Biogeochemical patterns of created riparian wetlands: Tenth-year results (2003)

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Introduction

As part of a long-term, large-scale experiment on self-design, two wetland basins at The Olentangy River Wetland Research Park were set up as a planting experiment, i.e., one basin was planted in 1994 with 2400 individuals of macrophytes representing 13 species while a second wetland basin remained unplanted (Mitsch et al., 1998). The basins have gone through 10 growing seasons by the end of 2003 that have been characterized as follows:

• Year 1 (1994) – Wetland 1 (W1) was planted in May with Wetland 2 (W2) as unplanted control. Essentially both basins were algal ponds with few macrophytes.

• Year 2 (1995) – Wetland 1 plants developed, particularly around the perimeter to about 13% macrophyte cover in August, compared to essentially no macrophyte cover in Wetland 2. Floods in late June and early August brought in large carp with waters remaining turbid through much of the rest of the year.

• Year 3 (1996) – Wetland 1 continued to develop in vegetation cover with about 39% cover. Unplanted Wetland 2, particularly after spring drawdown in both wetlands to install sedimentation markers, developed to about 35% macrophyte cover by August, essentially catching up with the planted wetland within 3 growing seasons.

• Year 4 (1997) – Macrophyte growth continued to increase in both wetlands with about 54% cover in Wetland 1 and 58% cover in Wetland 2.

• Year 5 (1998) – Macrophyte cover was similar in the two basins but Wetland 2 began to be dominated by highly productive *Typha* spp. while Wetland 1 still had a wider diversity of cover and was not dominated by *Typha* spp. In other words, Wetland 1 plant cover was now more diverse.

• Year 6 (1999) – Wetland 2 was dominated by *Typha* while Wetland 1 continued to be dominated by 3-4 of the planted species.

• Year 7 (2000) – Similar to 1999 except muskrats developed in the winter of 2000 and began to have a dramatic effect on ecosystem function.

Table 1. Water quality sampling at Olentangy River Wetland site in 2003.

Sample frequency	# Sampling stations	Period in 2003	Equipment	Parameters measured
continuous	4	outflows (2): Mar 28, 2003 inflow (W1): Nov 2, 2003 river: Oct 29, 2001	YSI 6600 sonde	temperature dissolved oxygen pH redox conductivity turbidity chlorophyll*
twice daily	3 (inflow-W1; two outflows)	Jan-Dec;	YSI 600xL sonde Hach turbidimeter(Lab)	temperature dissolved oxygen pH redox conductivity turbidity
weekly	7 (river; 1 inflow-W1; 2 middles; 2 outflows; swale)	Jan-Dec	YSI 600xL sonde Hach turbidimeter(Lab) LACHAT QuikChem IV(Lab)	temperature dissolved oxygen pH conductivity turbidity total phosphorus soluble reactive P $NO_3 + NO_2$

* chlorophyll measurement only in river after Nov 2, 2003

• Year 8 (2001)—Muskrat activity in the winter of 2000-2001 was extreme and vegetation cover was only a small percentage of what it was in previous years (see vegetation chapters in this report). This can be considered the year of maximum muskrat impact and vegetation cover was lower than any period since 1995. A continuous water quality sonde was installed in the Olentangy River on October 29, 2001.

Year 9 (2002)—Drawdown from April through June to allow plants to recover. Weekly water quality was not resumed after pumping began because of laboratory missing assignment, Both basins developed nice cover of *Schoenoplectus tabernaemontani*.

Year 10 (2003)—A pulsing experiment began in winter 2003 into both wetlands. Hydrologic pulses, usually of one-week duration, were administered to both wetland basins early in the months of February, March, April, May, June, and August. Continuous water quality probes were installed in the outflows of the two experimental wetlands on March 28, 2003 and in the inflow of Wetland 1 on November 2, 2003.

