Apr. 2010, Volume 4, No.4 (Serial No.29)
Journal of Environmental Science and Engineering, ISSN 1934-8932, USA

Control of Agricultural Nonpoint Source Pollution by Natural Wetland Management

F.D. Shields, Jr. and C.W. Pearce
Water Quality and Ecology Research Unit, USDA-ARS National Sedimentation Laboratory, Oxford, MS 38655-1157, USA

Received: December 2, 2009 / Accepted: February 20, 2010 / Published: April 20, 2010.

Abstract: Reduction of nonpoint source pollutants, principally sediment and nutrients moving from cultivated fields to surface waters, is a major challenge. Remnants of once-extensive natural wetlands occur across the agricultural landscape, and it has been suggested that these areas might be managed to yield improved wetland function in terms of trapping and retention of nonpoint source pollutants. An existing wetland in a severed meander bend cut off in the 1940s from the Coldwater River in Tunica County, MS, USA was modified by the construction of weirs equipped with water control structures. The wetland was a segment of old river channel about 500 m long and 20 m wide. Inputs to the wetland cell included sporadic flows due to runoff events from about 350 ha of cultivated fields and less frequent but larger flood events from the river. This type of flood event occurred only once during the study. Concentrations of sediment and nutrients in water were generally lower at the downstream end of the wetland cell than in the major inflow, an ephemeral slough. Mean values of turbidity, suspended sediment concentration, and concentrations of filterable and total phosphorus were 25% to 40% lower at the wetland cell discharge weir than in the slough. Mean concentrations of ammonia were 38% lower, but mean nitrate and nitrite concentrations were essentially unchanged by the wetland cell. Comparison of estimated input and output loads during periods when the wetland cell was not flooded by the river indicated that the wetland cell retained about 18% of input suspended sediment, 24% of phosphorus, and 29% of nitrogen input from cultivated fields. Wetland cell sediment and nutrient retention efficiency was greater for drier months, and declined during wetter periods with frequent runoff events.

Key words: Agriculture, nutrients, sediments, wetlands, ecological engineering.

1. Introduction

Nonpoint source pollution from cultivated fields has been implicated in extensive and chronic environmental degradation in aquatic ecosystems ranging from small streams to large estuaries and marine environments such as the Gulf of Mexico. Mitigation and management strategies are needed to address these issues, particularly with regard to sediments and nutrients. Wetland enhancement, creation and management are landscape-scale practices for which USDA conservation practice standards have been developed [1]. Enhancement, restoration and construction are terms that represent a continuum of activities that range from augmenting existing wetland functions through creating wetlands where they did not exist before. Constructed wetlands have been examined as tools for removing nitrogen (N) [2-5], phosphorus (P) [2, 4, 6, 7] and pesticides [8-12] from agricultural runoff.

Less work has been done on the ability of natural wetlands to attenuate agricultural pollution. Natural riverine wetlands serve as sediment storage zones at the landscape scale [13]. Five restored wetlands in Iowa effected an 85% mean reduction in total nitrogen (TN) concentrations in agricultural runoff [14], while an instream wetland created by a beaver dam in North Carolina reduced TN by an average of 37% [15]. Jordan et al. [16] reported performance of a restored wetland receiving highly variable inflows of agricul- tural runoff over a two-year period; although N concentrations were reduced, questions were raised regarding longer-term

C.W. Pearce (1987-), female, Bachelor of Science, research fields: wetland effects on water quality, environmental monitoring. E-mail: caseywpearce@gmail.com.

Corresponding author: F.D. Shields, Jr. (1953-), male, Ph.D., research fields: stream restoration, riverine physical aquatic habitat, agricultural impacts on stream water quality. E-mail: doug.shields@ars.usda.gov.

performance. Large scale restoration of riverine wetlands throughout the Mississippi River basin has been proposed as a solution for hypoxia in the Gulf of Mexico [17] and for problems of habitat loss [18]. This study seeks to demonstrate how a natural wetland receiving runoff from cultivated fields may be enhanced by adding and operating weirs to trap water and allow time to process sediments and nutrients. Additional findings regarding pesticide retention at the same site have been reported by others [19].

2. Site

An existing 1-ha wetland in a severed meander bend cut off in the 1940s from the Coldwater River in Tunica County, MS, USA was modified by the construction of weirs equipped with water control structures (Fig. 1). The weirs divided the old bendway channel into two segments or cells: a shallow lake and a wetland cell. The wetland cell was about 500 m long and 20 m wide. Inputs to the wetland cell included sporadic flows due to runoff events from about 350 ha of cultivated fields and less frequent but larger flood events from the river. Soils were primarily poorly drained Alligator (40%) or Sharkey clays (47%) with the remainder being Tensas silty clay loam. During the period of interest, crops were limited to soybeans (*Glycine max*) grown using no-till or minimum tillage. Field runoff was concentrated in a network of ditches feeding a slough that was tributary to the wetland cell through a 0.6-m diameter pipe culvert.

