Phosphorus Release from Soils in Restored Farmed Wetlands

By James A. Montgomery, Ph.D. and J. Marshall Eames, Ph.D.
DePaul University, Department of Environmental Science and Studies

Abstract

In northeastern Illinois, restored wetlands have been used to improve water quality in streams degraded by agriculture and urban development. The effectiveness of restored freshwater wetlands in reducing nitrogen in waterways is well documented; however, fewer studies address their effectiveness in removing phosphorous, despite the fact that phosphorus is frequently the limiting nutrient in these systems. Since 1998, we have conducted systematic water quality monitoring at Prairie Wolf Slough Wetland Demonstration Project (PWS), a restored palustrine emergent wetland located on abandoned farm fields adjacent to the Chicago River in Lake County, Illinois. Our objectives are to assess long-term spatial and temporal variations in soluble reactive (SRP) and total phosphorous (TP) and compute a mass balance and retention efficiency for these constituents. Water samples regularly are collected from five sites, including a swale carrying urban stormwater runoff into PWS, and the wetland's outlet to the Chicago River. Water quality and flow data indicate that the restored wetland acts as a point source for SRP and TP reaching the Chicago River. Long-term mean SRP and TP concentrations increased 279% between the inlet and outlet. Soil testing and analysis of phosphorus release from decaying vegetation suggest that net phosphorous export was likely due to exposure of P-laden sediment to anoxic conditions during flood events. Weekly synoptic sampling in 2008-2009 confirm these results and demonstrate the need for including both soil and water quality testing into wetland restoration planning, design and monitoring protocols.

Key Words: restored wetlands, phosphorus, nutrient retention, shallow marsh, water quality

Introduction

This study is part of a larger on-going project to study the role of restored wetlands in phosphorus dynamics of urbanizing Midwestern watersheds. The PWS site was drained and farmed for nearly a century and is believed to have been treated with rock phosphate fertilizers. Over the project's nearly 15 year duration, several studies have identified the following characteristics of PWS:

- Restored and constructed wetlands are being promoted as an ecotechnology for reducing nutrient and sediment in surface water runoff in Northeastern Illinois.
- PWS is a restored farmed wetland in Northeastern Illinois that has been functioning as a P source to the Middle Fork of the North-Branch Chicago River.
- Orthophosphate is the major inorganic form of phosphate, and includes the ions PO_4^{-3}, HPO_4^{-2}, and $H_2PO_4^-$. SRP (soluble reactive phosphorus) is the analytical measure of the biologically available forms of orthophosphate.
- The contributions of P from the upstream watersheds do not account for the P being released to the Middle Fork from PWS.
- The uptake of phosphate minerals by rooted wetland plants and subsequent release to the water column from decaying biomass is a source of P at PWS.
- The release of P directly from sediments exposed to repeated wet/dry cycles is proposed as a potential source of P at PWS.
- The decomposition of detritus material releases SRP to the water column increasing the amount of bioavailable P in the ecosystem and the potential for SRP to be transported to downstream aquatic habitats.
- Waterfowl may be an unaccounted source of P at PWS.

The focus of this study is to quantify the direct release of P from soils within the wetlands emergent zone. This supports the long-term objective of developing a quantitative model of phosphorus cycle in restored wetlands. It supports a second objective of providing guidance for restoration and water resources professionals.

