Progressive Management Practices for Drainage Systems on the Eastern Shore of Maryland

Principle Investigation:	Jason Keppler John Rhoderick Maryland Department of Agriculture
Timeframe:	October 2012 – September 2015
Grant #:	69-3A75-11-28
Submission Date:	December 2015

Deliverables:

A. Provide outreach and education, training and learning opportunities to 450 landowners and producers on the management of ditch drained agro ecosystems
B. Establish a core group of technical experts to assist landowners and producers with implementing new innovative drainage management practices
C. Provide cost-share funding for demonstration sites on new innovative practices for drainage ditches
D. Website, video and fact sheets of new technology and innovative BMP’s
E. Quantification of nutrients and sediment saved by BMPs
F. Site tours, workshops and producers meetings.

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Executive Summary

Field drainage has been utilized to enhance acres available for crop production. On Maryland's Eastern Shore 821 miles of Public Drainage exist and thousands of miles of crop field ditches and subsurface drains feed into this network of Public Drains. Research has shown that agricultural drainage, especially subsurface drainage, can have a significant impact on downstream surface waters.

A number of progressive management technologies exist that can potentially mitigate the impacts of nitrogen, phosphorus and sediment loss to downstream water quality. Through an NRCS Conservation Innovation Grant, the Maryland Department of Agriculture and its partners worked to deliver on the goals and objectives of the project. Those specific goals were to:

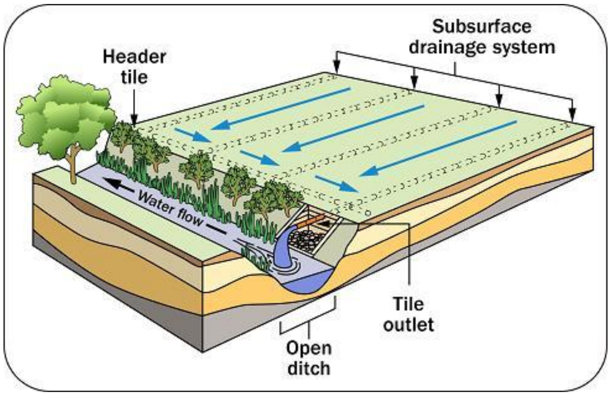
- Provide outreach and education, training and learning opportunities for 450 landowners and producers on the management of ditch drained agro-ecosystems.
- Establish a core group of technical experts to assist landowners and producers with implementing new innovative management practices.
- Provide funding for demonstration sites for progressive practices in drainage ditches.
- Create a website and video's of new Technologies and innovative, BMP's fact sheets etc.
- Quantify nutrients and sediment saved.
- Conduct site tours, workshops, producer meetings.

When the project started in late 2011, introducing landowners to new innovative drainage management technologies progress was lagging. As the project performance picked up in year two and three, additional drainage management practices were installed and demonstrated. Ultimately, we were able to exceed the project goals and establish continued financial and technical assistance programs for producers through Maryland NRCS cost-share programs and Maryland Department of Agriculture technical assistance programs. The Chesapeake Bay Program has utilized the results of our project to develop new Bay Model Best Management Practices (BMPs) for drainage management. As a result of this project, NRCS has established two new interim conservation practice standards, 782 - Phosphorus Removal Systems and 605 - Denitrifying Bioreactors.

Introduction

There is often an inherent conflict between the intended use drainage ditches as an effective conveyance system to move water quickly versus a natural functioning stream. Previous research has established that ditches can be significant sources of nutrient and sediment transport. Although drainage ditches, which are often channeled streams, cannot be fully restored, there are a number of innovative BMPs that can be used that will allow continued drainage but also enhance water quality and environmental benefits.

Poorly drained agricultural land



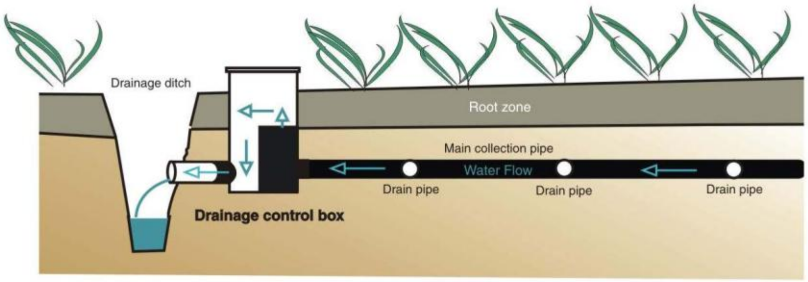
The Maryland Department of Agriculture has regulatory responsibility to assure maintenance plans are developed and approved for 101 drainage systems. To help producers and landowners who benefit from the drainage system achieve their water quality goals and maintain the integrity of local drainage systems, the Maryland Department of Agriculture identified a number of opportunities to target new innovative ditch management practices within the poultry intensive region of the Eastern Shore of Maryland. Utilizing progressive technologies such as, Water Control Structures, Biofilters, Phosphorous-Sorbing Materials (PSMs), Weedwiper Treatments, Hydromodification, Algal Turf Scrubbers, and Offline Wetlands, we developed a program to improve water quality in drainage system on the Eastern Shore.

We provided outreach, education, technical resources and implemented restoration of sites for producers and landowners in target watersheds utilizing the most promising drainage technologies for nutrient and sediment reductions. In many instances, these sites coupled together some of the newer technologies such as biofilters and phosphorous filters, or hydromodification and offline wetlands to maximize nutrient and sediment reduction effectiveness. We worked with landowners and farmers to adopt a new management options for drainage ditches, such as increased buffer setbacks and utilization of the "weed wiper" instead of chemical spraying for vegetation management. Implementation of innovative technologies in this project became part of Maryland's Watershed Implementation Plan to address the Chesapeake Bay TMDL. Improved knowledge of the nutrient transport process and education on newer drainage ditch management practices assisted in developing new NRCS practices for biofilters and phosphorus filters.

The scope of evaluating, developing and demonstrating the most promising and progressive BMPs required that we work with the key personnel for each of the respective practices, these people were part of a project team that in many cases worked across the various BMP projects.

Water Control Structures

Water quality control structures are highly effective mechanism to reducing nitrogen in drainage ditches. In the summer months with flash boards or risers in place they effectively back up and hold water. This causes the ditches to go anoxic and effectively utilize all the nitrogen available in the water. Utilizing field level drainage control structures out flows to the main lines or drainage laterals can be controlled and “can significantly reduce the amounts of nutrients reaching the water systems relative to the inputs at the field edge” (Evans et al, 1996). Research from North Carolina showed up to a 60% reduction in nitrogen is possible. Utilizing a National Fish and Wildlife Foundation grant between 2006 and 2008, University of Maryland researchers and scientist from the Agricultural Research Service worked with the Maryland Department of Agriculture to quality the nutrient reduction potential for this practice in drainage ditches on the Eastern Shore. With the data, we established a nitrogen reduction efficiency for the practice. With the 2011 CIG we were able to begin establishing demonstration sites and educating landowners about the benefits nutrient and sediment of water control structures and how proper water management could enhance water retention in the root zone of the cropfield. University researchers provided presentations at public drainage meetings and supported our efforts to establish a BMP credit for nutrient reductions at the Chesapeake Bay Program.



Key Personnel: Brian Nieldman, Associate Professor University of Maryland, Joshua McGrath,Associate Professor University of Kentucky, Gene Hahn, Scientist, University of Kentucky, Clinton Gill, Research Assistant, University of Maryland.

In 2013 Maryland Department of Agriculture Cost-Share program established Water Control Structures as a BMP with funding available at 87.5%. Since its adoption over twenty structures have been installed benefiting over 3,500 acres of drained cropland.

Weed Wiper Technology

Public Drainage Associations on the Lower Eastern Shore traditionally contract to have the drainage ditches cleared out of all vegetation in order to maximize the conveyance capacity of the system. This can be handled in two ways; mowing and chemical spraying. Spraying of the ditches with a broad-spectrum herbicide totally eradicates all vegetation and habitat which has a potential negative environmental impact. Mowing is usually done to a cut height of 2” to 6” on the maintenance access and bank slopes. While this efficiently keeps the ditches open and moves the stormwater through the system away from the fields, it provides very little “roughness” or trapping efficiency for sediments, nutrients and flow alternation.

Based upon some previous 319 grant funding a promising new alternative maintenance option is currently being utilized in some drainage systems in the Upper Choptank watershed. Utilizing specialized applicator equipment to selectively apply herbicides to just the tall growing woody vegetation in drainage ditches, the “weed wiper” technology is gaining support. The benefit of this practice is that it leaves the low growing vegetation in the ditch to continue to maintain stability on horizontal and slope areas of the ditch. The “weed wiper technology,” instead of broadcast spraying for total vegetation eradication, can work to increase the roughness on the banks and to provide a continued wildlife habitat.

Working with the Public Drainage Associations and the Public Drainage Management Program at the Maryland Department of Agriculture, we were able to retain the services of a trained application specialist for 4 years of “weeding wiping on 50 miles of drainage each year. In addition a video presentation was developed of the management technique and over 250 copies were distributed to producers in Maryland, Delaware and Virginia’s Eastern Shore. The project has developed into an independent operation that is now self sufficient and is expanding to new drainage ditch management in Delaware.

Key Personnel:

> David Harris – Farmer/Weed Wiper Operator, Paul Biddle – Public Drainage Coordinator, Upper Eastern Shore, Mike Dryden, Public Drainage Coordinator Lower Eastern Shore.

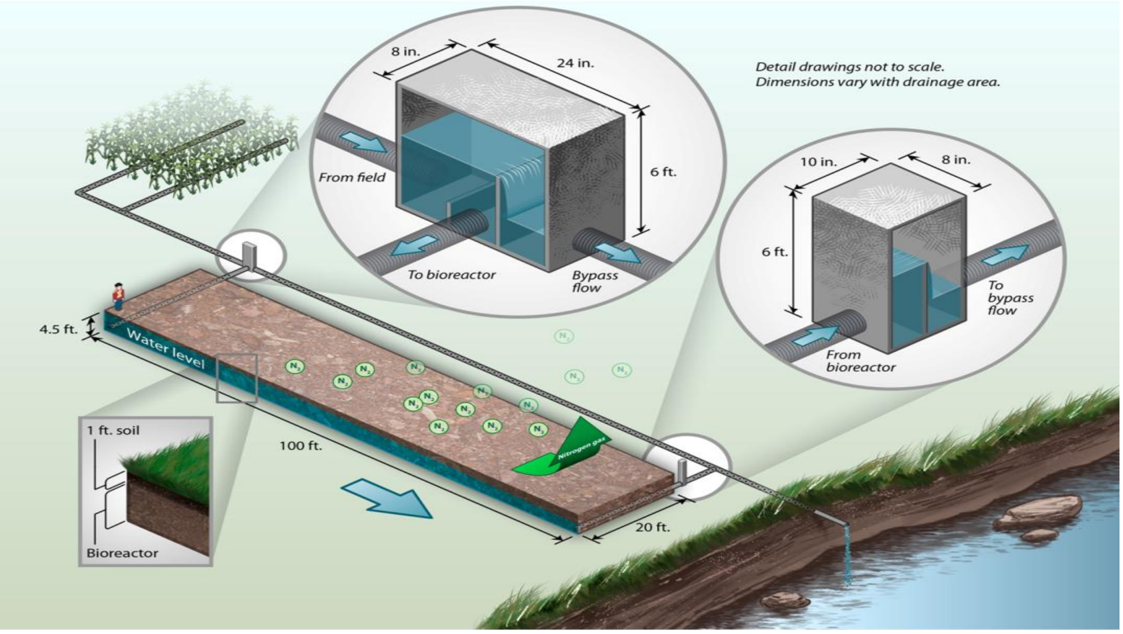
The program established the economic advantage of selective vegetation removal. Weedwiper applications could cost from one-third to one-half the cost of annual mowing to maintain ditch function with increased water quality benefits. The program produced a video to demonstrate the “weed wiper technology.”

Bioreactor/Denitrification Walls

Dozens of woodchip bioreactors have been implemented and cost-shared in the Midwest. A thorough review outlining the state of current Midwestern bioreactor research is provided in Christianson et al. 2012b. Woodchip bioreactors are able to reduce annual agricultural drainage nitrate loads between 23% and 98% (Verma et. al., 2010, Woli et al., 2010).

Denitrification walls have been installed at nitrate-contaminated groundwater sites around the world, with extensive research on the practice occurring in New Zealand and Florida. Denitrification walls can remove as much as 100% of nitrate loads if placed properly (Schmidt and Clark, 2012(a)), and maintain high levels of denitrification of >15 years (Long et al., 2011).

Neither of these techniques has been used in Maryland prior to this grant project, however. The use of bioreactors and walls in Maryland to reduce nitrate levels could be on groundbreaking advancement for these technologies in the Chesapeake Bay region. The design and performance information on these systems from the Midwest (and other areas) create an ideal foundation for this work to proceed in the Eastern Shore of Maryland.



We successfully installed 2 bioreactors with denitrification walls on field ditches in the fall of 2013. One site, received daily effluent on an 85 acre field with runoff values of up to 45 mg/L in the drainage ditches. The second site is on an all organic farm with drainage tile and utilized poultry manure as a fertilizer source was exporting up to 15mg/L nitrate.

After the initial installation, through some trial and error, we were able to increase the efficiency of the reactors by increasing the flow distribution into the reactor and by adjusting the retention time in the reactor. We utilized two years of data to establish relative efficiency for the practices from 60% to 90% for nitrate removal. Subsequently we were able to establish 4 additional bioreactors with National Fish and Wildlife Foundation funding at other farm sites based upon the farm tours we initiated. We now have three organizations and two engineering firms to do designs and installation on this practice.

Key Personnel:

> John Shepard, Manager Caroline Soil Conservation District, Craig Zinter, Manager, Talbot Soil Conservation District, Tim Rosen, Senior Scientist, Mid Shore River Conservancy, Drew Koslow, Scientist, Reef to Ridges, John Thompson, Sassafras Riverkeeper.

In 2015 Maryland NRCS adopted the Bioreactor standard and made the practices an EQIP eligible BMP. At this time four additional bioreactors are planned for 2016.

Phosphorous Sorbing Materials (PSMs)

It had previously been assumed that the main transport path for P was overland flow because of phosphorus attachment to sediment particles. Due to this, phosphorus was thought to be relatively immobility. As a result, most of the efforts to control P losses focused on BMPs treating overland flow. However, some more recent studies (Kleinman et al., 2007; Vadas et al., 2007) have shown that in artificially drained, coarse textured soils with high P concentrations, large amounts of P can be lost through subsurface pathways. This situation cannot be addressed by overland flow BMPs. Additionally, Eghball et al. (2003) and Schulte et al. (2007) estimate it would take years to remove this excess P through crop harvest.

