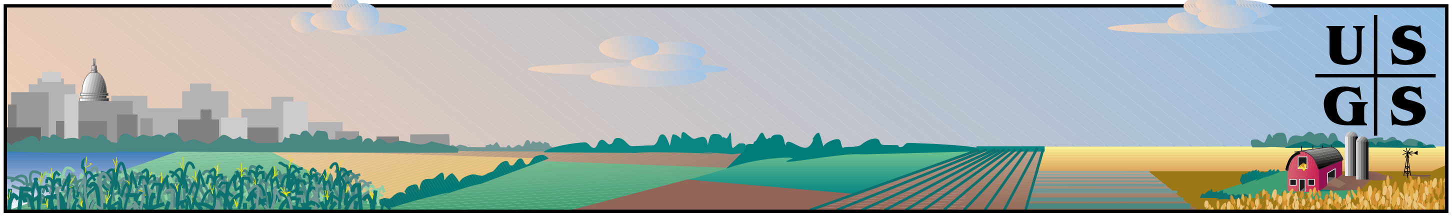

Sediment and Nutrient Trapping Efficiency of a Constructed Wetland Near Delavan Lake, Wisconsin, 1993–1995

by John F. Elder and Gerald L. Goddard

Summary

Jackson Creek Wetland—a 95-acre shallow prairie marsh containing three sediment retention ponds—was constructed in 1992 to reduce sediment and nutrient inflow to eutrophic Delavan Lake. The function of the wetland as a retention system for suspended sediments and nutrients (total and dissolved phosphorus, total ammonia plus organic nitrogen, dissolved ammonia, and nitrite plus nitrate nitrogen) was studied from February 1993 through September 1995. Input and output load computations were based on water flow (discharge) measurements and periodic sampling of suspended sediments and nutrients at the three inflowing streams and at the wetland outflow. Results of the study indicated consistent sediment retention throughout the year; at times, as much as 80 percent of the inflow load was retained in the wetland. Nutrient retention was generally of lesser magnitude and much more variable. Although the annual budgets confirm net retention for all nutrient forms except ammonia, data analysis over shorter time scales show that outflow loads actually can exceed inflow loads during the late spring and summer months—the period of greatest likelihood of algal blooms in the lake. This result demonstrates that the nutrient-trapping function of the wetland is variable because of the complexity of the system. Awareness of such variability can help to maintain realistic expectations and effective management practices.

