Article 93

Technical Note #53 from Watershed Protection Techniques. 1(4): 210-213

Pollution Dynamics Within Stormwater Wetlands: Organic Matter

Wetland designers use basic parameters such as surface area, rainfall frequency, input concentrations, and overflow rates to design wetlands to achieve a desired nutrient removal rate. While this approach has proven effective for secondary wastewater treatment, much less is known about wetlands designed for stormwater runoff.

Great variation exists in the pollution pathways of stormwater runoff. "Black box" studies of constructed wetlands, in which inflow and outflow concentrations are measured to yield the mass balance, tell us part of the story. We still don't really know where exactly in the system the bulk of nutrients are being removed. Pollutant pathway studies in mesocosms can tell us more about the relative importance of the individual nutrient removal processes (e.g., filtration, adsorption, ion exchange, assimilation, denitrification) and consequently the suitability of one wetland design or another for stormwater treatment.

Existing data on the nutrient removal rates of stormwater ponds and wetlands vary considerably due to the differences in type, location, size, maintenance, or age of the wetlands. "Wetlands" span the continuum from ordinary wet ponds to carefully planted marshes. Some argue that the vegetation in constructed wetlands is superfluous because the nutrient removal depends only on the surface area of muck. By examining sediment, water (plankton), and vegetation pathways separately, we can identify the key components in a stormwater wetland design.

Controlled experiments with mesocosms make it possible to both study individual nutrient pathways in isolation and control inflow nutrient concentrations to see how removal pathways respond to input concentrations. If enough data are gathered, equations can be derived which water quality managers can actually use to predict the efficiency and load capability of different wetland designs.

Table 1: Removal Rates (mg/m^2/day) and Efficiencies (% Decrease per Day) of Mesocosm Components (Johengen and LaRock, 1993)

	Nitrate N		Ammonium N		Phosphate P	
	Rate	Eff.	Rate	Eff.	Rate	Eff.
Summer						
Plants (growing in sediment)	270	96	246	93	202	72
Sediment alone (unvegetated)	188	76	210	87	185	78
Plants alone*		20		6		0
Water column (plankton)	55	22	155	65	86	37
Fall						
Plants	145	35	285	75	281	73
Sediment alone	72	17	164	43	228	68
Plants alone*		18		32		5
Water column	8	3	64	30	11	4

* Not physically measurable, for comparison only, obtained by subtracting sediment alone from sediment plus plants.

Note: Efficiencies but not rates can be compared between seasons since different influx concentrations were used (0.5 mg/l in summer and 1.5 mg/l in fall for each nutrient).

Are Wetland Plants Really Necessary?

There are multiple removal pathways in pond sediments: pollutants may be broken down through physical and biological processes in the top muck layer and parent soils underneath, some pollutants return to the water column, and nutrients are taken up by plants (Figure 1). In one mesocosm experiment (Johengen and LaRock, 1993), vegetation rooted in sediment was found to be effective at removing nitrogen and phosphorus, but so was unvegetated sediment. In another mesocosm experiment, Crumpton (1993) found little difference between mesocosm cells with plants and those containing unvegetated sediments. Indeed, the amount of nitrate removed could be predicted solely as a function of the inflow concentration. The living plants themselves accounted for little of the nitrogen removal through uptake (Table 1). However, the removal processes that occur in the sediment are dependent on the deposition of organic matter, which increases as the vegetation becomes more established. The plants provide a necessary litter layer and aerobic zone for microbial activity and more significantly, the supply of organic carbon (decaying plants) to promote the denitrification process.

Bare or newly planted wetlands can be jump-started in effect by adding "detritus" (such as hay or leaf litter) in the first season. Thereafter, stormwater wetlands are self-sustaining, high-capacity nitrogen removers, unlike wastewater wetlands which operate on a different principal[1]. In this sense, the vegetation is essential to the system. Mature vegetated wetlands have a removal capacity that is as much as five times higher than the unvegetated zones (Crumpton, personal communication). Because it is the *supply of organic carbon* that determines nutrient removal - much more so than uptake by living plants - nitrogen removal can be expected to continue after the plants have died back in the fall, except where the soil is completely frozen.