In attempting to develop new BMPs that would effectively remove dissolved P, research turned toward phosphorus sorbing materials (PSMs). PSMs can precipitate dissolved P into solid forms using precipitation and/or adsorption. Many different PSMs exist and include: current agricultural amendments, water and waste treatment materials, and industrial byproducts. Different materials use different methods of creating solid forms of P, for example materials containing amorphous forms of iron and aluminum adsorb P, while materials containing calcium and magnesium cause P to precipitate.

Penn et al. (2007) first recognized the advantage of placing PSM filters in drainage ditches to target concentrated and convergent flow from agricultural systems. The first PSM filter design from Penn et al. (2007) was a confined bed system using 200 kg of acid mine drainage residual, which uses both iron and aluminum oxides to adsorb phosphorus. This system had both successes and drawbacks. On one hand, during the first storm event, the filter removed 99% of the dissolved P that entered the material. On the other hand, during an extreme flow event, the filter only intercepted 9% of the storm flow. In addition, this design required a significant drop between the ditch bottom and outflow tile in order to keep the iron oxidized so as not to release the phosphorus, a condition that is not always feasible on the Delmarva Peninsula.

To study various PSMs, Stoner et al. (2012) tested 12 common byproducts for phosphorus sorption capacity in a series of laboratory flow-through experiments. They examined two types of fly ash, one type of steel slag, four types of acid mine drainage residuals, three drinking water residuals, flue gas desulfurization gypsum and one soil amendment. Using different retention times and inflow phosphorus concentrations, they were able to model maximum phosphorus removal conditions for each material. All of this information informed the creation of a field pilot program for PSM filters on the Delmarva.

This project had three main objectives. The first was to test materials other than acid mine drainage residuals in field conditions. Two materials were selected: flue gas desulphurization gypsum, hereafter gypsum, and electric arc furnace slag, hereafter slag. The second objective was to develop and demonstrate structure designs other than the confined bed system, and then improve the designs as results indicated. Three design types were selected: a tile drained filter system, a cartridge filter system and a stormwater pond box filter system. The objective was to achieve a 20% P reduction. The third objective was to provide monitoring data on filter material performance as part of a collaborative effort at Oklahoma State to create a software PSM design model.

In addition to four existing long term monitored sites, four additional box filter sites on drainage ditches were installed and monitored to test the two materials, design new filters and verify the Oklahoma State design software performance.

Key Personnel:

> Dr. Joshua McGrath, Associate Professor, University of Kentucky, Gene Hahn, Scientist,University of Kentucky, Clinton Gill, Research Associate University of Maryland, Jarrod Miller, University of Maryland Extension, Chad Penn, University of Oklohoma, Anne Balwin, Delaware NRCS.

Final outcome of this project was the finalization of the design software which became part of the development of the National NRCS Standard (782) “Phosphorous Renewal System.” The project team drafted and finalized the standard which is being adopted in Maryland and Delaware.

Hydromodification

Previous works in the Midwest has established that drainage systems can be reengineered to create a two tier drainage flow channel. The low flow channel is dug, at grade and sized to handle the base flow conditions. This is initially confined to ½ of the channel width. A second tier or flood plain bench is constructed parallel to the low flow channel and is stabilized and vegetated to create a flood plan wetland. By reengineering the drainage channel to provide some sinuosity and a flood plan bench, the rate of water movement is slowed and natural stream functions partially restored such as improved wild life habitat. Hydromodification increases sediment entrapment and enhances denitrification.

Utilizing video and presentation from the work done in Indiana and Ohio on two stage ditch designs and the NRCS "Open Channel" Practice Standard (code 582) we had two tours of an existing hydromodification project on Maryland's Eastern Shore. Based upon comments received and a lack of interest, in the hydromodification site we dropped the practice as a ditch management option. Concerns were expressed about the need to take additional cropland out of production to create an area 4 times the base flow condition to for a flood plain bench. Local farmers offered an alternative that would accomplish the same goal at ¼ of the cost.

Working with NRCS engineers, drainage managers, and landowners we modified the concept to focus on “off-line wetland opportunities adjacent to drainage ditches and to created two demonstration sites.

Key Personnel:

> Mike Dryden, Drainage Coordinator, Lower Eastern Shore, Kevin Keenan, District Manager, Wicomico County Soil Conservation District, Anne Baldwin, NRCS Area Engineer.

Landowners, drainage managers, highway engineers and environmental group were supportive of the redesigned practice and we proceeded to utilize CIG funding from this grant to create 2 demonstration sites. Since the 2012 installation, an additional 6 sites were funded with NFWF funding. In 2014, a NRCS RCPP grant established this practice for drainage management on the Delmarva/Lower Eastern Shore. In 2016 two additional sites will be constructed with RCPP funding.

Project Background

Agricultural drainage ditches are common on the Eastern Shore of Maryland. In many cases, fields are divided only by the network of ditches constructed to aid drainage. Private ditches may only be a few feet to a few yards wide, while larger ditches may be many yards wide.

In the Lower Eastern Shore of Maryland these ditches have a total of approximately 821 miles of constructed channels and a drainage area of over 220,000 acres. Drainage systems were established under Article 25-section 52-95 of the Annotated Code of Maryland, often referred to as the Maryland Drainage Law. A majority of the drainage systems were constructed in the early 60’s and 70’s. They were originally constructed for agricultural purposes - farmers and landowners were provided with an outlet to drain their low lying often flooded croplands. By doing this it enabled them to more economically manage and farm their land. Today drainage systems provide an outlet for transportation, housing, and municipal development and municipal storm water management have been connected to or superimposed upon the original agricultural network. Ditches that were originally designed to convey the flow from agricultural land are stressed or destabilized due to additional urban capacity requirements. The historic wetlands loss in the agricultural area would suggest that half of the existing crop land acres were once wetlands. Due to the extensive in field ditching and associated construction of Drainage systems through the federal Public Watershed assistance program (PWA) approximately 60% of the water courses are altered systems.

Previous studies have shown that the addition of controlled drainage management provides an effective way of minimizing the losses of sediment nitrogen and phosphorous to downstream surface waters. The development of methods to reduce artificial drainage systems water quality impacts has become an important focus for drainage managers and the scientific community. Although the drainage ditches, or channelized streams, cannot be fully restored, some innovative BMPs exist that can be utilized to allow continued drainage but also enhance water quality and environmental benefits.

Drainage management consists of both surface and subsurface components. To effectively manage sediment and nutrient loss management must consider both components.

In crop field tile drains create a conduit for water to rapidly leave a field and with it a new pathway for nutrient loss. On Maryland's Eastern Shore subsurface drainage acts as a release for nitrate and dissolved phosphorus. Subsurface tile drainage interrupts the natural denitrification process that would occur. Subsurface drainage allows nitrates that would move vertically through the soil profile to ground water and slowly towards surface waters to reroute horizontally and directly into a surface water body. Also, recent studies have shown that in subsurface drainage in course textured soils with high phosphorous concentrations, the dissolved "P" is lost through the drainage tile. Based on previous research by USGS, up to 70% of the dissolved phosphorous leaving crop field on Maryland's Eastern Shore is from subsurface drainage water.

In 1999, at the request of Maryland's Tributary teams and the Maryland Bay Cabinet, a Public Drainage Taskforce was formed to evaluate how to balance the need to provide drainage of land for farming, developmental areas, public transportation, etc., while at the same time reducing nutrients export, sediment loads and providing shading and other habitats qualities. Taskforce recommendations supported programs that implement progressive maintenance techniques and particularly efforts that enhance the water quality benefits of drainage ditches and that are consistent with Chesapeake Bay improvement efforts. The Taskforce recognized that a lack of scientific research and Best Management options existed to help farmers and landowners mitigate nutrients once moved from the land to the waterway.

Over the next 10 years through a number of Conservation Innovation Grants, National Fish and Wildlife Foundation grants and Chesapeake Bay Trust grants, the Maryland Department of Agriculture and the scientific and research staff at the University of Maryland have investigated a number of new nutrient reduction technologies and developed management recommendations to improve drainage ditch function and address agricultural losses of nutrients. While these demonstration projects have effectively quantified the reduction potential if producers were to adopt the practices no coordinated program to increase adoption of the practices exist. Current soil conservation district staff lack the technical training in the dynamics of drainage management and nutrient transport to convince producers of the benefits of new innovative technologies. To increase producer's adoption of these practices a focused improved management support system was needed.

With CIG funding we were able to provide increased outreach and education, establish a core group of technical expert to assist in implementing new innovative technologies, fund demonstration sites, create outreach materials, and provide technical training.

Review of Methods

As outlined in the original CIG proposal, Component #1 consisted of a walking inventory of drainage ditches on the Eastern Shore of Maryland. Maryland has 110 Public Drainage Association responsible for 821 mile of ditches. Each year they are required to conduct an update to this annual operation and maintenance plan. Based upon landowner meetings and walking inventories of the drainage system an annual report is generated of drainage issue. In house, at MDA, drainage management plans and report are reviewed for sites that would provide opportunity for sediment, nitrate or phosphorous reductions.

Utilizing a core group of technical experts and researchers we developed informational fact sheets and develop a short video focused on drainage management as educational outreach tools to solicit project sites from farmer and landowners. We attended winter producers meeting, county ag meetings, and drainage association annual meetings to increase producers knowledge and improve on a management support system for the innovative drainage technology." Based upon our outreach and development of demonstration sites, to evaluate the various drainage practices, we conducted and coordinated individual tours for prospective producers and arranged farmer to farmer meetings as a way to foster a greater understanding and to discuss management. Farmers and landowners were eager to provide management perspectives and offer up additional ideas that were incorporated in later projects. Examples included utilizing a 12" ditch witch to engineer a 2 stage ditch with flood plain benches and mixing phosphorous-sorbing slag with nitrate reducing mulch in woodchip bioreactors.

Component #2 of the project was to select sites and to design and install appropriate treatment technologies for the sites. Based upon the previous walking inventories and interest by producers we had a multitude of sites that allow us to demonstrate and test a broad suite of innovative drainage management technologies. Utilizing our research experts and monitoring results we conducted training of soil conservation staff and other conservation partners.

Hydromodification

Hydromodification is the ability to recreate the natural function of engineered drainage to perform as a sediment and nutrient trap. Drainage ditches are typically constructed with a trapezoidal cross section and the excavated soil is placed as a spoil bank along side of the ditch. Although designed to carry a 24 hour storm event, they now often carry the increased flow caused from expansion on impervious surfaces from highway, towns and development. Historically drainage systems management and maintenance has mainly consisted of cleanouts and mowing. The open flow system and periodic scouring of sediments from ditches limit nutrient reduction capacity. By reengineering the drainage channel to provide some sinuosity and a flood plain bench, the rate of water movement is slowed and natural stream functions partially restored such as improved habitat. Another option is the recreate the flood plan or wetland feature of a drainage channel by rerouting the water course through un-utilized land to act as a relief flood plain. Utilizing funding from this grant, we initially established a ¼ mile two tier drain channel as a hydromodification demonstration site and as a way of fostering a greater understanding of the concept. Subsequent tours of the site by producers and landowners failed to generate any interest in pursuing the hydromodification practice. Reasons for the disinterest typically focused on the width of the additional flood plain, rodent control, annual maintenance needs and construction costs.

Drainage managers in Delaware had been working on reclaiming underutilized land adjacent to drainage ditches to create a secondary channel for storm water events that occurred during high flow events. These “relief channels” were connected to the main drainage ditches through a high flow inlet. Soil conservation engineers on Maryland’s lower Eastern Shore reengineered the basic parameters of the off line storm water capture practice to expand the holding capacity of the off line channel design and to provide a mechanism for water to gradually flow back into the main channel. This redesign because the mechanism to create a series of “off-line” wetlands. These off line wetlands areas were established by creating a armored breach in the side of the drainage channel to partially divert water greater than a 1” storm event. High flow storm water would flow out into a low land area adjacent to the drainage ditch. Typical flood plain areas were located in woodlands and could be up to a ¼ acre to ½ acre. A water control structure and pipe on the lower end of the flooded wetland would allow water to gradually flow back into the main channel when water levels had receded in the main channel. This type of “off line” flood plain recreation became the preferred hydromodification practice for landowners and producers because it did not take away cropland acres.

We installed two of these sites on the Kitts Branch PDA and conducted tours for county engineers, environmental groups and PDA managers. Environmental and conservation groups liked the wildlife benefits of the practice. In 2015 an EQIP RCFP proposal was submitted and approved to install additional “off-line” wetlands and Maryland’s lower Eastern Shore.

Weed Wiper Technology

Originally created in Florida for vegetation control in orange orchids, a specialized applicator equipment was custom built to selectively apply herbicides to just the tall woody growth in the drainage ditch. This allows the low growing vegetation to maintain stability on the horizontal and slope areas of the ditch. The applicator bar is mounted on a 12' swivel boom attached to a tractor. Running at 2-3 miles per hour the boom and applicator run up on side and then the other side of the ditch. The applicator bar would scrap the tree bark and applies a pre mixed herbicide to the woody growth. The herbicide would travel down the tree to the root and within 90 days killed the tree. The soft vegetation/grasses in the ditch remained unaffected. Trapping efficiency and vegetation "roughness" are maintained in the ditch to provide sediment capture and nutrient uptake.

Based upon cost comparisons the weed wiper application cost about $350 per mile and is good for three years. These compare to annual mowing costs for drainage ditch maintenance which average $250 per mile but must be done on an annual basis. The weed wiper cost advantage is ½ of the traditional cost of ditch maintenance.

Phosphorus Sorbing Materials (PSMs)

The Phosphorus removal structure is a large, landscape scale filter for dissolved phosphorus, intended to intercept and trap phosphorus from "hot spots" before reaching a surface water body. The Phosphorus removal structure has four basic principles:

1. Contains solid media with high affinity for P, commonly known as a " P sorption material," or PSM.
2. PSM is contained and placed in a hydrologically active area with high dissolved P concentrations.
3. High dissolved phosphorus water is able to flow through the contained PSM.
4. The PSM is able to be removed and replaced after it is no longer effective.

Many PSMs are by-products from different industries, and therefore can be obtained for low or no cost. Some examples include steel slag and acid mine drainage treatment residuals.

A phosphorus removal structure can be constructed in many different ways and be effective. Some options include a box structure, confined bed and tile drain structure.

Phosphorous Sorbing Materials (PSMs) filled structures are placed within drainage ditches to act as a "P" filter. Preliminary field scale testing of proposed systems and a removable canister type model has shown a high likelihood of success, removal of 55-95% of the P from treated drainage systems. We focused our work on two different prototypes in Maryland through this program. The first consisted of installing under drains in the drainage ditch behind a water control structure with a gypsum blanket 1/2 to 2” thick applied on top. This slow rate infiltration system allows for low to moderate flow to be treated. The second option was more applicable for heavy or storm flow systems, where a lot of water can pass through a cage. Utilizing an iron slag, these filters are very porous and utilize large 2-4" particles to react and capture the phosphorous in the water column.

