Natural Resources Conservation Service

CONSERVATION PRACTICE STANDARD

PHOSPHOROUS REMOVAL SYSTEM

CODE 624

(no)

DEFINITION

A system to remove dissolved phosphorus from surface runoff, subsurface drain, or ditch flows consisting of a phosphorus sorption media within a containment structure.

PURPOSE

Use this practice to accomplish one or more of the following purposes:

- Improve water quality by reducing the concentration of dissolved phosphorus in runoff and subsurface agricultural drainage flows.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where phosphorus presents a resource concern to surface water bodies and is mobilized and transported as a dissolved constituent. Critical source areas of dissolved phosphorus in agricultural areas include subsurface (tile) drains, soils with phosphorus levels greater than the phosphorus sorption capacity, livestock heavy use areas, manure storage and handling areas, and other areas with high impervious surface area and converging flows.

This standard is not intended to address resource concerns related to particulate phosphorus. Excess particulate matter and sediment may foul the phosphorus sorption media and reduce the performance and lifespan of the dissolved phosphorus removal system.

CRITERIA

General Criteria Applicable to All Purposes

Divert dissolved phosphorus laden influent through a bed of phosphorus sorption media where it will be in contact with the media for a design retention time sufficient to provide for removal of the phosphorus via sorption to the media before flowing out of the media bed or chamber by gravity.

Design the system as a gravity flow system. Design the system inlet and outlet such that flow is distributed evenly through the media chamber. Use water control structures as needed to maintain desired water level in the system, with appropriate freeboard. Design water control structures with criteria from NRCS Conservation Practice Standard (CPS) Structure for Water Control (Code 587).

Performance and capacity. Design the system to achieve a minimum cumulative reduction of 30% of the 5-year load, assuming treatment of 100% of annual flow volume. Load “reduction” is defined as the percent of dissolved phosphorus mass that is retained within the system relative to the total mass within the pre-treated influent.

Design the system to achieve a minimum lifespan of 5 years for the phosphorus sorption media, assuming treatment of 100% of annual flow volume and a minimum lifespan of 10 years for all other components.

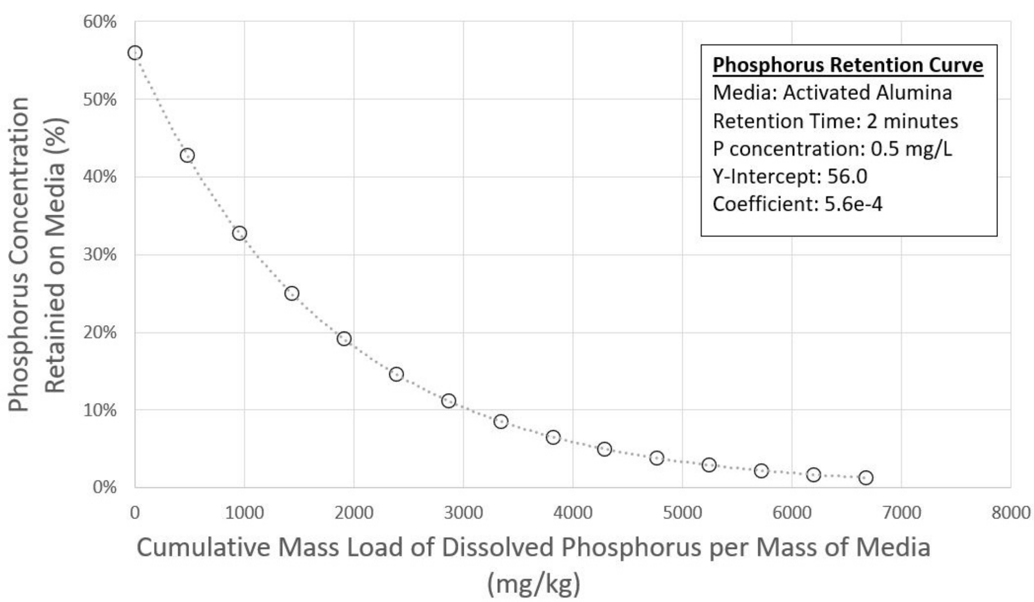
Media. Select a phosphorus sorption media based on availability, performance, and expected influent water characteristics at the site. Examples of acceptable phosphorus sorption media include: activated alumina, steel turnings mixed with gravel (8% steel by mass), steel slag, aluminum coated steel slag, pelletized drinking water residuals, mine drainage residuals, fly ash-sand mixtures, and gypsum waste.

