Foreseeing critical phosphorus cycle transitions in constructed wetlands: applied to the new Tres Rios arid-land constructed wetlands with the city of Phoenix

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Abstract

Constructed wetland ecosystem design and management plans often do not provide the necessary insight into phosphorous (P) cycle dynamics to allow regulatory and management agencies to foresee and adapt to system changes in order to maintain P removal rates as required by law. Insights into critical transitions in wetlands to steady-state P cycling incorporate complexity and will add useful focus into constructed wetland management plans. These insights will allow for better design and management of constructed wetland ecosystems. Three objectives exist within the scope of this project: (1) the results of a dynamic systems model (the Kadlec-Knight K-C* Dynamic Model) will be compared to sample data from the new City of Phoenix Tres Rios constructed wetland system to understand the relationship between nutrient uptake and nutrient release by biomass decay, specifically the rate of a modeled 'critical slow down' in state variables will be compared against sample results; (2) the relationship between the CAP LTER community and the City of Phoenix Water Department will be developed through the co-production of research, in line with CAP LTER III objectives; and (3) a working database will be created to synthesize wetland sample data collected by the City of Phoenix Water Department over the past decade to compare experimental results to a larger temporal scale. The City of Phoenix Water Department recently constructed the Tres Rios wetland system to improve the performance of their 91st Avenue Wastewater Treatment Plant and meet new water quality standards issued by the Arizona Department of Environmental Quality.

Introduction

Constructed wetland ecosystem design and management plans often do not provide the necessary insight into phosphorous (P) cycle dynamics to allow regulatory and management agencies to foresee and adapt to system changes in order to maintain P removal rates as required by law (NPDES Permit No. AZ0020524). A successful management plan must capture the complexities of wetland ecosystem P cycles while simultaneously considering management needs and limitations. To date, most ecosystem management plans are designed to address single problems or stresses and subsequently implement singular solutions. This approach is flawed because: (1) it cannot deal with synergistic phenomena in these complex systems, including cascading effects; (2) it provides little insight into causality, and; (3) it does not adequately account for feedbacks both within and beyond the system. Insights into critical transitions in wetlands to steady-state P cycling incorporate complexity and will add useful focus into management plans. These insights will allow for better design and management of constructed wetland ecosystems. The City of Phoenix Water Department constructed the Tres Rios treatment wetland system to improve the performance of the 91st Avenue Wastewater Treatment Plant and meet new water quality standards issued by the Arizona Department of Environmental Quality. Recently decommissioned pilot study wetlands suggest that the constructed wetland system would successfully polish effluent while supporting high-quality wetland habitat for migratory waterfowl and shorebirds, including endangered species, and protecting downstream residents from flooding at a lower cost than retrofitting their existing treatment plant. The new Tres Rios constructed wetlands are approximately 500-acres (EPA, 2004).

Research Objectives

•Model phosphorus (P) dynamics within the Tres Rios constructed wetland system to better understand critical transitions to steady-state P cycling the water column and storage of P in dead biomass.

•Further develop the relationship between the CAP LTER community and the City of Phoenix Water Department through the co-production of research, in line with CAP LTER III objectives.

• Create a working database to synthesize wetland sample data collected by the City of Phoenix Water Department over the past decade to compare experimental results to a larger temporal scale. This working data base will also be submitted to the CAP LTER Information Manager for use by other researchers.

A dynamic systems model will be created to understand the relationship between nutrient uptake and nutrient release by biomass decay. The Kadlec-Knight K-C* Dynamic Model (Kadlec & Knight, 1996) will be used to study the 'critical slowing down' (Scheffer, et al., 2009) of state variables (specifically biomass P storage and water column P concentration) in the wetland system indicating a transition to steady-state phosphorus cycling.

