The Distribution of Nutrients in Urban and Agricultural Ponds Used in Determining the Cost Effectiveness of a Biochar Filter BMP

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PURPOSE

⇒ Determine the concentration and distribution of dissolved and total phosphorus in a range of pond types including agricultural, urban, and golf course drainage.

⇒ Explain any variability in concentration by pond and depth using a wide range of possible related parameters such as dissolved iron, pH, and dissolved oxygen.

⇒ Model the potential costs and benefits of a biochar filter.

⇒ Assess the benefits of applying such a phosphorus filter to the sample ponds.

BACKGROUND

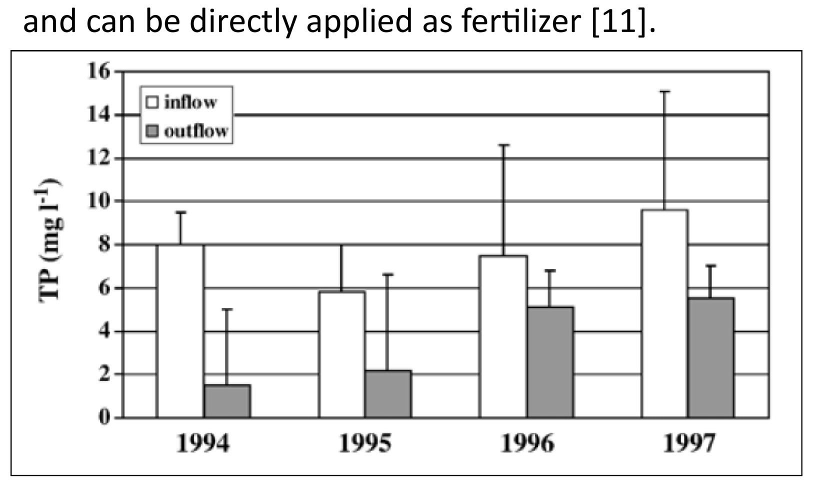
⇒ Phosphorus is often the limiting nutrient for algae and cyanobacteria in freshwater [3].

⇒ Phosphorus builds up and becomes saturated: in a pond in the Czech Republic, the percent removal of total phosphorus declined from 80% to 40% over a 4 year period [9]. For saturated ponds a new best management practice (BMP) may be required.

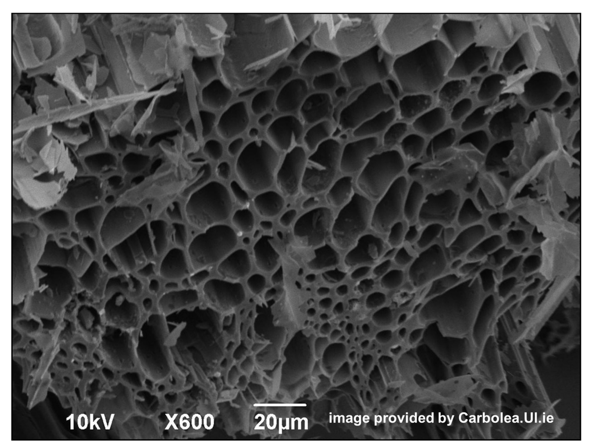
⇒ Uptake and sequestration by plants and algae tends to be slow and reversible [2].

⇒ Phosphate filters have been attempted with various substrates including limestone, carbonaceous sand, iron-rich sand, and biochar [1].

⇒ Biochar has shown promise since it has high sorption capacity, can be made from waste materials, and can be directly applied as fertilizer [11].



