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Prairie Wolf Slough: A Case Study Illustrating the Need for Incorporating Land Use History and Soil Quality Assessment in Wetland Restoration Planning, Design and Monitoring

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INTRODUCTION

This poster presents a cautionary tale of what can happen if past land use history and soil quality indicator assessment are not incorporated into wetland restoration protocols. In particular, "legacy P" derived from point and non-point sources in agricultural land uses is of concern in wetland restoration (Steinman & Ogdahl, 2016; Sharpley et al, 2013). Legacy P may be temporarily stored and subsequently remobilized or recycled within wetlands, and wetlands may serve as a source of or sink for P, with residence times on the order of years, decades and centuries (Aldous et al, 2007).

Since 1998 we have monitored water quality at Prairie Wolf Slough Wetland Demonstration Project (PWS), a peri-urban restored farmed wetland in north suburban Chicago **(Figure 1)**. The restoration was undertaken to demonstrate the efficacy of restored wetlands in improving stormwater quality in the Chicago River watershed. The results of the first phase of this project were published in Montgomery & Eames (2008), who found that while PWS was effective in reducing concentrations and loadings of salts, DO, NO_3-N, NH_4-N, and SO_4-S, total solids (TS) and total suspended solids (TSS), it exported P to the adjacent Chicago River. However, the authors did not investigate other potential sources and pathways of P into and out of the wetland, including legacy P or P inputs via atmospheric deposition. In addition, in 2004 the Illinois Department of Transportation widened Illinois Route 22 (IR-22), which forms the northern boundary of PWS, resulting in the hydraulic disconnection of a residential storm sewer sub-basin (sub-basin 5; **Figure 2**) that delivered runoff from residential land use impervious surfaces to PWS during high precipitation events .

Research Questions:

1. What impact did widening of IR-22 widening have on P dynamics?
2. What are other potential sources and pathways of P (e.g. including legacy P) into and out of PWS?

OBJECTIVES

1. Describe the spatial and temporal changes that have occurred in stormwater discharge and concentrations and loadings of TP and SRP over the lifetime of this investigation (1998-2014).
2. Evaluate the impacts of road widening on spatial and temporal variations in stormwater discharge and P concentrations and loadings into and out of PWS.
3. Quantify the contributions of both legacy soil P and atmospheric P deposition to the P pool.
4. Compute hydrologic and P mass balances and retention efficiencies.
5. Develop best practices concerning restoration design and post-restoration soil and water quality monitoring for practitioners engaged in wetland restoration planning and design.

SITE DESCRIPTION

PWS is a peri-urban restored farmed wetland in unincorporated Lake County, Illinois (T43N, R12E, Sec 17; **Figure 1**), located approximately 50 km north of the Chicago Loop. Owned and managed by the Lake County Forest Preserve District, PWS drains a 98 ha (242 ac) residential/commercial sewershed, consisting of five sub-basins **(Figure 2)** into the Chicago River. The site encompasses 14.1 ha (35 ac) and was drained for farming in the early 1900s. In 1994, 10.1 ha (25 ac) of the site was restored 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/m^2) and ≈ 3 ha was open water. Nearly all the stormwater entering PWS flows through a swale leading from a detention basin ("inlet" – subbasin 3, **Figure 2**). The marsh water elevation and discharge to the Chicago River are controlled by an adjustable rectangular weir ("outlet"). Sub-watersheds 1-3 and 5 are a mixture of retail, office parks and single family residential uses. Ecological communities include open-water marsh, savanna, mesic and wet prairie. East of the Chicago River is an unrestored previously farmed field that serves as an analog site against which to compare the impacts of restoration on P dynamics (**Figure 3**).