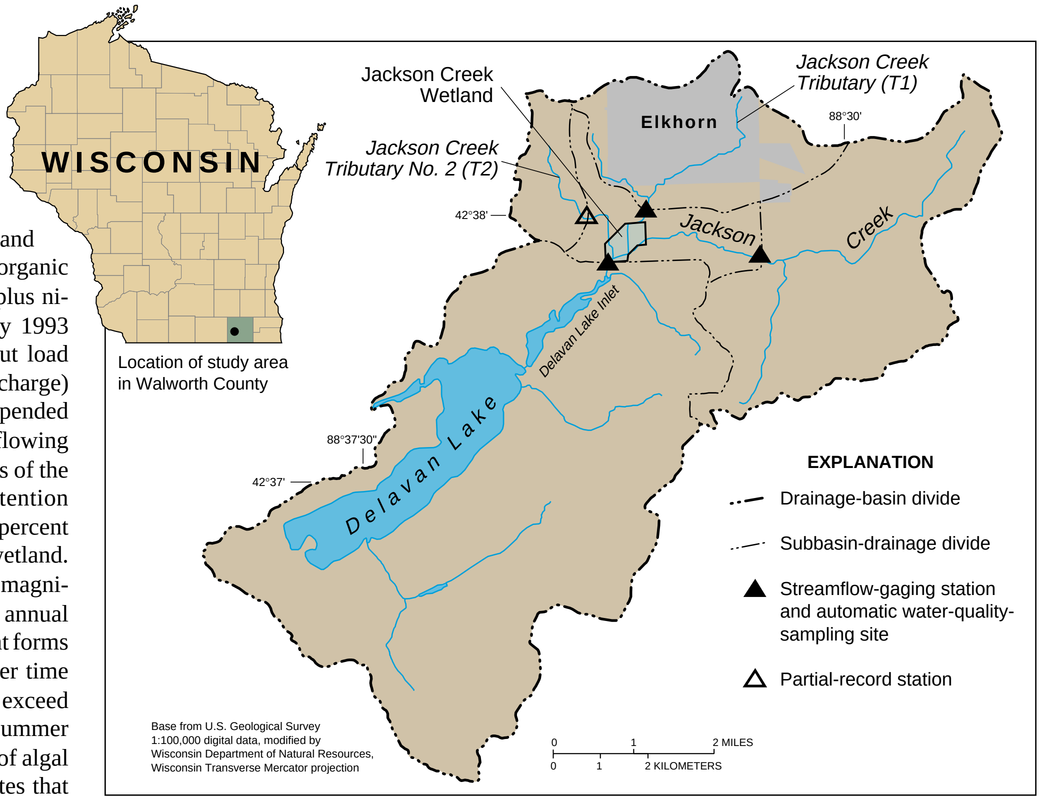

Figure 1. Location of Delavan Lake, Jackson Creek Wetland, three inflowing streams (Jackson Creek and its tributaries), and outflow of wetland to Delavan Lake Inlet.

Delavan Lake and Jackson Creek Wetland

Delavan Lake (fig. 1), a highly valued and heavily used sport fishery and recreational lake in southeastern Wisconsin, has been plagued by water-quality degradation and algal growth during the past 15 years. A severe blue-green algal bloom occurred in the summer of 1983 despite modifications two years earlier to divert sewage and septic tank effluent out of the drainage basin of the 2,072-acre eutrophic lake.

The algal growth problems led to intensive, long-term hydrologic and water-quality studies and a detailed rehabilitation plan (University of Wisconsin, 1986). Among other recommendations, the plan called for construction of a wetland at the confluence of Jackson Creek and its two tributaries, which combine to form the principal inflow to Delavan Lake (fig. 1). The purpose of this wetland was to reduce sediment and nutrient inflow to the lake and thus contribute to its long-term protection and maintenance.

Jackson Creek Wetland was constructed in fall 1992 when a 15-acre wetland north of Mound Road was enlarged to 95 acres (fig. 2). Water from the wetland flows into the Delavan Lake Inlet 2.0 miles upstream from Delavan Lake (figs. 1 and 2A). Nearly all surface-water inflow to the wetland is through three streams—Jackson Creek, Jackson Creek Tributary (T1), and Jackson Creek Tributary No. 2 (T2). The combined drainage area of 16.6 square miles is used principally for agriculture although there has been some recent change, with increased residential and commercial development in the Jackson Creek and T1 subbasins. Details of the geology, soils, and land use are described in a previous report on Delavan Lake (Field and Duerk, 1988).

In addition to areas of sedge meadow, wet prairie, and shallow-water marsh, the wetland contains three retention ponds along its upstream edge at the mouths of the inflowing streams (fig. 2). Jackson Creek, T1, and T2, respectively, flow into the east, north, and west ponds. Surface areas of these ponds are about 3.4, 1.2, and 1.2 acres, respectively. Each pond has 1–4 outlet swales which distribute runoff into the wetland.

This fact sheet describes the design, approach, and principal findings of a study of Jackson Creek Wetland conducted by the U.S. Geological Survey in cooperation with the Town of Delavan. The primary objective of the study was to assess the effectiveness of the wetland as a retention system for suspended sediment and nutrients.

Table 1. Drainage areas of Jackson Creek and tributaries

BASIN	DRAINAGE AREA, in square miles GAGED	UNGAGED	TOTAL	PERCENT UNGAGED
Jackson Creek	8.96	1.02	9.98	10.2
Jackson Creek Tributary (T1)	4.34	.22	4.56	4.8
Jackson Creek Tributary No. 2 (T2)	1.36	.70	2.06	34.0
Total	14.66	1.94	16.60	11.7