The contribution of the substrate micro-organisms in phosphate removal is also stressed in these studies (Figure 2, Table 1). Like nitrate removal, phosphate removal rates are greater in the sediments than in the water column. Phosphate removal in vegetated and unvegetated sediment remains high in the fall, after the plants have died back. In the vegetated sediment experiments, the sediment accounted for 80 to 100% of the phosphorus removal (Johengen and LaRock, 1993) .

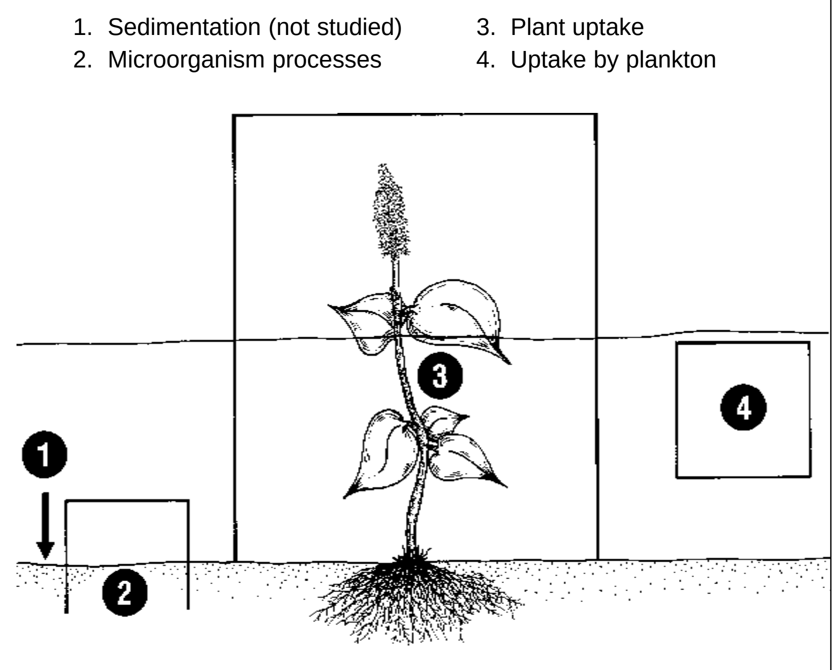
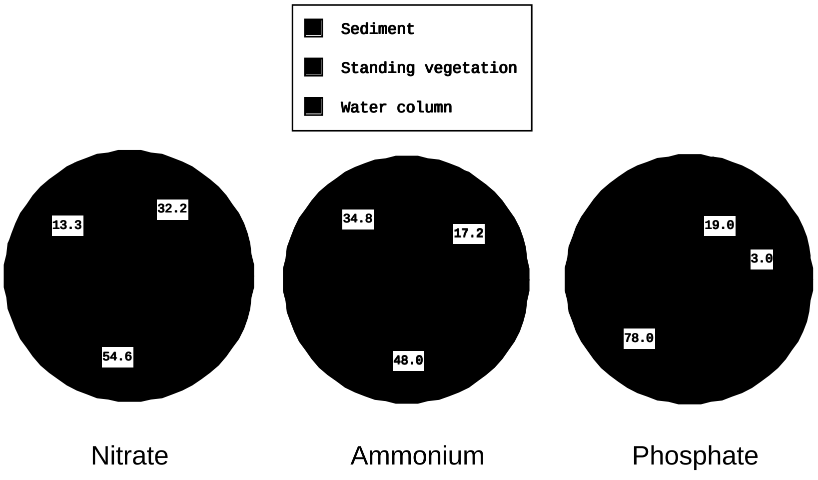


Figure 1: Isolated Nutrient Removal Pathways in a Mesocosm Experiment



Note: Based on removal efficiency data from Table 1, averaged for summer and fall.

Figure 2: Contribution of Different Wetland Components to Nutrient Removal

How Much Nitrogen Can a Wetland Take?

The chemical conditions suitable for the denitrification process that converts nitrate to nitrogen gas exist in wetlands but few actual measurements of denitrification have been made. In controlled mesocosms, Crumpton found that the denitrification rate was only limited by the amount of nitrate put in; a higher influx resulted in higher nitrate processing. It would at first seem unlikely that removal could continue indefinitely. In Crumpton's mesocosms, a dose of 8 mg/l N was completely removed in five days and 20 mg/l was removed in seven days—a time period within the residence time of a typical wetland.