Weirs consisted of low earthen embankments placed at right angles to the old river channel and covered with stone riprap (Fig. 2). Each weir included a water control structure that consisted of a 0.3 m diameter pipe that penetrated the embankment bisected by a flashboard riser "manhole." Flash boards (also called stoplogs) could be added or removed through the manhole to adjust the controlling elevation of the water control structure (Fig. 2). Weir water control structures were operated to retain water during March - November, and were opened to allow more frequent connection to the Coldwater River during December, January and February. Weir elevation during March – November corresponded to a mean wetland cell water depth of 0.15 m. Wetland cell water surface elevation (and thus water depth) reflected local precipitation and runoff as well as flooding from the river (Fig. 3).

3. Methods

Hydrologic and water quality data were collected from the wetland cell and its major inflows and outflows over an 18-month period between 15 June 2007 and 27 November 2008. Precipitation records were obtained using a rain gage on site, and missing data were replaced with daily totals from nearby stations. During this period of time, river stages in the reach adjacent to the wetland cell were generally below the level needed for flow from the river into the wetland cell. Self-contained loggers measured water pressure (converted to water surface elevation using surveyed data) at 15 min intervals and basic water quality variables including pH, turbidity, and dissolved oxygen at 4 hr intervals. The inflow rate of agricultural runoff into the wetland cell was measured at 5-min intervals using an acoustic Doppler device placed in a pipe that connected the tributary slough to the wetland cell. Relatively small inflows that occurred in gullies were not measured. Weekly grab samples of water were collected from the downstream (northern) end of the wetland cell and from the three main adjacent water bodies: the Coldwater River, the lake cell and the tributary slough (Fig. 1).

Water samples were preserved via chilling and transported to the laboratory for analysis. Physical and chemical water parameters including turbidity, total solids (TS), dissolved solids (DS), ammonia (NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N), total nitrogen [TN (NO_3-N + NO_2-N + total Kjeldahl N)], soluble (filterable) P , total P (TP), and chlorophyll *a* were analyzed using standard methods (Table 1). Wetland cell flora was sampled using a visual, qualitative survey along seven transects in October 2008.

