Removing dissolved phosphorus from non-point sources with P removal structures

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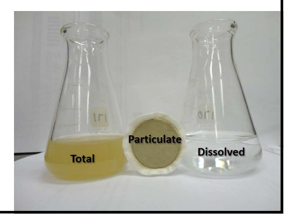
Target Form: Dissolved P

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



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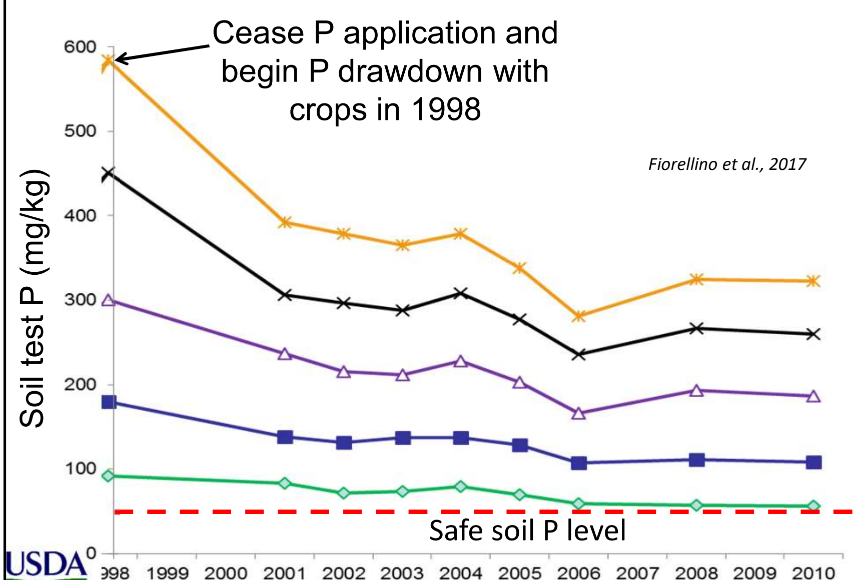
"Legacy Phosphorus"



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During That Long Time Period of Drawdown, You are Still Losing P

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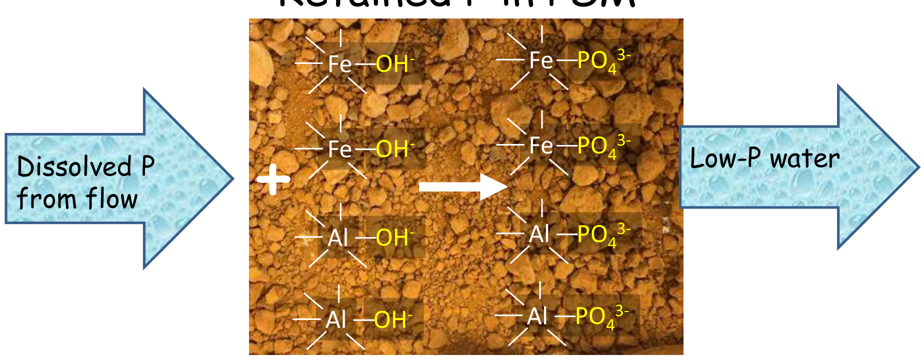
P Removal Structure Theory

Retained P in PSM



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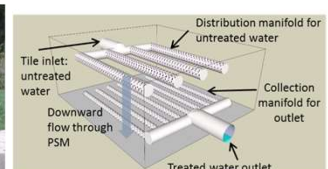
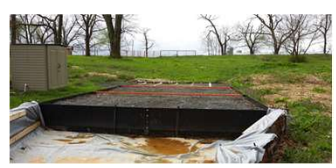
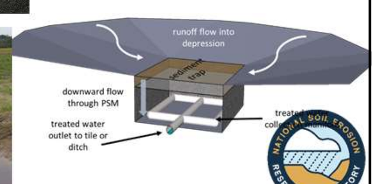
3 Necessary Components

- 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

Manufactured PSMs

Steel slag

Fly ash

Drinking water treatment residuals

Waste recycled gypsum

Manufactured PSMs

- Tend to be efficient
- Most are extremely expensive
- Examples
  - "Fe Osorb®"
    - (Bio-Max: ABS Materials)
  - "Imbrium"
  - "Acti-guard": Axens Solutions

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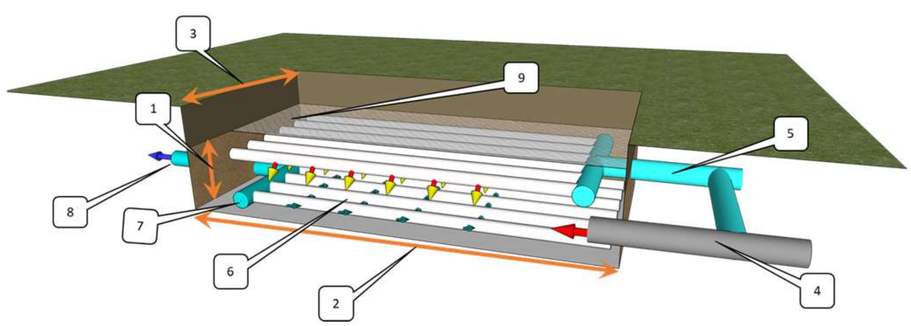
Physical Components

- Distribution system for un-treated inflow water
  - Usually perforated pipe
- PSM bed
- Drainage/collection pipes for removing treated water from structure
  - Treated water must be removed so un-treated water can enter
    - Usually perforated pipe



NRCS Standard 782

United States Department of Agriculture

782-ICPS-1

Natural Resources Conservation Service

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 sorption 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, bauxite mining waste, 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, tile drains, 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 particles. If adsorbed P is a concern, use the criteria found in NRCS Conservation Practice Standard (CPS) 350, *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.