One of the goals of the CIG program was to establish and work with a core group of technical experts. We were fortunate to link up with Dr. Chad Penn at Oklahoma State University. Dr. Penn is a leading expert in PSM research. Dr. Penn was developing new design software for PSM’s filters. Based upon our collaboration with Dr. Penn, this project had two main objectives. The first was to test materials other than acid mine drainage residuals in field conditions. Two materials were selected: flue gas desulphurization gypsum, hereafter gypsum and electric arc furnace slag, hereafter slag. The second objective was to develop and test structure designs other than the confined bed system, and then improve the designs as results indicated. Three design types were selected: a tile drained filter system, a cartridge filter system and a stormwater pond filter system. The objective was to achieve a 20% P reduction.

The material selection process involved a number of considerations. First, it was important to compare materials with different phosphorus sorption properties in similar environments. Second, in order to be developed into an effective low cost BMP, the materials needed to be relatively low cost in the quantities used. Third, the materials had to be locally sourced in order to reduce the transport costs. The gypsum is a byproduct derived from the use of lime to scrub sulfur out of the flue gas in coal fired power plants. The particular gypsum used was obtained from US Gypsum in Baltimore, Maryland. This byproduct gypsum is a relatively pure form of calcium sulfate. The gypsum works best in conditions of longer retention time, and is thus more effective in baseflow events rather than storm events. Slag is a byproduct of steel production which was obtained from steel plants in Seaford and Claymont, DE. It has mostly calcium oxides along with some amorphous Fe oxides, and works best in conditions of short retention times.

The first design was a tile drained filter system used with the gypsum. First, the ditch was dipped out, geotextile was put down and a layer of gypsum was put in. Four tile drains were wrapped in geotextile and laid down the length of the ditch, leading to a perpendicular manifold which all of tiles fed into. A layer of gypsum was then laid on top of the tiles. The water flows to the tile drains through the gypsum from all sides of the ditch. This system uses approximately 80,000 kg of gypsum, depending on ditch size. Gypsum provides a good growth medium which aides in re-vegetation after construction.

The next filter design was the cartridge system used with the slag. These cartridges had perforated outer ring and a perforated inner ring, between which the slag was placed. The water flowed through the outer ring, through the slag, and through the inner ring after which it flowed downward into a pipe. Nine of these cartridges were installed per site, each flowing into a common manifold. Each cartridge contained approximately 27 kg of slag.

The final filter design was the stormwater pond filter system. This system used custom made boxes, designed with the same concept of the cartridge system. Each box was 1.2 by 1.2 by 1.8 m with a perforated 16 cm PVC pipe in the center. Again, the water flowed into the side of the box, through the slag and to the PVC pipe, flowing downward into a manifold. Four of these boxes were used in this system, each containing approximately 1,200 kg of slag.

The sites near Marion Station, Westover and Barclay each have two parallel primary ditches, both flowing into a common secondary ditch. At each of these sites, one ditch contained a gypsum tile drained filter system and one contained a slag cartridge filter system. The site near Centreville h•as a stormwater pond system containing the slag boxes.

The sampling at Marion Station, Westover and Barclay were set up the same for both the gypsum and slag. The untreated water comes down the ditch until it reaches a flow control structure. The water backs up against the flow control structure and then enters the filter. After exiting the filter, the now treated water flows into a concrete vault and into an H-flume where the flow rate is measured and a water sample is taken. At the same time, a sample is taken from the pre-treated ditch water so a one to one comparison can be made between the water entering the filter and the water exiting the filter. Any flow over the flow control structure at the end of the ditch is also recorded. A quarter bottle is taken every two hours, filling a one liter bottle fully in eight hours.

The sampling at Centreville was similar. The water flows down a ditch on the far side of the top filter, where it encounters a flow control structure. This diverts the water into the pond, essentially collecting all the runoff from the poultry production section of the property. The water then flows through the filters where it enters a pipe that leads it to the main ditch. In that pipe is a weir to measure flow as well as a sampler tube to take a sample. Again, another sampler takes water from the pond at the same time for a one to one sample and again the bottles fill a quarter of the way every two hours.

The samples were collected using Teledyne ISCO 6712 automatic samplers. The level and rainfall were measured using the same sampler with the 720 Submerged Probe Flow Module and the 674   Rain Gauge respectively. These systems were powered using a custom solar panel and battery system. The data was downloaded and partially analyzed using the Flowlink monitoring software.

The bottles from each site were collected once a week and the data from the samplers was downloaded. The samples are brought back to the lab where pH, EC and total solids were measured and recorded. Two subsamples of water were then split off from the main sample to measure for dissolved reactive phosphorus and total phosphorus. The sample for dissolved reactive phosphorus was passed through a 0.45 micrometer filter and analyzed using the colorimetric molybdate reactive phosphate test on the Lachat. The sample for total dissolved phosphorus was digested using the potassium persulfate autoclave method and also analyzed using the molybdate reactive phosphate test.

In March of 2014 the preliminary results of this and other PSM work were published in the Journal of Soil and Water Conservation in a paper entitled " Phosphorus Removal Structures, A Management Option for Legacy Phosphorus." Attached to this report is a final paper from the University of Maryland outlining the updated results of the PSM work.

Bioreactors

Working with the Maryland Midshore Riverkeepers, Virginia tech researchers and NRCS technical staff in the Midwest, we partnered on the installation of 2 bioreactors with denitrification walls on field ditches in the fall of 2013. One site, Edwards, receives daily effluent on an 85 acre field with nitrate runoff values of up to 45mg/L in the drainage ditches. Groundwater supplies approximately 75% of the water to the crop field drain tile. As the main water source, it supplies the majority of the nitrogen in the form of nitrate, which moves readily through the soil drainage tile line. The property drainage system intercepts both surface and groundwater from multiple fields and discharges this water via one pipe to a ditch that drains to Cherry Creek, a tributary of the Choptank River.   The drain tile woodchip bioreactor was sized at 30 wide by 100' long. This size woodchip bioreactor will effectively treat baseflow from the drainage tile line and the first flush of a storm event for the 85 acre site. The Mid Shore Riverkeepers consulted experts in bioreactor research in the Midwest and at Virginia Tech University to assist in engineering and design.   The surface soil was scraped away and a 30' by 100' by 4' chamber is dug in the subsoil. An impervious plastic liner is installed and 1" to 4" shredded woodchips are added. The adjacent tile line is breached and a 90 degree pipe with a level spreader is installed with a flow converter box (Agri-Drain). A second flow box with adjustable baffles is installed on the down slope section of the tile and reconnects the biofilter to the tile line. Down slope baffles are set to height to maintain a 2' anoxic zone in the chamber. A top plastic liner is installed and the site is covered over and planted with the surface soil that was initially scraped away.

Initial monitoring of nitrate removal results at the Edwards farm were less than expected based upon the design parameters. After one year of operation, the site was opened up to allow for slight modifications to the perforated corrugated HDPE pipe that inlets and outlets water from the practice. This allowed for greater amount of water to flow into the practice increasing the treatment capacity. The next year's results reflected a significant improvement in performance.

The second bioreactor was constructed on the Mason Farm, an all organic farm, with drainage tile and had utilized poultry manure as a fertilizer source.

Again groundwater supplied up to 66% of the water source in the drain tile. During wet weather events the pipes drains a low pocket of a 66 acre crop field. Nitrate values at the outlet average 15mg/L. To reduce the Nitrate by 90% we installed 30 feet by 100 feet woodchip reactor with an in-line water control structure to divert base flow and the first flush of storms into the woodchip bioreactor, which paralleled to the ditch. Water levels in the bioreactor are dictated by a capacity control structure and the treated water discharged back into the ditch. This project is immediately downstream of a section of two-stage ditch that was constructed by the The Nature Conservancy and the Chesapeake Bay Foundation, funded by the Chesapeake and Atlantic Coastal Trust Fund.

With a 3 foot relief in drainage topography, we were able to maintain good flow through this bioreactor. Results indicated that with some adjustments to retention time we could meet the 90% nitrate reduction goal. Adjustments were made to the flash boards based upon monthly monitoring or seasonal hydrologic conditions.

One of the unintended consequences of both of the bioreactor process relates to the need to maintain an anoxic condition in the reactor chamber. In an anoxic condition the phosphorus in the wood chips is released and elevates the dissolved “P” levels. This condition allows high dissolved phosphorus to flow out of the reactor. This condition is temporary at the startup of the system and only last for about three months. The system flushes and “P” levels return to normal. We are currently experimenting with adding iron slag to the woodchips to capture the dissolved phosphorus and prevent its release. Following successful implementation of these practices, NRCS developed a provisional Maryland Design Standard for woodchip reactors. Farmers were enthusiastic about these practices because they require minimal maintenance, take little or no land out of production, are edge-of-field practices, and have a life span of at least 15-20 years.

Based upon the success of these two initial bioreactors, six additional sites are under construction or planned in 2016. Based upon a five year intensive monitoring program to evaluate the nitrate reduction efficacy of the practice, we are pursuing acceptance as an agricultural best management practice within the Chesapeake Bay Program and as Maryland Agricultural Cost Share (MACS) practice.

Discussion of Quality Assurance

As detailed earlier the purpose of the project was to provide outreach, education, technical resources and implement restoration of drainage sites for producers and landowners in target watersheds. Utilizing the most promising drainage technologies for nutrient and sediment reductions, we conducted multiple presentations, tours, and technical education classes. Our project team utilized our engineering partners and University research scientist to develop information to be disseminated. All information was peer reviewed within the team member for quality assurance prior to release. These sites coupled together some of the newer technologies such as water control structures, biofilters, phosphorus filters, or hydromodification and offline wetlands to maximize nutrient and sediment education effectiveness provided a valuable way to educate. We worked with landowners and farmers to develop new management options for drainage ditches, such as increased buffer setbacks and utilization of the "weed wiper" instead of chemical spraying for vegetation management. Implementation of innovative drainage technologies support Maryland's Watershed Implementation Plan to address the Chesapeake Bay TMDL. The construction work was supported in collaboration with Maryland Department of Agriculture Engineering Technicians and Drainage Management Planners under the direction of the NRCS area engineer in the Caroline and Talbot County SCD offices.

Two of the innovative drainage practices we developed and showcased, woodchip bioreactors and phosphorus sorbing materials, did have a limited monitoring component to them.

Utilizing CIG funding, we cost-shared in the construction work for the woodchip bioreactors, with the Midshore Riverkeeper Conservancy. The major portion of the project, planning, engineering, design and monitoring was paid for by the Maryland Chesapeake and Atlantic Coastal Bay Trust Funds. Therefore, the monitoring plan, sampling procedures, custody, calibration and the data analysis were carried out per the requirements of the Bay Trust Fund grant. These procedures require adherence to the protocols for BMP data integrity sufficient to present to a peer review panel of national experts for determination of BMP efficiency and verification as outlined in the Chesapeake Bay Program BMP protocol. Essentially the monitoring of the woodchip bioreactor sites required initial weekly composite sampling progressing to monthly sampling utilizing ISCO samples. The samples were collected, stored, and transported according to University of Maryland sample processing procedures to the University of Maryland lab at Horn Point. Data analysis was handled by senior scientist at the Midshore Riverkeeper conservancy. After five years of data collection, a peer review panel will be formed by the Bay Program to review the results that monitoring effort is ongoing at this time.

The Phosphorus Sorbing Materials (PSM) was a collaboration with Dr. Joshua McGrath, University of Maryland/ Kentucky along with his graduate students and Dr. Chad Penn, University of Oklahoma. This work built upon work originally started in 2010 and expanded the number of sites and monitoring samples to allow for a March 2014, published, peer reviewed paper entitled “Phosphorus Removal Structures a Management Option for Legacy Phosphorus” in the Journal of Soil and Water Conservation. The full study design, sampling procedures and data analysis as conducted by the University of Maryland team can be found in the appendix of this report.

Findings

Over the course of the project all the original project deliverables were met. In some areas we exceeded expectations. Specifically, we were able to establish two NRCS practices standards and create alternative funding sources to continue the establishment of innovative drainage management practices. We partnered on two woodchip bioreactors that became part of the NRCS design standard 605 - Denitrify Bioreactor. Based upon our collaboration and monitoring effort on Phosphorus Sorbing Material (PSM) we partnered in the development of the NRCS standard 782 - Phosphorus Removal Systems.

NRCS EQIP funding is now available for Denitrify Bioreactors in Maryland. Six additional reactors are under construction or are planned to be built in 2016. Phosphorus Removal Systems are a new NRCS Practice standard and Maryland EQIP funding will be available in 2017. Currently three additional Phosphorus Removal Systems are planned in 2016 utilizing alternative funding.

Conclusions

We were able to successfully demonstrate to a broad audience of farmers, landowners, producers, and environmentalist the benefits of drainage management practices. We were able to learn from these individuals what made sense in terms of economics, management and operation for drainage systems on Maryland’s Eastern Shore. We received good feedback on new ideas or some modification to demonstrate BMP’s in the field. We established a core group of technical experts that could communicate one on one with landowners and producers, and assist in implementing new innovative drainage practices. We created media interest for public television specials, video presentations, legislative tours, and farm meetings. We were able to quantify benefits of some of the practices and we established conservation practice standards and created a continued funding for new drainage ditch practices.

Ditch Management Project Final Report

Project Title: MDA-UMD Ditch Management Project
Project Number: MDA-1890
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Introduction and Background

The Chesapeake Bay is the largest estuary in the United States. Over the years there has been a sustained effort to try to preserve and restore the Bay, with a lot of the focus on the continuing problem of eutrophication. Eutrophication occurs when additions of nutrients to the surface waters create algal blooms, which then die off and create zones of anoxic conditions, unsuitable for life. Nutrient pollution from nitrogen and phosphorus can come from a variety of sources, but a major contributor is agriculture.

The purpose of this research was to focus on phosphorus (P) contributions to the bay from the Delmarva Peninsula, a mostly flat, low-lying region with poorly drained coastal plain soils. As such, the area had to be extensively ditched to drain water enough for effective agriculture. These ditches run for a total of 1,321 km and drain 74,060 hectares of land area. The Delmarva Peninsula also has a high density poultry industry and the litter from this poultry has historically been land applied to farmland in the form of fertilizer, usually at nitrogen (N) rates. This has typically led to an over application of P, because of poultry litter's low N/P ratio, and therefore, elevated soil P concentrations.