This study reports water quality results for the 10th year (2003). Other studies of the water quality of these wetlands are reported for Year 1 (Mitsch et al., 1995), Year 2 (Wehr and Mitsch, 1996; Mitsch and Nairn, 1996; Nairn and Mitsch, 1997), Year 3 (Mortensen et al., 1997; Mitsch and Carmichael, 1997; Nairn and Mitsch, 1997; Vorwerk and Mitsch, 1998), Year 4 (Mitsch and Montgomery, 1998; Spieles and Mitsch, 1998), and Years 5-9 (Mitsch et al., 1999, 2000, 2001, 2002; Mitsch and Zhang, 2003). Two

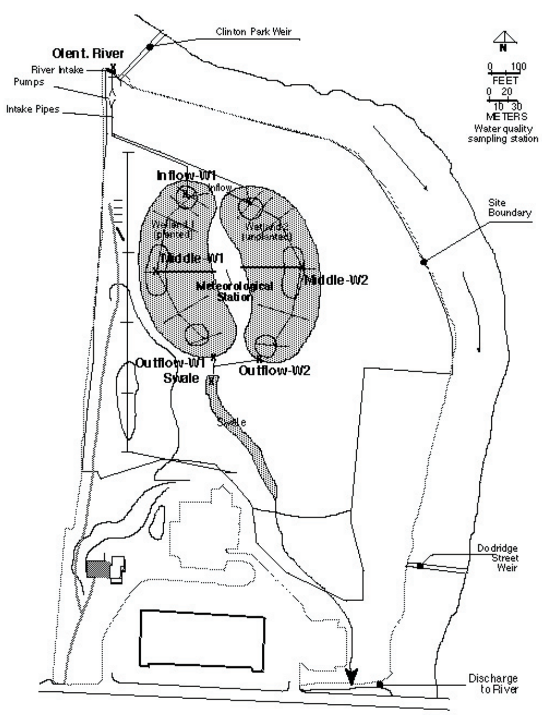

Figure 1. Location of water sampling stations used in 2002 for the experimental wetlands.

undergraduate honors theses (Wehr, 1995; Vorwerk, 1997), one Master's thesis (Harter, 1999), two Master's theses from Europe (Mortensen and Lanzky, 1996; Kang, 1999) and four dissertations (Nairn, 1996; Spieles, 1998; Liptak, 2000; Ahn, 2001) have also investigated aspects of water quality at the site. Eight journal articles (Mitsch et al., 1998; Kang et al., 1998; Nairn and Mitsch, 2000; Spieles and Mitsch, 2000; Ahn and Mitsch, 2002; Anderson et al., 2002; Harter and Mitsch, 2003; Spieles and Mitsch, 2003) have been published on water quality of these experimental wetlands.

Methods

A summary of the water quality monitoring protocol for the two experimental wetlands in 2003 is shown in Table 1. Locations of the various sampling stations are shown in Figure 1.

Weekly Sampling

Weekly water sampling, instituted in late April 1994 continued through 2003. Samples were taken at 7 stations in 2003 as in previous years. One 1000 ml sample was collected at each of the 7 sites. Water samples were taken to the Ecosystem Analytical Laboratory at Ohio State University (early part of 2003) and then to Laboratory I in the Heffner Wetland Research and Education Building (after May 2003) where subsamples were filtered and frozen for later measurement of soluble reactive phosphorus. Unfiltered samples were preserved with concentrated H_2SO_4 (2 ml/liter sample) and frozen for later analysis of total phosphorus and nitrate+nitrite (NO_3+NO_2). A raw sample was also stored for any new or additional analyses to be added. Sample preparation and preservation was usually completed within 48 hours of original collection.

Daily Sampling

Two-per-day water sampling, also initiated in 1994, continued through 2003 by the staff and students of the Olentangy River Wetland Research Park at Ohio State University. Inflow of Wetland 1 (determined after several studies to represent the inflow to both basins) and the outflows of Wetland 1 and Wetland 2 were monitored for temperature, dissolved oxygen, pH, conductivity, and redox with a YSI probe. Instruments were calibrated and checked for battery power frequently. Each time a 100-ml Nalgene bottle was used to take a sample for later measurement of turbidity in the lab at each of the three stations.

Sample Analysis

Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA, 1998) and EPA Methods for Chemical Analysis of Water and Wastes (USEPA, 1983) were followed. Total phosphorus, soluble reactive phosphorus, and nitrate+nitrite were analyzed on a quarterly or more frequent basis on a Lachat QuikChem IV automated system and Lachat methods (USEPA, 1983). Both total phosphorus and soluble reactive phosphorus

Table 2. Summary of water quality measurements at Olentangy River experimental wetlands, 1996 through 2003. Two -per-day sampling refers to dawn-dusk sampling done almost every day that water is flowing. Numbers are average ± std. error (# of samples).