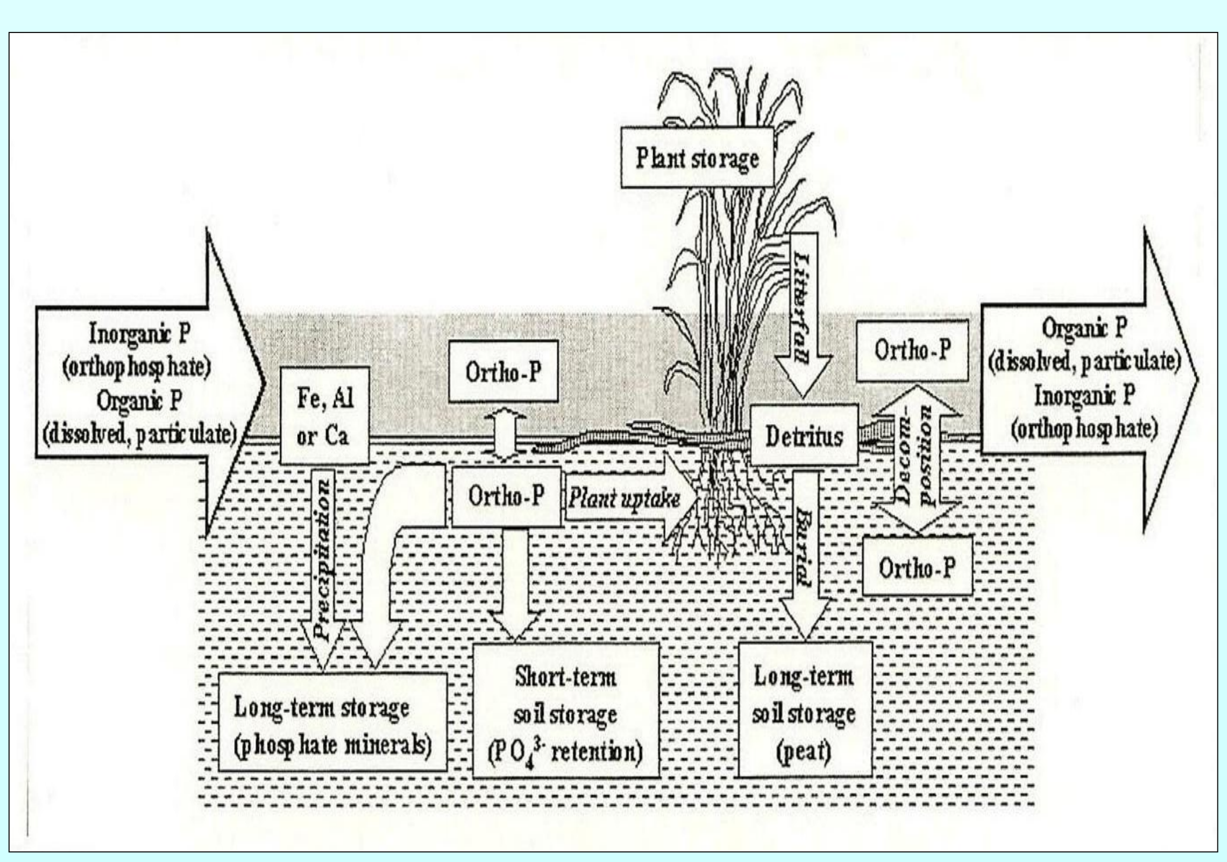

Figure 1: A conceptual model of the fate of phosphorus in wetland similar to Prairie Wolf Slough.

Site Description

PWS is a constructed wetland located in unincorporated Lake County, Illinois (T43N, R12E, Sec 17). It is owned and managed by the Lake County Forest Preserve District. The wetland drains 98 ha (242 ac) into the Middle Fork of the North-Branch Chicago River **(Figure 2)**. The site is approximately 14.1 ha (35 ac) in total area and was drained for farming in the early 1900s. In 1994, 10.1 ha (25 ac) of the site was restored from farmland to wetland and the remaining 4 ha (10 ac) was left as a woodland. The wetland was hand-planted with 61,000 plugs (≈ 1 plug/m²) and approximately 3 ha was open water. Nearly all the off-site water discharging to the wetland flows through a swale from a from a detention basin (inlet). The marsh water elevation and discharge to the Middle Fork of the North Branch is controlled by an adjustable weir (outlet). The upstream watershed is a mixture of retail commercial, office parks and suburban single family residential uses. The shallow marsh typically has a depth of ≤ 0.5 m. During hot, dry summers, water levels have dropped exposing the bottom sediments.