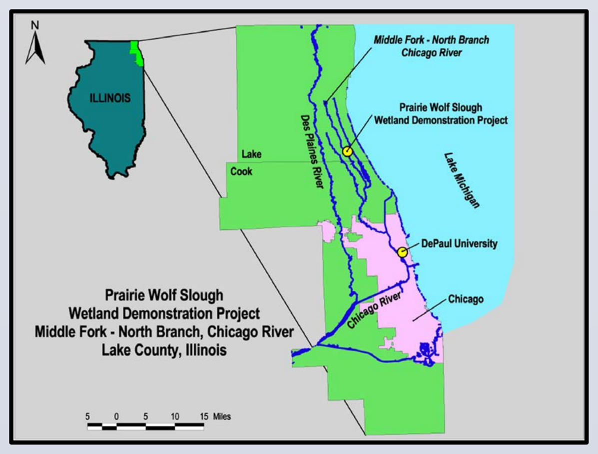

Figure 1

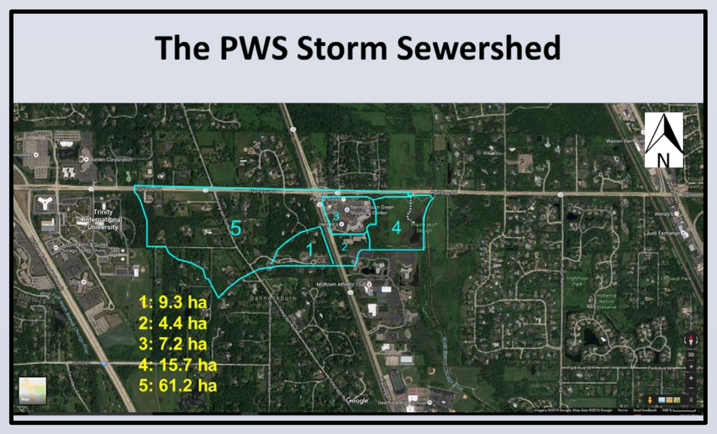

Figure 2

Figure 3

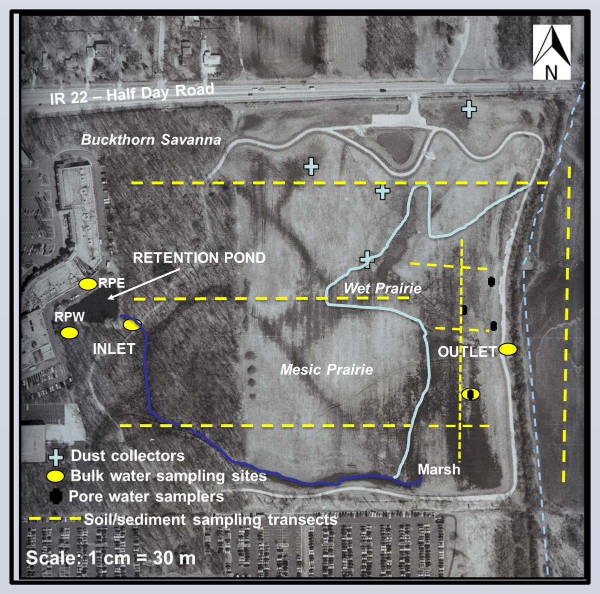

Figure 4

RESULTS

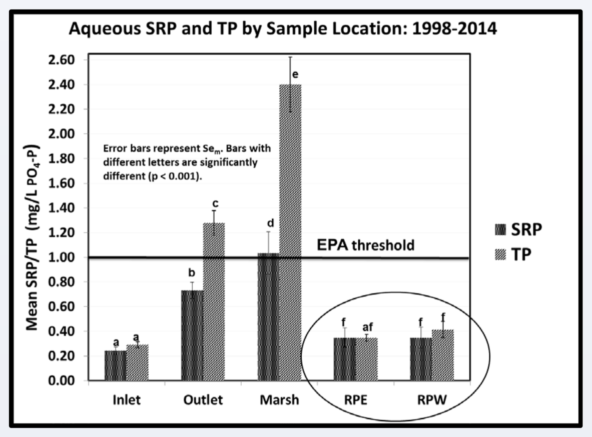

Figure 7

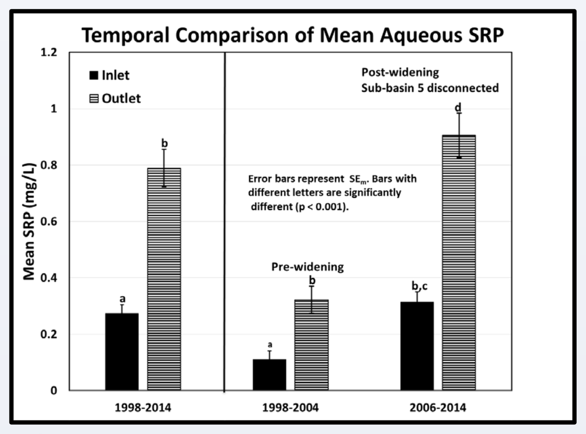

Figure 8

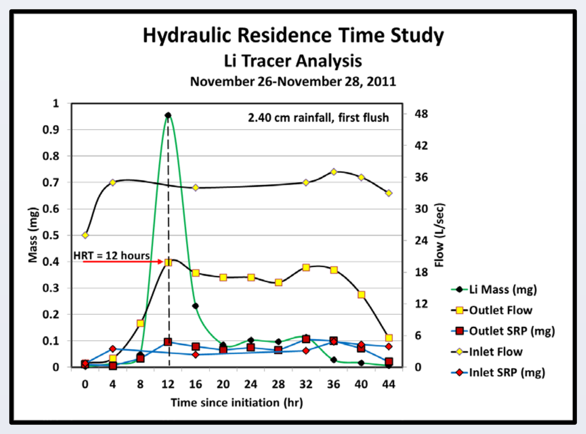

Figure 9

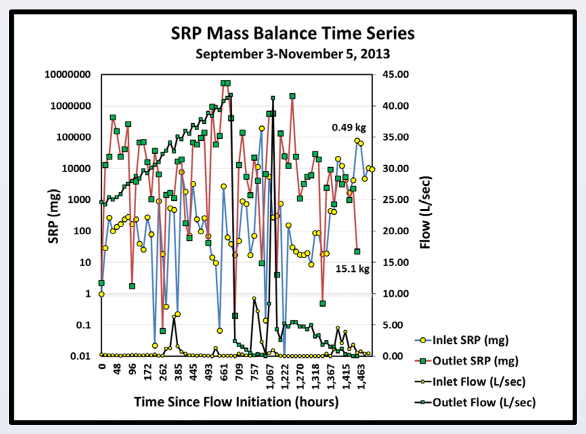

Figure 10

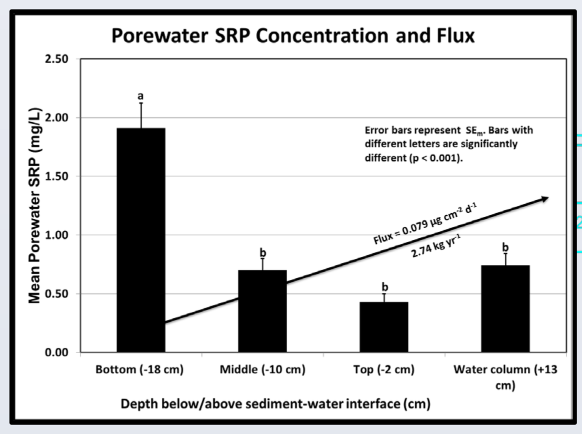

Figure 11

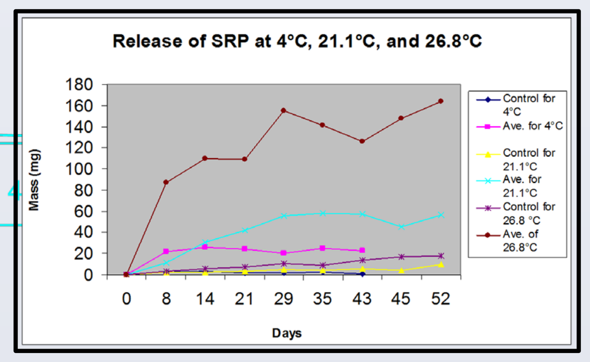

Figure 12

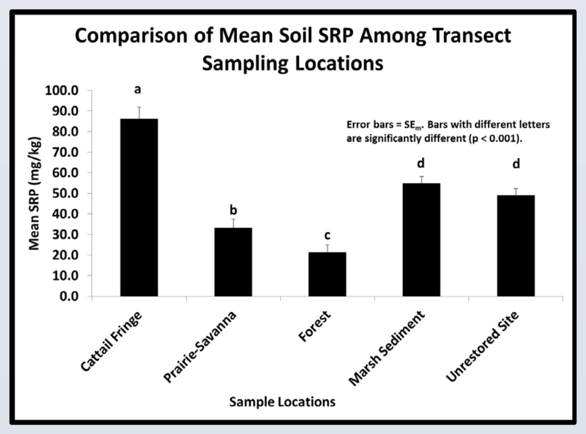

Figure 13

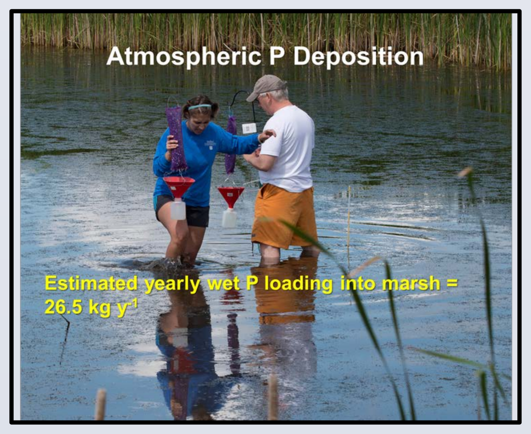

Figure 14

MATERIALS AND METHODS

- Bi-monthly synoptic bulk water samples collected at the inlet, outlet and marsh sites since 1998 **(Figure 4)**. Temperature, pH, DO, SPC, redox measured *in situ* using YSI™ 600 XL sonde.
- Inlet flow measured with a 90° V-notch weir and at outlet with a rectangular weir.
- Bench scale measurement of SRP release via cattail biomass decomposition measured using twelve 19-L aquaria, each with 400 g of dried biomass, at three temperature regimes.