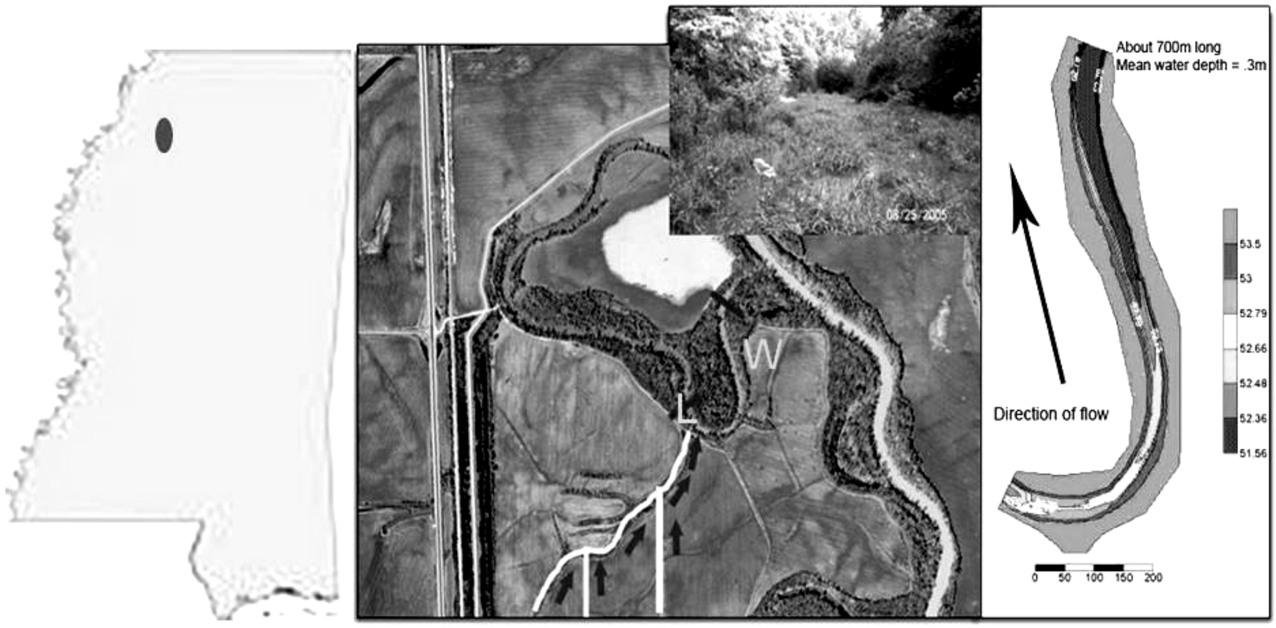

Fig. 1 Managed wetland on west side of Coldwater River, Tate and Tunica Counties, MS. Inset photo shows wetland prior to construction of weirs used to manage water levels, which are shown as bars on aerial photo. Arrows along drainage ditch and slough indicate the flow in the channels of runoff from about 350 ha of cultivated lands. Wetland topography shown on contour map to right; elevations are in m referenced to NAVD 88. Site location shown on map to left.

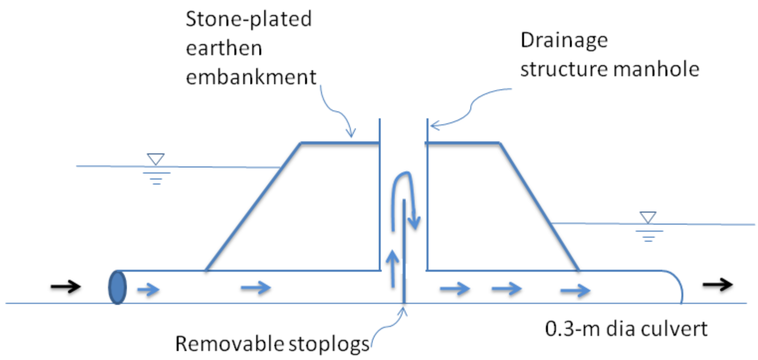

Fig. 2 Schematic of water control structures and weirs shown as bars in Fig. 1.

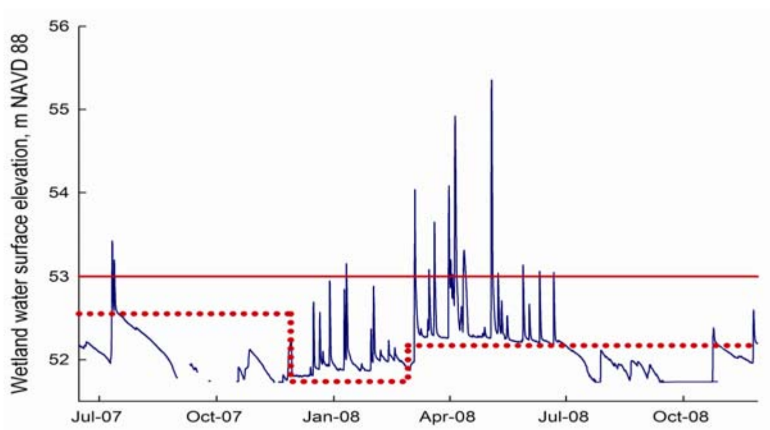

Fig. 3 Stage hydrograph for wetland during period of interest. Crest of weir at downstream (river) end of wetland is shown as solid red line, and the elevation of adjustable stoplog crest is shown as the red dotted line.

Time series for flow through the tributary slough pipe and water surface elevations in the wetland cell and adjacent river, lake cell and tributary slough were constructed using interpolation and subsampling to obtain time series with a frequency of 0.05 day^{-1}. Wetland cell water surface area and volume were computed at each time step using formulas that were derived from a digital elevation model constructed using survey data. Flows into and out of the wetland cell were computed at each timestep. Flows over the stone weirs were estimated based on broad-crested weir formulas and head differences, while flows through the water control structures were estimated using a rating curve based on data provided by the structure manufacturer. Noise in the 0.05 day^{-1} time series of wetland cell storage volume and flows was damped by computing daily averages. A water budget was constructed by setting up the Eq. (1) at each daily time step:

$$\Delta S(t) = [Q_{evap}(t) + a_1 Q_{pipe}(t)^{b_1} + a_2 Q_{lstone}(t)^{b_2} + a_3 Q_{ldrain}(t)^{b_3} + a_4 Q_{wstone}(t)^{b_4} + a_5 Q_{wdrain}(t)^{b_5}]\Delta t \quad (1)$$

Eq. (1)

