Phosphorous Retention in Constructed Wetlands: A Review on Development and Research

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Abstract— This paper aims to provide and inspire sustainable solutions for the performance and application of CWs by giving a comprehensive review of CWs' application and the recent development on their sustainable design and operation for Phosphorous Retention. Phosphorus (P) is often the key nutrient found to be limiting in both estuarine and freshwater ecosystems. This article reviews the processes and factors regulating P retention in streams & wetlands and evaluates selected methodologies used to estimate P retention in these systems. This paper aims to provide and inspire some new ideas in the development of intensified CWs mainly for retention of Phosphorus (P).

Key words: DOP, DURP, DIP

I. INTRODUCTION

Phosphorus (P) is one of the major nutrient-limiting in freshwater ecosystems. Eutrophication poses the most serious threat to the long-term health and function of estuarine environments around the world. Eutrophication of most fresh water systems is limited by phosphorus (P) concentration (Kennish, 2011). The rapid increase in human activity has substantially accelerated the eutrophication process, altering the geochemical cycles of carbon, nitrogen and phosphorous. In addition to natural sources, nutrients can enter aquatic ecosystems via point and non- point sources resulting from anthropogenic origins such as: (a) Municipal and industrial sewage discharges, (b) Runoff from fertilizers and manure applied to agricultural land (c) Diffuse sources in catchment areas. Non point sources generally are of greater relevance than point sources since they are larger and more difficult to control. CW effectively absorbed both nitrogen (N) and phosphorus (P) emanating from the waste treatment plant (Erler et.al., 2011). Compared to conventional treatment systems, constructed wetlands are low cost, easily operated and maintained, and have a strong prospective for application in developing countries(Mustafa, 2013). Constructed wetlands have been used for wastewater treatment for more than fifty years (Vymazal, 2014). Free surface water constructed wetlands (CWs) provide a relatively cheap and potentially effective buffer between tertiary wastewater treatment plants and natural waterways (Vymazal, 2007). Lucas and Greenway, 2011 reported that After 80 weeks, cumulative PO4-P retention in the a by-product of water treatment; or Krasnozem soil(K) and red mud(RM) soil treatments ranged from 79% to 95%, whereas PO4-P retention in the WTR treatments ranged from 95% to 99% of the input load. According to Persson and Wittgren, (2003) the hydraulic conditions depend mostly on L:W ratio, which determines both the effective volume ratio and the dispersion in wetlands. Wetland shape, i.e. L:W was positively related with P and particle retention. However, the results indicate that there may be a hydraulic load breakpoint, when the P and particle retention will drop even if the L:W ratio is high.(Johannesson, et.al.,2014). Several studies have shown that in runoff from agricultural fields in clay and silt dominated areas, the P is transported predominately as particulate P (PP) (Koskiaho, 2003; Gottschal et al., 2007; Ulen, 2004;). However, periods of P release have been observed in several constructed wetlands (e.g., Braskerud, 2002) and Koskiaho et al., 2003 attributed this to the annual development of vegetation with re suspension occurring during seasons with decaying vegetation. Bratieres et al., 2008 reported that P removal in treatments evaluated for 8 months can exceed 90% at storm-water concentrations. We hope that this knowledge will provide managers with a better understanding of the processes that control P cycling. The purpose of this article is to: (1) Present a critical review of the processes and factors regulating P retention in streams and wetlands, (2) Design Parameter for P retention and (3) Identify and evaluate laboratory and field methods used to estimate P retention.

Sr. No	Country Name	% Phosphorous Retention	Reference
1	Dunhill, Irland	42.92%	Dunne et.al., 2005
2	Johnstown Castle, Irland	91.36%	Dunne et.al., 2005
3	USA	18%	Reddy, et.al.,1996
4	USA (Milkhouse wetland)	68%	Newman et.al., 2000
5	USA, (Municipal wetland)	54%	Newman et. al., 2000
6	Canada	5-28%	Pant et. al.,2001
7	Northern Ireland, UK	86%	O'Neill et al., 2011

Table 1: Summary of Seven Wetlands for Phosphorous Retention

II. PHOSPHORUS RETENTION MECHANISMS

Reddy K R et al. 1991 suggested Phosphorus entering a wetland or stream is typically present in both organic and inorganic forms. The relative proportion of each form depends on soil, vegetation, and land use characteristics of the drainage basin. To trace the transport and transformations of P, it is convenient to classify forms of P entering into these systems as: (1) dissolved inorganic P

(DIP), (2) dissolved organic P (DOP), (3) particulate inorganic P (PIP) and (4) particulate organic P (POP) where,

- Total Phosphorus (TP)
- Dissolved total P (DTP)
- Total P in solutions filtered through 0.45 um membrane filter
- Dissolved reactive P (DRP) or Soluble Reactive P (SRP)

Water samples filtered through 0.45 um membrane filter and analyzed for ortho-P.