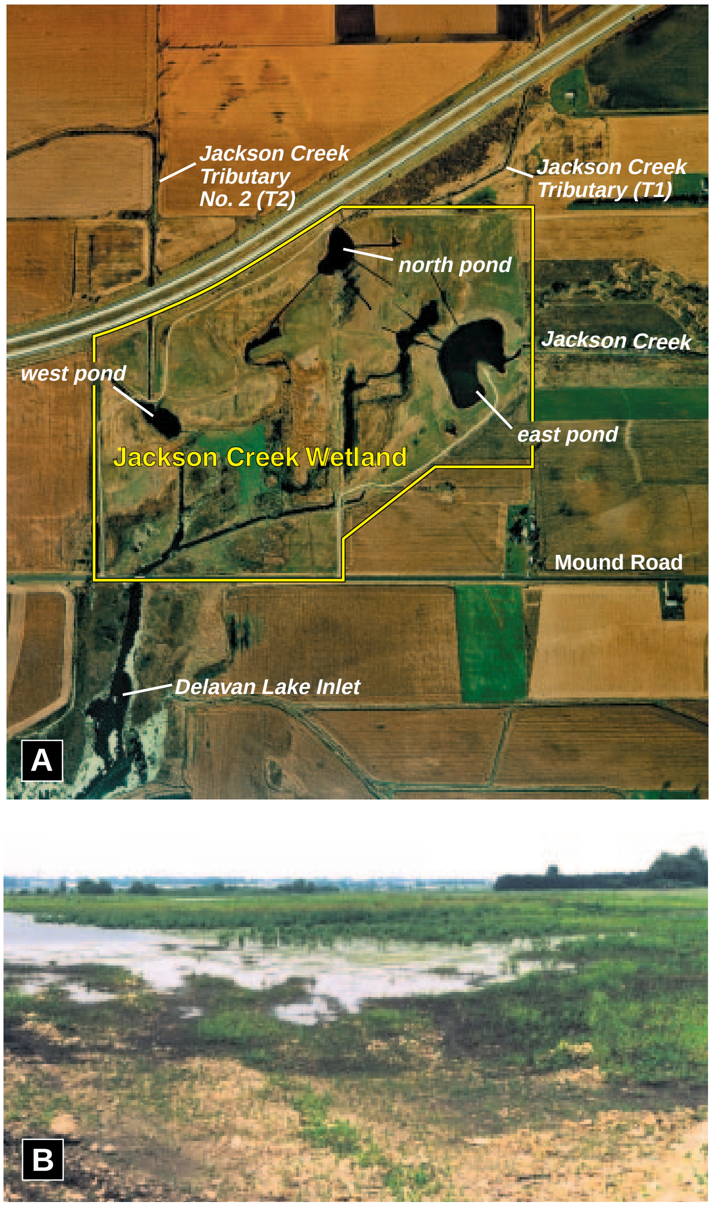

Figure 2. A. Aerial view of Jackson Creek Wetland, showing inflowing and outflowing streams, and sediment retention ponds (photograph supplied by Rust Environment and Infrastructure, Inc., Milwaukee, Wis.). B. Partial view of Jackson Creek Wetland, looking northeast.

Methods of Data Collection, Sampling, and Analysis

Water flow (discharge) was measured continuously at gaging stations located upstream from the Jackson Creek Wetland at the Jackson Creek and T1 sites, and at the wetland outflow weir at Mound Road. Inflow through T2 was also measured periodically. The inflow measurements accounted for 88 percent of the drainage area of the wetland (table 1). The remaining 12 percent of the area—the intervening areas between the gaging stations and the wetland inflow points—could not be monitored because of backwater effects from the ponds. Sediment and nutrient contributions from the ungaged area within each subbasin were estimated by calculating the load/drainage-area relation for the gaged area and applying it to the ungaged area.

Samples for the determination of suspended-sediment and nutrient concentrations were collected at least monthly, using the equal-width-increment (EWI) method described by Guy and Norman (1970). During storms, frequent samples were collected by means of refrigerated automatic water-quality samplers. The water samples were analyzed for concentrations of suspended sediment, total phosphorus, dissolved orthophosphate, total ammonia plus organic nitrogen (Kjeldahl nitrogen), dissolved ammonia, and dissolved nitrite plus nitrate nitrogen. Standard colorimetric techniques on an autoanalyzer (Fishman and Friedman, 1989) were used for analysis of these constituents.