Where $\Delta S(t)$ is the change in wetland cell water volume (m^3) during timestep t, which is of length Δt (1 day = 86,400 s); Q_{evap} is the rate of evaporation, Q_{pipe} is the discharge through the pipe, Q_{lstone} and Q_{wstone} were the flows over the stone-plated weirs at the upstream and downstream ends of the wetland cell, respectively and Q_{ldrain} and Q_{wdrain} were the flows through the water control structures at the upstream and downstream ends of the wetland cell, respectively. Each discharge, Q_i, is in units of $m^3 \cdot s^{-1}$. Evaporative losses (Q_{evap}) were assumed equal to observed pan evaporation values in $m \cdot s^{-1}$ (personal communication, Charles Wax) times the mean daily wetland cell water surface area in m^2. Since the left hand side of the equation was known at each timestep, the adjustment coefficients, a_i and exponents, b_i were computed using the Solver utility within Microsoft Excel.

Linear interpolation of the measured weekly concentrations was used to obtain time series of water quality variables (concentrations) at a daily interval for load computations. The validity of using linear interpolation of weekly values to estimate daily concentrations was examined by plotting concentration time series on the same axes as flow hydrographs. An example is shown in Fig. 4, which shows that TP levels in the tributary slough were insensitive to storm events. The validity of using linear interpolation of weekly values for concentration for load computations was further tested by computing correlation coefficients between the sampled concentrations and the total flow occurring for the 72-hr period prior to sampling. Concentrations were not correlated with antecedent flows (r^2 values < 0.02 except for inflow TN, for which r^2 = 0.17). In other words, concentrations were no higher or lower during wetter periods. Loads of sediment and nutrients entering and leaving the wetland cell were computed at each daily timestep by multiplying the corresponding concentration times the adjusted flowrate.

Concentrations of all water quality analytes sampled at the primary wetland cell inflow (the tributary slough) and at the downstream end of the wetland cell were compared using a Mann-Whitney rank-sum test. Parametric tests were not used because concentrations were not normally distributed.

4. Results

Plant populations were dominated by grasses (*leersia)*, sedges (*cyperus, carex)* and duckweed (*lemnaceae)*. Mature forest lined the banks of the old river channel that comprised the wetland cell, and woody species occasionally occurred in the wetland cell itself.

Rainfall was below local monthly norms for 14 of the 18 months of the study period. Total precipitation during the study period (1070 mm) was about 60% of normal. Daily total rainfall was greater than 63.5 mm (2.5 inches) for only five days. Wetland cell stage fluctuated in response to runoff events; flooding from the river was almost nonexistent during the study period. The only connection of the river with the wetland cell occurred for 6 hrs on July 8, 2008 and contributed about 650 m^3 of water to the wetland cell. Results of the water budget computations for the 18-month period of interest are summarized in Table 1 below. About 84% of the estimated inflow was comprised of runoff from the adjacent cultivated fields that were drained by the tributary slough. The remaining 16% of the inflow was primarily made up of flow from the lake cell into the wetland with a very small amount of flow from the Coldwater River. Limited center pivot irrigation occurred on fields within the wetland watershed during the study period, but runoff from irrigation was never observed.

Continuously monitored water quality constituents displayed characteristics typical of wetland conditions (Table 2). Relatively low mean and median dissolved oxygen concentrations are due to nighttime algal respiration. Concentrations of all grab-sampled water quality constituents except for NO_2-N, NO_3-N and chlorophyll *a* were higher in the tributary slough than in the downstream end of the wetland cell (Fig. 5). Except for these three constituents, median values were significantly different ($p \leq 0.021$, Mann-Whitney rank sum test). Medians of NO_2-N, NO_3-N and chlorophyll *a* were not significantly different between the two water bodies. Mean values for tributary slough concentrations were 86% (chlorophyll *a*) to 166% (suspended solids) of the wetland cell means.

Net fluxes of solids and nutrients over the period of interest are presented in Table 3. Inflow from the tributary slough dominated loading to the wetland cell. Yields of TN, TP and NO_3-N from the 350 ha of cropland that were drained by the tributary slough were about 0.49, 0.24, and 0.054 tonnes $km^{-2}\cdot yr^{-1}$, respectively. Our estimates indicate that the wetland cell retained about 18% of the sediment, 24% of the N and 29% of the P that reached it via inflows from the lake, tributary slough or river. Examination of monthly flux values indicate that the wetland cell was most

5. Discussion

A certain level of uncertainty attends the values in Tables 1 and 3 because flow computations were subject to bias caused by slight errors in measuring water surface elevations, particularly the differences in water surface elevations occurring over the stone weirs. However, the major inflow to the wetland cell, which occurred through the 0.6 m pipe draining the tributary slough, was not subject to such error as it was measured using an acoustic Doppler flow meter. Additional uncertainty arises because, as noted above, we did not collect water quality samples during actual runoff events. Water samples were collected at regular, weekly intervals whether or not water was flowing into or out of the wetland cell. We assumed that the concentrations and values we measured were representative of levels occurring during flow events; this assumption was supported by the low correlations between antecedent flow and concentrations.