- Dissolved Organic P (DOP)
- DTP – DRP = DOP
- Particulate inorganic P (PIP)

Particulate matter or soil extracted with acid

- Particulate organic P (POP)
- TP-PIP = POP

Most confusion can be overcome by carefully defining P forms. Here, P is simply defined as dissolved reactive P (DRP) if previously filtered (<0.45 mm) and detectable by colorimetry, otherwise samples without the filtration method specified (but still largely inorganic P) are termed reactive P (RP). A filtered and unfiltered sample subjected to a digestion for TP yields total dissolved P (TDP) and TP, with PP calculated as the difference between TP and TDP. A fraction commonly defined as dissolved organic P (DOP), but more accurately described as dissolved unreactive P (DURP) due to the aforementioned interference, is obtained as the difference between TDP and DRP (Mc Dowell et al., 2004)

III. Guidelines for Determining P

For determining amount of phosphate following points should be considered.

1) The total orthophosphate test is largely a measure of orthophosphate. Because the sample is not filtered, the procedure measures both dissolved and suspended orthophosphate. The EPA-approved method for measuring total orthophosphate is known as the ascorbic acid method. Briefly, a reagent (either liquid or powder) containing ascorbic acid and ammonium molybdate reacts with orthophosphate in the sample to form a blue compound. The intensity of the blue colour is directly proportional to the amount of orthophosphate in the water.
2) The total phosphorus test measures all the forms of phosphorus in the sample (orthophosphate, condensed phosphate, and organic phosphate). This is accomplished by first "digesting" (heating and acidifying) the sample to convert all the other forms to orthophosphate. Then the orthophosphate is measured by the ascorbic acid method. Because the sample is not filtered, the procedure measures both dissolved and suspended orthophosphate.
3) The dissolved phosphorus test measures that fraction of the total phosphorus which is in solution in the water. It is determined by first filtering the sample, then analyzing the filtered sample for total phosphorus.
4) Insoluble phosphorus is calculated by subtracting the dissolved phosphorus result from the total phosphorus result (APHA 2012).

IV. Construction Details and Other Important Information

- The location of the HFCW should be safe from flooding.
- If available, natural slope avoids the need for pumps.
- HFCW should be integrated into the landscape as much as possible and should have a pleasant appearance.
- Surface water must be diverted away from the HFCW.
- If the existing soil has a permeability coefficient of < 10-8 m/s, no artificial sealing layer is necessary for sewage treatment applications. In this case a density test (after Procter) has to be performed. According to Biswas, D, 2001 Constructed wetland systems in soil with a higher permeability require sealing of the bottom and sides so that untreated or partly treated wastewater cannot infiltrate to the groundwater. This can be achieved by concrete or plastic tank
  1) Plastic liner, thickness
  2) 1 mm, root resistant, preferably from polyethylene or equivalent material. The liner has to be protected against damages caused by rocks of the existing soil and by sharp edged gravel of the drainage layer. Geotextiles may be used for revention of such damages. The liner should be UV resistant, if exposed to the sun
  3) Clay sealing with a verified thickness of 30 cm. The clay sealing has to be compacted properly.
  4) Mixture of existing soil with bentonite or very fine clay (two layers of 20 cm each, mixed and compacted separately). After finishing the sealing a leakage test should be carried out by filling the bed with water. If the loss is less than 2 mm overnight, the sealing is satisfactory.
- PVC pipes (Ø 100 mm) with 25 mm drilled holes are acceptable for inlet and outlet manifolds.
- Inlet structures must distribute the incoming wastewater uniformly across the infiltration cross-section, without leading to clogging of the filter media.
- The outlet manifold should connect to either a swivelling standpipe or a flexible hose in a manhole to permit water level control in the HFCW.
- The construction of in- and outflow devices must allow for cleaning with mechanical or high pressure flushing tools.
- A freeboard of at least 20 cm (distance from bed surface to the upper edge of the lateral sealing) is to be provided.
- Local plant species should be used on the bed. The preferred species include: cattail, sedge, rush, soft stem bulrush, and reeds. Decorative, flowering plants can be used especially around the edges of the bed.
- The HFCW should be protected from unauthorized access, but be accessible for maintenance. There should be free access to all operational points, like manholes, pumping stations, maintenance locations and sampling points. The access has to be constructed in a way, that crossing of the HFCW is avoided (USEPA, 1991).

V. CONCLUSION

Phosphorus retention in wetlands is regulated by a variety of biological, physical and chemical factors. When evaluating wetlands P assimilation, one must consider both short-term storage assimilation into vegetation, microorganisms, periphyton and detritus and long-term storage assimilation by soil and accretion of organic matter. In wetlands, over 80% of the P stored during active growth phase of vegetation was released into the water column during senescence and decomposition of the detrital tissue.

If surface water is at higher concentrations there is still capacity for further P accumulation Wetlands typically function as net sinks for total P.

Phosphorus retention by stream systems is dominated by physical processes such as flow velocity, discharge, and water depth. However, the same biological and chemical processes that regulate P retention in wetlands regulate P in streams. Abiotic processes controlling P retention in streams are dominated by sediment sorption reactions. However, biological uptake can account for the majority of dissolved P transformations in streams. Long-term storage of P in stream sediments is inhibited by rapid mobilization and transport that occurs during storm events.

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