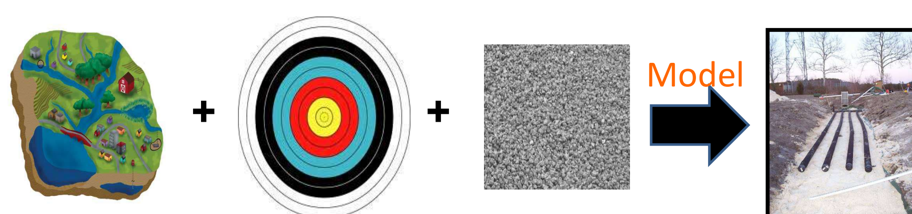
*Refer to Stoner et al., 2012, and PhROG software. **These are critical assumption that need testing.

NRCS, Interim
February 2016

P-TRAP
PHOSPHORUS TRANSPORT REDUCTION APP

Design Software

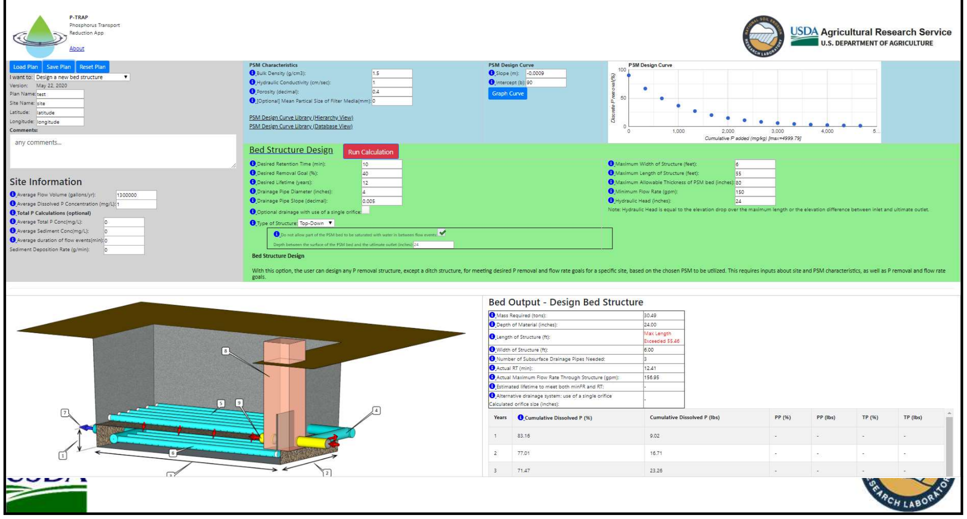
Input			Output
Site hydrology	P removal & lifetime	PSM characterization	Design parameters
1. Peak flow rate	1. Target P removal (%)	1. P sorption	1. Area
2. Annual flow volume	2. Target lifetime	2. Safety	2. Mass of PSM
3. Dissolved P level		3. Physical properties	3. Depth of PSM
4. Max footprint			4. Pipe reqmt



P-TRAP Software

Google: “P-Trap phosphorus”

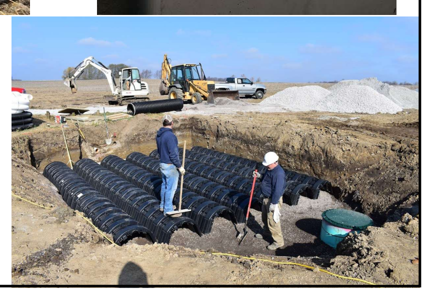
https://www.ars.usda.gov/nserl/ptrap



- If site is worth treating, it will require a large mass of PSM.

- High flow rate
- Sufficient contact time
- Useful lifetime

Why?



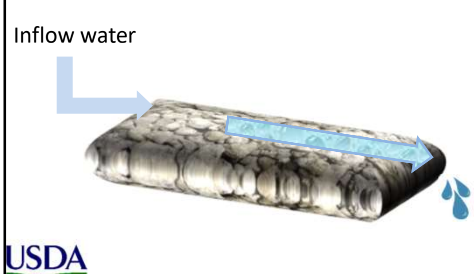
Cartridge Filters and small modular boxes?

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

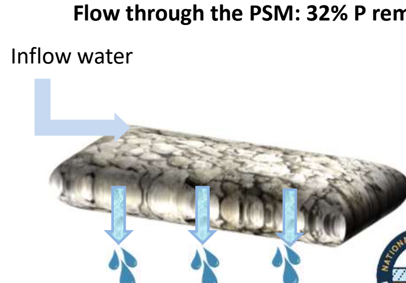
Filter Sock?