- Pore water TP and SRP measured at three depths below the sediment surface in the marsh using acrylic samplers mounted on aluminum frames **(Figure 5)**.
- All bulk water and aqueous samples analyzed for TP and SRP following APHA (2005) methods.
- Soil SRP and TP extracted using Mehlic 3 and measured using the molybdovanadate method (Hach™ Method 8048) on a Chinchilla™ EasyChem analyzer.
- Hydraulic residence time (HRT) measured using Li ion tracer added to flow at inlet on 11/26/11. Samples collected at outlet every 4 hours from (11/26/11 – 11/28/11) using an ISCO™ sampler. Li concentration measured using Flame AA spectrometry.
- SRP and flow mass balance computed during period of 9/3/13 – 11/5/13. Samples collected every 6 hours using an ISCO™ sampler.
- Atmospheric SRP and TP deposition measured using dust samplers (**Figure 6)** constructed by Shah (2014).
- Water quality data analyzed for three time periods: (**1) 1998-2014 (Comprehensive); (2) 1998-2004 (Pre-IR 22 widening); (3) 2006-2014 (Post-IR 22 widening).**
- Statistical analyses – performed using R (R Core Team, 2012) on the following data sets:
  - **Bulk Water P:** We tested whether mean SRP and TP at the outlet **(Figure 4)** were significantly greater than the inlet using Wilcoxon signed rank paired t-tests. SRP and TP concentrations did not meet the assumption for normality and were $\log_{10}$ transformed.
  - **Porewater P**: ANOVA was used to test for differences in mean concentrations among porewater chambers. Data were natural log (ln) transformed for normality prior to analysis. Means were compared using Tukey's HSD.
  - **Soil "Legacy" P**: ANOVA used to test for differences in SRP among habitats along down-gradient hydrologic transects **(Figure 4)**. Data were natural log transformed for normality prior to analysis. Means were compared using Tukey's HSD.

Figure 5

Figure 6

DISCUSSION

Figure 7: Outlet SRP and TP concentrations are significantly greater than all other sampling locations. SRP and TP concentrations at RPE/RPW are similar to inlet, indicating the retention pond is filtering out P-laden sediments. SRP and TP concentrations at marsh are both > 1.0 ppm EPA threshold for eutrophication and significantly greater than all other locations, indicating internal P cycling.

