Using P Removal Structures to Decrease Dissolved P Losses from High P Soils in the WLEB

Chad Penn
USDA Agricultural Research Service
Target Form: Dissolved P

Target Source: Legacy P Soils
(at least 100 mg/kg M3-P)
Dissolved P is a more potent eutrophication agent than particulate P

- Aquatic organisms can immediately uptake dissolved P from water
- Particulate P
  - Degree of bioavailability depends on the conditions
    - Some sediment that contains P may not release any P
    - Some may actually adsorb dissolved P
“Legacy Phosphorus”

Cease P application and begin P drawdown with crops in 1998

Fiorellino et al., 2017
During That Long Time Period of Drawdown, You are Still Losing P
PO₄⁻³
FePO₄⁻³
Fe
PO₄⁻³
Al
PO₄⁻³
Al
OH⁻
Fe
OH⁻
Al
OH⁻
Al
OH⁻

P Removal Structure Theory

Retained P in PSM

Dissolved P from flow

P-free water
3 Necessary Components

- Effective PSM in sufficient quantity
- Sufficient flow rate and contact time
- Ability to retain and replace PSM
Many Types of Structures
Phosphorus Sorption Materials

- Metal filings
- Steel slag
- Drinking water treatment residuals
- Manufactured PSMs
- Fly ash
- Waste recycled gypsum

Photo Credit: K.D. Chamberlain
Design Software

Input

- Site hydrology
  1. Peak flow rate
  2. Annual flow volume
  3. Dissolved P level
  4. Max footprint

- P removal & lifetime
  1. Target P removal (%)
  2. Target lifetime

- PSM characterization
  1. P sorption
  2. Safety
  3. Physical properties

Output

- Design parameters
  1. Area
  2. Mass of PSM
  3. Depth of PSM
  4. Pipe reqmt

Model
P-TRAP Software

Google: “P-Trap national soil erosion lab”
If a site is worth treating, it is going to require a large mass of PSMs
Cartridge Filters and small modular boxes?

- Portable, easy to install
- Only works in limited situations
  - Is it worth using them?
  - Limited amount of PSM
- Poor flow rate
Filter Sock?

Limited mass, contact, and contact time

Flow over the PSM: 6% P removal

Flow through the PSM: 32% P removal
Current State

• The technology is effective but can be improved
  – Many structures constructed and monitored throughout the world
    • Penn et al., 2017; Water (review paper)

• Current research is dedicated to decreasing cost and improving efficiency
NRCS Standard 782

INTERIM CONSERVATION PRACTICE STANDARD
PHOSPHORUS REMOVAL SYSTEM
Code 782
(each)

DEFINITION
A system designed to remove dissolved phosphorus (P) from surface runoff, subsurface flow, or groundwater usually consisting of a portion media with a high affinity for dissolved P, a containment structure that allows flow through the media and retains the media so that it does not move downstream, and a means to remove and replace the media.

PURPOSE
This practice is applied for the following purpose:
To improve water quality by reducing dissolved phosphorus loading to surface water through the sorption of phosphate (dissolved) P from drainage and runoff water.

CONDITIONS WHERE PRACTICE APPLIES
This practice applies where phosphorus (P) presents a resource concern to surface water bodies and is mobilized and transported as a dissolved constituent and where a phosphorus sorption product is available locally. Sources of phosphorus sorption material (PSM) include steel slag, drinking water residuals, acid mine drainage residuals, brannack mining wastes, paper mill waste, fly ash, and gypsum waste. PSMs are typically high in Calcium (Ca), Aluminum (Al), and Iron (Fe). Sources of dissolved P in agricultural areas include: ditches, levees, livestock heavy use areas, manure storage and handling areas, fields saturated with P relative to the soil sorption capacity, and other areas with high impervious surface area and converging flow. Sites typically have runoff containing dissolved phosphorus > 0.5 mg L^-1.

This standard is not for treatment of particulate phosphorus, which is typically bound to soil particulate. If phosphorus P is a concern, use the criteria found in NRCS Conservation Practice Standard (CPS) 185, Sediment Basin or CPS 638, Water and Sediment Control Basin.

CRITERIA
General Criteria Applicable to All Purposes
Divert phosphorus-rich flow into a bed of sorption media where the water is in contact with the media for a certain amount of time (retention time, RT) before being able to freely flow out of the material by gravity.