The loads of nutrients entering the wetland cell through the tributary slough were converted to annual yields for comparison with work by others. Our estimates for TN and TP yields were about 0.50 and 0.84 tonnes $km^{-2}\cdot yr^{-1}$, respectively. These values are lower than six-year means of 4.2 and 2.1 tonnes $km^{-2}\cdot yr^{-1}$ for N and P respectively, from Delta lands growing conventional till cotton [20] and to a three-year mean of 3.2 tonnes $km^{-2}\cdot yr^{-1}$ for N from Delta lands growing conventional till cotton and soybeans [21]. About 24% of the TN and 29% of the TP were retained in the managed wetland cell during our study period; these values are in line with an observed 37% mean retention of TN by an instream wetland created by a beaver dam in North Carolina [15]. We note that the wetland cell: watershed area

Table 1 Water budget for wetland cell. Positive values indicate net flow into wetland cell, and negative values indicate flows out of wetland cell.

Term (m^3)	Sum (m^3)	Maximum ($m^3 \cdot day^{-1}$)	Mean ($m^3 \cdot day^{-1}$)	Median ($m^3 \cdot day^{-1}$)	Adjustment coefficient (a_i)	Adjustment exponent (b_i)
ΔS	259	22,400	0.33	-5.28		
$Q_{evap}\Delta t$	-3,620	0	-6.8	-5.83		
$a_1 Q_{pipe}(t)^{b_1}\Delta t$	900,800	77,070	1,710	1,740	1.00	0.98
$a_2 Q_{istone}(t)^{b_2}\Delta t$	168,000	172,800	310	0	2.00	0.00
$a_3 Q_{idrain}(t)^{b_3}\Delta t$	-47,600	50	-90	0	1.00	1.00
$a_4 Q_{wstone}(t)^{b_4}\Delta t$	-98,800	0	-190	0	2.00	0.50
$a_5 Q_{wdrain}(t)^{b_5}\Delta t$	-925,000	637	-1740	0	1.00	1.00

Table 2 Summary statistics for wetland water quality constituents measured using in-situ logger.

Variable	N	Mean	Median	Standard deviation
DO (mg/L)	3127	4.71	3.98	3.72
pH	3127	6.72	6.74	0.43
Turbidity (NTU)	3127	28.0	12.7	66.3
Specific Conductivity (uS/cm)	3127	128	123	51
Temperature (℃)	3127	21.99	24.59	7.16

Table 3 Flux of water, solids and nutrients for wetland cell. Net percentages > 0 indicate retention.

Constituent	Tributary slough into wetland cell	Into wetland cell from lake cell	From wetland cell into lake cell	Into wetland cell from river	From wetland cell into river	Wetland cell (net)*
Water, 10^3 m^3	901	170	53	0.6	1,020	0.26**
Total solids, kg	199,558	22,536	7,433	129	176,173	38,618 (+17%)
Dissolved solids, kg	76,974	9,349	4,135	43	68,305	13,926 (+16%)
Suspended solids, kg	122,584	13,187	3,297	86	107,868	24,692 (+18%)
TN, kg	2,551	425	75	1	2,194	708 (+24%)
NH_3, kg	22.1	1.0	0.6	0.0	18.10	4.4 (+19%)
NO_3, kg	283.6	20.7	8.7	0.1	164.5	131 (+43%)
TP, kg	1,229	99	29	0.4	916	384 (+29%)
Filterable P, kg	272	25	9	0.1	187	102 (34%)

* Net retention percentages for each constituent were calculated by the following formula: $\left(1-\frac{total\ out\ of\ wetland}{total\ into\ wetland}\right)\times 100$

