NRCS CIG Grant #69-3A75-12-218
CONSERVATION INNOVATION GRANTS
Final Report

Grantee Name: Illinois River Watershed Partnership	
Project Title: Removing dissolved phosphorus in runoff with phosphorus removal structures	
Agreement Number:	
Project Director: Chad Penn	
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Period Covered by Report: 7-1-13 to 6-1-16	
Project End Date: June, 2016	

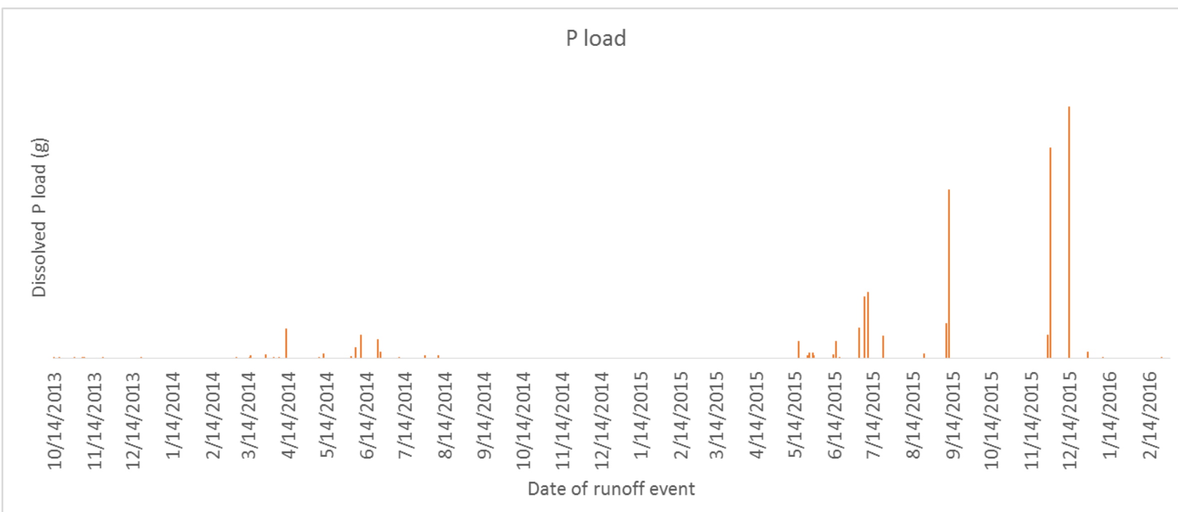
During this three year project, a P removal structure was custom designed, constructed, and monitored for effectiveness. For pictures and details of the construction process, please visit www.p-structure.blogspot.com. This data set also provided another opportunity to test the ability of our design software in predicting the performance of the structure (Phrog). The structure was a great opportunity to showcase the technology to the public and especially the water quality stakeholders: local poultry producers, non-profit organizations, local NRCS personnel, and industries that produce potential P sorption materials (PSMs) as by-products. This project received national attention through several media outlets, conferences, peer reviewed publications, and ultimately helped to promote and disseminate the technology. This has led to several other structures that were constructed in the U.S. and beyond. Because of the efforts of this project, we had the opportunity to design a P removal structure in North Dakota, Maryland, Ohio, and Canada. Several other opportunities exist. Although not yet completed, we began filming a series of videos on the topic of P transport to surface waters and the P removal structures, to be made available on YouTube. We are currently utilizing other funding to complete this task.

Although not part of the funded project, we are about 60% in completing a book dedicated to design and construction of P removal structures, to be published by Springer. The purpose of the book is to enable non-profit organizations, contractors, NRCS personnel, and other state and federal agencies to be able to design site-specific P removal structures. Again, although not funded by this grant, we completed the creation of design software (P removal online guidance: Phrog) through a grant from the OSU Technology Transfer. This software allows for site-specific design of P removal structures in minutes.