Limited mass, contact, and contact time

Flow over the PSM: 6% P removal



Flow through the PSM: 32% P removal



High flow rate and long RT = BIG STRUCTURE

- $Retention\ time = \frac{total\ pore\ volume\ of\ PSM\ bed}{Q}$
- Higher flow rates (Q) result in less RT
- If a high RT is required, then flow rate must be kept to a minimum
- BUT if a high RT is required AND a high flow rate is also required:
  - Then the total pore volume of PSM bed must be increased
    - i.e. increase mass of PSM

Current State

- The technology is effective but can always 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

How are they different from N bioreactors?

- Flow rates and water volume
  - Want to capture the high flow rates
  - Therefore, short retention time
    - Seconds to minutes, not hours
  - Delivers the most P
- Chemical, not biological
  - Therefore faster

How are they different from wetlands?

- Wetlands reduce particulate P, not dissolved P
- However, wetlands can be used in combination with a P removal structure
  - Much interest from GLC and USACE
  - More later….

Confined Bed Structure

Penn et al., 2014; JSWC

- 40 tons treated slag
- Handled ~ 1000 gpm flow
- $5 K

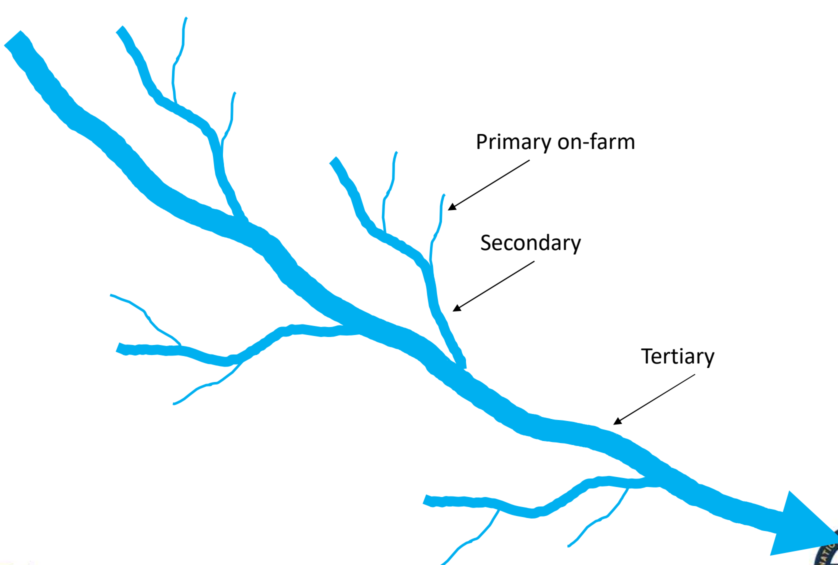
Ditch Filter

- 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

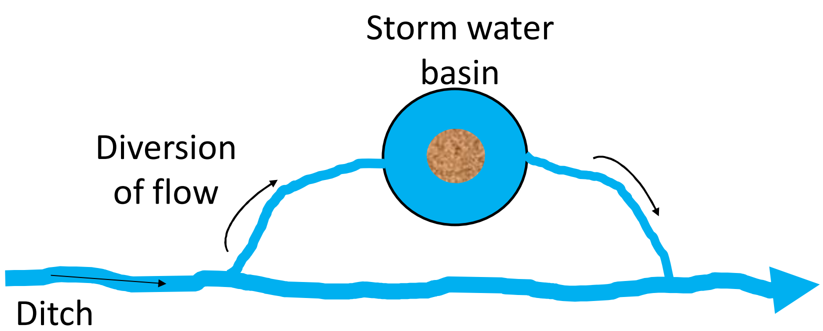
Ditch Filter

- Only recommended for primary on-farm ditches in the Mid-West
  - Problem is that downstream secondary ditches fill up with water and will likely wash-out all PSMs
- For secondary receiving ditches, consider ditch by-pass filters:

Ditch Hierarchy

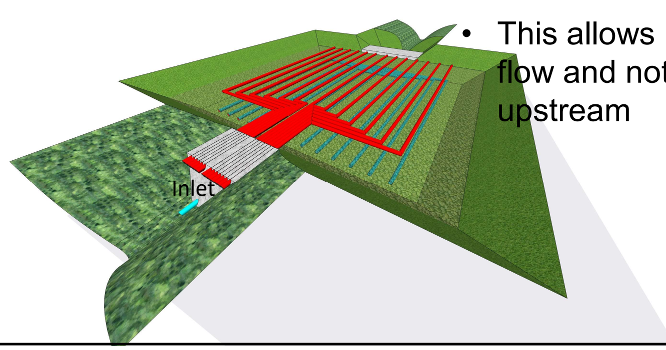


Ditch by-pass filter for non-primary ditches:



Option for non-primary ditches: “weep pipe” with dam

- Construct within ditch
- Single blue pipe at inlet keeps ditch flowing at base-flow
  - Low elevation “pass-through” with no treatment
    - Solid, not perforated
- perforated red pipes at top of dam convey storm flow into PSM bed
- This allows unit to treat storm flow and not back-up water upstream



Penn et al., 2019, Critical Reviews in Environmental Technology: https://doi.org./10.1080/10643389.2019.1642836

Blind Inlets

- Replacement of tile riser with gravel bed within field depressions
- Reduce particulate P via sediment filtration
  - Variable performance: ~ 40% over 12 yr
- Little to nothing for dissolved P

Gonzalez, Penn, Livingston; Water, 2020.