** This net value includes 3.62 x 10^3 m^3 of outflow due to evaporation.

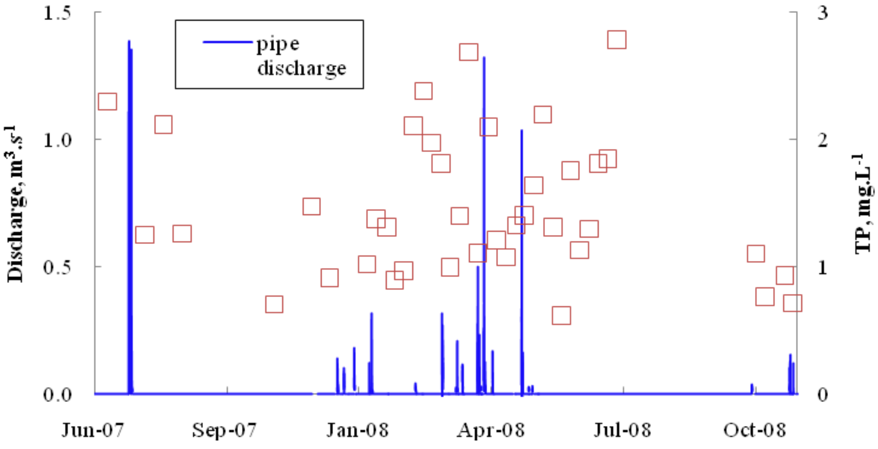

Fig. 4 Discharge through tributary pipe and total phosphorus concentration in tributary slough versus date.

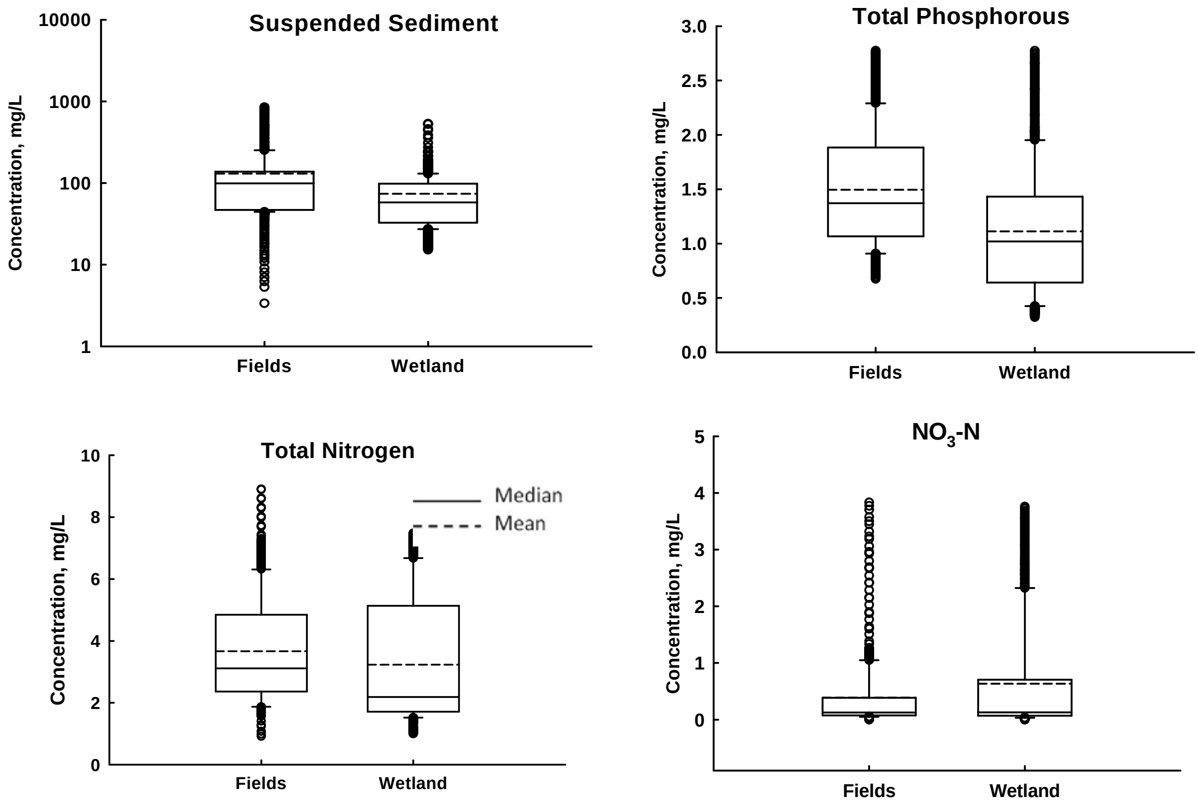

Fig. 5 Box and whisker plots for selected water quality constituent concentrations of samples collected from the primary inflow to the managed wetland, a slough that conveyed runoff from about 100 ha of cultivated fields (labeled "Fields"), and for samples collected from the downstream end of the wetland (labeled "Wetland"). Medians of all constituents except for NO_3-N were significantly different ($P \leq 0.013$).