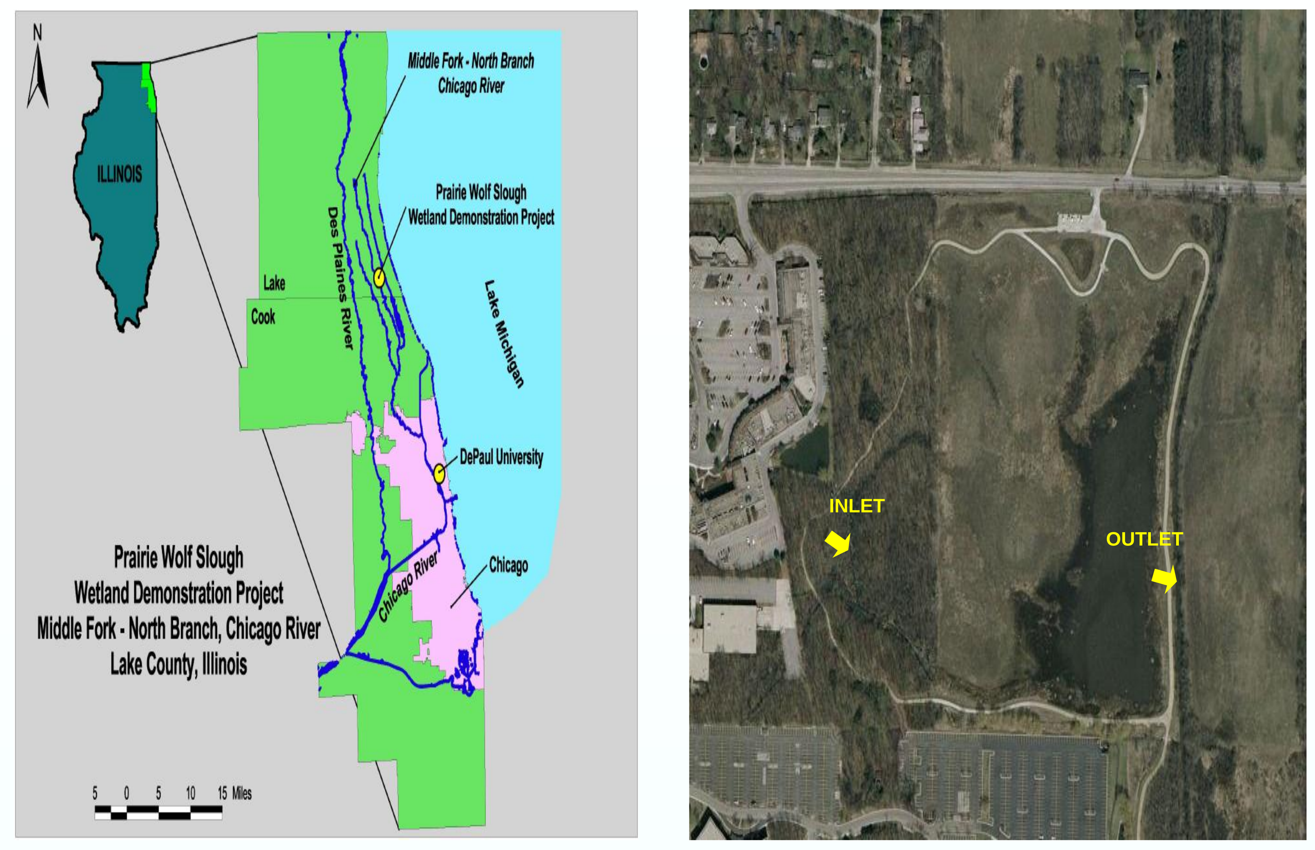

Figure 2: Location map and aerial photo of Prairie Wolf Slough at the Middle Fork, Chicago River