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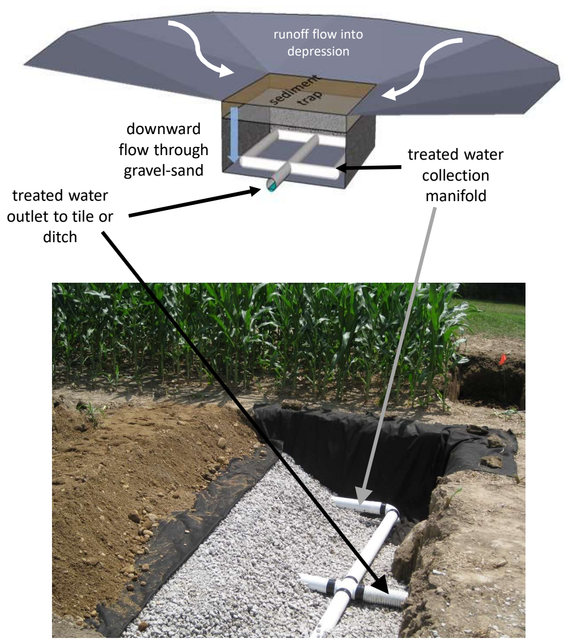
Blind Inlets



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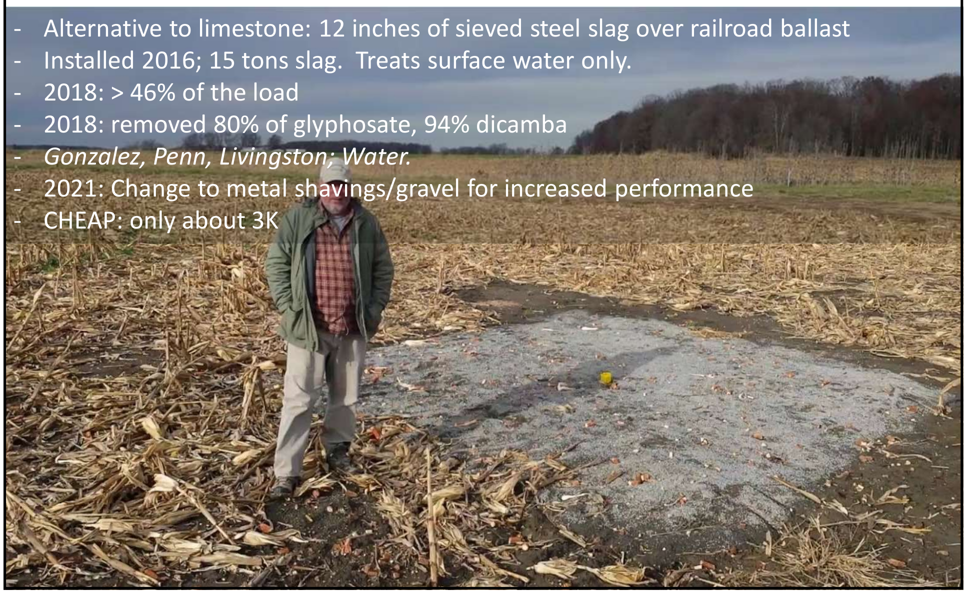
Modified blind inlet: Auburn, IN

- 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.*
- 2021: Change to metal shavings/gravel for increased performance
- CHEAP: only about 3K

