A Plant Management Strategy for Maximizing Sustainable Nutrient Removal in Floating Islands

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Introduction

The subject of this white paper is the removal of nutrients via floating treatment wetlands, and in particular, the removal pathways and the fate of removed nutrients. There is a persistent notion that in order for floating treatment wetlands to be effective, the standing crop of biomass must be routinely harvested and removed. This is based in part, on the perception that the primary removal mechanism occurs by plant uptake of nutrients. In 2009, probably the definitive work on treatment wetlands was published by Robert Kadlec. The 30-year study of the Houghton Lake wetland is complete and comprehensive, providing a real-world example of how wetland treatment systems function over-time. Interestingly, the wetland developed a “floating island” character on its own accord, thus presenting very good information on these types of systems.

The focus of the Kadlec study was for nutrient removal. However, nitrogen was fairly easily removed as ammonia was quickly converted to nitrate, and nitrates were subsequently reduced to background levels or even characterized as undetectable. The fate of nitrogen is difficult to quantify due to mechanisms that include both the release to the atmosphere as nitrogen gas, as well as nitrogen fixing. Although the wetland performed very well for removing both TN and TP, the current regulatory interest seems focused on the fate of phosphorus. The rest of this paper will quote extensively from Kadlec’s 2009 paper as it relates to phosphorus (See Kadlec, 2009).

Study Description and Results

The continuous 30-year study involved lagoon-treated wastewater that discharged to a natural peat wetland to further remove nutrients. Known as the Porter Ranch, the site is located near Houghton Lake, Michigan. Even though this is a wastewater study, the long-term removal mechanisms described should apply to wetland treatment of any low strength nutrient source, including stormwater.

The aerated wastewater lagoon was afforded high detention times (six months) and provided relatively high quality effluent that was discharged to the treatment wetland. Nutrient levels for input to the wetland system averaged approximately 3.5 mg/l TP, and 7 mg/l dissolved inorganic nitrogen (DIN). Nutrients discharged from the wetland system averaged approximately 40 ug/l TP (94% removal), and 85 ug/l (95% removal) of DIN.

Several years after startup, a dense root mat started to float in the areas of the effluent inflow. The floating mat grew to approximately 30 cm thickness, containing an interwoven mesh of roots and rhizomes. By 2002, the floating wetland mat occupied 27 ha of the 100-ha irrigation zone. Water flow was entirely under this mat, leaving the mat surface as a zone of damp or dry litter. The fact of under-mat flow meant that the water was exposed to the root zone of the plants, rather than the stem zone.

For the first 8 years, both sorption and biomass content increased, as the wetland expanded to meet the additional flow from the lagoon. Thereafter, both the sorbed and biomass pools of phosphorus remained relatively unchanged. The removed phosphorus was in part stored in new soil sorption, in part in increased plant and microbial biomass, and in part in new soil accretions. Phosphorus sorption was based on a 30 cm soil horizon and laboratory isotherms, plus water-column phosphorus concentrations. Measured biomass phosphorus was used to calibrate an allocation model (Kadlec, 1997). The sum of the modeled storages was calibrated to be the same as the observed removal. Over the entire study period, accretion was the dominant storage mechanism.

The antecedent sorption sites in the wetland apparently became saturated over a period of about 3 years, and stored only about 3% of the added phosphorus over the study period. During the first 9 years, the formation of new biomass had a significant effect on phosphorus removal, and stored about 10% of the added phosphorus. Thereafter, **accretion of decomposition residuals** was the principal mechanism for phosphorus removal (Kadlec, 1997, 2009), and stored about 80% of the added phosphorus.

These observations have far-reaching implications for understanding and evaluating the potential of various wetland ecosystems for phosphorus removal. Studies of nutrient uptake capabilities of different wetland plants can be very misleading, because short-term growth and storage results are generally not sustainable. Side-by-side comparisons of plant varieties over a few months are of essentially no value in understanding the long-term sustainable potential of a wetland containing them (Kadlec, 2009).

The sustainable removal potential for a treatment wetland is governed by accretion, which is the "back end" of the biogeochemical cycle, while plant uptake is the "front end" (Kadlec, 2009).

Leakage of small amounts of phosphorus to downstream locations in the wetland probably occurred, via the mechanism of episodic floc movement. Sediment transport involves resuspension, advective flow and redeposition. Suspension can be caused by bioturbation, gas release, as well as by shear-induced release of particles from sediments. Settling rates were high (as indicated by lab measurements), and filtration was presumably effective in the dense litter layer. Consequently, this sediment spiraling was of limited magnitude, with annual travel distances estimated to be in the range of 10-100 meters (Kadlec, 2009).

Summary

Throughout the project, the sustainable mechanism of phosphorus accretion in new soils and sediments has functioned to immobilize phosphorus. In the later years (years 9-30), accretion was the only operative mechanism, because sorption and biomass expansion had reached their limits. Over the course of the project, accumulations of 10-30 cm were produced, which contained about 80% of the removed phosphorus. The removal rate model parameter remained stable over the post-startup period, indicating that the wetland displayed no tendency to lose its phosphorus sequestration capability. In other words, the wetland showed no signs of "wearing out" or "becoming saturated" (Kadlec, 2009).

Conclusions

Wetland vegetation need not be harvested in order for the system to effectively remove nutrients. Clearly, routine harvesting of plant tissues from a treatment wetland serves to boost short-term biomass uptake. However, this process would very likely be deleterious to the accretion process which is the primary nutrient removal engine. Routine harvesting could at best, maximize removals on the order of 10% or so, while accretion accounts for approximately 80% of the long-term sustainable removal potential.

It should be noted that for very small concentrations of TP, on the order of 100 ug/l or less, removal and replacement of plants could conceivably reach proportionally higher removal rates. However, it is unlikely that the associated added expense would be cost effective when compared to the removal efficiencies that would be obtained by accretion alone in these same systems (Kadlec communication, 2010).

It appears from Kadlec's work that in order to maximize treatment efficiency and to provide for long-term, sustainable nutrient removal, the floating wetland plants should be allowed to flourish. Cycling through growth, death and decomposition returns most of the biotic uptake, but an important ***un-decomposable residual*** contributes to long-term accretion in newly formed sediments and soils. Such accretion was the dominant removal mechanism at Houghton Lake. Phosphorus is immobilized and sequestered within the soils underlying the wetland. For TP concentrations typically associated with stormwater, harvesting of plants appears an unnecessary expense, and likely is counterproductive in the long-term.

References

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