Assess phosphorus sorption media for toxicity considering both safety (metals and sodium) and method of disposal. If not documented from source or supplier, analyze phosphorus sorption media for water-soluble trace metal concentrations (arsenic, chromium, lead, zinc, copper, selenium, cadmium, and nickel). Ensure that the quality of discharge water from treatment structures is not detrimental to downstream waters. Direct discharge of effluent to waterways may require a permit.

Media Chamber. Determine the size of the phosphorous removal system media chamber based on the properties below. Design software such as P-Trap (Penn et al, 2021) may be used to facilitate system design.

- Phosphorus retention curve specific to media, for phosphorus concentration, and residence time.
- Physical properties of phosphorus sorption media: hydraulic conductivity, bulk density, porosity.
- Flow rate at design retention time.
- Average annual total flow volume.
- Average influent dissolved phosphorus concentration.
- Hydraulic head.
- Site-specific constraints.

Figure 1: Example phosphorus retention curve for use in designing a dissolved phosphorus removal system showing phosphorus removal as a function of total phosphorus load (Penn et al. 2021).



A phosphorus retention curve is a relationship between the total load of influent dissolved phosphorus and amount retained on the sorption media (figure 1). The “retention curve” is developed for a specific media, residence time, and dissolved phosphorus concentration representative of those to be found on site. If a phosphorus retention curve is not available for the media of interest, one must be created. A phosphorus retention curve is developed by flowing a solution of known phosphorus concentration through a chamber containing a known mass of sorption media, sampling and measuring the phosphorus in the effluent at regular intervals, plotting phosphorus retained (%) versus cumulative phosphorus load (mg per kg of media) and deriving the best fit exponential equation (Penn & Bowen, 2017).

The residence time of the phosphorus removal system must be greater than or equal to the retention time used to develop the phosphorus retention curve used for design of the media chamber.

NOTE: Phosphorus retention curves for many common phosphorus sorption media can be found in a repository hosted by USDA National Soil Erosion Research Laboratory (Penn & Frankenberger, 2020). Development of phosphorus retention curves for media not contained within the repository is available upon request from the USDA National Soil Erosion Research Laboratory.

Protection. Use geotextile lining when needed to prevent the migration of soil particles into the phosphorous removal system, based on the soils and geology of the site.

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

Use of this standard requires compliance with all applicable federal, state, and local laws and regulations.

Additional Criteria for Subsurface Drain Systems

For systems treating subsurface drain flow, determine the phosphorus removal system residence time using a design flow as the maximum of the subsurface drain flow corresponding to a drainage coefficient of 0.125 inches over the area serviced by the drainage system or 80 percent of the capacity of the drain system main.

Determine total annual system flow using appropriate hydrologic model or method such as DrainMod (Skaggs, 1980) or other appropriate method. Refer to Title 210, National Engineering Handbook (NEH), Part 650, Chapter 14, “Water Management (Drainage)” for guidance on determining flow in drainage systems.

Provide a system bypass capable of conveying the maximum flow of the drain system using a Structure for Water Control (CPS 587).

Do not use calcium-rich phosphorus sorption media such as regular steel slag for subsurface drain systems or those treating groundwater.

Depending on the site-specific conditions, the phosphorus media chamber may constitute:

- Polyethylene or polypropylene tank.
- Excavated in-ground trench.
- Concrete tank.

Provide access ports to the media chamber for inspection and replacement of the phosphorus sorption media as appropriate.

Grade the structure site to minimize overland runoff into the containment structure. Allow for settlement as appropriate.

Remove or convert any surface inlets to blind inlets using criteria for an Underground Outlet (CPS 620) to filter particulates and prevent clogging of media chamber.

Additional Criteria for Confined Bed Systems

Locate the confined bed system in a concentrated flow path to treat surface flow or a combination of surface and subsurface flows.

Determine the residence time of the system with a design flow comprised as the sum of surface and subsurface design and annual flows.

For surface flow use a design flow of 80% of the peak flow generated by a 2-year 24-hour storm frequency event in the up-grade contributing area of the proposed system location. Base the surface flow design flow and total annual flow volume calculations on an appropriate surface hydrology model. Refer to Title 210, National Engineering Handbook (NEH), Part 630, “Hydrology” for guidance on calculating surface runoff flows.

Determine subsurface design and annual flows using the criteria specified under Additional Criteria for Subsurface Drain Systems.

Additional Criteria for Blind Inlet Systems

Locate the modified blind inlet system within an enclosed depression in a field containing subsurface drains.