Methods

- Water samples have been collected bi-monthly at inlet, outlet and marsh sites since 1998 and are analyzed for TP, SRP and other constituents following protocols from American Public Health Association, American Water Works Association and Methods of Soil Analysis.
- Temperature, pH, dissolved oxygen, conductivity and oxidation-reduction potential were measured *in situ* using YSI 600 XL sonde.
- Level and discharge at the inlet and outlet were measured at 30-minute intervals using an ISCO bubbler flowmeter and more recently using a HOBO U20 Water Level Data Logger.
- Phosphorus concentrations in upland soils and deposited sediment in the marsh, and soil from an analogous abandoned farm site on the east side of the river were analyzed using Mehlic 3 extraction and molybdovanadate method. Samples were filtered and tested using the Hach™ method 8048 on the DR5000 UV-Vis spectrophotometer for soluble phosphorus.
- A soil phosphorus depth profile was developed for the PWS site using the results from the soil extractions.
- Weather data including precipitation, temperature, wind velocity, humidity, solar radiation and soil temperature were collected at PWS from an on-site weather station located at the outlet.
- Release of P from detritus over two months was estimated from bench scale studies using aquaria, known biomass loading, and three temperature regimes. SRP was analyzed following USEPA method 300.0 (A).
- Wetland hydrology and flow patterns are being evaluated using Li ion tracer studies.
- Release of soluble reactive phosphorus from root-zone soil strata is being evaluated using soil water diffusion samplers, which consist of an aluminum frame with acrylic diffusion chambers mounted at selected depths **(Figure 7)**.

Results

The average annual flow from 2007-2008 at the inlet was 18.1 m³/hr and at the outlet 13.5 m³/hr. The total annual discharge at the inlet was estimated to be 1.32 x 10⁵ m³ and 0.979 x 10⁵ m³ at the outlet. This results in 3.41 x 10³ m³ of storage and a retention efficiency of 26%. Outlet discharges generally exceed those at the inlet from January through June and is attributed in part to snowmelt. The change in discharge balance may in part be attributed to higher evapotranspiration during the summer and fall.

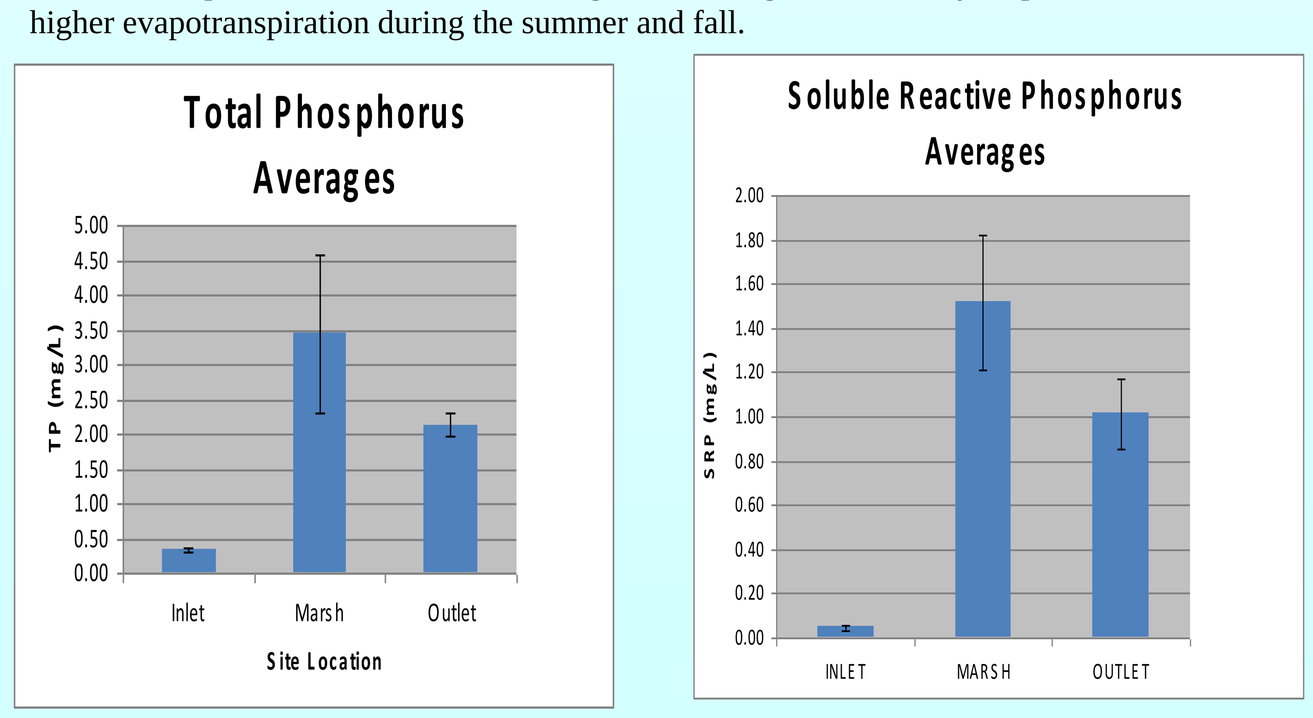

Figure 3: Long term average TP and SRP concentrations in the inlet, open marsh, and outlet waters at PWS. Average values among the three sample locations are significantly different (p<0.05).