Parameter	Year	Olent. River	Inflow	Middle-W1	Middle-W2	Outflow-W1	Outflow-W2	Swale
Total P, μg-P/L	1996	185±15 (40)	191±18 (30)	85±11 (33)	77±9 (34)	68±8 (34)	64±9 (35)	62±9 (33)
	1997	149±16 (46)	146±17 (45)	99±7(39)	113±13 (38)	125±20 (41)	120±12 (43)	94±7 (44)
	1998	244±28 (47)	186±16 (46)	129±15 (47)	133±14 (47)	98±10 (47)	98±11 (47)	31±7 (47)
	1999	194±35 (48)	126±11 (44)	99±11 (43)	138±22 (41)	92±17 (44)	76±12 (45)	70±9 (45)
	2000	159±19 (49)	138±12 (48)	137±30 (41)	148±32 (40)	72±16 (46)	90±19 (47)	86 ±14 (46)
	2001	122±7 (43)	112±6 (42)	86±8 (38)	87±8 (36)	69±7 (41)	83±7 (43)	80±9 (40)
	2003	150±21 (37)	121±16 (35)	103±25 (24)	67±15 (22)	137±24 (35)	130±17 (37)	120±18 (36)
SRP, μg-P/L	1996	58±8 (38)	70±11(29)	19±4 (33)	16±4 (33)	8±1 (33)	9±2 (33)	9±2 (32)
	1997	50±6 (48)	67±12 (47)	23±3 (40)	25±3 (39)	26±3 (37)	23±3 (40)	37±13 (39)
	1998	89±11 (47)	82±10 (46)	45±9 (47)	45±9 (47)	27±6 (47)	31±7 (47)	31±7(47)
	1999	97±10 (47)	94±10 (43)	46± 8 (45)	33±6 (44)	27±4 (47)	24±4 (46)	23±4 (48)
	2000	83 ±9 (46)	82±9 (46)	27±4 (39)	27±4 (40)	19±4 (45)	27±5 (46)	31±6 (44)
	2001	67±9 (42)	60±8 (41)	38±6 (34)	22±3 (33)	23±5 (36)	25±6(37)	35±8 (36)
NO_3 + NO_2, mg-N/L	1996	4.60±0.41 (38)	4.42±0.42 (29)	3.08±0.38(34)	2.89±0.32(34)	2.97±0.40(34)	3.30±0.38(34)	3.19±0.47(31)
	1997	4.89±0.97 (48)	4.23±0.75 (47)	2.92±0.62 (39)	3.02±0.69 (39)	3.51±0.71 (42)	3.55±0.71 (42)	3.45±0.71 (44)
	1998	2.79±0.39 (47)	2.72±36 (46)	2.06 ±0.35 (47)	2.02 ±0.33 (47)	1.83±0.32 (47)	1.67±0.34 (47)	1.82±0.33 (45)
	1999	1.94±0.24 (47)	1.91±0.24 (44)	1.51±0.29 (42)	1.46±0.25 (44)	1.33±0.28 (45)	1.28±0.24 (45)	1.20±0.23 (47)
	2000	4.74±0.63 (49)	4.35±0.48 (48)	3.63±0.55 (41)	2.93±0.44 (42)	2.85±0.62 (45)	2.42±0.34 (46)	2.68±0.62 (43)
	2001	3.24±0.36 (42)	3.32±0.33(41)	2.42±0.37 (36)	2.26±0.38 (36)	2.14±0.34 (40)	2.56±0.37 (42)	2.41±0.32 (40)
	2003	3.10±0.30 (47)	4.06±0.33 (38)	2.32±0.29 (37)	2.03±0.30 (37)	2.39±0.34 (46)	2.28±0.32 (47)	2.12±0.28 (49)
Turbidity, NTU [1]	1996		35±3 (319)			21±2 (404)	20±2 (407)	
	1997		28±2 (453)			26±2 (426)	27±2 (447)	
	1998		25±2 (446)			16±1 (459)	16±1 (462)	
	1999		25±2(493)			19±1 (524)	20±1 (521)	
	2000		29±2 (436)			17±1 (442)	19±1 (449)	
	2001		17±1 (359)			17±1 (358)	18±1 (370)	
	2002*		22±3 (80)			29±2 (77)	30±2 (77)	
	2003		23±2 (154)			28±3 (139)	22±2 (146)	