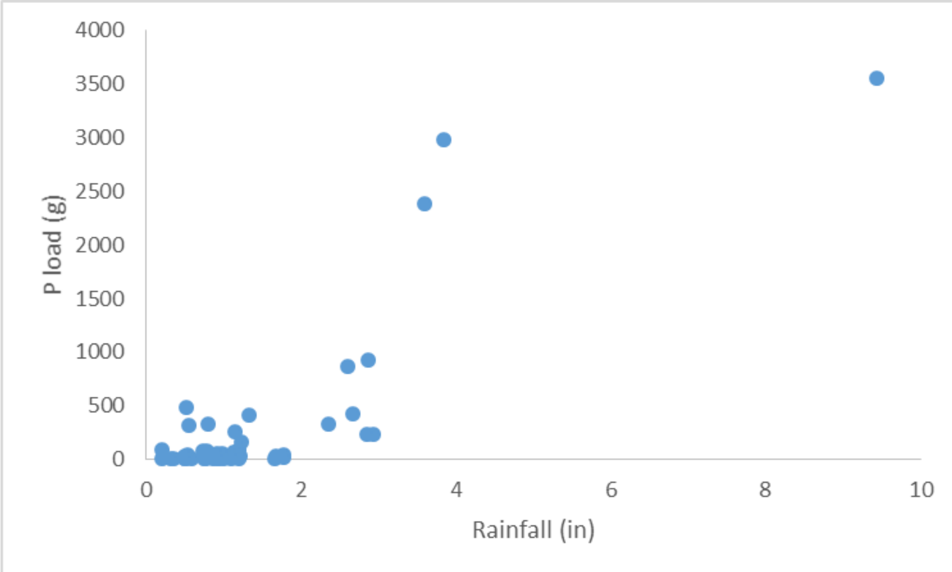
Flow and P loading at the demonstration site

As planned, the structure was constructed to gather runoff from around 16 poultry barns, and treat the dissolved P before runoff into Green Creek, located within 100 yards. The structure was designed with the assumption that the typical dissolved P concentration ranged from 1 to 2 ppm, as determined by grab samples. Also, through cooperation with the local NRCS office, a site survey and application of the Curve Number Method resulted in a prediction of about 2 million gallons runoff per year. Through this, we estimated about 45 lbs of dissolved P loss from the site per year. However, after about 2.5 years of monitoring, we learned from our constant monitoring that the annual flow volume was only about 600K gallons per year. However, our grab samples underestimated the typical dissolved P concentrations as the average dissolved P concentrations often ranged from 1.5 to 17 ppm. Thus, after about 2.5 years, there was about 32 lbs of dissolved P that left the poultry barns in the form of runoff. Clearly, this demonstrates the importance of accurate estimation of the average annual flow volume since it has such a tremendous impact on the estimates for dissolved P loads: we initially estimated 45 lbs/yr while there was truly only about 13 lbs of dissolved P lost per year.

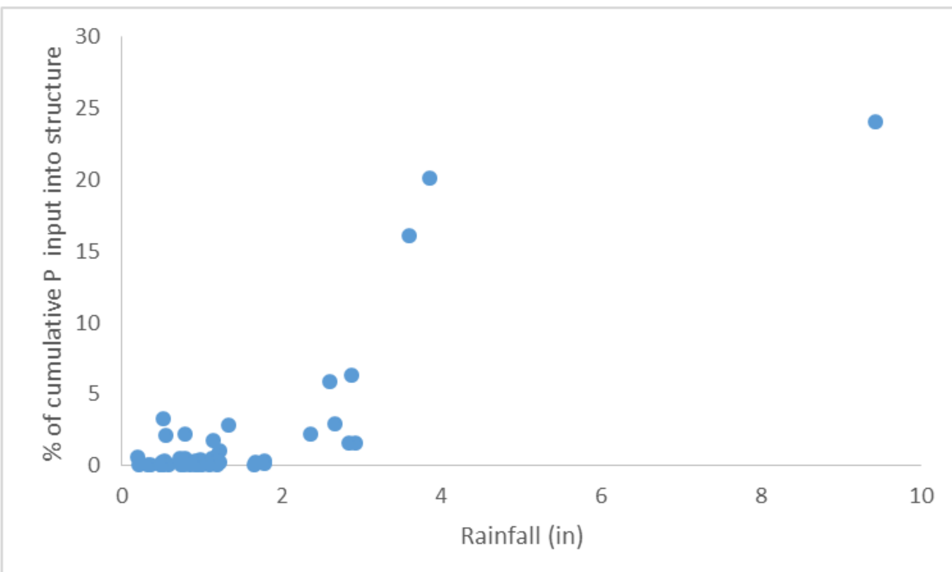
In agreement with the general “rule of thumb” that most P is lost during the large rainfall events that occur less frequently, we observed that three rainfall events resulted in the greatest dissolved P load:



In general, the next figure shows that the greatest load of dissolved P lost was from rainfall events that produced over 3 inches:



Finally, these three rainfall events resulted in the transport of about 60% of all the dissolved P during that time period:

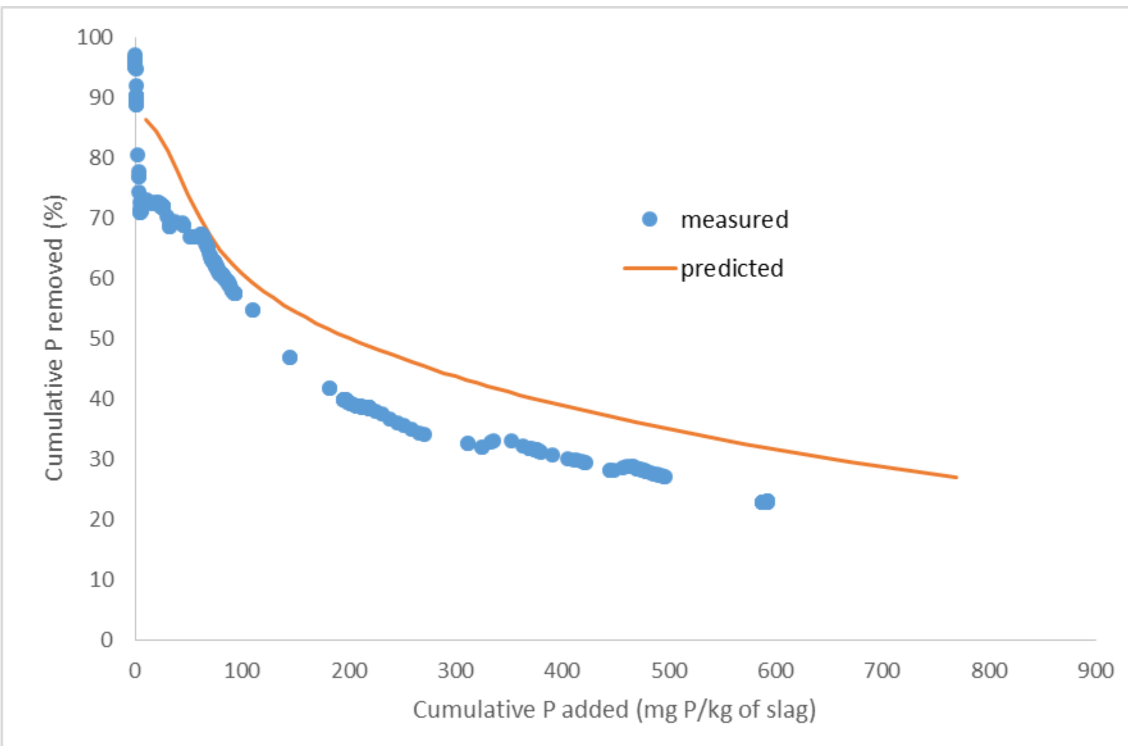


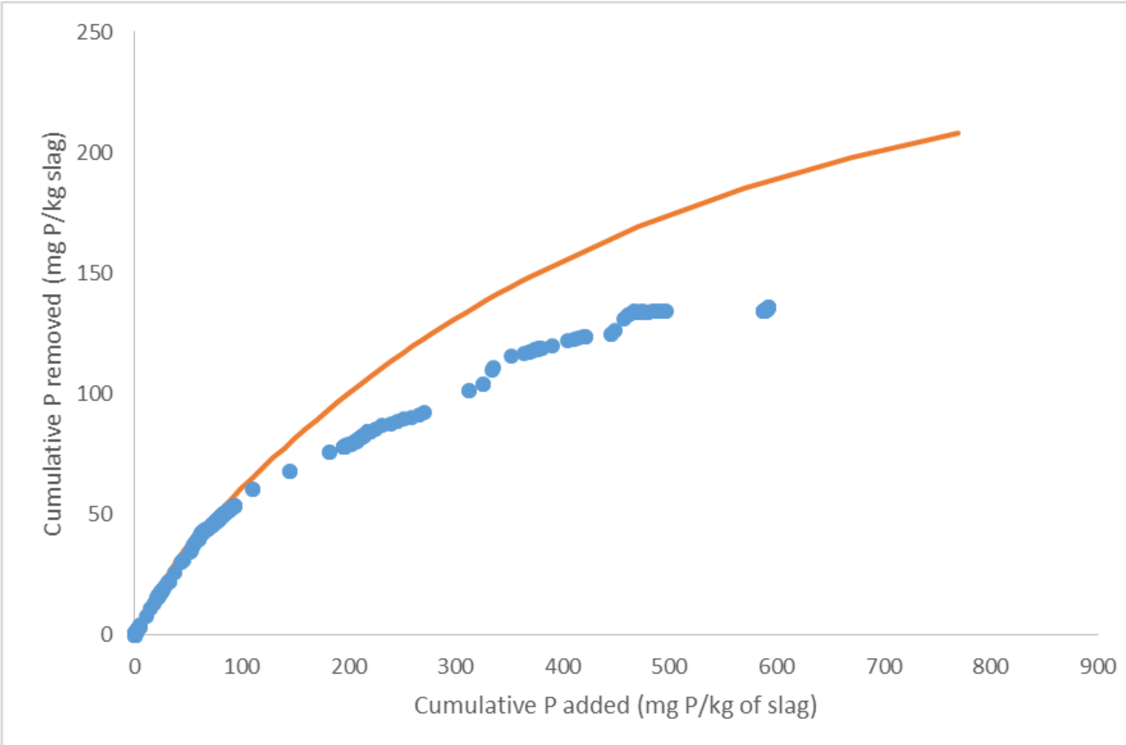
This reinforces the notion that large storm events tend to deliver the majority of the P load, and therefore the P removal structures must be designed to handle these high flow rates that are delivered during those events. During the enormous flow event that occurred in mid-December, 2015, we personally visited the site to observe that the P removal structure was able to handle 100% of the flow rate produced by this catastrophic event. Flow rates for that event exceeded 600 gpm.