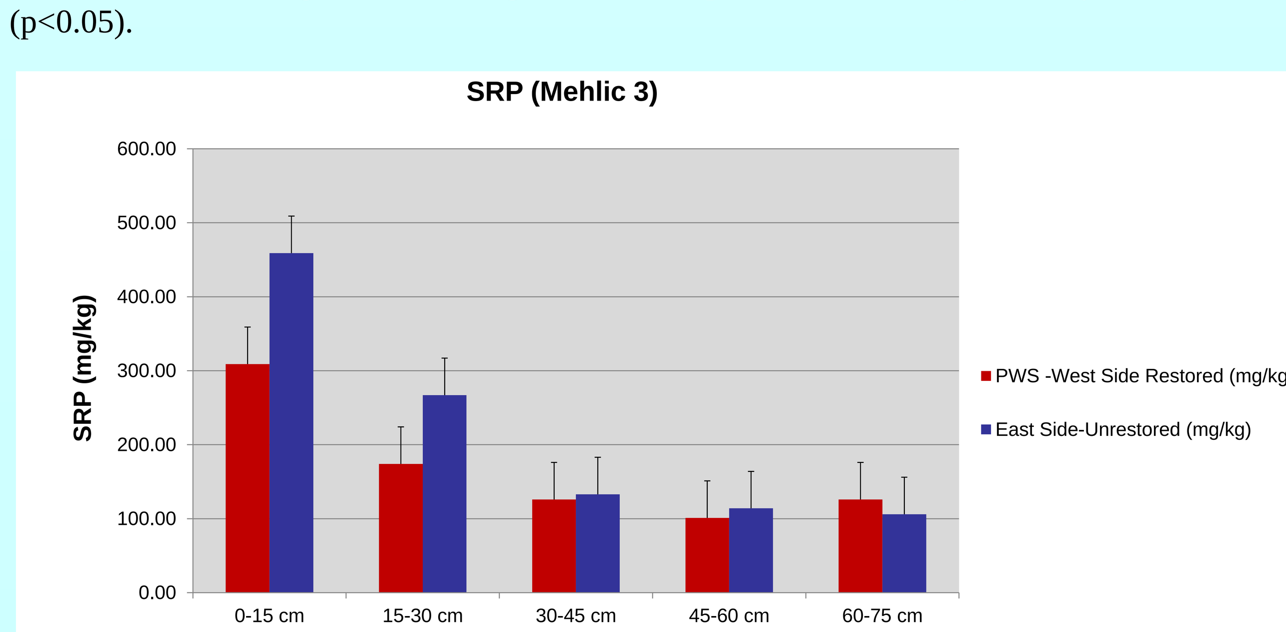

Figure 4: Average levels from PWS sediment and soils compared to analogous unrestored site. Bars represent standard error. The averages at depths 0-15 cm and 15-30 cm are significantly different (p < 0.05).

