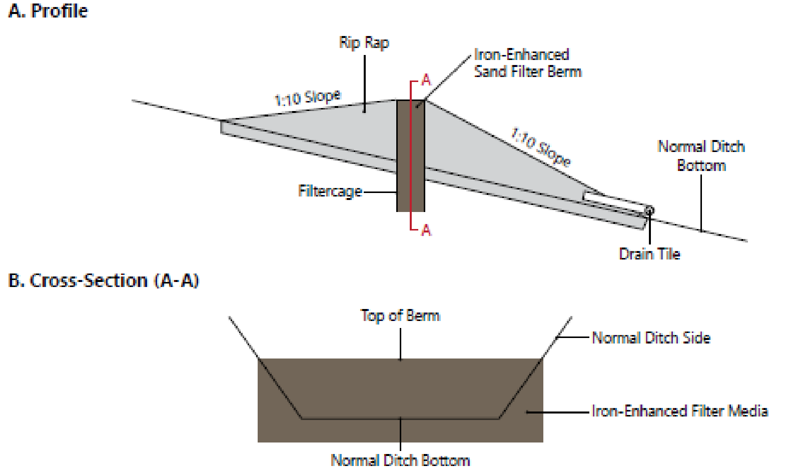
- Performance – William Street Pond, Roseville, MN
  - Median removal efficiency for dissolved phosphorus was 73.8 percent (29 samples over four years)
  - Median removal efficiency for total phosphorus was 67.5 percent (29 samples over four years)

University of Minnesota Saint Anthony Falls Laboratory (Erickson, Weiss, and Gulliver 2015)

Configuration 3: Ditch Check Dams

- Check dams intercept and detain stormwater as it flows through roadside ditches
- Particles settle behind the dam
- The dam contains an insert of a geotextile sock filled with sand mixed with iron filings
  - Five percent iron filings by weight
  - Size distribution of the iron filings should be similar to that of the sand

Figure 6.3
General Design of Iron-Enhanced Sand Filter Ditch Check Dams



Note: drawing is not to scale.

Source: University of Minnesota Saint Anthony Falls Laboratory and SEWRPC

Configuration 3: Ditch Check Dams

- Performance – Stillwater, MN
  - Monitored 57 rainfall events
  - Reduced dissolved phosphorus mass by between 15 and 54 percent
  - But performance dropped over time
    - Cumulative dissolved phosphorus mass retention dropped from 42 percent to 23 percent over three years
    - Most treatment was provided by the bottom four inches of the filter
    - Mixing the media might extend the insert's useful life

University of Minnesota Saint Anthony Falls Laboratory (Natarajan and Gulliver 2015, Natarajan, Gulliver, and Weiss 2019)

Design Considerations

- Use high purity iron containing no toxic impurities
- Assume a sorption capacity of 5 ounces of phosphorus per ounce iron
- Assume a filtration rate of 10 centimeters per hour to estimate surface area to treat a known peak flow rate
- The filter must be able to drain and dry out
  - Surround the filter with an impermeable liner
  - Outlet underdrain must be placed above high-water elevation of downstream conveyance system or receiving water body
  - Underdrain should be large enough
- Exclude vegetation from the media
  - Pores formed by roots can short circuit the media

Maintenance

- Routine maintenance
  - Perform about four times a year
  - Inspect the filter
  - Remove trash and debris
  - Remove vegetation growing on the filter surface
  - Remove obstructions to the underdrain
  - Rake the filter to break up the surface

Maintenance

- Non-routine maintenance
  - Perform as needed
  - Break up any clumps of iron shaving conglomerates that have formed
    - Clumping is more prevalent when the filter remains submerged for more than two days
  - Remove the top 1 to 1.5 inches of sand and accumulated solids and organics and replace with clean, washed sand
  - Perform testing to determine the filtration rate
  - Replace filter media when phosphorus sorption capacity is exhausted
    - Estimated media life is about 30-35 years (not field tested)

Costs – Stand Alone IESFs

Name	Year	Filter Area (square feet)	Cost ($)	Cost per unit area ($/sf)	Comments
Beam Avenue Maplewood MN	2009	12,000	235,000	195	
Long Lake Apple Valley MN	2012	5,400	136,284	25	Two filters
Good Lake Scandia WA	2018	8,751	190,000	21	
Hansen Park New Brighton MN	2018	4,800	440,211	92	Four filters

Costs – Pond Perimeter IESFs

Name	Year	Filter Area (square feet)	Cost ($)	Cost per unit area ($/sf)	Comments
Settler's Glen Stillwater MN	2013	2,500	298,462	119	
Centennial Green Blaine MN	2015	4,275	39,180	8	
Wilmes Woodbury MN	2015	1,700	140,000	82	
Golden Lake Circle Pines MN	2015	4,725	171,000	36	

For More Information

- Oak Creek Watershed Restoration Plan
  - Description and literature review
    volume 2, pages 89-95
  - Design and maintenance considerations
    volume 3, pages 303-306

    https://www.sewrpc.org/SEWRPC/Environment/Restoration-Plan-Oak-Creek-Watershed.htm

- Minnesota Stormwater Manual

  https://stormwater.pca.state.mn.us/index.php/Iron_enhanced_sand_filter_(Minnesota_Filter)

Acknowledgements

- The review of iron-enhanced sand filters was conducted as part of the development of the Oak Creek watershed restoration plan. That study was funded by

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city of South Milwaukee

Proud Past ... Promising Future

Milwaukee County Parks

MMSD

Partners for a Cleaner Environment

Southeastern Wisconsin Regional Planning Commission

Kenosha · Milwaukee · Ozaukee · Racine · Walworth · Washington · Waukesha

Thank You

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