Performance and prediction of P removal structure on the demonstration poultry farm

Overall, the P removal structure removed 23%, or 7.5 lbs of dissolved P during the 2.5 yrs in which it was monitored. Although the structure is still currently able to remove dissolved P from runoff, its capacity has greatly diminished, as predicted. Thus, the structures now behaves such that it is only able to remove appreciable dissolved P when runoff concentrations are extremely high, such as when a poultry house cleanout is conducted. Also, although a treated slag material was used in this structure, which is not sensitive to retention time, we observed that near the end of the useful lifetime of the PSMs, the treated slag began to display a sensitivity to retention time.

The Phrog software modelling was fairly successful in predicting the performance of the structure. To the current point of P loading to the treated slag (about 600 mg/kg), Phrog predicted about 30% cumulative removal, or about 190 mg/kg which equals about 10.5 lbs of P removed for that structure compared to measurements of 23% and 135 mg/kg (7.5 lbs) of cumulative P removed.





Although not tested, is was clear that the P removal structure trapped a large amount of particulate P and total P. This was evident by the amount of sediment that had accumulated in the slag contained in the structure. Several plants, in fact, had begun to flourish in the PSM bed. However, based on the 100-yr event that occurred in December of 2015, the sediment loading did not appreciably diminish the hydraulic conductivity of the structure.

Conclusions and recommendations

The P removal structure can trap an appreciable amount of dissolved P if the structure is placed in the proper environment, and is properly designed and constructed. To aid in this effort, we developed the Phrog software (www.phrog.okstate.edu) for use in structure design.

It is extremely important to note that construction of a P removal structure does not necessarily translate to successful removal of dissolved P. It requires much more than designing a structure to meet a certain hydraulic retention time. Most important, is the required mass of the PSM for meeting the user defined P removal goals and lifetime, as a function of the conditions of the site and the characteristics of the PSM. Particularly, all PSMs behave differently from each other, even PSMs that are produced from the same facility. Without proper knowledge of the P sorption characteristics of the specific PSM to be implemented under flow-through conditions, it is impossible to properly design a P removal structure for meeting user-defined P removal goals for a site of interest. Thus, a thorough characterization of each PSM must be conducted prior to every design, or conversely, if a structure is constructed with a “black box – cookie cutter” P removal structure, there is no way to predict how it will truly perform in P removal and lifetime unless the PSM is properly characterized. That is one reason why the Phrog software was developed: by conducting thousands of flow-through analysis on many different PSM materials, users need only to obtain a routine characterization of their PSM to be able to predict P removal under flowing conditions specific to P concentrations and retention time. This model was validated and recently published in Chemosphere. A demonstration of the Phrog software is found on the Phrog website under “tutorials”. The software is currently being used by several non-profits, NRCS, and state agencies. While the use of the software is very intuitive, the biggest challenge is estimating some of the inputs required for a design, such as average annual flow volume and average dissolved P concentrations. For this reason, one chapter of the book in progress will instruct readers on how to estimate such values. The book will also contain one chapter dedicated to use of the Phrog software. This book, “Construction and design of phosphorus removal structures for improving water quality”, should be available in Spring, 2017.

A draft version of the NRCS interim standard for the P removal structure is pasted below for reference. Also below is a list of extension and published products from this project.

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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

<u>General Criteria Applicable to All Purposes</u>

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.

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** for the reactive material, and a 10 year minimum lifespan for all structural components), 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:

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.

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.

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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D) Provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

1. A listing of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number;

2. The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biannual and cumulative payment amounts must be submitted.

3. A self-certification statement indicating that each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.