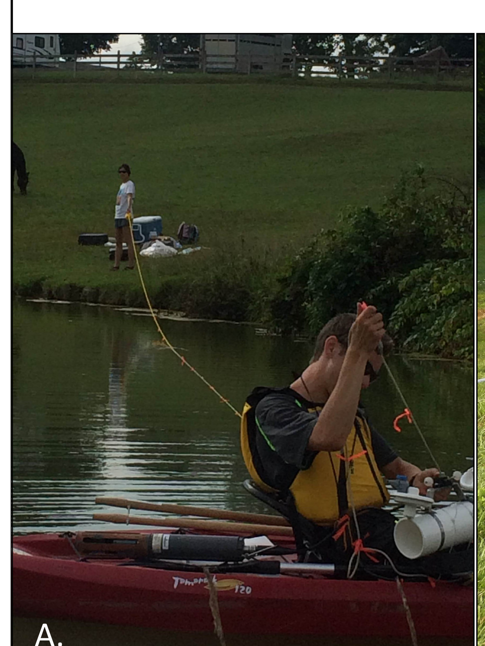
Data on a Czech retention pond depicting a decline in the ability of to remove phosphorus [9].

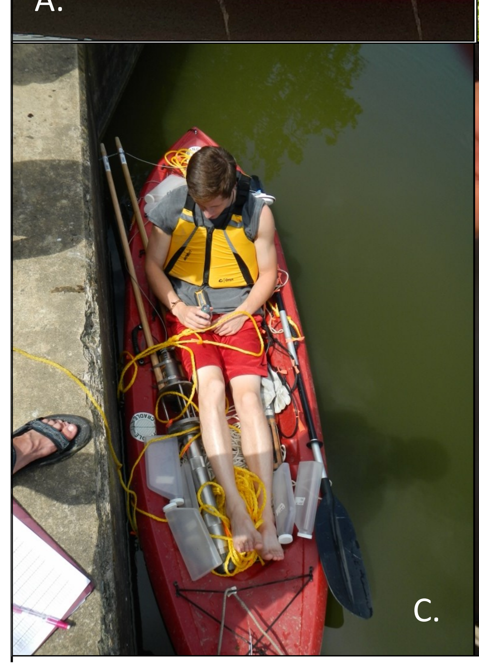


A SEM micrograph illustrating the porosity and, consequently, high surface area of biochar.

MATERIALS AND METHODS

1. Pond water was sampled using a van Dorn sampler at 0.25 m intervals in each pond at the inlet, middle, and outlet. Simultaneously, a YSI Sonde was used to measure temperature, conductivity, dissolved oxygen, pH, and turbidity.
2. Sediment samples were collected using a 2 inch diameter corer modified for shallow water usage.
3. Concentrations: A SEAL autoanalyzer/colorimeter was used for dissolved and total phosphorus and nitrate, ion chromatography for sulfate, a NDIR analyzer for dissolved organic carbon, and ICP-AES for dissolved iron.
4. Sediment samples were frozen for future analyses.





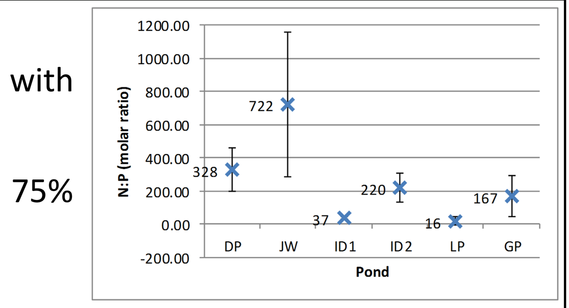
A. Using the van Dorn depth sampler at the JW agricultural pond.
B. Sample collection at GP; note the outlet pipe and mooring to maintain position.
C. Preparing to take samples at the middle of DP.
D. Taking redox measurements, these data were found to be unreliable due to a very long equilibration requirement.