Suspended-sediment and nutrient loads were computed by use of the integration method (Porterfield, 1972) at sites for which continuous discharge data were available. For the T2 site, loads were computed by use of a method described by Field and Graczyk (1990). The input load to the wetland was calculated as the sum of the load measured at the gaging station plus the estimated load from the ungaged area. The time period for load and budget calculations was the water year—the 12-month period from October 1 to September 30 (the water year is designated by the calendar year in which it ends).

The volume of sediment accumulation in the retention ponds was considered to be equivalent to the annual change (decrease) in pond volume. On each pond, 10–14 parallel cross-sections were established and served as reference points for four surveys. All the ponds were surveyed initially between October 1992 and May 1993, and subsequently in October 1993, 1994, and 1995. Cross-section areas at an elevation of 929.00 feet were computed using the Channel Geometry Analysis Program (Regan and Schaffranek, 1985). By averaging the areas of adjacent cross-sections, multiplying this average area by the distance between the cross sections, and summing these section volumes, the total pond volume was computed.

Six bottom-sediment cores collected with an acrylic gravity corer (3-inch inside diameter) were used to determine bulk density of the deposited sediment. The mass of sediment retained in the pond was then calculated as the product of bulk density and volume of sediment accumulation.

Sediment outflow from each pond was calculated as the difference between inflow and accumulation in the pond. The combined outflow from the three ponds was compared to the measured wetland outflow to determine the amount of deposition within the wetland downstream from the ponds.

Nutrient and Sediment Retention in the Wetland

Changes in Retention Ponds

Sediment accumulated in the ponds each year. Total accumulations ranged from 310 to 2048 yd^3 (cubic yards) during the study period (table 2). In the north and west ponds, most sediment was deposited at their downstream ends. In the east pond, however, 58 percent of the deposition was at the upstream end; this was probably due to the larger size and the non-circular shape of the pond, in addition to redirection of much of the flow through the three outlet swales near the middle of the pond.

Mean bulk densities of the deposited sediment in the north and east ponds were very similar— 0.49 and 0.50 ton/yd^3 (0.58–0.60 g/cm^3). By contrast, the mean sediment bulk density in the west pond was only 0.29 ton/yd^3 (0.35 g/cm^3). The feeder stream for the west pond, T2, is predominantly a wide, low-gradient channel, inhabited by abundant attached vegetation. Such an envi-

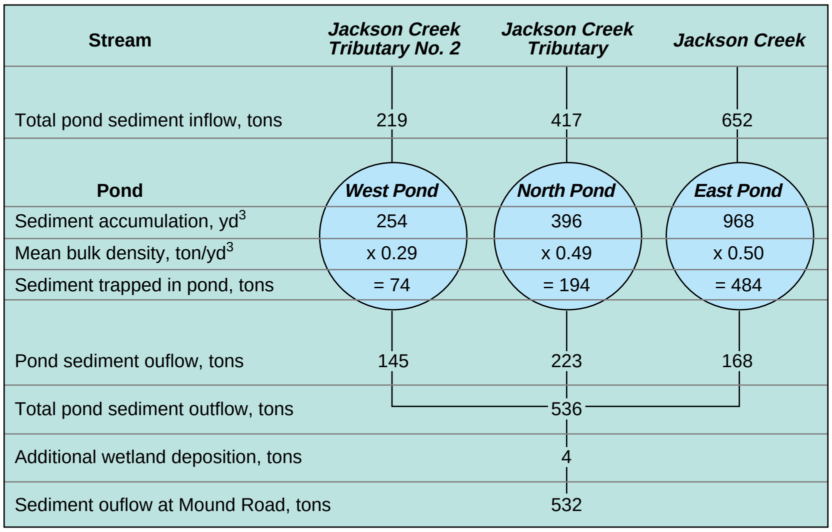

Figure 3. Suspended-sediment budget for Jackson Creek Wetland, water years 1994–95.