It had previously been assumed that the main transport path for P was overland while sorbed to sediment particles due to P's relatively high immobility. Because of this, most of the efforts to control P losses have focused on overland flow best management practices (BMPs) However, some more recent studies (Kleinman et al., 2007; Vadas et al., 2007) have shown that in these artificially drained, coarse textured soils with high P concentrations, large amounts of P can be lost through subsurface pathways. This situation cannot be addressed by overland flow BMPs. Additionally, Eghball et al. (2003) and Schulte et al. (2007) estimate it would take years to remove this excess P through crop harvest. Another, more immediate solution is needed.

In attempting to develop new BMPs that would effectively remove dissolved P, research turned toward phosphorus sorbing materials (PSMs). PSMs can precipitate dissolved P into solid forms using precipitation and/or adsorption. Many different PSMs exist and include: current agricultural amendments, water and waste water treatment materials, and industrial byproducts. Different materials use different methods of creating solid forms of P, for example materials containing amorphous forms of iron and aluminum adsorb P, while materials containing calcium and magnesium cause P to precipitate.

Penn et al. (2007) first recognized the advantages of placing PSM filters in drainage ditches to target concentrated and convergent flow from agricultural systems. The first PSM filter design from Penn et al. (2007) was a confined bed system using 200 kg of acid mine drainage residual, which uses both iron and aluminum oxides to adsorb phosphorus. This system had both successes and drawbacks. On one hand, during the first storm event, the filter removed 99% of the dissolved P that entered the material. On the other hand, during an extreme flow event, the filter only intercepted 9% of the storm flow. In addition, this design required a significant drop between the ditch bottom and outflow tile in order to keep the iron oxidized so as not to release the phosphorus, a condition that is not always feasible on the Delmarva Peninsula.

To study various PSMs, Stoner et al. (2012) tested 12 common byproducts for phosphorus sorption capacity in a series of laboratory flow-through experiments. They examined two types of fly ash, one type of steel slag, four types of acid mine drainage residuals, three drinking water residuals, flue gas desulfurization gypsum and one soil amendment. Using different retention times and inflow phosphorus concentrations, they were able to model maximum phosphorus removal conditions for each material. All of this information informed the creation of a field pilot program for PSM filters on the Delmarva.

Objectives

This project had two main objectives. The first was to test materials other than acid mine drainage residuals in field conditions. Two materials were selected: flue gas desulphurization gypsum, hereafter gypsum, and electric arc furnace slag, hereafter slag. The second objective was to develop and test structure designs other than the confined bed system, and then improve the designs as results indicated. Three design types were selected: a tile drained filter system, a cartridge filter system and a stormwater pond filter system. The objective was to achieve a 20% P reduction.

Methods

The material selection process involved a number of considerations. First, it was important to compare materials with different phosphorus sorption properties in similar environments. Second, in order to be developed into an effective low cost BMP, the materials needed to be relatively low cost in the quantities used. Third, the materials had to be locally sourced in order to reduce the transport costs. The gypsum is a byproduct derived from the use of lime to scrub sulfur out of the flue gas in coal fired power plants. The particular gypsum used was obtained from US Gypsum in Baltimore, Maryland. This byproduct gypsum is a relatively pure form of calcium sulfate. The gypsum works best in conditions of longer retention time, and is thus more effective in baseflow events rather than storm events. Slag is a byproduct of steel production which was obtained from steel plants in Seaford and Claymont, DE. It has mostly calcium oxides along with some amorphous Fe oxides, and works best in conditions of short retention times.

The first design was a tile drained filter system used with the gypsum. First, the ditch was dipped out, geotextile was put down and a layer of gypsum was put in. Four tile drains were wrapped in geotextile and laid down the length of the ditch, leading to a perpendicular manifold which all of tiles fed into. A layer of gypsum was then laid on top of the tiles. The water flows to the tile drains through the gypsum from all sides of the ditch. This system uses approximately 80,000 kg of gypsum, depending on ditch size. Gypsum provides a good growth medium, so after installation the filter re-vegetates.

The next filter design was the cartridge system used with the slag. These cartridges had perforated outer ring and a perforated inner ring, between which the slag was placed. The water flowed through the outer ring, through the slag, and through the inner ring after which it flowed downward into a pipe. Nine of these cartridges were installed per site, each flowing into a common manifold. Each cartridge contained approximately 27 kg of slag.

The final filter design was the stormwater pond filter system. This system used custom made boxes, designed with the same concept of the cartridge system. Each box was 1.2 by 1.2 by 1.8 m with a perforated 16 cm PVC pipe in the center. Again, the water flowed into the side of the box, through the slag and to the PVC pipe, flowing downward into a manifold. Four of these boxes were used in this system, each containing approximately 1,200 kg of slag.

This report represents data from four sites near Marion Station, Westover, Barclay and Centreville. The sites near Marion Station, Westover and Barclay each have two parallel primary ditches, both flowing into a common secondary ditch. At each of these sites, one ditch contained a gypsum tile drained filter system and one contained a slag cartridge filter system. The site near Centreville has a stormwater pond system containing the slag boxes.

The sampling at Marion Station, Westover and Barclay were set up the same for both the gypsum and slag. The untreated water comes down the ditch until it reaches a flow control structure. The water backs up against the flow control structure and then enters the filter. After exiting the filter, the now treated water flows into a concrete vault and into an H-flume where the flow rate is measured and a water sample is taken. At the same time, a sample is taken from the pre-treated ditch water so a one to one comparison can be made between the water entering the filter and the water exiting the filter. Any flow over the flow control structure at the end of the ditch is also recorded. A quarter bottle is taken every two hours, filling a one liter bottle fully in eight hours.

The sampling at Centreville was similar. The water flows down a ditch on the far side of the top filter, where it encounters a flow control structure. This diverts the water into the pond, essentially collecting all the runoff from the poultry production section of the property. The water then flows through the filters where it enters a pipe that leads it to the main ditch. In that pipe is a weir to measure flow as well as a sampler tube to take a sample. Again, another sampler takes water from the pond at the same time for a one to one sample and again the bottles fill a quarter of the way every two hours.

The samples were collected using Teledyne ISCO 6712 automatic samplers. The level and rainfall were measured using the same sampler with the 720 Submerged Probe Flow Module and the 674 Rain

Gauge respectively. These systems were powered using a custom solar panel and battery system. The data was downloaded and partially analyzed using the Flowlink monitoring software.

The bottles from each site were collected once a week and the data from the samplers was downloaded. The samples are brought back to the lab where pH, EC and total solids were measured and recorded. Two subsamples of water were then split off from the main sample to measure for dissolved reactive phosphorus and total phosphorus. The sample for dissolved reactive phosphorus was passed through a 0.45micrometer filter and analyzed using the colorimetric molybdate reactive phosphate test on the Lachat. The sample for total dissolved phosphorus was digested using the potassium persulfate autoclave method and also analyzed using the molybdate reactive phosphate test.

Data Analysis

Data was cleaned and analyzed using Statistical Analysis Software (SAS) version 9.3. Due to the size and complexity of the data generated this was a cumbersome process. We reserve the right to revise the results presented within this report for future publications and will notify project sponsors of additional publications and revisions that are produced in the future.

Flow monitoring began at the ditch sites (Marion, Westover, and Barclay) in 2009 and in 2010 at the one retention pond site (Centreville). Table 1 provides general details on the size of the dataset generated. As described above, there were two monitoring stations at each ditch, one for the overflow that bypassed the filter and one monitoring flow through the filter. At the Centreville site there was a bypass labeled as ditch as well as the overflow. In total we analyzed 6,861 samples. Cumulatively the samplers monitored 412,342 hours of flow representing 3.76 X 10^8 liters of flow. The dataset itself consisted of 5,663,057 points, representing one line of data for every data point the samplers collected, which generally occurred every five minutes.

Due to the nature of flow in these systems and the way the samplers were arranged at the outset of the study there was not always a sample collected that represented the inflow P concentration to the filter. However, using the lessons learned from this project we were able to modify the sampling equipment to avoid this issue in the future if sampling of these sites is to continue. In fact, the way the samplers are currently set up data analysis would be much easier and the data would be much more useful.

A second challenge presented by these systems was obtaining a clean sample from the filter outflow. Due to the flat topography and the flow characteristics of these sites whenever there was a larger storm event there was no way to move water out of the sample vaults fast enough. Therefore, larger storm events resulted in the filter samples being contaminated. However, there was no clear way to determine when this would occur. However, we used our best professional judgement to make this delineation and attempted to clean out samples that were contaminated. Nonetheless, a dataset this large presented a unique challenge. Again, using what was learned through this project we modified the sample collection design prior to shutting down the systems. If re-started, this problem should be greatly reduced for all but the largest storms.

Table 1. Flow and chemistry dataset descriptions.

			Flow Monitoring							Laboratory Samples		
Site	Material	Type	Start	Finish	Datapoints	Average Flow Rate (l/s)	Max Flow Rate (l/s)	Total Volume (l)	Time Monitored (hours)	No. Samples Analyzed	First Sample	Last Sample
Barclay	Gypsum	Filter	1/5/2010	9/25/2013	449237	4.04	263761.00	28021850	30648	840	1/5/2010	6/14/2013
Barclay	Gypsum	Overflow	3/1/2010	10/19/2013	458086	4.50	643.39	14120319	29922	764	3/29/2010	6/15/2013
Barclay	Slag	Filter	1/5/2010	8/21/2013	426350	9.57	4836.70	1.29E+08	28521	970	1/5/2010	4/13/2013
Barclay	Slag	Overflow	2/1/2010	8/31/2013	435786	26.52	1029.85	12917381	29902	776	2/22/2010	4/7/2013
Marion	Gypsum	Filter	2/24/2010	5/11/2013	317798	3.93	910.08	24461827	23299	554	2/25/2010	2/9/2013
Marion	Gypsum	Overflow	8/1/2009	3/9/2013	321685	322.17	62213.10	19867578	27151	187	8/2/2009	1/21/2013
Marion	Slag	Filter	1/14/2010	7/31/2013	368057	4.98	1054.53	36029619	23637	597	1/27/2010	1/21/2013
Marion	Slag	Overflow	8/1/2009	3/9/2013	332538	2.07	154.86	11959610	26319	169	8/2/2009	1/19/2013
Centreville	Slag	Ditch	8/17/2010	5/28/2014	316876	0.05	4.04	100439	25351	47	8/18/2010	8/1/2013
Centreville	Slag	Filter	8/10/2010	8/31/2013	331909	0.23	11.71	10831614	26489	447	8/18/2010	6/14/2013
Centreville	Slag	Overflow	8/17/2010	9/30/2013	344970	0.30	11.71	3949045	27220	532	8/18/2010	6/14/2013
Westover	Gypsum	Filter	2/1/2010	7/31/2013	398175	4.60	21601.30	13483726	28740	273	2/3/2010	3/5/2012
Westover	Gypsum	Overflow	8/1/2009	7/31/2013	388481	218.59	62213.10	36348211	30389	273	8/2/2009	3/4/2012
Westover	Slag	Filter	1/21/2010	7/31/2013	331278	3.57	975.23	9689648	25954	189	1/21/2010	3/5/2012
Westover	Slag	Overflow	8/2/2009	7/31/2013	441831	3.07	352.18	24718705	28800	243	8/2/2009	3/4/2012

Current Equipment Status

All of the sites are currently shut down in order to complete the data analysis portion of the project. The Centreville site can be restarted with routine maintenance. At the Marion Station and Barclay sites, the gypsum filters can be restarted with routine maintenance. The slag cartridge filters at these sites have been replaced by two slag boxes, and can also be restarted with routine maintenance. The gypsum filter at Westover can be restarted, however the cartridge slag filters need to be replaced by box filters. This would take approximately two days of work.

In addition to the sites with data, three additional box filter systems were installed in ditches. Two were installed near Berlin and one near Ridgely. All of these sites have the filters installed as well as the sampling equipment. The two sites in Berlin can be started with routine maintenance, while the Ridgely site requires approximately a day of work to complete.

Results

This report will focus on dissolved reactive P (DRP) and total P (TP) concentrations analyzed in collected samples. The filters were designed to chemically remove dissolved reactive P from the water column. However, they also remove some portion of the particulate P through mechanical filtration. In ditches, previous work has indicated that most of the total P is dissolved P. Furthermore, what particulate P moves down the ditch is dominated by detached organic material such as algae (gowing during low-flow events). However, because of the geographic distribution of our sites and funding restraints we could only collect samples from the field once per week on average. Therefore, the samples could have sat in the Isco units for a week or more, cooking in the sun. As a result we would expect that the distribution of P as measured in the sample in the lab probably does not represent the distribution in the field. One could argue that our total P numbers are more reliable. Nonetheless, because of the spotty nature of our data set we thought it valuable to present both variables.

In order to estimate filter performance the flow data had to be broken up into discrete events. However, as mentioned before, sometimes inflow samples were not collected close enough to a filtered sample to draw conclusions. In other instances, samples were contaminated because of extremely high flow rates that our sampling strategy could not handle. Sometimes the batteries in one sampler or the other would die during a storm event and therefore samples would be missed. For all these reasons the dataset of good concentrations for dissolved reactive P does not represent the same series of events as those where good data was obtained for total P concentrations. Moreover, the events that could be analyzed and summarized in this report only represent a small fraction of the total amount of flow analyzed. In regards to DRP we are able to present results from 1,543 of the 6,861 samples collected and for TP we are able to present results from 1,785 of the bottles collected. This represents about 22 and 26% of the total samples analyzed (Tables 2 and 3).

One of the major limitations of previous filter designs was flow interception, or how much of the total ditch flow went through the filter. Current filter designs, particularly the Centreville “box” filter, appear to greatly improve on previous filter performance reported. The Centreville filter intercepted approximately 90% of the flow for the events covered in the DRP and TP datasets. The gypsum bed filters ranged from 53-95% flow interception for the DRP events and 39-96% flow interception for the TP events (Tables 2 and 3).