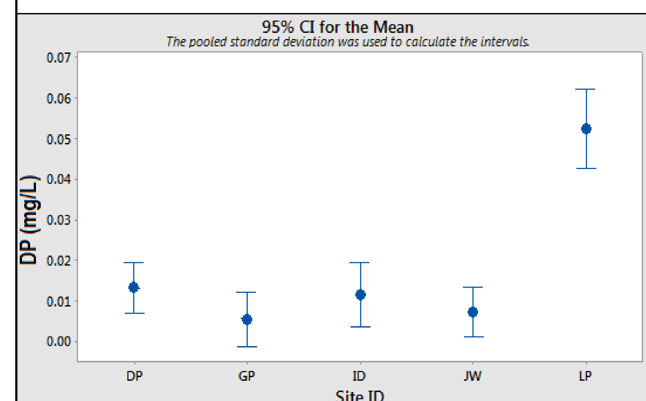
RESULTS

For nutrient level comparison:

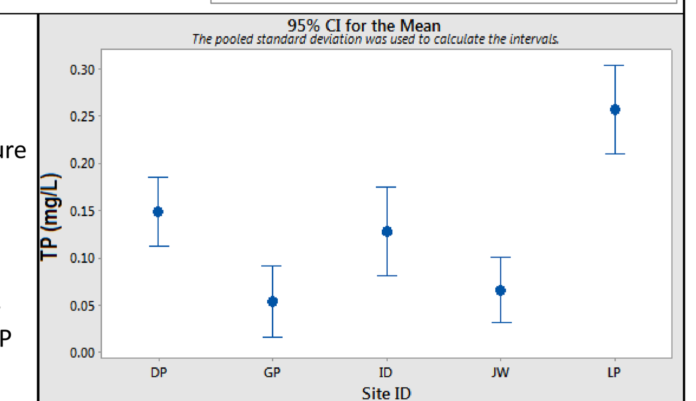
⇒ Toxin producing cyanobacteria *Microcystis* require ~0.022 mg/L phosphorus [5] with an optimal N:P ratio of 7-9. N:P>23 indicates P deficiency for algal growth [4].

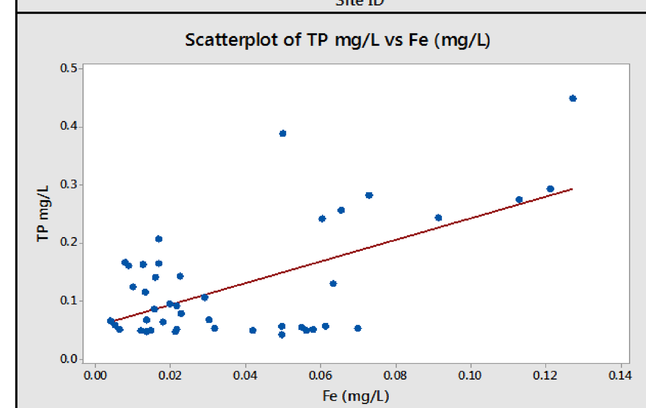
⇒ USEPA: 25% of lakes & reservoirs in ecoregion XI are below 0.008 mg/L and 75% below 0.045 mg/L [7].



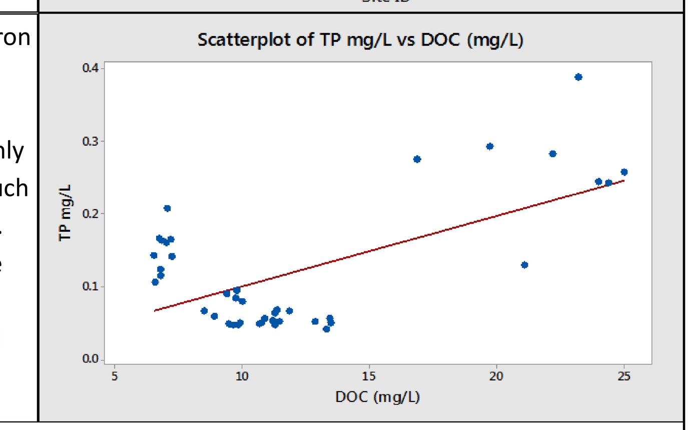


Left: Confidence intervals comparing dissolved phosphorus in each pond. LP had significantly more than all other ponds, likely due to the larger cow pasture watershed , and the average pH of 9.2.
Right: Confidence intervals comparing total phosphorus in each pond. LP was significantly higher than all other ponds, while DP was statistically greater than GP & JW.