Table 2. Annual changes in pond volumes, 1993–95 (Annual change = sediment accumulation)

	POND VOLUME, in cubic yards				TOTAL SEDIMENT ACCUMULATION	
	1992	1993	1994	1995	cubic yards	tons
West Pond:						
Amount	5,719	5,664	5,618	5,409		
Change		-55	-46	-209	310	90
North Pond:						
Amount	5,828	5,515	5,130	5,119		
Change		-313	-385	-11	709	347
East Pond:						
Amount	12,526	11,446	11,261	10,478		
Change		-1,080	-185	-783	2,048	1024

ronment favors settling of dense sediment particles in the channel before they can reach the pond.

A suspended-sediment budget for Jackson Creek Wetland in water years 1994–95 is summarized in fig. 3. The west, north, and east ponds retained 34, 47, and 74 percent of sediment inflow, respectively. The combined retention of 752 tons (58 percent of inflow) leaves an estimated total sediment outflow from the ponds of 536 tons. Nearly all this amount (532 tons) was measured in the wetland outflow at Mound Road. The residual 4 tons of sediment was presumably trapped in the wetland between the ponds and Mound Road.

Nutrient and Sediment Trapping Function

Comparisons of inputs and outputs of suspended sediments and nutrients (table 3 and fig. 4) show the variable effectiveness of the Jackson Creek Wetland as a filter for these substances. As previously indicated, suspended sediments were consistently retained in the wetland. The retention was greater than 20 percent at all times except the winter/early spring period, and during the growing season, retention was frequently greater than 80 percent. For nutrients, however, the trapping effectiveness of the wetland was much less consistent. With the exception of ammonia, total nutrient loads generally decreased substantially between the inflows and the outflow on an annual time scale (table 3). The inflow:outflow ratio, however, was highly variable seasonally (fig. 4) and was frequently less than 1, an indication of net release instead of retention. The annual budget by itself thus provides incomplete information about the dynamics of nutrient transport through the system.

An example of the limitations of the annual-scale nutrient budget is evident in the 1994 phosphorus data (fig. 4). The season of greatest transport during that year was, by a large margin, the winter/early spring period. That period was also the time of greatest fractional retention of total and dissolved phosphorus. This combination of high transport and uptake accounted for nearly all of the annual net retention; it overshadowed later small-volume releases during low-flow periods. In fact, virtually all retention in 1994 occurred during a single month: February. Nearly all other months were actually periods of net phosphorus release, reflected by the large positive changes during the third and fourth quarters. Phosphorus mobilization during spring and summer might be due to increased solubility in anaerobic conditions (Mitsch and Gosselink, 1993, p. 141) which could, in turn, be caused by higher rates of microbial respiration in warmer temperatures.

Are these seasonal variations only a curiosity or could they have important implications for downstream aquatic ecosystems? Although no direct evidence of their significance is available, the fact that phosphorus releases tended to occur in late spring and summer makes them coincident with the likely timing of algal blooms downstream in Delavan Lake Inlet and Delavan Lake. Further indication of a potential problem is the fact that the proportional release of dissolved orthophosphate—the fraction that is available for algal uptake—was even greater than that of total phosphorus.

The lack of coupling between suspended sediment and nutrient transport dynamics is also notable. The suspended material presumably is retained because of the reduced velocity of water flow, which allows the material to settle. One might expect that the nutrient loads would be largely associated with oxidized suspended sediments and, therefore, would be entrained together with the sediments. However, this was clearly not the case; net release of nutrients often coincided with substantial retention of sediments. This result indicates that biogeochemical processes mobilized the sediment-associated nutrients and thus prevented their effective retention in the wetland, at least periodically.

Climate is an additional factor that could have important effects on nutrient load characteristics. Precipitation at Lake Geneva National Weather Service Station, 7 miles southeast of Jackson Creek Wetland, was 3.59 inches above normal during the 1993 study period (February–September). It was 12.19 inches below normal in water year 1994 and 4.74 inches below normal in water year 1995. The high water flows in 1993 produced heavy nutrient loading into and out of the wetland, which is evident in the results given in table 3 and fig. 4. The abnormally high flow volumes and velocities that year may also have reduced the nutrient retention effectiveness of the wetland, as indicated by the relatively low net retention numbers in 1993 (table 3).