Table 2. Dissolved Reactive P: Filter Performance

Site	Material	Flow Events	Filter Samples	Overflow Samples	Ditch Samples	Total Volume (l)	Filtered Volume (l)	Intercepted Flow (%)
Barclay	Gypsum	15	297	289	0	3501511	2700517	77%
Marion	Gypsum	18	47	43	0	3548900	1863237	53%
Westover	Gypsum	5	22	29	0	299229.8	282975.5	95%
Barclay	Slag	15	188	187	0	2135069	1930642	90%
Marion	Slag	11	27	17	0	4202702	2422529	58%
Westover	Slag	12	79	79	0	3734442	1879202	50%
Centreville	Slag	12	130	103	6	307530.4	275310.8	90%

Table 3. Total Phosphorus: Filter Performance

Site	Material	Flow Events	Filter Samples	Overflow Samples	Ditch Samples	Total Volume (l)	Filtered Volume (l)	Intercepted Flow (%)
Barclay	Gypsum	14	160	164	0	2948333	2356051	80%
Marion	Gypsum	19	74	66	0	512598.4	493675.8	96%
Westover	Gypsum	8	31	37	0	3402635	1343285	39%
Barclay	Slag	33	399	381	0	3501243	3019990	86%
Marion	Slag	17	44	29	0	5962125	4199828	70%
Westover	Slag	13	72	68	0	3186111	1366114	43%
Centreville	Slag	11	151	102	7	495310.2	459338.4	93%

There are two ways to report average concentrations from flow data, time-weighted and flow-weighted mean concentrations (TWMC and FWMC). These weighted concentrations are necessary to properly represent how the samples were collected. In some instances a single sample bottle, and therefore a single concentration result, might represent a few minutes of flow, while in other instances a single result might represent 24 hours of flow. Likewise, sometimes a single sample represents many thousands of liters of flow and in others a single sample might only represent a couple of liters. We have presented both TWMC and FWMC in Tables 4 and 5. In order to understand the difference between TWMC and FWMC it is helpful to think about them in terms of what impact of P in the water column you are trying to evaluate. TWMC probably best represents how we think about concentration and is likely what people mean when they ask about “the average P concentration” in a water body. It is the concentration that algae or other organisms would respond to in the aquatic environment. FWMC is probably the most often quoted and also probably the most often misused concentration. It represents the concentration that is being delivered to a receiving body of water – because it is weighted based on flow. This is the concentration that is used to calculate loading to the receiving water body.

In Tables 4 and 5 the input concentration is the concentration that was measured by the overflow sampler. Again, this was the most problematic sample to collect because of the flow characteristics of our site and limitations of how our samplers were originally wired, plumbed, and programmed. To calculate the input TWMC we used the concentration measured by the overflow sampler, but the time measured by the filter. So this concentration is the time-weighted concentration flowing into the filter. The filtered TWMC used the concentration in the sample collected from the discharge of the filter and the time from that sampler. Finally, only the Centreville site had a ditch Isco and it rarely was triggered because the filter was so efficient at capturing flow. In fact only data from six and seven samples are presented for the ditch in the DRP and TP events, respectively (Tables 2 and 3). Like the TWMC, the FWMC input samples used the chemistry from the overflow sampler, but the flow data from the filter sampler. The efficiency of the filter is presented for both concentrations as the input concentration minus the filtered concentration and then divided by the input concentration. The amount of P bypassing the filters through the ditch or over the overflow cannot be considered when evaluating filter efficiency in regards to reducing P concentrations. TWMC and FWMC efficiency were very similar. The gypsum filters reduced the TWMC 26 – 46% and FWMC 28 – 47% on average over all events reported here. The slag cartridge filter TWMC efficiency ranged from 27 – 47% and FWMC efficiency ranged from 29 – 46%. Finally, the Centreville filters had an efficiency of 23 and 22% for TWMC and FWMC, respectively.

Table 4. Dissolved Reactive P: Filter effect on time and flow weighted concentrations

		Time Weighted Mean Concentration				**Flow Weighted Mean Concentration**			
Site	**Material**	**Input (mg/L)**	**Filtered (mg/L)**	**Ditch (mg/L)**	**TWMC Efficiency (%)**	**Input (mg/L)**	**Filtered (mg/L)**	**Ditch (mg/L)**	**FWMC Efficiency (%)**
Barclay	Gypsum	0.17	0.06		44	0.19	0.08		43
Marion	Gypsum	0.57	0.34		46	0.65	0.37		47
Westover	Gypsum	0.81	0.56		26	0.88	0.56		28
Barclay	Slag	0.20	0.14		35	0.28	0.15		41
Marion	Slag	0.96	0.64		27	0.97	0.62		29
Westover	Slag	0.45	0.27		47	0.44	0.26		46
Centreville	Slag	0.68	0.50	0.47	23	0.68	0.51	1.32	22

Table 5. Total Phosphorus: Filter effect on time and flow weighted concentrations

		Time Weighted Mean Concentration				Flow Weighted Mean Concentration			
Site	Material	Input (mg/L)	Filtered (mg/L)	Ditch (mg/L)	TWMC Efficiency (%)	Input (mg/L)	Filtered (mg/L)	Ditch (mg/L)	FWMC Efficiency (%)
Barclay	Gypsum	0.48	0.30		43	0.52	0.32		44
Marion	Gypsum	1.58	1.06		38	1.64	1.06		39
Westover	Gypsum	1.30	0.81		35	1.38	0.82		36
Barclay	Slag	0.57	0.32		45	0.62	0.36		45
Marion	Slag	1.49	0.99		29	1.51	0.97		33
Westover	Slag	0.88	0.55		29	0.90	0.57		28
Centreville	Slag	1.04	0.67	0.60	29	1.03	0.67	2.16	29

Another way to evaluate filter performance is by looking at how it affected P load going downstream. To calculate load one simply multiplies the TWMC times the total volume of flow. For both DRP and TP we calculated the cumulative ditch load (g), which is the total amount of P that would have gone downstream if no filter were installed at the sites. Cumulative P removed (g) is the amount P retained by the filter. Cumulative P bypass (g) is the amount of P that went over the overflow or down the ditch bypass (Centreville site only). Each of the previous measures are the total sum for all events presented. The average removal is simply the average across the events presented. System efficiency at load reduction is the cumulative P removed divided by the cumulative ditch load.

We can see that most of the filters did an adequate job at reducing load going downstream. Excluding the Marion site, the other filters had a system performance for DRP load reduction of 16 – 41% and 15 - 28% for total P. However, the events presented for DRP at the Marion site (Table 6) both the gypsum bed filter and slag cartridge filters seemed to do poorly, 13 and 9%, respectively. This is likely a combination of bias created by the types of events that produced useable results, the volume of flow at Marion in the events presented here, and the higher concentrations evident at that site in those events. Most of the events that were useable at Marion had a large amount of overflow and that site tended to have higher concentrations in those events. Generally, it looks like 20 – 40% load reduction can be achieved with an average removal of 15 – 30 g of P per storm event.

Caution should be exercised in extrapolating these results to other sites, filter designs, and PSMs. Even if the same PSM is utilized (e.g. slag or gypsum) there is a large amount of variation in them between sources. Furthermore, site characteristics (hydrology, chemistry) will have a very large impact on expected performance. Nonetheless, this large data set, covering many years, indicates that passive filter technology is an option to meet short term water quality goals.

Table 6. Dissolved Reactive P: Load reductions.

Site	Material	Cumulative Ditch Load (g)	Cumulative P removed (g)	Cumulative P Bypass (g)	System Efficiency (%)	Average Removal (g)
Barclay	Gypsum	1365	317	487	23%	21.2
Marion	Gypsum	3415	446	1573	13%	24.8
Westover	Gypsum	586	189	6	32%	37.8
Barclay	Slag	1344	549	248	41%	36.6
Marion	Slag	6212	570	2322	9%	51.8
Westover	Slag	2210	354	1259	16%	29.5
Centreville	Slag	205	44	37	21%	3.7

Table 7. Total Phosphorus: Load reductions.

Site	Material	Cumulative Ditch Load (g)	Cumulative P removed (g)	Cumulative P Bypass (g)	System Efficiency (%)	Average Removal (g)
Barclay	Gypsum	3830	1062	1006	28%	75.9
Marion	Gypsum	855	311	46	36%	16.4
Westover	Gypsum	7222	1059	4189	15%	132.4
Barclay	Slag	3399	842	680	25%	25.5
Marion	Slag	4609	507	1146	11%	29.8
Westover	Slag	7116	1732	4168	24%	133.2
Centreville	Slag	531	142	53	27%	12.9

Nutrients

Nitrate- Oakland View

	Before	**After**	**Before**	**After**		
Date Sampled	**NO3 (mg N per L)**	**NO3 (mg N per L)**	**NO3 Load (lbs/d)**	**NO3 Load (lbs/d)**	**Load Reduction**	**Concentration Reduction**
11/20	9.1	0.1				99.3%
11/26	9.1	0.1				99.3%
11/27	1.0	0.3				67.2%
12/3	0.0	0.0				
2/7	13.4	0.7	4.0	3.3	15.6%	94.9%
2/12	20.6	0.0	16.8	15.0	10.7%	99.9%
2/17	13.6	0.9	7.2	6.1	15.5%	93.3%
3/11	17.5	0.1	13.5	12.7	6.0%	99.4%
4/28	2.4	0.1	0.3	0.1	62.3%	95.9%
8/8	18.2	0.1	0.8	0.6	19.91%	99.5%
8/14	0.1	0.1				
8/20	16.2	0.1	0.6	0.3	47.40%	99.4%
Average	**10.1**	**0.2**	**6.2**	**5.5**	**25.4%**	**97.8%**

Nutrients

Nitrate- Mason’s Heritage

	Before	**After**	**Before**	**After**		
Date Sampled	**NO3 (mg N per L)**	**NO3 (mg N per L)**	**NO3 Load (lbs/d)**	**NO3 Load (lbs/d)**	**Load Reduction**	**Concentration Reduction**
3/11/2014	6.4	0.1	0.62	0.55	11.6%	98.4%
4/28/2014	6.2	0.1	0.80	0.37	53.5%	98.4%
8/8/2014	28.6	0.1	0.00	0.00	99.6%	99.6%
8/14/2014	9.0	0.1	0.49	0.01	98.9%	98.9%
8/20/2014	7.8	0.1	0.02	0.00	98.7%	98.7%
Average	**11.6**	**0.1**	**0.39**	**0.19**	**72.5%**	**98.8%**

Innovative Technology (BMPs) for the Remediation of Groundwater Nutrients

John Rhoderick
Maryland Department of Agriculture
July 15, 2014
MASCD

Passive Phosphorus Removal System

University of Maryland-Department of Environmental Science & Technology

Gene Hahn, Faculty Research Associate
Clint Gill, Graduate Research Assistant

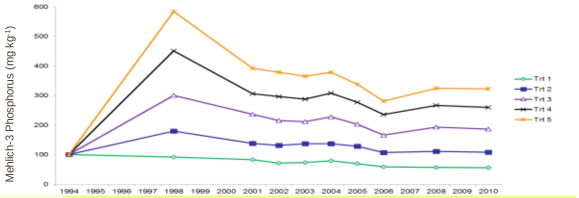
Passive Phosphorus Removal System

- Background and Benefits
  - P transport in ditches
  - Dissolved P loss
  - Use of P sorbing materials (PSMs)
- Designing P Filters
  - Basic structure design
  - Material selection
  - Design Guidance

P Filter Background and Benefits

Need for P Filters

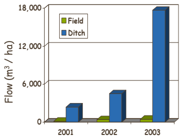
- High soil P concentrations contribute to long-term, slow P leak
- This is referred to as a "legacy" P issue



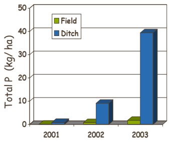
Ditch P Transport

- Legacy P releases dissolved P over many years
- There are no BMP's designed to control dissolved P transport
  - dissolved P is most dangerous to aquatic ecosystems
- Ditches provide direct transport path for dissolved P
- Majority of the P in ditches gets there through shallow subsurface flow
- Ditches provide ideal collection point for treatment

Field runoff vs. total ditch flow



Surface runoff from the field only accounted for 3-9% of annual ditch flow.



Surface runoff from the field only accounted for 5-22% of annual ditch P export

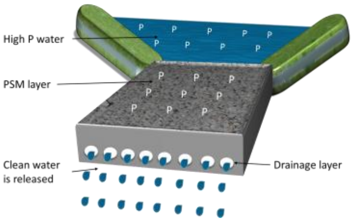
Courtesy: P. Kleinman

Ditch Filter History

- High P loading from Delmarva ditches
- No effective BMP's to reduce loading
- Concept started as land application of P sorbing materials (like gypsum).
- Became apparent that it was more cost-effective to place PSM's in a confined structure
- Have utilized numerous PSM's in the lab and field

Basic Design

Basic Design



Basic Ditch Filter

- Structure filled with P sorbing materials (PSMs)
  - Any material that chemically sorbs P through precipitation or fixation reactions
  - Fe, Mg, Al, or Ca containing materials, or combination of these elements
  - Typically focused on industrial residuals
- Alter hydraulic head in ditch to force flow through filter material
- Confine material in some sort of structure

Confined Bed

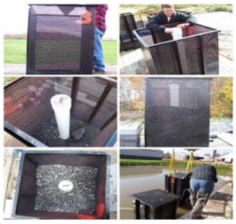
- Good for large filter
- Ideal for drainage swales that require high peak flow and little water backing
  - Achieved through shallow PSM with large surface area

Tile Drain

- Similar to bed, but without confinement
- Allows large amount of material to be used
- Use flow control to build head
- Low cost
- Probably best option, but there seems to bias with landowners

Box Filter

- Easily switch out material
- Modular design – integrates with flow control
  - Agri-Drain
- Small ditches or pond overflow
- Drawback: Small amount of material

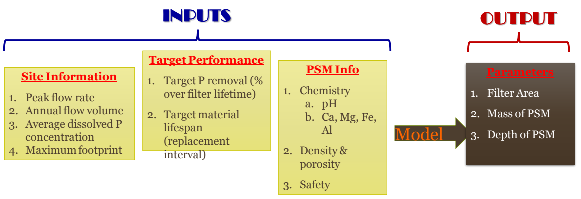


Performance

- Slag confined bed: 43% removal
- Gypsum tile drain: initial (limited) data indicates 67% removal
- Box style filter approximately 20% load reduction
  - Approximately 50% when flow is good
  - Reduced FWMC of TP 25%
  - Reduced FWMC of DRP 29%
- To date model predicts P removal accurately
- Need robust field data to validate model and to predict overflow versus flow through
  - 4 ditches with tile filters
  - 3 ditches with cartridge filters
  - 2 ditches (1 ag and 1 golf course) with confined bed filters
  - 1 retention pond with box filter
- Developing complete guidance for government and private stakeholders

Design Guidance

Design Model



INPUTS

Site Information

1. Peak flow rate
2. Annual flow volume
3. Average dissolved P concentration
4. Maximum footprint

Target Performance

1. Target P removal (% over filter lifetime)
2. Target material lifespan (replacement interval)

PSM Info

1. Chemistry
   a. pH
   b. Ca, Mg, Fe, Al
2. Density & porosity
3. Safety

Model

OUTPUT

Parameters

1. Filter Area
2. Mass of PSM
3. Depth of PSM

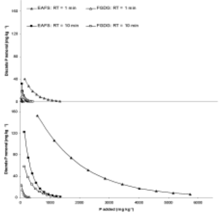
Material Selection

- Material selection process
  - ***Material availability***
  - ***Cost/transportation***
  - Potential contaminants
  - P sorption characteristics
  - Physical properties
- Simple analysis of PSM provides
  - Total P removal ability (pounds of P removed per pound of PSM)
  - Lifespan of filter material
  - Flow rate through material
- Dozens of materials tested
  - Gypsum
  - Steel slag
  - Acid mine drainage residuals
  - Fly ash
  - Etc. etc. etc.