---

[1] Nitrogen in sewage wastewater is in the form of ammonium, not nitrate. Ammonium denitrification requires aerobic conditions - the reason for aerating devices in some of these systems. Also, the phosphorus in the wastewater system will be higher than in a typical stormwater wetland.

Table 2: Stormwater Wetland Mesocosm Studies

	Johenegen and LaRock, 1993	**Crumpton, 1993**
Site	Jackson Co., Florida	Iowa State Univ. Experimental Farm
Type	Newly constructed filtration impoundment/artificial marsh built on stream, designed to receive stormwater from urbanized watershed; "mesocosms" are Plexiglass isolation chambers (Figure 54.1).	1. Array of 48 mini-wetlands (polyethylene cells) containing planted cattail. 2. Bench-top micro-chambers for sediment-only study.
Dimensions	2.5-ha marsh 45 cm deep (avg), 2 m deep outfall pool (2 m deep).	Wetland cells: 3.35 m diam., 90 cm deep, 60 cm soil. Microcosms: 2-in. diam. sealable cells for tracer injection into sediment and gas measurement
Soil	Clay bottom, some detritus	Obtained from a drained wetland
Vegetation	Planted *Pontedaria*, volunteer duckweed	Planted cattails
Methodology	Isolation, controlled enrichment (nitrate, phosphate, ammonium), and sampling (for inorganic and organic solids, total phosphorus and nitrogen, ammonium and nitrate, orthophosphate, chlorophyll-a, and dissolved oxygen) of bare sediment, plankton in water column, and aquatic plants (rooted in sediment) in Plexiglass chambers; values of nutrient uptake from these isolated pathways compared with overall inflow/outflow measurement.	Mesocosms tested for repeatability and approximation to natural systems after one growing season; static and flow-through wetland cells given controlled enrichment, concentration of nitrate in water measured. Bench-top sediment-only cells injected with isotope tracer to measure denitrification rate.
Results	• pH and dissolved oxygen not a factor in nutrient removal • Plant systems most effective in removing nitrogen (ammonium and ammonia the same) • Sediment most effective in removing phosphate, ammonium removed at a greater rate than ammonia • Water column (plankton) removal efficiency poorer than plants and sediment (half the phosphate); ammonium assimilated over ammonia • High phosphorus removal capacity of the sediments makes possible nutrient removal at low N:P ratios • Duckweed had significant N and P removal effect in sediment and water column chambers but not in macrophyte chambers (probably out-competed) • Removal rates in sediment and water column increased with higher concentration	• Nitrate removal in wetlands can be modeled based solely on nitrate influx and diffusion path from anaerobic sediment to surface • Decaying plant litter provides the site for denitrification • Sealed microcosm experiments with labelled nitrogen confirm that nitrate removal rate is linear and increases with increasing influx concentration. Later sealed mesocosm results also confirm this.

Crumpton conducted further studies for longer time periods and at higher influx concentrations (30 mg/l, the upper limit of agricultural waste) and still saw a 10 to 25% daily nitrogen removal. Crumpton's mesocosm results suggest that well-designed stormwater wetlands can achieve higher nitrogen removal rates than are customarily measured in mass balance studies where removal seldom exceeds 40 to 50% (Schueler, 1994). Longer residence times, a larger supply of organic matter, and shallower water depths all appear to be design variables worth pursuing.

—JMC

References

Crumpton, W. G., T. M. Isenhart, and S. W. Fisher. 1993. "Fate of Non-Point Source Nitrate Loads in Fresh Water Wetlands: Results From Experimental Wetland Mesocosms." *Constructed Wetlands for Water Quality Improvement*, ed. G. A. Moshiri, 632 pp. Lewis/CRC Press.

Johengen, T. H., and P. A. LaRock. 1993. "Quantifying Nutrient Removal Processes Within a Constructed Wetland Designed to Treat Urban Stormwater Runoff." *Ecological Engineering* 2: 347-366.

Schueler, T. R. 1994. "Review of Pollutant Removal Performance of Stormwater Ponds and Wetlands." *Watershed Protection Techniques* 1(1): 17-19.