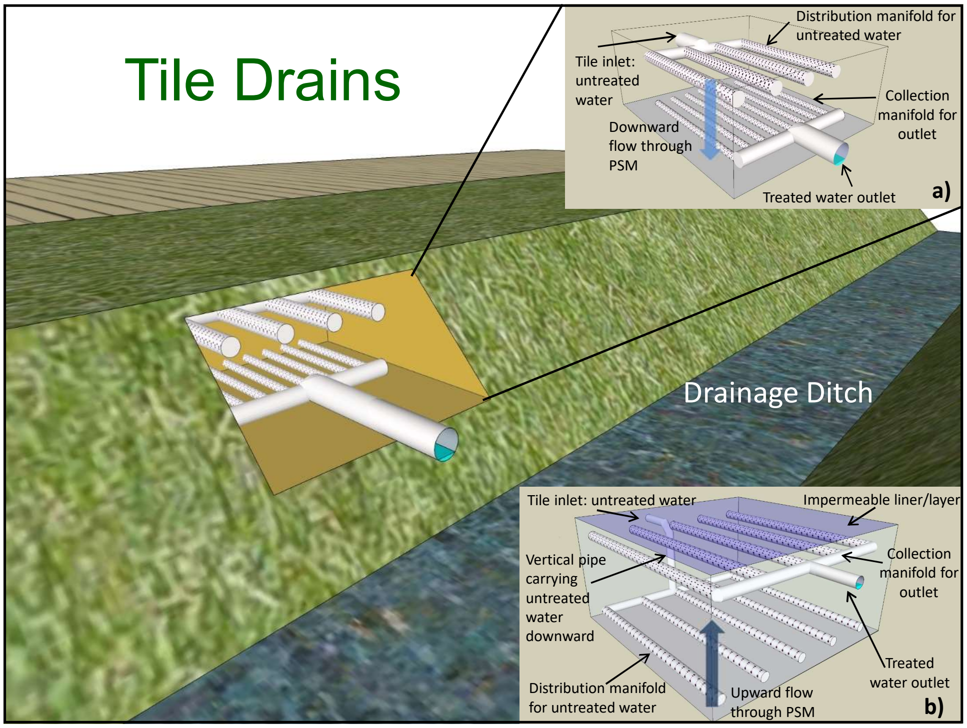


Modified bio-retention cell

- Urban blind inlet
- Same principle, but urban setting

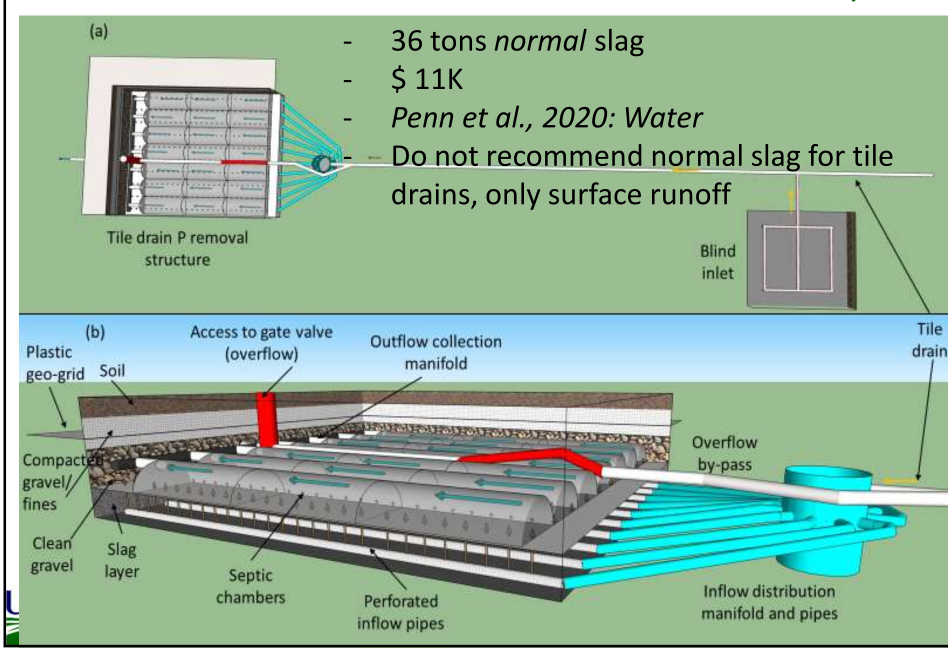
Kandel et al. 2017; Water

Tile Drains



Subsurface Tile Filter: Waterloo, IN

- 36 tons *normal* slag
- $ 11K
- *Penn et al., 2020: Water*
- Do not recommend normal slag for tile drains, only surface runoff