Table 3. Summary of annual inflow and outflow loads, Jackson Creek Wetland, 1993–95 [Incomplete data for water year 1993; suspended-sediment loads in tons, nutrient loads in pounds; all rounded to 3 significant figures]

CONSTITUENT	LOADS INFLOW	LOADS OUTFLOW	CHANGE IN WETLAND	PERCENT CHANGE
		February–September, 1993		
Suspended Sediment (tons)	2,480	1,500	-980	-40
Total Phosphorus	11,100	10,100	-1000	-9
Dissolved Phosphorus	6,080	5,500	-580	-10
Ammonia plus Organic Nitrogen	45,900	40,100	-5800	-13
Dissolved Ammonia	7,550	8,920	1370	18
Nitrite plus Nitrate Nitrogen	126,000	133,000	7000	6
		Water Year 1994		
Suspended Sediment (tons)	874	246	-628	-72
Total Phosphorus	5,370	3,260	-2110	-39
Dissolved Phosphorus	1,990	1,750	-240	-12
Ammonia plus Organic Nitrogen	19,300	15,200	-4100	-21
Dissolved Ammonia	2,660	3,390	730	27
Nitrite plus Nitrate Nitrogen	42,100	37,400	-4700	-11
		Water Year 1995		
Suspended Sediment (tons)	413	286	-127	-31
Total Phosphorus	2,700	2,370	-330	-12
Dissolved Phosphorus	1,060	925	-135	-13
Ammonia plus Organic Nitrogen	11,500	15,800	4300	37
Dissolved Ammonia	744	1,060	316	42
Nitrite plus Nitrate Nitrogen	83,700	80,800	-2900	-3