Figure 8: Outlet mean SRP was significantly greater than inlet mean SRP in comprehensive, pre-widening, and post-widening time periods. Mean SRP increased 189%, 192% and 188% between the inlet and outlet sites for the comprehensive, pre-widening and post-widening time periods, respectively. We hypothesized that excess stormwater and snowmelt runoff from the residential subdivision in sub-basin 5 contributed excess SRP into PWS (sub-basin 4). However, after sub-basin 5 was hydraulically disconnected from PWS during IR-22 road widening, post-widening outlet mean SRP concentration increased 182% from the pre-widening outlet concentration. This increase may indicate that the excess stormwater and snowmelt runoff generated from impervious surfaces in sub-basin 5 and delivered to PWS during the pre-widening period effectively diluted SRP concentrations at the outlet.

Figure 9: HRT = ~12 hours. 3,257,770 L were stored in the marsh (60% retention). 37 g of SRP was exported from the marsh in the Chicago River. For the period, 22 April 2012 thru 10 May 2013 (data not shown) 219 kg of SRP was exported from PWS through the outlet to the Chicago River. During the same time period, we estimated that the inlet contributed only 6.4 kg. That accounts for less than 3% of the SRP loading to the river. In a subsequent study (data not shown) from 31 July to 18 November 2013, 85.7 kg of SRP was exported while only 1.8 kg or 2.1% was accounted for at the inlet.

Figure 10: Average flow rate increased 1,940% between inlet and outlet. 862,000 L of stormwater were exported to the Chicago River due to increased flow contributions from sub-basins 1 and 2 **(Figure 2)** which deliver stormwater to a dry-bottom detention pond in sub-basin 2. Water from the detention pond flows through a swale that is confluent with the swale draining a wet bottom retention pond in sub-basin 3. SRP mass concentration increased 3,800% between the inlet (0.45 kg) and outlet (17.5 kg).

Figure 11: Mean SRP in -18 cm chamber is significantly greater than mean SRP in all other chambers. There is an upward flux (computed using Fick's First Law) of SRP to water column, contributing as much as 2.74 kg yr^{-1} of SRP.

Figure 12: Bench-scale studies show a positive correlation between water temperature and the release of SRP from cattail biomass. At typical summer water temperatures (27°C), the mean SRP release rate after five days was 217 mg kg^{-1} of biomass, and 409 mg kg^{-1} of biomass after six weeks. Mean summer SRP release after six weeks was 7.3X greater than mean winter SRP release.

Figure 13: Mean SRP in the cattail fringe was significantly greater than all other habitats. There was not significant difference in mean SRP between the marsh sediment and the unrestored ("analog") site **(Figure 3).**

Figure 14: Using the average daily rates developed from our atmospheric deposition study (Shah, 2015), we estimated that the marsh covered by cattails could contribute 17. 3 kg of SRP and the open water marsh another 9.2 kg. This suggests that as much as 26.5 kg of SRP or 12% of the exported SRP (219 kg) could result from atmospheric deposition on the 3.4 ha marsh. During the subsequent study later in 2013, we estimated that 7.7 kg of exported SRP or 9% could be explained by atmospheric deposition.

CONCLUSIONS

Concentrations and mass loadings of stormwater P at the outlet were significantly higher than at the inlet for the 18 year duration of this study. Other sources and pathways of P into PWS include **legacy P** derived from pore water flux from marsh sediment, P release due to cattail biomass decomposition, P release resulting from wind-induced resuspension of sediments, and atmospheric P deposition. The fact that there was no significant difference in P concentrations between the marsh sediments and the soils collected from the unrestored "analog" site, both of which were farmed and probably received inputs of rock phosphate, supports our conclusion that excess P into PWS came from various legacy P and atmospheric sources. Twenty years after restoration was completed, PWS remains a point source of P into the Chicago River. Understanding the link between wetland soil quality and water quality is an important consideration in selecting candidate sites for restoration. Detailed site history of a candidate restoration site should be conducted, and potential legacy P sources should be identified and quantified, particularly if water quality improvement is a prime goal. **Finally, most importantly, post-restoration management practices must include long-term monitoring (5-10 years) of water and soil quality.**

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