Subsurface Tile Bed Filter, NE OH

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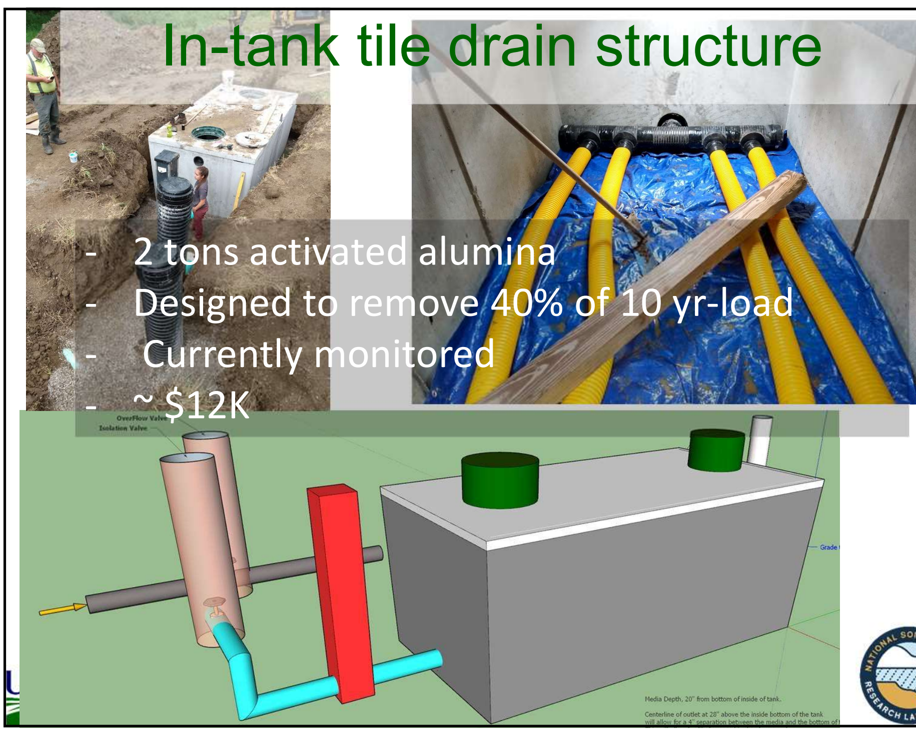
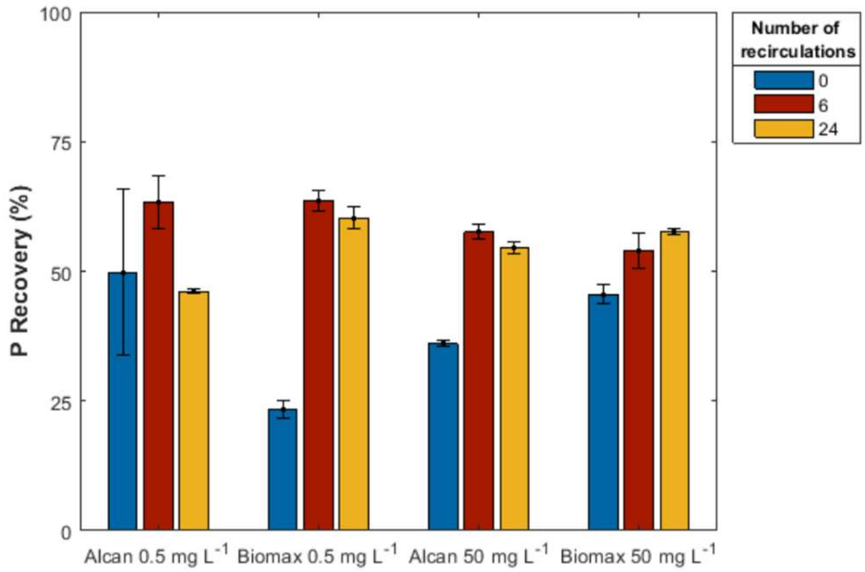
In-tank tile drain structure



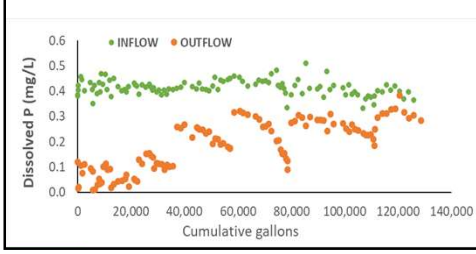
- 2 tons activated alumina
- Designed to remove 40% of 10 yr-load
- Currently monitored
- ~ $12K

Scott et al., 2020. *Water*.



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: $300/ton for metal



- Buried bed filter for tile drain: metal shavings/gravel
- Swine farm in Holland, MI
  - Top-down flow
  - Bottom drainage pipe layer shown

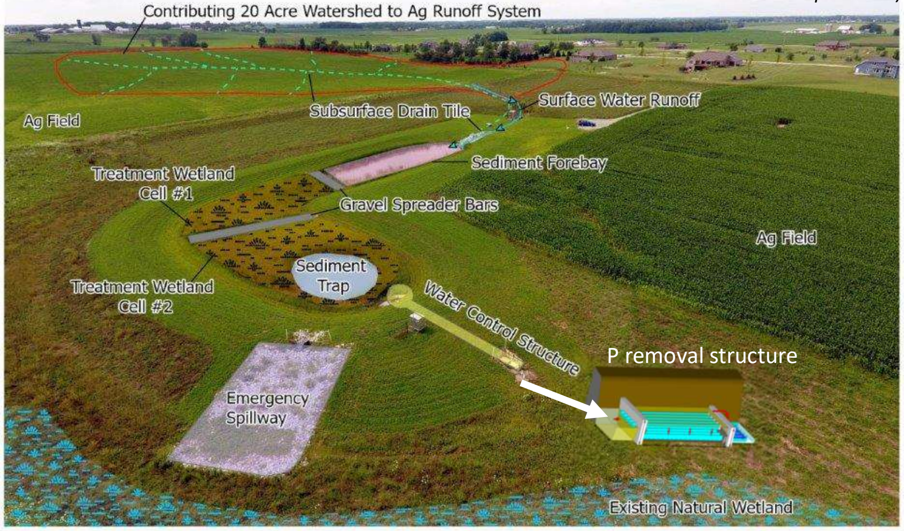
- Buried bed filter for tile drain
- Swine farm in Holland, MI
  - Top-down flow
  - Upper layer of inflow drainage manifold shown here
  - Covered with a tarp before burial

- Buried bed filter for tile drain
- Swine farm in Holland, MI
  - Completed
  - Used flow-control as bypass
  - Cost ~ $7,000
    - Levy Co./Plant Tuff