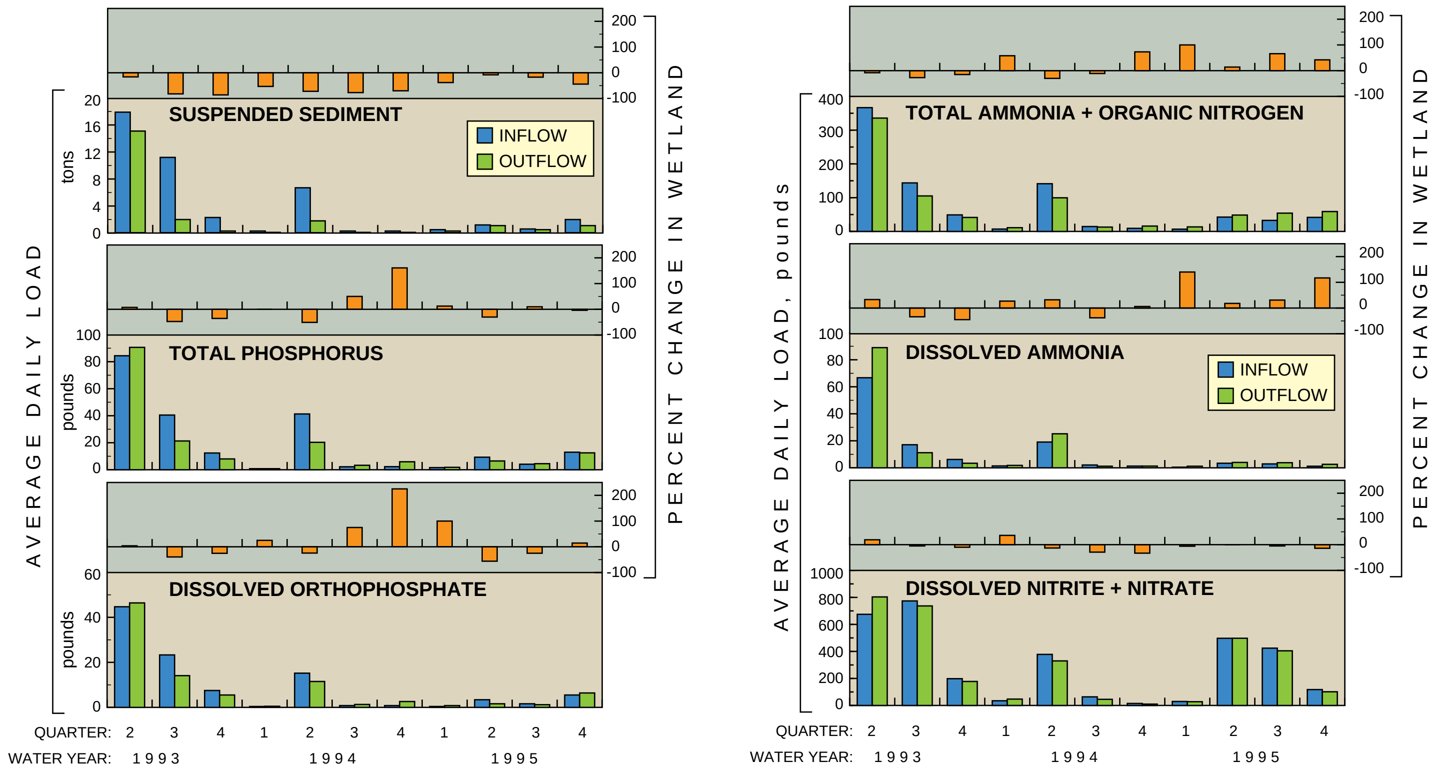

Figure 4. Average daily loads of suspended sediment and nutrients at inflow (total of all stream inflows) and outflow of Jackson Creek Wetland, and percent change in wetland. Negative percent change indicates retention; positive percent change indicates release. Data shown by quarter, water years 1993–1995; quarter 1 = October–December, quarter 2 = January–April, quarter 3 = May–June, and quarter 4 = July–September. Second quarter of 1993 = February–April (no data for January).

Implications of Study Results for Wetland Management

The Jackson Creek Wetland retained suspended sediment effectively and consistently, trapping 46 percent of the input load during the study period. However, the wetland apparently is not continuously effective as a site for nutrient retention, even in its current status as a relatively young and highly productive ecosystem. This finding, although illustrating some limitation of the wetland as a nutrient sink, does not necessarily conflict with the general concept of nutrient retention in the wetland. As observed in other wetlands (Elder, 1988; Richardson, 1988), the variability reflects the capacity of the system to function not only as a sink but also, periodically, as a facilitator of nutrient transformation and transport. The results of this study thus illustrate the complexities of biogeochemical cycles in any ecosystem, wetlands included. Understanding these complexities may help us to avoid placing unrealistic expectations on natural or constructed wetlands as systems with unlimited filtering capacity.

References

Elder, J.F., 1988, Factors affecting wetland retention of nutrients, metals, and organic materials. in: Kusler, J.A., and Brooks, G., eds. Wetland Hydrology, Chicago, IL, Association of State Wetland Managers, Inc., p. 178–184.

Field, S.J., and Duerk, M.D., 1988, Hydrology and water quality of Delavan Lake in southeastern Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 87-4168, 61 p.

Field, S.J., and Graczyk, D.J., 1990, Hydrology, aquatic macrophytes, and water quality of Black Earth Creek and its tributaries, Dane County, Wisconsin, 1985-86: U.S. Geological Survey Water-Resources Investigations Report 89-4089, 38 p.

Fishman, M.J., and Friedman, L.C., eds., 1989. Methods for determination of inorganic substances in water and fluvial sediments: U. S. Geological Survey, Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Guy, H.P., and Norman, V.W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 59 p.

Mitsch, W.J., and Gosselink, J.G., 1993, Wetlands: New York, Van Nostrand Reinhold, (2nd Ed.), 722 p.

Porterfield, George, 1972, Computation of fluvial sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C3, 66 p.

Regan, R.S., and Schaffranek, R., 1985, A computer program for analyzing channel geometry: U.S. Geological Survey Water-Resources Investigations Report 85-4335, 49 p.

Richardson, C.J., 1988, Freshwater wetlands: transformers, filters, or sinks?: Forem (Duke University), v. 11, p. 3–9.

University of Wisconsin, Institute for Environmental Studies, 1986, Delavan Lake: a recovery and management study: 332 p.

For more information, please contact:

District Chief
U.S. Geological Survey
6417 Normandy Lane
Madison, WI 53719
(608) 274-3535
www: http://wwwdwimdn.er.usgs.gov

Layout and illustrations: Michelle Greenwood
Banner graphic: Karen Lonsdorf

U.S. Department of the Interior
U.S. Geological Survey
Fact Sheet FS-232-96