Structure Selection

- Structure selection
  - P loads
  - P concentrations
  - Flow rates
  - Peak flow versus base flow
  - Slope
- Land owner preference
  - Bed filter probably provides best cost:benefit ratio, but the filter box seems to be most popular
- Type of material used
- Area available for filter
- Fall available between inflow and outflow

Design Model



- Currently developing a user friendly model based on laboratory characterization and flow-through P sorption experiments.
  - Use for designing P removal structures for target loads
  - Use to predict the life of a constructed structure
  - Users need only a simple characterization of the materials to plug into model

Additional Support

- Design model will be available online by September 2014
  - www.p-structure.blogspot.com
  - Will provide interactive design guidance based on user inputs
- NRCS Standard will be completed by mid-Summer 2014

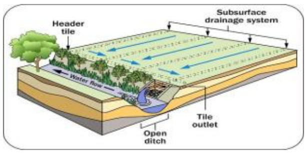
Woodchip Bioreactor

Treating artificial agricultural drainage

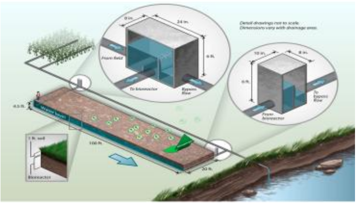
Drew Koslow, Choptank Riverkeeper
Timothy Rosen, Watershed Scientist

Ditching and tile drainage is effective, but….

- Concentrates nitrate
- Reduces processing
  - Loss of ecosystem services
- Increases transport



Missouri Land Improvement Contractors Association, Ontario Ministry of Agriculture and Food



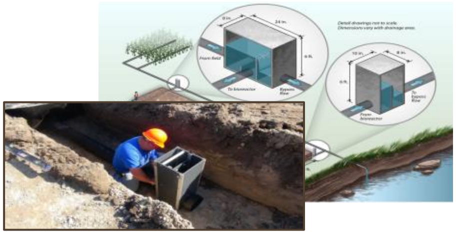
Components

Woodchip Trench

Components

Diversion Structure

Components

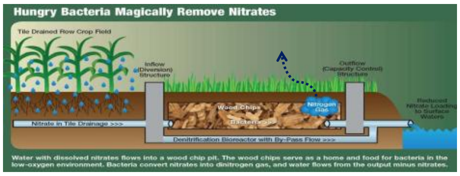


Capacity Control Structure

Instillation

Woodchip Bioreactor Basics

Nitrate Removal



Hungry Bacteria Magically Remove Nitrates

Water with dissolved nitrates flows into a wood chip pit. The wood chips serve as a home and food for bacteria in the low-oxygen environment. Bacteria convert nitrates into dinitrogen gas, and water flows from the output minus nitrates.

Denitrification Reaction Sequence

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Effectiveness

- 23% to 98% reduction in nitrate load
  - Temperature
  - Retention Time
- Lifespan of greater than 15 years
- Low Maintenance
- Cost Effective
  - Less than $3.50 per kg N removed
- Edge of field

Oakland View Farms

Mason's Heritage

Data Collection

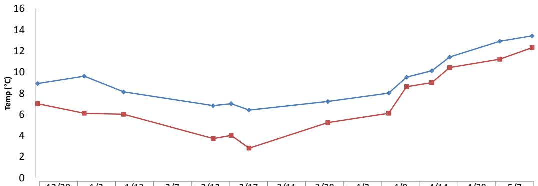
- Continuous
  - Water Height- Pressure Loggers (30 min intervals)
- Weekly
  - Discharge/Water Height (Chun and Cooke, 2008)
  - Basic Water Quality
    - DO (mg/l), DO %, pH, Specific Conductance (us/cm), Temperature
- Monthly
  - Nutrients
    - Nitrate, Ammonium, Total Nitrogen, Ortho-Phosphate, Total Phosphorus

Water Quality

- Temperature
- Dissolved Oxygen Saturation
- Dissolved Oxygen Concentration
- Specific Conductance
- pH

General Water Quality

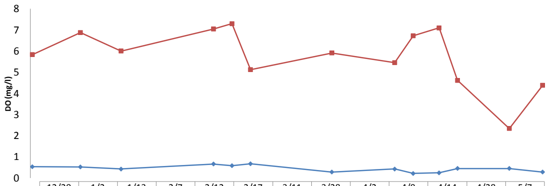
Temperature in Celsius



	12/20	1/2	1/13	2/7	2/12	2/17	3/11	3/28	4/2	4/9	4/14	4/28	5/7
Box 2	8.9	9.6	8.1	6.8	7	6.4	7.2	8	9.5	10.1	11.4	12.9	13.4
Box 1	7	6.1	6	3.7	4	2.8	5.2	6.1	8.6	9	10.4	11.2	12.3

General Water Quality

Dissolved Oxygen Concentration (mg/l)



	12/20	1/2	1/13	2/7	2/12	2/17	3/11	3/28	4/2	4/9	4/14	4/28	5/7
Box 2	0.53	0.52	0.42	0.66	0.58	0.67	0.28	0.42	0.21	0.24	0.45	0.45	0.28
Box 1	5.83	6.87	6	7.04	7.29	5.12	5.91	5.45	6.72	7.09	4.61	2.34	4.38

Nutrients

- Total Nitrogen
- Ammonium
- Nitrate
- Total Phosphorus
- Ortho-phosphate

Nutrients

Nitrate (mg/l)

	Box 1	Box 2	Box 1	Box 2		
Date	NO3-N (mg/l)	NO3-N (mg/l)	NO3 Load (lbs/d)	NO3 Load (lbs/d)	Load Reduction	Concentration Reduction
11/20	9.14	0.07				99.28%
11/26	9.13	0.07				99.28%
11/27	0.97	0.32				67.18%
12/3	0.01	0.03	0.000	0.000	-97.86%	-97.86%
2/7	13.41	0.68	3.307	0.033	15.60%	94.92%
2/12	20.60	0.03	14.977	0.003	10.73%	99.85%
2/17	13.64	0.91	5.973	0.080	15.55%	93.33%
3/11	17.50	0.10	12.723	0.005	6.01%	99.43%
4/28	2.41	0.10	0.114	0.009	62.29%	95.85%
AVERAGE	**9.65**	**0.26**	**6.18**	**0.02**	**22.0%**	**94.0%**

Nutrients

Total Phosphorus (mg/l)

	Box 1	Box 2	Box 1	Box 2		
Date	TP (mg/l)	TP (mg/l)	TP Load (lbs/d)	TP Load (lbs/d)	Load Reduction	Concentration Reduction
11/20	1.58	112.00				-6988.61%
11/27	2.63	40.10				-1424.71%
12/3	32.40	22.40	0.000	0.013	30.86%	30.86%
2/12	0.48	2.31	0.352	0.202	-40.54%	-377.27%
4/28	2.24	2.49	0.106	0.218	-7.25%	-11.16%
AVERAGE	**7.87**	**35.86**	**0.15**	**0.14**	**-6.0%**	**-1754%**

Nutrients

Orthophosphate (mg/l)

	Box 1	Box 2	Box 1	Box 2		
Date	PO4 (mg/l)	PO4 (mg/l)	PO4 Load (lbs/d)	PO4 Load (lbs/d)	Reduction	Concentration Reduction
11/20	1.10	115.00				-10354.55%
11/27	2.55	40.40				-1484.31%
12/3	20.30	21.00	0.000	0.012	-3.45%	-3.45%
2/12	0.37	0.46	0.058	0.040	-2.73%	-25.41%
3/11	0.28	1.48	0.000	0.069	-25.69%	-424.82%
4/28	1.80	1.40	0.070	0.123	14.44%	22.22%
AVERAGE	**4.40**	**29.96**	**0.03**	**0.06**	**-4.0%**	**-2045%**

How well are they working?

- Highly efficient at reducing nitrate
  - 94%-98% efficiency (concentration)
- Load reduction low
  - Amount of water diverted into bioreactor
  - 22% load reduction
- Ammonium treatment variable
  - Depends on influent concentration
  - Source during periods of low influent concentration
- Bioreactor is leaching phosphorus
  - High at onset as bound phosphorus is freed (anaerobic conditions)
  - Will continue at some level

Questions?

doi:10.2489/jswc.69.2.51A

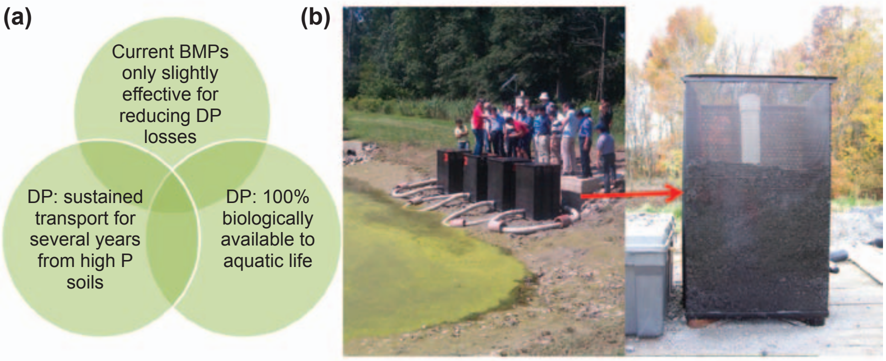
Phosphorus removal structures: A management option for legacy phosphorus

Chad Penn, Joshua McGrath, James Bowen, and Stuart Wilson

Phosphorus (P) loading is considered a primary contributor to surface water eutrophication (Daroub et al. 2009). Phosphorus moves from soil to surface water as dissolved or particulate P. Particulate P is typically not 100% bioavailable, having to enter solution (through dissolution or desorption) before being available for uptake. On the other hand, transported dissolved P is immediately 100% bioavailable to aquatic biota. In addition, dissolved P can be released over very long periods of time from high P source areas on the landscape even when practices are used to control particulate losses. Therefore, dissolved P is generally considered more problematic for water quality, both due to its immediate impact on the ecosystem and difficulties in controlling its movement.

Figure 1

(a) Justification for the cost and construction of a dissolved phosphorus (DP) removal structure best management practice (BMP), and (b) example of a P removal structure in Maryland designed to treat runoff water from a poultry farm as the water drains from a retention pond into a ditch through the filtration material (steel slag).



The term "legacy P" is often used to refer to accumulated P that can serve as a long-term source of P to surface waters. Terrestrial P legacies result from past management decisions that lead to high soil P concentrations (Sharpley et al. 2013). Soil P dynamics are such that once soil P concentrations are elevated it can take many years for them to decrease below levels of environmental concern. These high-testing soils are able to release dissolved P for many years, even after all P applications have ceased. Most examples of the slow recovery of terrestrial legacy P is for agricultural settings; however, it is important to note that legacy P can be found anywhere soil P has accumulated, including horticultural, residential, and golf course settings. For example, Sharpley et al. (2009) showed that soil Mehlich-3 concentrations only decreased 4.6 mg kg^{-1} y^{-1} (9.2 lb ac^{-1} yr^{-1}) after eliminating P applications while growing continuous corn (*Zea mays* L.). Multiple examples of long-term soil P draw down are provided by Sharpley et al. (2013). As long as soils remain high in soil P concentrations, they can act a source of P to surface waters if there is hydraulic connectivity.

Although current best management practices (BMPs) are effective at reducing the transport of particulate P or direct transfer of applied P, they tend to be mostly ineffective for dissolved P loss from the terrestrial legacy P pools. This is due to the fact that most BMPs are focused on reducing erosion or placement of fertilizer P below the surface. For example, vegetated buffer strips are a viable BMP for trapping sediment (and therefore particulate P), but those accumulated sediments can potentially increase dissolved P release (Deng et al. 2011). Penn et al. (2012) monitored a 61 ha (150 ac) watershed dominated by a residential neighborhood and found that that there was little to no particulate P, while dissolved P concentrations ranged from 0.3 to 1.5 mg L^{-1} (0.3 to 1.5 ppm). Similarly, if subsurface flow to tile drainage or ditches is the dominant hydrologic process that transports P, then conventional BMPs will do little to reduce dissolved P losses in the short term (Vadas et al. 2007). Other BMPs, such as manure transport programs, P draw down by crops, and nutrient management, can reduce or prevent soil P from increasing, but as previously mentioned, such BMPs require appreciable time for soil P concentrations to decrease. During that time period, significant amounts of dissolved P can be lost.

The temporal disconnect between water quality goals and the length of time that legacy terrestrial P remains a viable source, the difficulty in controlling dissolved P loss from soil, and the immediate bioavailability of dissolved P justify investment in a new BMP for reducing dissolved P transport to surface waters (figure 1). The P removal structure is a new BMP that can decrease dissolved P loading in the short term until terrestrial legacy P concentrations decrease below levels of environmental concern. Phosphorus removal structures contain P sorbing materials (PSMs) and can be placed in a location to intercept runoff or subsurface drainage with high dissolved P concentrations. As high P water flows through the PSMs, dissolved P is sorbed onto the materials (typically by ligand exchange or precipitation mechanisms), allowing low P water to continue to the outlet. An example of a P removal structure is shown in figure 1. While P removal structures vary in form and appearance, they include three common elements: (1) the use of a filter material that has a high affinity for P, (2) containment of that material,

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and (3) the ability to remove that material and replace it after it becomes saturated with P (i.e., when it no longer removes P). Researchers throughout the world have examined various materials that may serve as a PSM in this fashion (Claveau-Mallet et al. 2011; Klimeski et al. 2012; Vohla et al. 2011; Lyngsie et al. 2013). While the operational theory of P removal structures is simple, proper design of a structure for specific site conditions and a given lifetime is more involved. Here we provide a case study example of design and construction of a P removal structure for a poultry farm located in eastern Oklahoma.

ASSESSMENT OF SITE LOCATION

There are three site requirements for construction of a P removal structure:

- Elevated dissolved P concentrations in runoff. For most PSMs, it is generally not worthwhile to construct a P removal structure unless the dissolved P concentrations are greater than 0.2 mg L^{-1} (0.2 ppm). Most PSMs are unable to sorb appreciable amounts of P from low concentration water for prolonged periods due to the equilibrium law (Le Chatlier's principle), although there are some PSMs capable of this.
- Hydraulic connectivity. The runoff or subsurface drainage produced at the site must have the potential to reach a surface water body.
- Flow convergence. The potential to channel the runoff water into a single point for treatment is necessary to build an effective filter. This is inherent to a site if there is a drainage ditch, culvert, subsurface drainage outlet, or similar convergence point. Otherwise, the flow must be manipulated so that it will converge into a single point for treatment.