Combine with treatment wetlands or WaSCOB

(Jeremy Freund, Outagamie County Land Conservation Department)

Contributing 20 Acre Watershed to Ag Runoff System

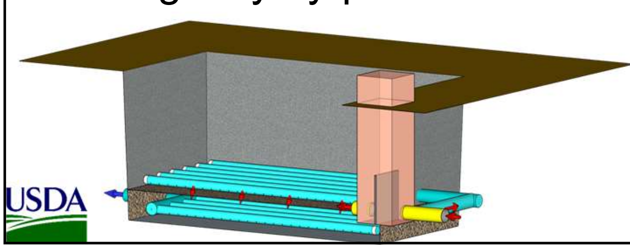


Combine with treatment wetlands or WaSCOB

- Advantage
  - Wetland drops out sediment
    - Removed particulate P
    - Prevents clogging of P removal structure
  - Provides a hydraulic buffer for surface water
    - Don’t need to treat 2000 gpm if you can store it and slowly release
      - Although it still needs to be treated at a reasonable flow rate
    - Water table control structure can do this for tile drainage

Agridrain water table control structures

- Build head to increase flow rate
- Allows soil to temporarily store water while being drained into P removal structure
  - Important for tank structures where flow rate is less
- Emergency by-pass



Economics

- Cost: 3K to 20K
  – Depends on size, site, P removal goal
- Similar cost as wastewater treatment
- 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
  Used in MN for urban stormwater (bio- retention cells)

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Do not use normal slag for treating subsurface drainage unless you plan to replace media annually

- Don't use any Ca-based PSM for subsurface drainage
- Works fine for surface water
- Works good for silage runoff

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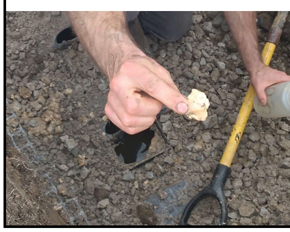
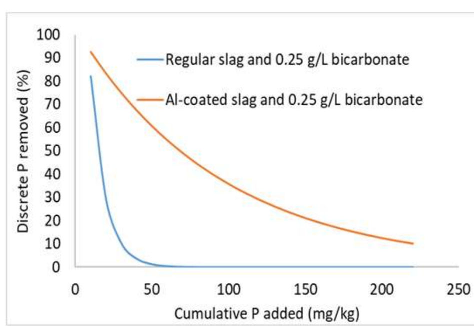
Ca-based PSMs

- NOT effective for treating tile drainage or other sources rich in bicarbonate
  - Precipitates Ca-carbonate more than Ca-phosphate if
    - Clogs structu ity
    - Examples: b c arc furnace slag, fly-ash



Ca-based PSMs

- Bicarbonate can reverse P removal
- Only use alkaline Ca-based PSMs to treat surface water
- P removal highly dependent on pH
- Alternatives:
  - coat alkaline Ca-based PSMs with Al
  - Brown slag



Slag must be sieved to remove fines

Caution: true quantitative evaluation of performance requires flow rate and load measurements

Event	Concentration in	concentration out	Flow volume	% reduction	load in mg	load out mg
1	0.208333333	0.07	8000	66.4	1666.66667	560
2	0.166666667	0.09	500	46	83.3333333	45
3	0.017857143	0.01	20000	44	357.142857	200
4	0.322580645	0.34	80000	-5.4	25806.4516	27200
5	0.555555556	0.18	1000	67.6	555.555556	180
6	0.175438596	0.06	2000	65.8	350.877193	120
7	0.138888889	0.07	6000	49.6	833.333333	420
8	0.120481928	0.05	300	58.5	36.1445783	15
9	0.113636364	0.04	900	64.8	102.272727	36

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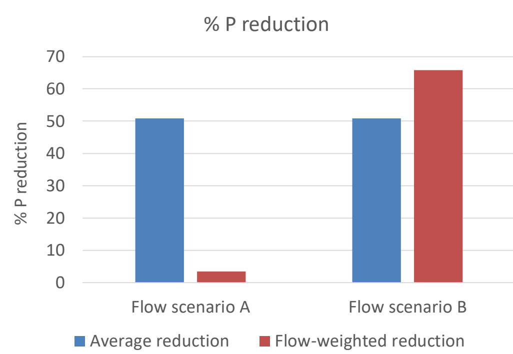
Flow-weighted concentrations:

P delivery depends on flow volume

- Example: 0.5 ppm for an event that only delivers 10,000 gallons does not carry as much **weight** as 0.2 ppm at 1 million gallons
- You cannot average regular concentrations

Here, we used the exact same flow concentrations, and calculated % reduction based on average concentration and flow-weighted concentration for two different flow volume scenarios with the same concentrations