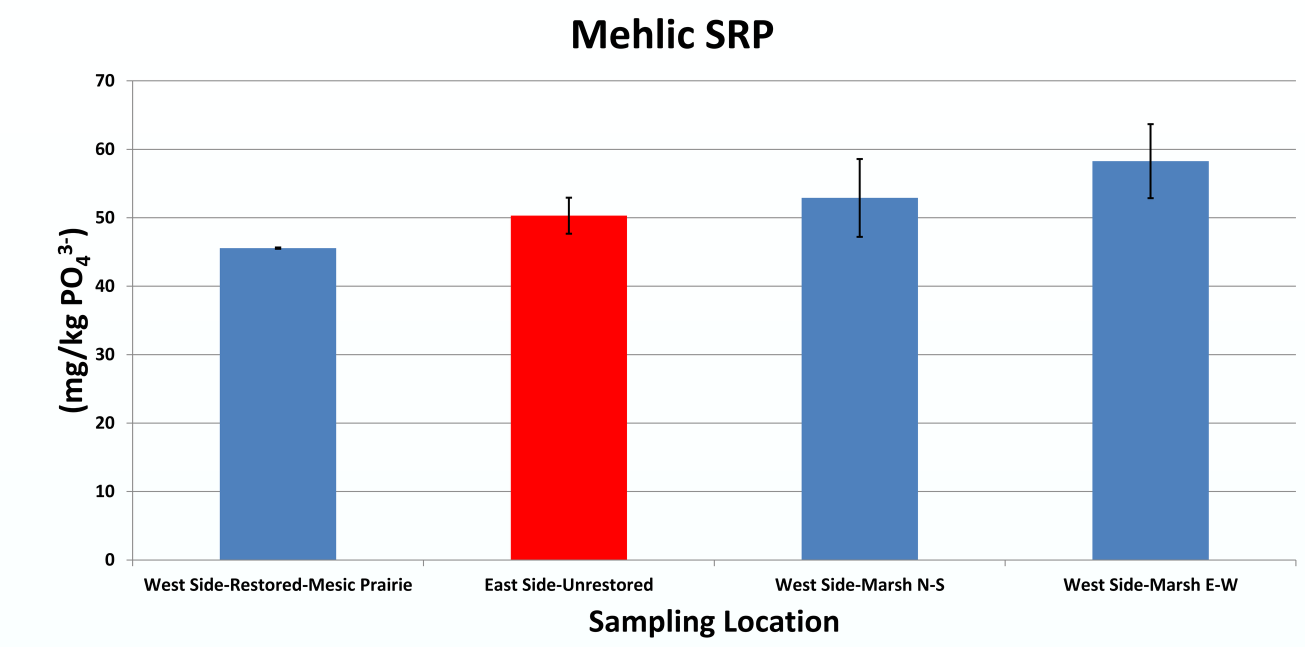

Figure 5: Comparison of Mehlic 3 mean SRP concentrations between restored and unrestored sites. Mean SRP in the West Side restored mesic is nominally less than the other sample locations; however, these means are not statistically significant (p = 0.13).