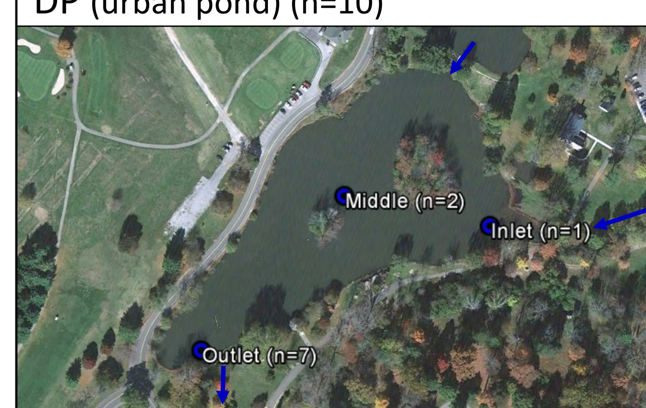




Left: The positive relationship between iron concentration and total phosphorus matches theory since iron is known to bond with phosphorus. The data are highly scattered, because many other factors such as pH, DOC, and turbidity also explain TP.
Right: Scatterplot illustrating the positive relationship between dissolved organic carbon (DOC) and total phosphorus in all ponds.

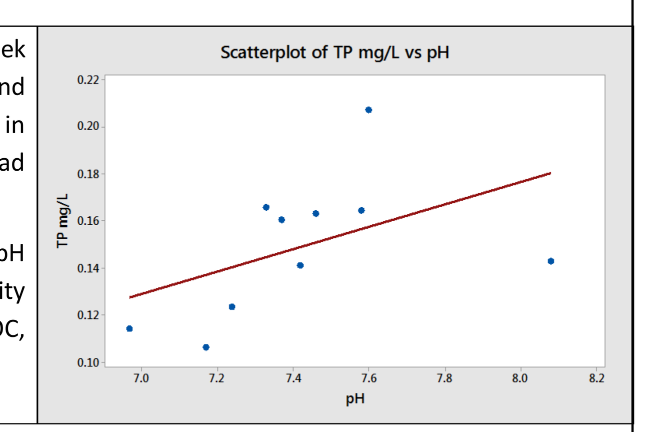


DP (urban pond) (n=10)

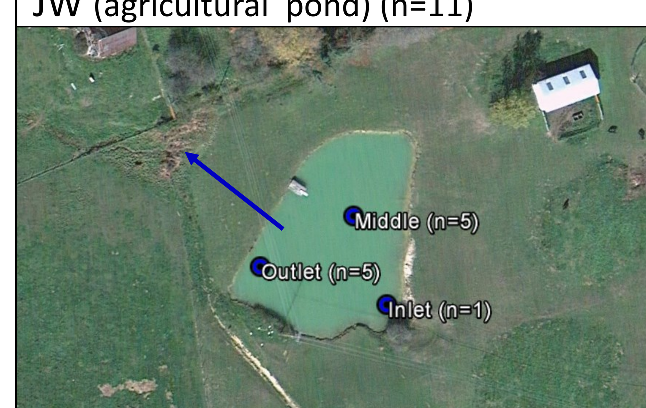


Left: DP has natural inputs from Stroubles Creek and Webb Branch which are spring-fed and drain most of the impervious surfaces in Blacksburg. This is the only pond that had continuous outflow.

Right: The positive relationship between pH and TP in pond DP may evince biological activity or may be related to higher amounts of DOC, which tends to increase acidity.