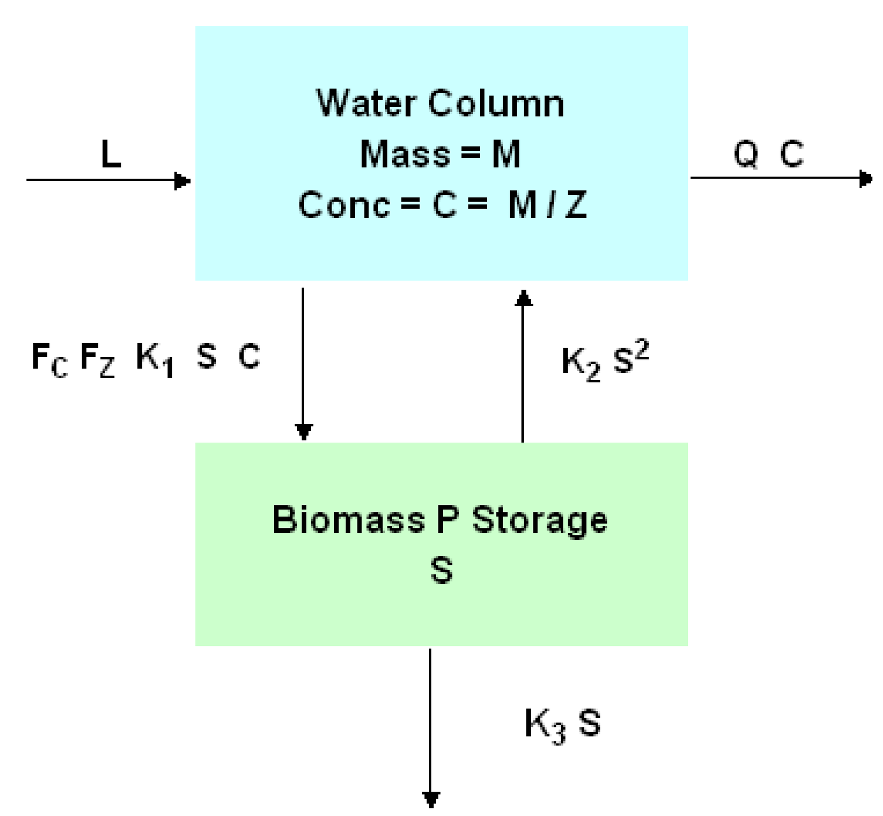

Figure 1: Phosphorous cycling framework; Where, M = water column P storage (mg/m2), S=Temporary P storage in biota (mg/m2), Z=Water column mean depth (m), L=P load (mg/m2-yr), Q=Outflow (m/yr), K1=Maximum uptake rate (m3/mg-yr), K2=Recycle rate (m2/mg-yr), K3=Burial rate (1/yr), Fz=Depth multiplier, Fc=Conc Multiplier (Walker & Kadlec, 2008).

The following equations comprise the model to be used to understand phosphorus cycling in the system:

Storage: $K_1 C = K_2 S + K_3$
Overall: $L - QC = K_3 S$
Solution for C: $C = (K_2 L + K_{32})/(K_3 K_1 + QK_2)$
Solution for S: $S = (K_1 C - K_3)/K_2$

The model will be run initially to predict rates of phosphorus uptake through time as plant species are established, ending in steady state phosphorus cycling. Then test plots throughout the wetland site, containing artificially high percentages of detritus, will be sampled to determine the rate of transition to steady state P cycling as detritus releases P; sample results will be compared to model results to study assumed non-linearity with time of the transition to steady state. The model will then be modified to better predict the non-linear system shift to steady state P cycling per detritus build-up.

Expected Results

•A better understanding of changes in the rates of phosphorous cycling in arid-land constructed wetlands related to critical transitions to steady-state nutrient cycling to be communicated to a wider audience in peer-review publication form and to the City of Phoenix during a project 'close-out' workshop.

•A good standing relationship with the City of Phoenix Water Department thereby allowing future researchers to easily obtain permissions and data related to urban constructed wetlands research.

• Opportunities for undergraduate students to become involved in urban wetlands research and the CAP LTER.

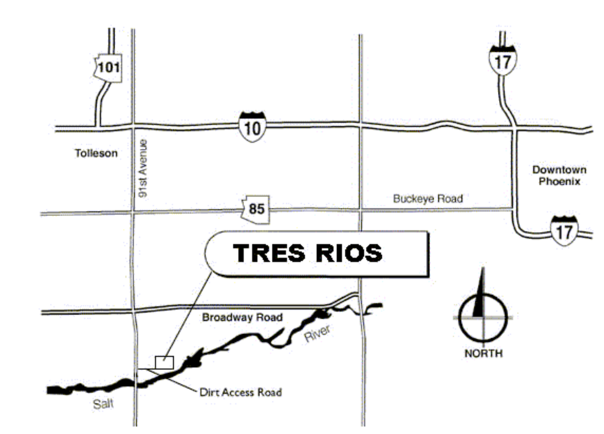

Figure 2. Location of Tres Rios constructed wetlands within Phoenix metro area. http://phoenix.gov/TRESRIOS/faq.html

Conclusion

The proposed work will inform designers and managers of constructed wetland water treatment systems with regards to rates of transitions to steady-state nutrient cycling, thereby allowing them to better incorporate this dynamic into design models and ultimately leading to more effective treatment systems and the protection of our national waterways.

References

DSWA. (2008). *Design Documentation Report for the Tres Rios Environmental Restoration Project Phase II*. Phoenix, AZ: DSWA Inc.

EPA. (1998). *A Handbook of Constructed Wetlands*. Washington, D.C.: EPA.

EPA. (2004). *Constructed treatment wetlands*. Washington, D.C.: EPA.

Kadlec, R., & Knight, R. (1996). *Treatment Wetlands*. Boca Raton, FL: Lewis Publishers.

Scheffer, M., Bascompte, J. B., Brovikin, V., Carpenter, S., Dakos, V., Held, H., et al. (2009). Early- warning signals for critical transitions. *Nature* , 53-59.

Walker, W., & Kadlec, R. (2008). *Dynamic Model for Stormwater Treatment Areas*. Washington, D.C.: U.S. Army Corps of Engineers.