ratio for our site was approximately 1:350, which is likely too small and resulted in excessive loading rates, especially during wet periods. Standard practice for constructed wetland design for this region of Mississippi results in a wetland cell:watershed area ratio of about 1:70 (personal communication, Paul Rodrigue). Our average hydraulic loading rate was 0.02 $m^3 \cdot s^{-1} \cdot ha^{-1}$. In contrast, a set of four experimental wetlands along the Des Plaines River in Illinois experienced hydraulic loading rates of 0.0013 to 0.0066 $m^3 \cdot s^{-1} \cdot ha^{-1}$ with removal rates of 92%, 84%, and 85% for suspended solids, NO_3-N and TP, respectively [22]. Mitsch et al. [17] reported loading rates of 0.006 to 0.010 $m^3 \cdot s^{-1} \cdot ha^{-1}$ for two 1-ha wetlands receiving pumped inflow from the Olentangy River in Ohio and 0.0005 to 0.004 $m^3 \cdot s^{-1} \cdot ha^{-1}$ for a 260 km^2 wetland receiving pumped inflow from the Mississippi River in southern Louisiana. The higher loading rate for our site was not a result of a design error; the location for the boundary between the lake cell and the wetland cell was selected to use the existing landscape features to protect lake cell size and quality.

Although they are ecologically rich features of the riverine corridor, instream wetlands such as the one described here are nonideal for treatment of polluted waters due to highly variable inputs of water and pollutants. Our study did not examine conditions during seasons when frequent overflow from the river into the wetland cell occurs. We anticipate that sediment and nutrient retention during those periods is complex due to the rapid changes in wetland cell volume, surface area and water quality that occur during inundation. Interestingly, Mitsch et al. [23] reported that three floodplain wetlands subjected to steady inflow and pulsed inflow during successive years exhibited similar or higher levels of nutrient retention during the year with pulsed inflow.

6. Conclusions

The modified natural wetland described here retained about one-fourth of the TN input and one-third of the TP input during an 18-month period with minimal river flooding. It also retained about one-fifth of the suspended sediment input. Soluble nutrients were reduced more than total nutrients: nitrate and filterable P loads leaving the wetland were 43% less and 34% less, respectively than those entering. Additional study is needed to assess managed wetland performance during flooding and over longer periods of time. Further research is also needed to identify the processes (e.g., sedimentation, plant uptake, microbial activity) responsible for pollutant removal by the wetland and the factors that control those processes.

Acknowledgments

Cooperation of landowners Dennis Paulk and the Norfleet Family trust is gratefully acknowledged. Karen Myers, Paul Rodrigue and Karrie Pennington read an earlier version of this paper and made many helpful comments.

References

[1] R.R. Lowrance, T.M. Isenhart, W.J. Gburek, F.D. Shields, Jr., P.J. Jr. Wigington, S.M. Dabney, Landscape management practices. in: M. Schnepf, , C. Cox, (Eds.), Environmental Benefits of Conservation on Cropland: The Status of Our Knowledge, The Soil and Water Conservation Society, Ankeny, Iowa, 2006.

[2] D.F. Fink, W.J. Mitsch, Seasonal and storm event nutrient removal by a created wetland in an agricultural watershed, Ecol Eng (2004) 213-225.

[3] M. Reinhardt, B. Muller, R. Gachter, B. Wehrli, Nitrogen removal in a small constructed wetland: an isotope mass balance approach, Environ Sci Technol 10 (2006) 3313-3319.

[4] D.A. Kovacic, R.M. Twait, M.P. Wallace, J.M. Bowling, Use of created wetlands to improve water quality in the Midwest-Lake Bloomington case study, Ecol Eng (2006) 258-270.

[5] A.K. Sovik, P.T. Morkved, Use of stable nitrogen isotope fractionation to estimate denitrification in small constructed wetlands treating agricultural runoff, Sci Total Environ 1 (2008) 157-165.

[6] M. Reinhardt, R. Gachter, B. Wehrli, B. Muller, Phosphorus retention in small constructed wetlands treating agricultural drainage water, J Environ Qual 4 (2005) 1251-1259.

[7] B.C. Braskerud, K.S. Tonderski, B. Wedding, R. Bakke, A.G.B. Blankenberg, B. Ulen, J. Koskiaho, Can constructed wetlands reduce the diffuse phosphorus loads to eutrophic water in cold temperate regions?, J Environ Qual 6 (2005) 2145-2155.

[8] J.L. Bouldin, J.L. Farris, M.T. Moore, S.Jr. Smith, W.W. Stephens, C.M. Cooper, Evaluated fate and effects of atrazine and lambda-cyhalothrin in vegetated and unvegetated microcosms, Environ Toxicol 5 (2005) 487-498.