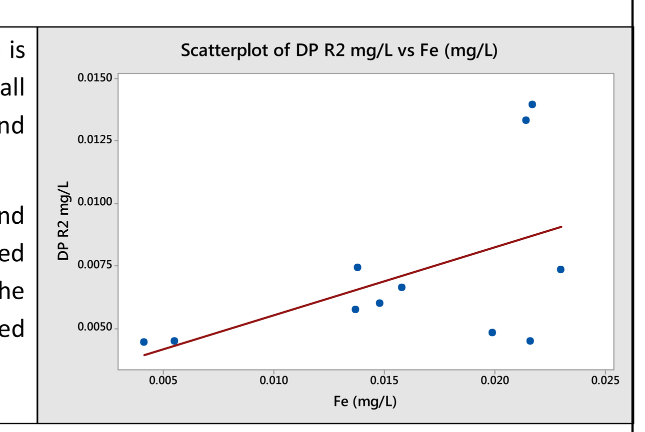


JW (agricultural pond) (n=11)

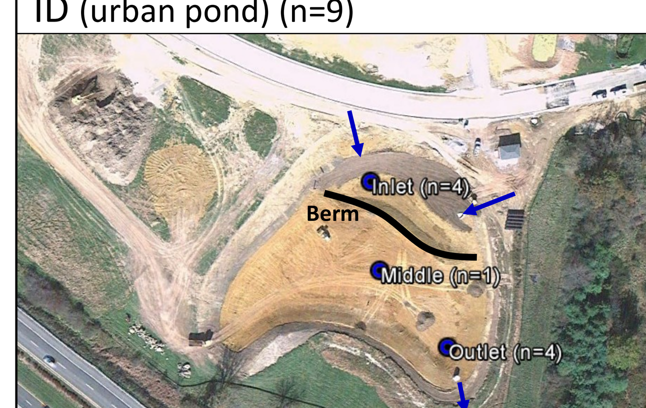


Left: JW pond (estimated volume of 2000m^3) is fed by horse pasture drainage and has a small outlet pipe. Its watershed is relatively small and it was previously used as a swimming hole.

Right: The positive relationship between Fe and DP in the JW pond matches theory; reduced iron is more soluble and tends to release the phosphorus complexed with it. Still, dissolved phosphorus was very low at this pond.

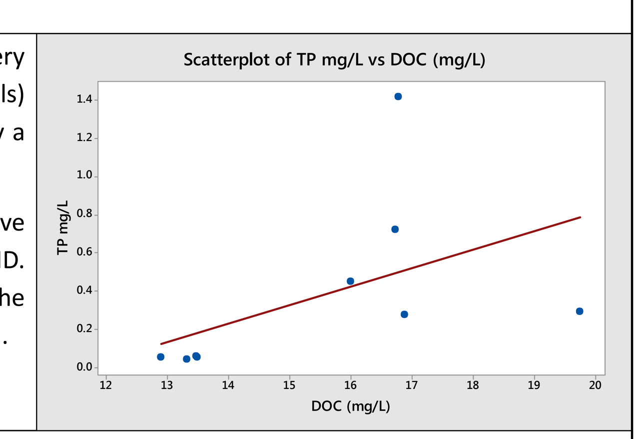


ID (urban pond) (n=9)

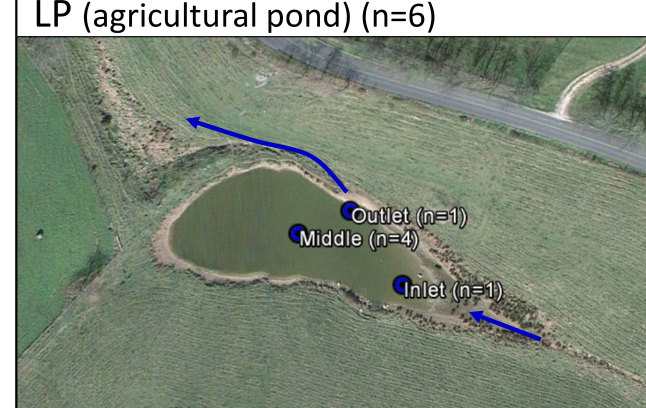


Left: ID pond is not complete in this imagery from 2011, the inlet (fed by two storm outfalls) was separated from the middle and outlet by a rock and soil berm.