The site used in this case study was a 3.6 ha (9 ac) subwatershed with several poultry houses (figure 2). Poultry litter spillage occurred near the entrance to the houses, and the site was hydrologically connected to a nearby creek, located within the Illinois River Watershed. An elevation survey and visual observations during runoff events were used to determine the exact location of the structure (figure 2). Starting in September of 2012, grab samples of runoff were taken and analyzed for dissolved P, which consistently showed dissolved P concentrations ranging from 1 to 2 mg L^{-1} (1 to 2 ppm). Therefore, all three site requirements were met for this particular location regarding construction of a P removal structure.

SITE DATA COLLECTION REQUIRED FOR STRUCTURE DESIGN

In addition to estimates of runoff dissolved P concentrations, it was necessary to estimate the peak flow rate, average annual flow volumes and dissolved P load, and hydraulic head. The average annual flow volume and peak flow rate were calculated using site information required for estimating the Natural Resources Conservation Service curve number (CN). This included soil type (used to determine hydrologic soil group), ground cover, greatest length of flow, and slope. Each parameter, except for soil type and flow length, was determined via site visit. The CN was 78 since the cover was mostly pasture. The curve number was used in conjunction with precipitation depth for the design storm in order to estimate peak runoff flow rate. In our case, the structure was designed for a 2-year, 24-hour storm, which produces about 10 cm (4 in) of rainfall as estimated by standard USDA Natural Resources Conservation Service rainfall tables.

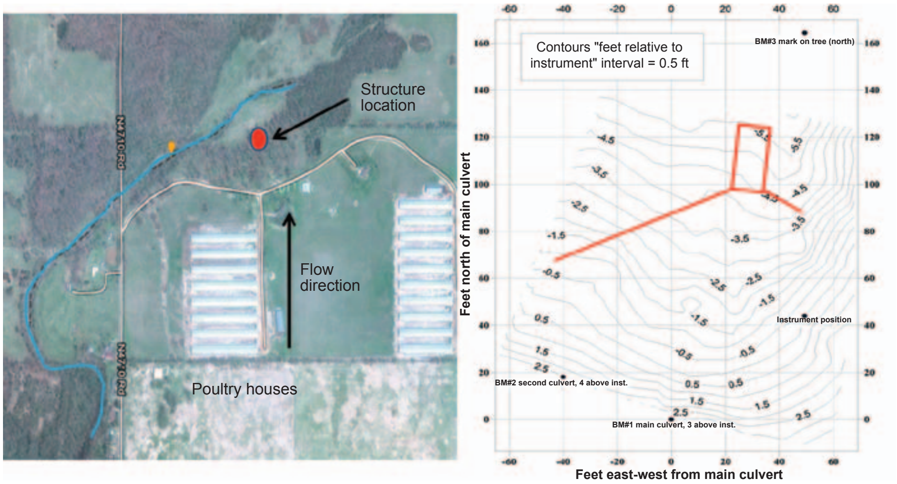
The CN method resulted in an estimated runoff depth of 5 cm (2 in) for this watershed (a 2-year, 24-hour storm). Runoff depth was then used to calculate peak flow rate by the Soil-Cover-Complex method and time of concentration (USDA SCS 1986). The time of concentration was calculated using the CN at 24 minutes, and the greatest length of flow was determined to be 331 m (1,059 ft). Therefore, the predicted peak discharge was calculated as 1.5 $m^3\ min^{-1}\ ha \bullet cm^{-1}$ ($0.9\ ft^3\ s^{-1}\ ac \bullet in^{-1}$). Based on the size of the watershed, this was equal to about 27 $m^3\ min^{-1}$ ($16\ ft^3\ s^{-1}$). Therefore, our goal was to design a structure that could handle at least this flow rate in order to treat all of the runoff produced from a 2-year, 24-hour storm.

Annual flow volume is necessary in order to estimate annual dissolved P load. This was achieved by the runoff coefficient method, which was simply based on cover, watershed area, and average annual rainfall depth (USDA SCS 1986). For an average annual rainfall depth of 112 cm (44 in), the average annual runoff volume at the site was determined to be 30 cm y^{-1} (12 in yr^{-1}) or 1.1 ha • m (9 ac • ft). Using the highest observed dissolved P concentrations for this site (2 mg L^{-1} [2 ppm]) and average annual runoff volume, the resulting average annual P load was estimated at 22 kg y^{-1} (48.5 lb yr^{-1}).

Hydraulic head is necessary to achieve flow through the P removal structure. Hydraulic head is the elevation difference between the entry point of flow into the structure and the elevation of the water

Figure 2

(a) Aerial view of the site described in this paper in which the phosphorus (P) removal structure was constructed, and (b) contour map showing (in red) the structure location and berms used to converge water into the structure.



body receiving the discharged water. While this may seem simple, hydraulic head often has to be manipulated in extremely flat landscapes such as those common to coastal plain regions. The site used for this case study had ample topographic relief necessary to generate the required hydraulic head. In order to estimate flow rates through the structure, hydraulic head was estimated by the elevation survey (figure 2).

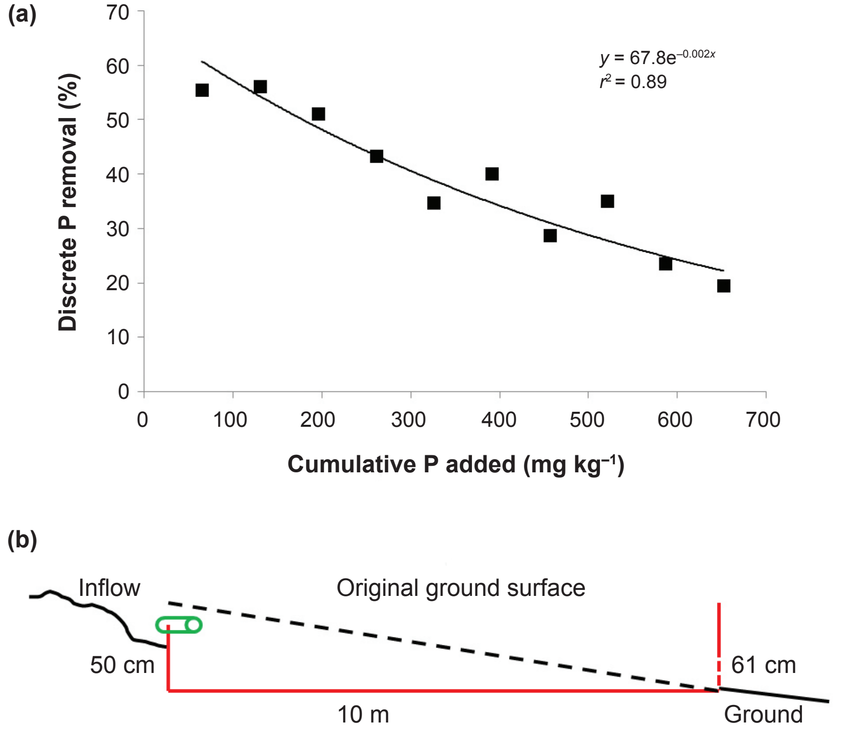
SIZING THE PHOSPHORUS REMOVAL STRUCTURE

Required Mass of Phosphorus Sorbing Materials. The necessary mass of PSM was determined from annual P load, typical dissolved P concentration in runoff (or drainage) water to be treated, P removal goal (i.e., the % of the annual P load that is desired to be removed), and characteristics of the locally available PSM. An annual P load of 22 kg (48.5 lb) was calculated in the previous section based on the highest observed dissolved P concentration of 2 mg L^{-1} (2 ppm). The structure was designed to remove ~50% of the load in year one. Proper design requires development of a design curve for the PSM utilized in the structure. A design curve is simply a quantitative description of the relationship between dissolved P loading to the PSM and the percentage of discrete P removal (figure 3). This must be determined in a flow-through setting. A batch P sorption experiment will not suffice. A batch sorption experiment in this context is only useful as an index to compare different PSMs, not to quantify how much P they would remove from a flowing solution. Penn and McGrath (2011) and Stoner et al. (2012) provide examples and discussion of flow-through versus batch P sorption experiments and their utility in determining discrete P removal.

A design curve is specific with regard to the retention time (i.e., contact time) and the inflow P concentration that is moving through the PSM. The design curve in figure 3 is specific to an inflow P concentration of 2 mg L^{-1} (2 ppm) and a retention time of 30 seconds. In other words, it takes 30 seconds for the solution to pass through the PSM. The P sorption is initially very high, but with further P loading, the PSM is not able to sorb as much P as it did previously. The shape of the curve varies between PSMs, retention times, and inflow P concentrations. A detailed discussion of design curves is provided by Stoner et al. (2012).

Figure 3

(a) Example of a phosphorus (P) removal curve as determined by a flow-through P sorption experiment conducted on a P sorbing material, and (b) side cutaway diagram of the P removal structure constructed on a poultry farm.



The design curve equation can be solved in the following multiple ways to provide the desired output:

1. Estimate the lifetime of the structure if a given mass of a specific PSM is to be placed in the structure. In this case, "lifetime" is defined as the amount of time until the P removal structure is no longer able to sorb P that flows into it.
2. Upon integration of the design curve, estimate how much P will be removed by the structure during that lifetime.
3. Upon integration of the design curve, estimate how much of the PSM (i.e., mass) will be necessary to remove a desired amount of P under the condition of the design curve.

An example of how to use design curve equations for proper design is found in Penn et al. (2012) and Stoner et al. (2012). At this particular site, we used the design curve to determine the appropriate amount of PSM to achieve the desired P removal (option 3 above). In designing the structure, we considered several locally available PSMs. An annual P load of 22 kg (48.5 lbs), inflow P concentration of 2 mg L^{-1} (2 ppm), and the design curve for each potential material were used to estimate the mass required of each material (table 1). Other PSMs may be available in different regions.

Because of the difficulty associated with conducting a flow-through P sorption experiment, a model was developed for predicting the equation of a design curve for a specific PSM under a given retention time, inflow P concentration, and selected PSM characteristics (chemical and physical). This model was developed for the following reasons:

- Conducting a flow-through experiment for every single individual PSM sample and every possible flow condition (i.e. inflow P concentration and retention time) is extremely time consuming and expensive.

Table 1

Required mass, area, and depth of several phosphorus sorbing materials (PSMs) for removing the indicated percentage of the year 1 P load (22 kg) and treat the peak flow rate for a 2-year, 24-hour storm on a poultry farm located in eastern Oklahoma. Calculations were made based on respective design curves (figure 3) and material and site characteristics. Lifetime indicates the number of years in which the theoretical structure would be able to remove P at this site under current conditions.

PSM	Mass (Mg)	Cumulative first year removal (%)	Lifetime (y)	Hydraulic conductivity (cm s^{-1})	Area (m^2)	PSM depth (cm)
WTR	7	37	21	0.01	286	2.3
AMDR	4	50	7	0.009	225	2.2
Fly ash*	3 (plus 95% sand)	50	3.6	0.03 (mixed with 95% sand)	406	13
>6.35 cm slag†	171	21	1.4	1.0	190	50
Treated >6.35 cm slag‡	36	45	3.5	1.0	40	50

Notes: WTR = Water treatment residuals from the AB-Jewel treatment plant located in Tulsa, Oklahoma. AMDR = acid mine drainage residuals from southeast Oklahoma.

* Fly ash from Muskogee, Oklahoma, mixed with 95% sand (60 Mg sand).

† Electric arc furnace steel slag from Ft. Smith, Arkansas (Tube City IMS).

‡ Steel slag treated for increased P sorption.

- There is variation in P sorption behavior between different PSMs and among the same type of PSMs that come from different sources and produced at different times.
- It is easier and less expensive to measure certain chemical and physical characteristics of PSMs and then predict a design curve than it is to conduct many flow-through P sorption experiments.

Data from over 1,000 flow-through experiments conducted on different PSMs under various conditions were used to develop a model to predict the equation for a design curve unique to any unknown material under given flow conditions. It was determined that among practical retention times for treating runoff and subsurface drainage (from seconds up to 20 minutes), retention time usually has little impact on P removal (Stoner et al. 2012). This is true for materials that dominantly remove P via fast kinetics by aluminum (Al) and iron (Fe) sorption (ligand exchange) and for calcium (Ca)-rich materials that have relatively high pH. For example, flue gas gypsum is an example of a Ca-rich material that is not highly buffered with regard to pH, and therefore the retention time does have a dramatic impact on P removal in a flow-through setting. Gypsum is one of the few materials that display this behavior.

While the details of this model for predicting the design curve will not be discussed here, the design curve is at the heart of the current program being developed, which essentially helps one to design a site-specific P removal structure in the same manner in which this paper describes. The design program can be found at http://soilchemistry.okstate.edu/phosphorus-removal-structures-1/design-a-structure.

Orientation of the Phosphorus Sorbing Materials. This part of the design is flexible and somewhat unique to the site. While PSMs can be oriented in different ways, the water must flow through the material in an amount of time (i.e., retention time) that is sufficiently short enough to treat most of the water. For example, one may design the water flow from the bottom of the sorption bed upward, laterally, or from the top downward. An advantage to flow design from the top downward is that it is free draining and avoids saturation with water during nonflow events, avoiding dissolution of P sorbed onto Fe-rich PSMs. Regardless of the water flow direction through the material, flow rate is dependent on hydraulic head, thickness of the PSM layer, and hydraulic conductivity of the PSM. In any of those situations, the standard Darcy Equation can be used to design the structure after you have determined the required mass of PSM, peak design flow rate, and site limitations such as area and slope (i.e., hydraulic head).

Often, the most limiting factor in structure design is hydraulic conductivity of the PSM. The dichotomy is that PSMs which have the best P sorption ability tend to have poor hydraulic conductivity, and PSMs with large hydraulic conductivity have low P sorption ability. Using a material with a low hydraulic conductivity translates to designing a structure that has a larger area, since thickness of the sorption bed must be lower in order to achieve a reasonable flow rate.

Determining the layout of the structure for a particular PSM is a function of the following parameters:

- required mass of PSM,
- hydraulic conductivity of PSM,
- porosity of PSM,
- bulk density of PSM,
- target peak flow rate for structure,
- maximum area for structure at site, and
- maximum hydraulic head at site.

Table 1 shows potential layouts for several PSMs local to the site. Each scenario can handle a 2-year, 24-hour storm event (27 m^3 min^{-1} [16 ft^3 s^{-1}]).

Table 1 clearly shows that PSMs with lower conductivity (water treatment residuals, acid mine drainage residuals, and fly ash) tend to have a greater P sorption ability and therefore require relatively small amounts of PSM and large area. On the other hand, use of the sieved steel slag also requires a large amount of area, not because of limited hydraulic conductivity, but because of the physical constraint of housing a large mass of material. We utilized treated slag since it was a compromise between the low hydraulic conductivity, high P sorption materials and the high hydraulic conductivity, low P sorption materials, such as the sieved steel slag. The suitable layout for each PSM in table 1 was estimated using the software developed for designing P removal structures.