[9] M.T. Moore, C.M. Cooper, S.Jr. Smith, R.F. Cullum, S.S. Knight, M.A. Locke, E.R. Bennett, Diazinon mitigation in constructed wetlands: Influence of vegetation, J. Water Air Soil Pollut 2007 313-321.

[10] J.L. Bouldin, J.L. Farris, M.T. Moore, S.Jr. Smith, C.M. Cooper, Assessment of diazinon toxicity in sediment and water of constructed wetlands using deployed Corbicula fluminea and laboratory testing, Arch Environ Contam Toxicol 2 (2007) 174-182.

[11] R. Budd, A. O'Geen, K.S. Goh, S. Bondarenko, J. Gan, Efficacy of constructed wetlands in pesticide removal from tailwaters in the central valley, California, Environ Sci. Technol. 8 (2009) 2925-2930.

[12] M.T. Moore, C.M. Cooper, S.Jr. Smith, R.F. Cullum, S.S. Knight, M.A. Locke, E.R. Bennett, Mitigation of two pyrethroid insecticides in a Mississippi Delta constructed wetland, Environ Pollut 1 (2009) 250-256.

[13] J.D. Phillips, Fluvial sediment storage in wetlands, Wat Resour Bullet 4 (1989) 867-873.

[14] A.G., Van der Valk, W.G. Crumpton, Evaluating the effectiveness of restored wetlands for reducing nutrient losses from agricultural watersheds, Leopold Center Progress Report (2004) 33-34.

[15] P.G. Hunt, K.C. Stone, F.J. Humenik, T.A. Matheny, M.H. Johnson, In-stream wetland mitigation of nitrogen contamination in a USA coastal plain stream, J. Environ Qual (1999) 249-256.

[16] T.E. Jordan, D.F. Whigham, K.H. Hofmockel, M.A. Pittek, Nutrient and sediment removal by a restored wetland receiving agricultural runoff, J. Environ Qual. (2003) 1534-1547.

[17] W.J. Mitsch, J.W. Day, L. Zhang, R.R. Lane, Nitrate-nitrogen retention in wetlands in Mississippi River Basin, Ecol. Eng. (2005) 267-278.

[18] J.W. Day, A.Y. Arancibia, W.J. Mitsch, A.L. Lara-Dominguez, J.N. Day, J.Y. Ko, R. Lane, J. Lindsey, D.Z. Lomeli, Using ecotechnology to address water

quality and wetland habitat loss problems in the Mississippi basin: a hierarchical approach, Biotechnol Adv. (2003) 135-159.
[19] R.E. Lizotte, F.D.Jr. Shields, S.S. Knight, C.T. Bryant, Efficiency of a modified backwater wetland in trapping a pesticide mixture, Ecohydrol 3 (2009).
[20] L.L. McDowell, G.H. Willis, C.E. Murphree, Nitrogen and phosphorus yields in run-off from silty soils in the Mississippi Delta, U.S.A., Agric Ecosyst Environ (1989) 119-137.
[21] J.D. Schreiber, R.A. Rebich, C.M. Cooper, Dynamics of diffuse pollution from southern watersheds, Water Resour 10 (2001) 2534-2542.
[22] J.H. Sather, Intensive studies of wetland functions: 1990-1991 research summary of the Des Plaines River Wetlands Demonstration Project, Wetlands Research, Inc.: Chicago, IL, 1992.
[23] W.J. Mitsch, L. Zhang, D.F. Fink, M.E. Hernandez, A.E. Altor, C.L. Tuttle, A.M. Nahlik, Ecological engineering of floodplains, Ecohydrol Hydrobiol (2008) 139-147.
[24] APHA, Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, D.C., 1998.
[25] APHA, Standard Methods for the Examination of Water and Wastewater, 17th ed., American Public Health Association, Washington, D.C., 1989.

Appendix:

Methods used in water quality analyses.

Parameter	Method Used	Standard Method[24]
Turbidity	Calibrated Hach electronic turbidimeter	N / A
Total Solids	Dried @ 105 ℃	2540 B
Dissolved Solids	Dried @ 105 ℃	2540 B
NH_4-N	Phenate method	4500-NH_3 D [25]
NO_3-N	Cadmium reduction method	4500-NO_3- E
NO_2-N	Colorimetric method	4500-NO_2- B
TN (NO_3-N + NO_2-N + TKN)	Block digestion & flow injection analysis	4500-Norg D
Soluble P	Ascorbic acid	4500-P.E.
Total P	Persulfate digestion; ascorbic acid	4500-P B; 4500-P E
Chlorophyll a	Pigment extraction & spectrophotometric determination	10200.H