Right: Scatterplot showing the positive relationship between DOC and TP in pond ID. The inlet DOC and TP were lower than the middle & outlet on the other side of the berm.

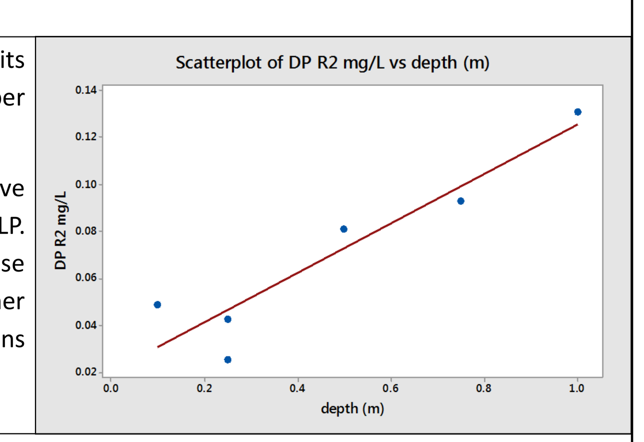


LP (agricultural pond) (n=6)



Left: LP is very algae-rich corresponding to its high nutrient levels. The source is an upper pond and pasture drainage.

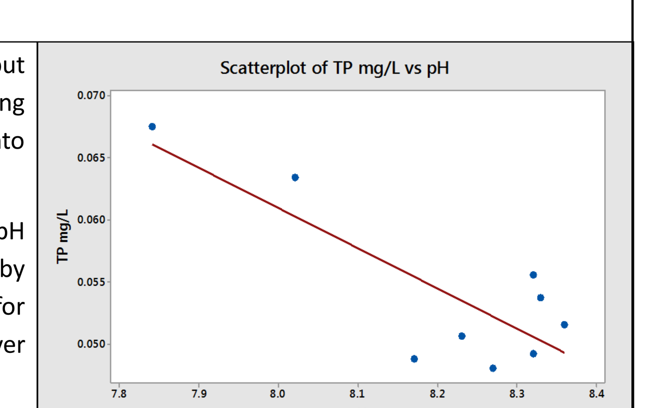
Right: Scatterplot demonstrating the positive relationship between depth and DP in pond LP. This was the sole instance when these correlated well, this may be due to the higher levels of DP which outweigh random variations seen in the other ponds.



GP (golf pond) (n=9)

Left: GP is adjacent to a spring-fed pond, but only connected via the groundwater, during high flow events this pond discharges into Roanoke River.

Right: The negative relationship between pH and TP in the GP pond is not explainable by DOC since DOC and TP are not correlated for this pond. TP was low for this pond—even over the range of 0.6 pH, TP changes minutely.



FILTER COST MODEL

Inputs: Isotherm and kinetic constants [11], biochar material properties [6][10], feed concentration, desired removal rate, desired flow rate (dependent on filter depth/length).

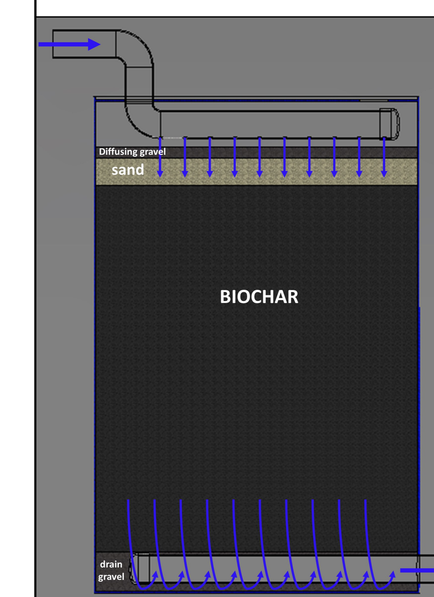
Outputs: Breakthrough time (filter life) is 3-6 months, benefit per volume treated (see below). The proposed trial filter in a 55 gallon barrel would cost under $500.