SITE PREPARATION FOR CONSTRUCTION OF THE STRUCTURE

Since there was no drainage ditch or subsurface drainage outlet at the site, it was necessary to manipulate flow to converge at a single point. Flow was only somewhat concentrated along the gravel road in front of the poultry houses and on the east-west gravel road. Runoff from the field flowed to the gravel road, which acted as a natural drainage swale. Earthen berms were constructed to direct flow to this swale and then the P removal structure (figure 2). Berms were seeded with tall fescue (*Festuca arundinacea* Schreb.) and covered with an erosion control mat.

The foundation for the structure (figure 2) was excavated, and the material was used for berm construction. We elected to use treated slag screened to greater than 6.35 cm (0.25 in). Using the design curve equation, we found that 36 Mg (40 tn) of slag were required. In order to meet desired flow rate of 27 m^3 min^{-1} (16 ft^3 s^{-1}) the material was arranged to 10 m (33 ft) long by 4 m (13 ft) wide by 0.52 m (20 in) deep. The foundation was made by cutting into the ground on the upslope side, producing a 10 m (33 ft) long flat surface that was 0.52 m (20 in) deep on the upslope side (figure 3).

Hydraulic head is critical to force water through the PSMs, which is a function of the slope of the site. As mentioned previously, some sites have very low topographic relief, such as ditch drained fields in coastal plain regions, and hydraulic head must be manipulated. A proven solution to this problem is incorporating flow control structures into filter design to increase hydraulic head, thereby increasing flow rate through the PSM and maintaining a more buffered and constant flow rate.

CONSTRUCTION AND INSTALLATION OF STRUCTURE

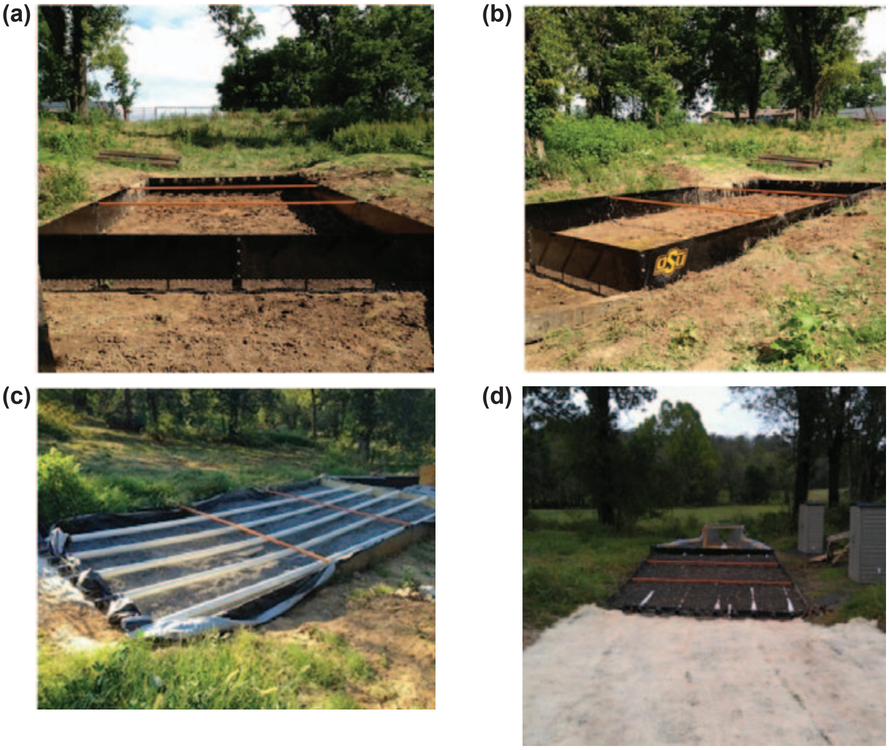
For this site, a simple bed-style structure where water flows through the PSM from the top into subsurface drainage pipes was utilized. The frame was 6.35 mm (0.25 in) carbon steel, and the structure was constructed in modular form for hand assembly in the field.

Figure 4a shows the structure from the perspective of the downhill (drainage) side looking up toward the uphill (inflow) side. Runoff enters the structure on the uphill side through 10 cm (4 in) diameter pipes connected to perforated pipes located just below the surface for the purpose of distributing runoff throughout the entire bed of PSMs (figures 4b and 4c). Note the expanded metal on the drainage side. The deep perforated pipes will drain treated water to the expanded metal, where the water can then exit the structure. The discharge side of the structure was designed to be removed when the PSMs become saturated with P, providing access for a skid-steer to drive in and remove the material. The completed structure is shown in figure 4d.

The discharge side is fitted with an H flume for monitoring flow rate. Two automatic samplers were installed to monitor inflow and outflow P concentrations and flow rates. Testing P concentrations alone is not sufficient to completely assess performance of a P removal structure. By also recording flow rates in real time, the cumulative volume of water passing through the structure can be calculated along with the total mass or load of P removed by the structure. Ultimately, load reductions are what are required to benefit water quality. An illustration of this principle is described in Sharpley et al. (2013). Briefly, the authors showed that the portion of the watershed that delivered 72% of the P load to the stream had the lowest runoff P concentration, while the area that had the highest runoff P concentration delivered only about 1% of the load. This also illustrates why the US Environmental Protection Agency regulates P loss through total maximum daily loads.

Figure 4

The frame of the phosphorus (P) removal structure from the perspective of looking from the (a) downhill (drainage) side toward the uphill (inflow) side, (b) side view, (c) structure partly filled with slag showing the attached inflow perforated pipes, and (d) the complete structure from the perspective of looking from the inflow toward the drainage side. Note the H flume for monitoring flow rates.



The site described in this paper is currently being used not only as a research site, but also to demonstrate this new tool for controlling dissolved P losses from terrestrial legacy P sources to stakeholders, including state and federal agencies, nonprofit organizations, producers, and the general public. There are also similar research and demonstration sites located in ditch-drained fields and poultry farms on the Delmarva Peninsula (Maryland, United States). Demonstrations and field-days will be conducted at these sites for several years.

WIDESPREAD IMPLEMENTATION AND FUTURE RESEARCH

Widespread adoption of P removal structures in the United States will depend on economic viability. For this technology to be economically viable, the value of clean water (or conversely the cost of nonpoint P losses) has to be internalized to the end user. To date, even with an increasingly aggressive regulatory approach, the reality is that the cost of nonpoint pollution is external to the market. It may require government investment (e.g., cost-share programs) to initiate widespread implementation of P removal structures. This type of early cost support is typically viewed as a mechanism to offset early adoption risk. There are also entities, such as golf courses, municipalities, or home owners associations, that may be willing to voluntarily bear the cost of P removal structure construction because they place value on reducing P loading, either as a matter of public image or for the intrinsic value of clean water. On the other hand, many agricultural producers are less likely to adsorb the cost of P removal structure construction because of the complete absence of economic incentive and because profit margins in agriculture typically do not support investment in the technology purely for intrinsic value.

Beyond initial support from a cost-share program, nutrient trading coupled with regulatory limits could eventually provide the economic incentive for construction of structures. For example, the Chesapeake Bay watershed is under a total maximum daily load limit imposed by the US Environmental Protection Agency, and most Bay states have initiated trading programs. These programs allow nutrient point sources to purchase credits from nonpoint sources to allow for discharge beyond their cap. The nonpoint sources install BMP's to remove the credited amount of nutrients, plus some efficiency factor to account for uncertainty associated with quantifying nutrient reduction through most nonpoint BMPs. For example, a point source might pay for 10-fold more P credits than they will actually be able to discharge.

Phosphorus filters provide clear advantages over other types of BMPs in such cap and trade systems. First, they provide more certain and verifiable nutrient load reductions than have been typically associated with BMPs in the past. Nutrient trading is often confounded by the simultaneous implementation of other BMPs that also contribute to nutrient loading reductions, making it difficult to determine whether nutrient loadings were reduced by nutrient trading or by other factors. The concept of additionality has emerged to describe the additional quantity of nutrient reduction which results from, and only from, the active presence of nutrient trading. It is now commonly accepted that additionality should be established before projects are implemented. A desirable feature of P removal structures is that additionality is readily established due to their operational features and location. Measurements can be taken at the outlet of the P removal structure to quantify the change in P levels relative to upstream, unfiltered water that might be influenced by other upstream BMPs. It is also expected that the P filtration structure, by providing a transparent accounting of the nutrient reduction, will reduce the risk and uncertainty often associated with the verification of nutrient trading, enabling markets to operate more efficiently.

Future research should focus on examining the economic potential and cost of widespread implementation. While the structure highlighted in this paper utilized a frame made of steel, this is not always necessary and costs could be greatly reduced by using earthen berms or other material. In addition, an assessment of P loading hot spots would permit one to target critical areas in order to maximize efficiency and minimize costs, i.e. "precision conservation" (Delgado et al. 2011). Last, there is also a need to further examine beneficial reuse of the spent PSMs.

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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.

Characteristics of the PSM need to be known prior to design. Characterize the PSM by pH, and the amount of Ca, Mg, Fe and Al. As appropriate, characterize the density and proposed gradation of the material.

For a desired lifespan* (typically years, use 1 year as a minimum**), design the system to achieve a realistic desired reduction* (%) in the dissolved phosphorous load, where a load "reduction" is defined as the percent of dissolved phosphorus mass that is retained in the structure relative to pre-treated water, over a desired period of time:

$$Load\ Reduction\ (\%) = \frac{(pretreated\ concentration * volume) - (treated\ concentration * volume)}{(pretreated\ concentration * volume)} \times 100$$

For applicable media, provide a hydraulic retention time (RT) through the phosphorus removal system sufficient to achieve the target load reduction in dissolved phosphorus at the design flow rate.

Determine the phosphorous removal system size and configuration based on:

- average annual flow volume
- maximum runoff flow rates for various size storms
- typical dissolved phosphorus concentrations to be treated
- hydraulic head
- area constraints
- maximum flow rate at design retention time
- desired load reduction (%)
- desired life span of media
- physical properties of media
    - hydraulic conductivity
    - bulk density
    - porosity
- chemical properties of media
    - phosphorus sorption characteristics (details provided in technical note to be developed)
    - toxicity analysis of proposed media considering both safety (metals and sodium) and method of disposal

If the peak flow rates and annual flow volume are not known, base the surface flow peak discharge and annual flow volume calculations on an appropriate hydrology model.

Design the phosphorus removal system capacity for the minimum detention time during the desired storm frequency event, using 25% of the 2 year - 24 hour storm** as a minimum. Check the stability of the media and hydraulic characteristics of the containment structure during a high flow event not less than the 10 year – 24 hour storm**.

Design the system as a gravity flow system. Design the structure inlet and outlet such that water flows evenly through the media.

Design water control structures as needed to maintain the water level in the system at desired elevations, with appropriate freeboard. Use criteria from NRCS CPS 587, Structure for Water Control.

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

Use material that is recyclable and/or disposable when it has used up its phosphorus removal capacity. Ensure all used media is disposed of in a proper manner following applicable permits, which may include disposal in a landfill.

The phosphorus sorption media can be contained in a variety of methods, as long as the material is properly retained during a high flow event and protected from erosion/washout. Media can be retained in a drainage ditch using a dam with appropriate subsurface drainage, held in boxes, tanks, or units made of metal, wood, plastic, etc., or media can be housed within earthen berms. Use geotextile lining, where needed to prevent the migration of soil particles into the phosphorous removal system, based on the soils and geology of the site.

Ensure that the quality of discharge water from treatment structures is not detrimental to downstream waters.

Grade the structure site to minimize overland runoff into the containment structure. Allow for settlement as appropriate. Dispose of excess soil removed during the installation of the system in a sound manner such as blending with the adjacent landscape or hauling away.

Where needed for safety or to prevent compaction of the media, identify the structure location with appropriate signage or fence the site to avoid equipment travel over the system.

Protect all disturbed areas from erosion within 14 days of construction completion by seeding and mulching.

Additional Criteria for Treating Surface Runoff Flow

Design the structure to drain completely during periods of low or no flow. This is to prevent the potential for anoxic conditions that would promote the dissolution of iron-rich minerals. If an iron rich phosphorus sorption media utilized, design the phosphorus removal structure to flow from the top-downward through the sorption media.

CONSIDERATIONS

Other conservation practices and management systems can achieve a reduction of phosphorous levels separately or in conjunction with this practice. Examples include Nutrient Management (590), Cover Crop (340), Drainage Water Management (554) and Waste Treatment (629).

Flow control structures can be used in drainage ditches in areas of low relief in order to achieve sufficient hydraulic head to reach the desired flow velocity and residence time.

Consider impacts of phosphorus removal systems installation and flow control structures on the proper flow and function of drainage systems such as tile systems and surface ditches.

If the treatment structure is part of an inlet into a pipe system that drains terraces or basins, provide measures so the structure does not plug from sedimentation in the basin.

Consider the effects on downstream water bodies or groundwater that may affect other water uses or users. For example, the initial flow from the system at start up may contain undesired contaminants.

PLANS AND SPECIFICATIONS

Plans and specifications for phosphorus removal systems shall describe the requirements for applying the practice to achieve its intended purpose.

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

As a minimum the plans and specifications shall include:

- A plan view of the layout of the phosphorus removal system and associated components
- Topographic map
- Typical cross sections of the phosphorus removal system showing elevations
- Profiles of the phosphorus removal system including critical inlet and outlet elevations
- Details of required structures for water level control
- Site characteristics, including maximum flow rates for various sized storms, typical dissolved P concentrations, average annual flow volume
- Seeding requirements, if needed
- The type of phosphorus removal media to be used, including all chemical and physical characteristics required for proper design
- Desired % load reduction and life expectancy
- Design peak flow rate
- Planned method of recycling or disposal
- Construction specifications that describe in writing site specific installation requirements of the Phosphorus Reducing System and associated components

OPERATION AND MAINTENANCE

Review the provided operation and management (O&M) plan with the land manager.
Include normal repetitive activities in the application, use, and repair and upkeep of the practice. Keep the plan site specific and include a description of the following as appropriate:

- All required inputs necessary to operate the system
- Planned water level management and timing
- Inspection and maintenance requirements of the Phosphorus Removal System and contributing drainage system, especially upstream surface inlets
- Phosphorus sorption media replacement schedule.
- Monitoring and reporting as required to confirm system performance and provide information to improve the design and management of this practice. Monitoring shall include water testing for phosphorus (both dissolved and total P) in milligrams per liter, at the phosphorus removal system inlet and outlet, at certain frequencies or specific dates, with a corresponding record of water level elevations or flow rates.

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