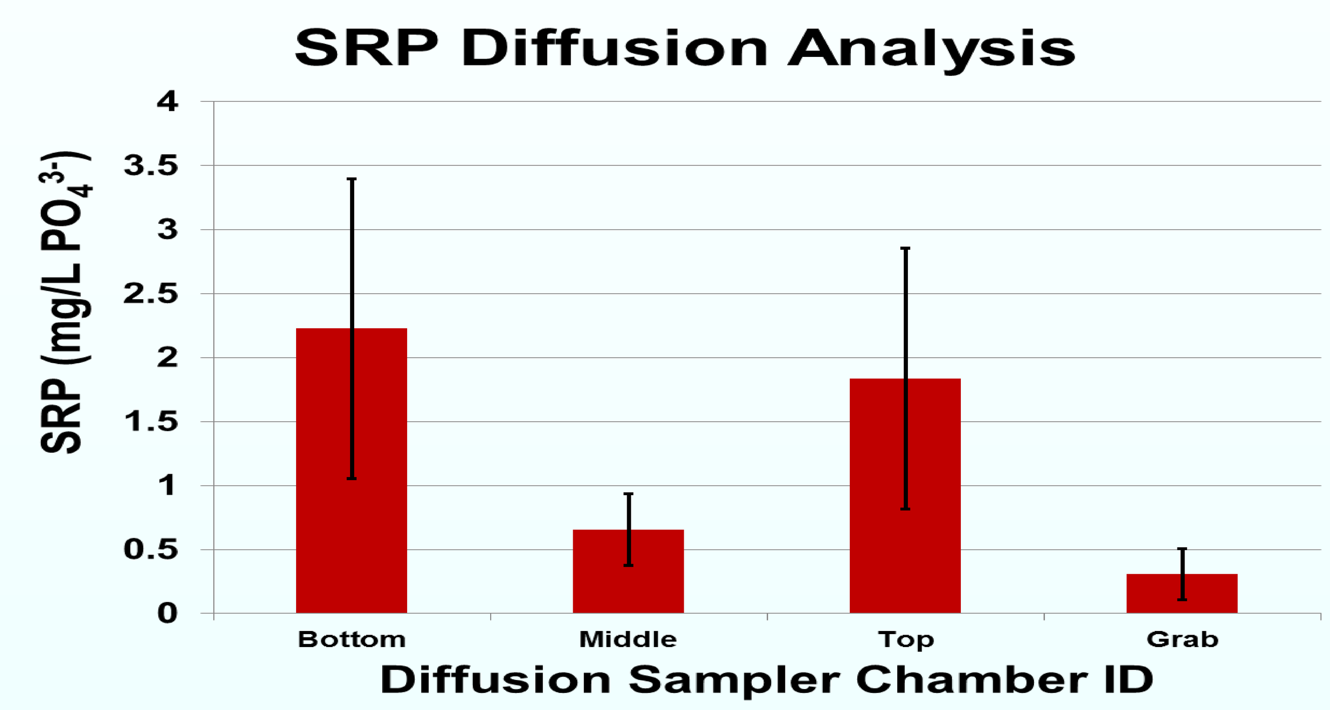

Figure 6: Comparison of mean SRP concentrations from three depths of marsh soil (bottom, middle, top) with the overlying water column (grab). (n = 5)

Discussion/Conclusion

Long-term monitoring of water quality at PWS led to the unexpected result that phosphorus was being exported to the Chicago River in greater quantity than was entering the marsh from adjacent land uses within the PWS watershed. Both TP and SRP concentrations are approximately an order of magnitude higher at the outlet than the inlet **(Figure 3)**. Our earlier studies demonstrated that suspended and dissolved solids were higher in the inlet waters than the outlet, suggesting that the source of P being discharged to the river is the marsh itself. This hypothesis has spurred the ongoing research at the site.

Building upon the conceptual model shown in **Figure 1**, we investigated other potential sources of P in the marsh, focusing upon the remobilization and release of P from sediments and soils in the marsh and surrounding prairie. Subsequent studies of soil in upland areas surrounding the palustrine marsh show significant depletion of soil SRP in the upper 30 cm when compared to the soils from the unrestored site east of the Chicago River **(Figure 4)**. No statistically significant difference in SRP was seen between soils deeper than 30 cm. Mean SRP concentrations from soils collected in upland areas surrounding the marsh (West Side-restored) were not statistically significantly different from mean SRP concentrations from soils collected on the east side of the Chicago River (East Side-unrestored). Also, mean SRP concentration in the West Side-restored prairie soil is not statistically significantly different than the West Side marsh N-S and E-W transects (p=0.13; **Figure 5**). Our earlier bench scale studies (data not shown) showed that SRP release from decaying plant material was temperature dependent and took place rapidly at temperature above 20° C. As much as 250 mg of SRP was released per kilogram of biomass (wet weight) in ≤ 21 days. We recently launched a study to examine the direct release of P from soil and accumulated sediment in the West Side-restored palustrine marsh. A prototype soil diffusion chamber apparatus was installed in the West Side-marsh **(Figure 7).** The approximate distance between each chamber was 7 cm. The apparatus was buried to a depth of 33 cm. Samples were drawn from each chamber using a 3-way Luerlock and a 60-mL syringe. **Figure 6** shows mean SRP concentrations for each chamber. Preliminary results based upon five samplings suggest an upward gradient in SRP from the mineral soil (bottom chamber) through a layer of senescing biomass (top chamber) to the water column. Mean SRP concentrations were statistically significantly different ($p < 0.1$). However, this process may be substantially more complicated. Based upon these results, we believe that P from the accumulated biomass and sediment in the West Side-marsh, and from the West Side-marsh soils, is being mobilized into the water column. Other potential sources of P include water fowl feces and atmospheric deposition. These will be the focus of new studies. **Past land use history and soil properties should be evaluated on candidate wetland restoration sites. Post-restoration management practices should include long-term monitoring (at least 10-20 years).**

Figure 7: Photos show the diffusion sampler in the lab, deployed at PWS, and during sample collection.

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