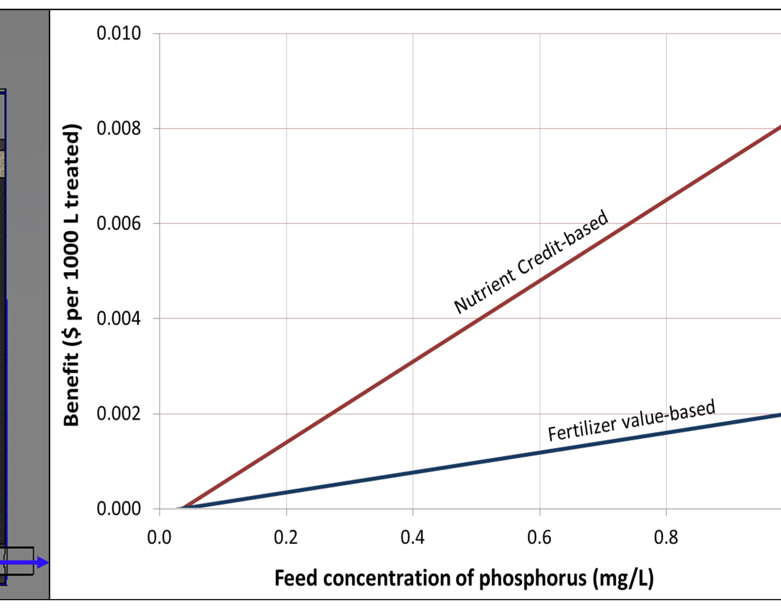
The median cost of other phosphorus BMPs is $2200/kg of phosphorus removed [8]. This system may cost between $500 and $1000/kg. While this method cannot be expected to turn a profit, for higher concentrations and larger installations, this may be cheaper than conventional BMPs.

Langmuir: $q_e = \frac{KQC_e}{1 + KC_e}$

$$v_c = \frac{v_s}{\varepsilon + \rho_{bulk} \frac{\partial q_e}{\partial C_e}}$$

The Langmuir isotherm and concentration velocity were used to determine filter life.





Left: Biochar trial filter with sand and gravel layers that prevent clogging and collects some TP.

Right: Plot showing benefits based on nutrient credit trading (red) and benefits of using collected phosphate (blue). These values are independent of flow rate.

SUMMARY

⇒ 5 sample ponds indicated that the nutrient concentrations in retention ponds in both urban and agricultural settings vary widely, especially given the five-fold difference between the 2 agricultural ponds.

⇒ On average TP was 11.8±8.2 times greater than DP indicating that filtration should also consider total phosphorus removal via straining of particulates.

⇒ The agricultural pond "LP" was found to contain the highest levels of DP and TP, this is likely due to the large area of cow pasture that it drains (at least 8 acres).

⇒ Over all we found maximum TP was correlated to low conductivity and high DOC. Conductivity tends to decrease with increasing DOC—elevated TP is indicated the presence of more organic matter.

⇒ Within each pond, DP and TP did not tend to vary significantly between the inlet, middle, and outlet.

⇒ Contrary to equilibrium principles, pH and iron were not correlated; however, DOC and iron were positively correlated (R^2=0.3) which may implicate chelation as a factor.

⇒ Removing phosphorus using a biochar filter could be cost effective provided that the biochar was bought and resold locally at value and/or nutrient credits could be obtained for implementing a filter BMP.

⇒ It is recommended that a trial filter be installed at pond "LP" to determine actual phosphorus removal rates, filter life, and effects on nutrient concentrations.

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