*Refer to Stone et al., 2012, and PESTOS software. "These are critical assumptions that need testing.

NRCS, Interim
February 2016
Completed Confined Bed Structure

- 23% of the 2.5 year load: still effective at that point
- 40 tons treated slag
- Handled ~ 1000 gpm flow
- $5 K

Penn et al., 2014; JSWC
Confined Bed

• Small prototype
  – Only 3 tons sieved slag
  – 8 month 25% removal with ¼ minus
  – 16 month 33% removal with 0.5 mm minus

Penn et al., 2012; Journal of Env. Qual.

$2.5 K
Ditch Filter

- Allows large amount of material to be used
- Easy to build
- Use flow control to build head
- Low cost (< $4K)
- Probably best option for ditches
### MD Ditch Filters - Mediocre PSMs: removal ~ 25% over 2 years

<table>
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<th>Site</th>
<th>PSM</th>
<th>Cumulative inflow P load</th>
<th>Flow-weighted inflow P concentration</th>
<th>PSM mass</th>
<th>Average P removal per event</th>
<th>Cumulative P removed</th>
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<tr>
<td></td>
<td></td>
<td>kg</td>
<td>mg L(^{-1})</td>
<td>Mg</td>
<td>g</td>
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*Penn et al., 2016; Chemosphere*
Subsurface Tile Filter: Waterloo, IN

- Removed 55% dissolved P load over 1.5 years
- 36 tons normal slag
- Short lived (little removal after 6 mo.)
- $11K
- Penn et al., 2020: Water
- Do not recommend normal slag for tile drains, only surface runoff
Tile drain outlet into ditch structure: GLSM, Ohio

- 50 tons Al coated slag
- 30% cumulative dissolved P load removal in 14 months
- Poorly constructed
- $9K
- Shedekar et al., 2020
Subsurface Tile Drain Filter:

30 tons Al-Coated slag: still removing 40 to 95% of DP per event, even after two years. No data on loads yet ($13K)
Blind inlet: Auburn, IN

- Alternative to limestone: 12 inches of sieved steel slag over railroad ballast
- Installed 2016; 15 tons slag. Treats surface water only.
- 2018: > 46% of the load
- 2018: removed 80% of glyphosate, 94% dicamba
- Gonzalez, Penn, Livingston: Water.

Replace tile riser with blind inlet:
Re-generatable tile drain filter

- Manufactured PSM (2.5 tons Fe-coated alumina)
- Designed to remove 40% of 10 yr-load: then re-generate PSM media in-situ
- Currently monitored
- ~ $12K
Metal shavings mix (sand or gravel)

- Pilot box: 300 lbs metal/sand or metal/gravel mix (8% metal)
- Received 130K gallons for overall 50% cumulative DP load reduction
- Cheap: $200/ton for metal
Economics

- Wastewater treatment cost of P removal is 50 to 800 dollars/lb P removed
- P removal structures are within that range
- Cost of P removal using rechargeable media is nearly cut in half at each regeneration.
- Metal shavings shows promise to be most economical
  < 10K for typical structure
  < $200/Lb removed
15y of structures: over 30 built

- Do not use regular slag for tile drainage, only surface water
- Need PSMs with both high flow rate and P sorption capacity at low cost
- 2nd gen structures removed 25-50% of cumulative load >1 yr
- 3rd gen structures
  - Lower mass
  - More efficient
  - Some rechargeable

Mobile demo P-removal structure in 2021.
Designing a Phosphorus Removal Structure

Some trade names are used in this course to provide an understanding of equipment form and function. The USDA does not endorse any specific company.
Lots more details…


Several structures being built over next several months: consider watching an installation. Locations and times are posted on twitter when known. See “House of Phos”: https://twitter.com/ChadPenn12
Special issue on P removal structures in Water:
https://www.mdpi.com/journal/water/special_issues/phosphorus_removal#info
CEAP

NRCS
Natural Resources Conservation Service
Questions?
Chad.penn@ars.usda.gov
House of Phos @ChadPenn12

Kevin King et al.; Larry Brown; Margaret Kalcic; Nathan Stoltzfus; Jay Martin et al; TNC; Justin McBride; OH NRCS; Aaron Heilers; Josh McGrath: NRCS Conservation Effects Assessment Project (CEAP)