In addition to the criteria for blind inlets contained in NRCS CPS Underground Outlet (Code 620) design the system using:

- Determine the residence time of the system using a design flow equal to the peak flow generated by a 2-year 24-hour storm frequency event in the contributing area of the inlet using an appropriate surface hydrology model or method. Refer to Title 210, National Engineering Handbook (NEH), Part 630, “Hydrology” for guidance on calculating runoff flows.
- Mix phosphorus sorption media with washed pea gravel or well sorted sand to ensure adequate drainage such that the inundated area is completely drained within a timeframe such that crop growth is not inhibited.
- Stratify the filter media with not less than 1 foot depth of the phosphorus sorption media mix on top of coarser media surrounding the inlet manifold with a layer of geotextile between the upper and lower media.

CONSIDERATIONS

Consider increased level of designed treatment for sites with high priority areas for source water protection or are upstream of community drinking water withdrawal sites. Also consider increased levels of treatment in watersheds where phosphorus water quality impairments have been shown to have impacted the designated use of downstream waterbodies.

Consider utilizing practices which reduce or attenuate flows upgrade of the phosphorus removal system to minimize the required size and extend the life span of the phosphorus removal system, such as NRCS CPS Drainage Water Management (Code 554) or Water and Sediment Control Basin (Code 638).

Consider utilizing CPS Drainage Water Management (Code 554), Saturated Buffer (Code 604), or Denitrifying Bioreactor (Code 605) in series with this practice for applications containing subsurface drainage systems where nitrate loading to surface waters is also a resource concern.

Utilize practices which reduce sediment and particulate loading, such as NRCS CPS Filter Strip (Code 393), Sediment Basin (Code 350), or Water and Sediment Control Basin (638) upstream within the flow path to the phosphorus removal system to reduce fouling of the phosphorus sorption media and maximize the lifespan of the system.

Utilize additional conservation practices and management systems to achieve a reduction of phosphorous levels in conjunction with this practice (e.g., NRCS CPS Nutrient Management (Code 590), Cover Crop (Code 340), and Waste Treatment (Code 629)).

Flow control structures can be used in areas of low relief to achieve sufficient hydraulic head to reach the desired residence time.

Design the phosphorus removal system to flow upward with an outlet at or near the elevation of the inlet where insufficient relief exists and or a downward flowing system would be impractical.

Consider impacts of phosphorus removal systems installation and water control structures on the proper flow and function of drainage systems and crop productivity.

PLANS AND SPECIFICATIONS

Prepare plans and specifications that describe the requirements for applying the practice according to this standard.

As a minimum, include the following items:

- A plan view of the layout of the phosphorus removal system and associated components.
- 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.
- Topographic map of flow contributing area.
- Site characteristics, including average and maximum flow rates, average annual flow volume, typical dissolved phosphorus concentrations, and average annual phosphorus load.
- The type of phosphorus removal media to be used and all chemical and physical characteristics such as, phosphorus retention capacity, required for design.
- Design annual load reduction and estimated life expectancy of phosphorus sorption media.
- Design flow rate.
- Specifications pertaining to the management of flow and water levels via structures for water level control.
- Specifications pertaining to the appropriate methods for recycling, recharging, or removal, disposal, and replacement of phosphorus sorption media.
- Construction specifications that describe in writing site specific installation requirements of the phosphorus removal system and associated components.
- Seeding requirements, if needed.
- Comply with all federal, state, and local permits

OPERATION AND MAINTENANCE

Prepare an operation and maintenance (O&M) plan and review it with the land manager and maintenance technician. Include normal repetitive activities in the application, use, 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.
- Planned inspection and maintenance requirements of the phosphorus removal system and contributing drainage system.
- Phosphorus sorption media replacement schedule and phosphorus sorption media disposal method.
- Planned recycling or recharging or removal, disposal and replacement or reuse of the phosphorus sorption media.
- Anticipated flow rates, phosphorus and total suspended solids concentrations, reduction targets, etc.

REFERENCES

Penn, C.J. and J. M. Bowen. 2017. Design and construction of phosphorus removal structures for improving water quality. Cham, Switzerland: Springer International Publishing AG. 228 p.

Penn, Chadand Jim Frankenberger. 2020. Phosphorus Sorption Media (PSM) Library. National Soil Erosion Research Lab. https://fargo.nserl.purdue.edu/p-trap/psmtable.html?ver=06032020

Penn, Chad and Jim Frankenberger. 2020. P-TRAP Phosphorus Transport Reduction App. National Soil Erosion Research Lab. https://fargo.nserl.purdue.edu/p-trap/#

Penn, C.J., , J. Frankenberger and S. Livingston Introduction to P-TRAP software for designing phosphorus removal structures. Agric Environ Lett. 2021; 6:e20043. https://doi.org/10.1002/ael2.20043