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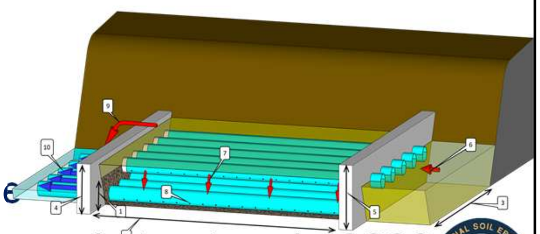
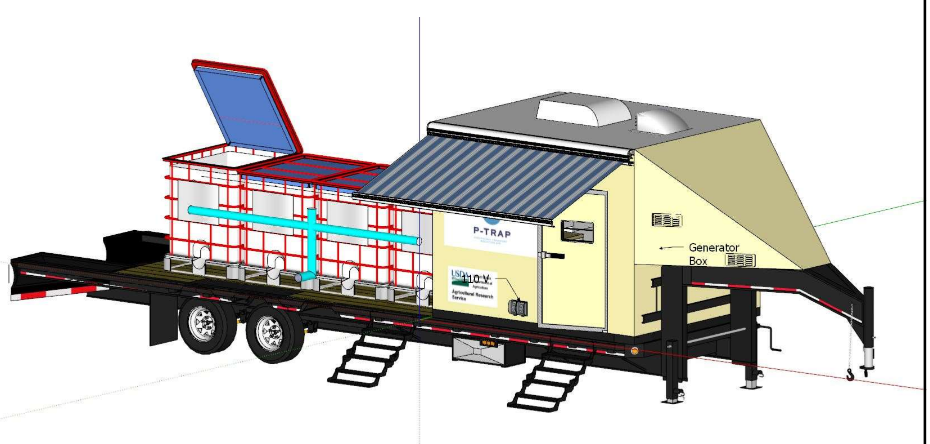
17y of structures: over 40 built

- 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

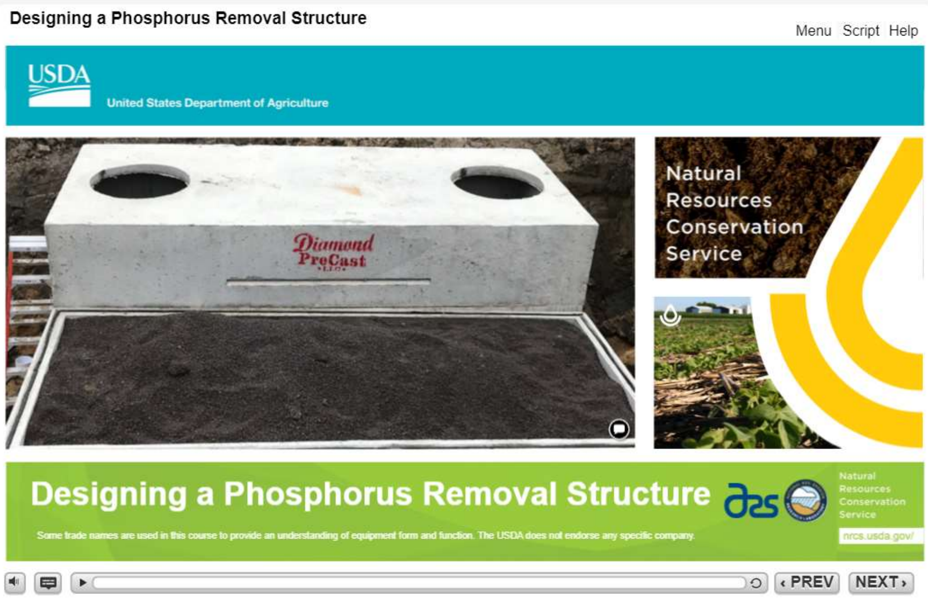


- Mobile demo P-removal structure in 2022

Mobile P-removal demo unit

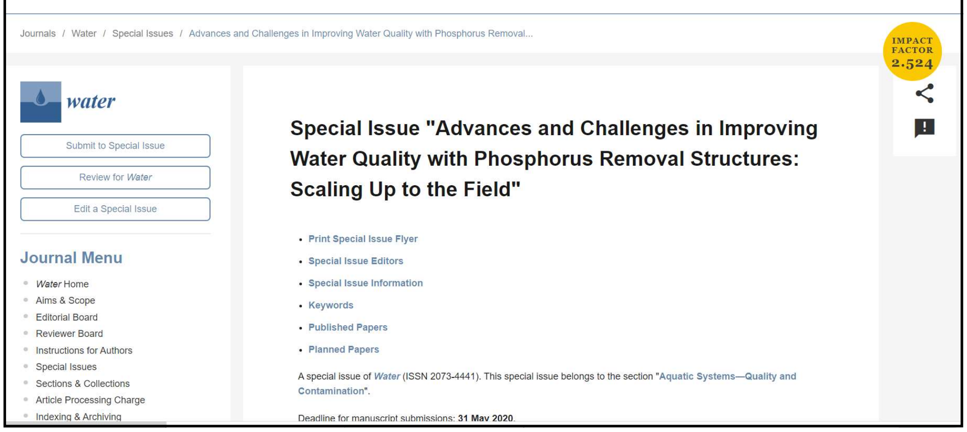


Training Modules In-Process: 2022



Special issue on P removal structures in *Water*:

https://www.mdpi.com/journal/water/special_issues/phosphorus_removal#info




Questions?
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