D.O., mg/L [1]	1996		9.69±0.19 (278)			10.55±0.21(336)	10.48±0.18(338)	
	1997		9.90±0.2 (454)			11.38±0.28 (412)	11.32±0.29 (430)	
	1998		9.40±0.14 (430)			11.98±0.26 (433)	11.66±0.25 (436)	
	1999		8.70±0.15 (463)			9.12±0.24 (486)	8.59±0.21 (489)	
	2000		9.96±0.18 (417)			10.81±0.24 (432)	9.46±0.21 (431)	
	2001		10.23±0.19 (353)			11.29±0.28 (353)	11.07±0.28 (362)	
	2002		10.72±0.33 (157)			11.07±0.43 (139)	10.82±0.39 (151)	
	2003		10.34±0.22 (184)			10.72±0.33 (180)	10.50±0.33 (194)	
Temp, °C [1]	1996		14.9±0.5 (302)			15.5±0.4 (373)	15.7±0.4 (373)	
	1997		13.2 ±0.4 (476)			13.7±0.4 (443)	13.7±0.4 (464)	
	1998		14.6±0.4 (456)			15.0±0.4 (471)	15.1±0.4 (475)	
	1999		14.9±0.4 (488)			14.8±0.4 (512)	14.6±0.4 (509)	
	2000		13.6±0.4 (478)			14.5±0.4 (487)	14.3±0.4 (486)	
	2001		14.0±0.4 (413)			14.7±0.5 (402)	14.9±0.4 (411)	
	2002		11.8±0.8 (159)			11.3±0.8 (141)	12.1±0.8 (153)	
	2003		11.8±0.5 (215)			12.6±0.6 (199)	13.1±0.6 (217)	
Cond., μS/cm [1]	1996		535±6(282)			452±5(349)	454±5(350)	
	1997		621±7 (401)			576±7 (364)	593±7 (385)	
	1998		539±6 (450)			487±5 (462)	502±6 (467)	
	1999		550±8 (488)			527±8 (513)	533±8 (512)	
	2000		454±5 (479)			421±4 (485)	441±5 (486)	
	2001		568±9 (410)			519±7 (400)	536±7 (410)	
	2002		651±11 (159)			631±10 (139)	631±12 (152)	
	2003		610±15 (215)			542±17 (193)	531±15 (218)	
pH [1]	1996		7.91±0.02(300)			8.17±0.03(367)	8.19±0.03(368)	
	1997		7.94±0.03 (443)			8.24±0.04 (412)	8.20±0.04 (431)	
	1998		8.18±0.04 (365)			8.47±0.04 (374)	8.38±0.04 (375)	
	1999		7.74±0.02 (480)			7.87±0.03 (502)	7.80±0.02 (502)	
	2000		7.73±0.01 (425)			7.93±0.02 (438)	7.76±0.02 (433)	

	2001	7.94±0.02 (412)	8.33±0.04 (402)	8.20±0.02 (411)
	2002	7.90±0.05 (148)	8.14±0.05 (128)	7.98±0.05 (136)
	2003	7.74±0.05 (194)	8.05±0.05 (181)	8.05±0.04 (203)
Redox, mV[1]	1996	394±4(213)	387±3(263)	384±3(265)
	1997	433±3 (338)	433±3 (352)	430±4 (377)
	1998	333±6 (440)	309±6 (450)	307±6 (456)
	1999	302±7 (436)	283±7 (460)	281±7 (457)
	2000	289±2 (376)	274±2 (386)	283±2 (383)
	2001	233±6 (263)	235±5 (234)	236±5 (242)
	2002	177±8 (81)	165±9 (75)	166±9 (80)
	2003	277±5 (203)	261±6 (184)	254±5 (207)

[1] two-per-day sampling
* winter data only

methods employed the ascorbic acid and a molybdate color reagent method. For soluble reactive phosphorus and total phosphorus, total phosphorus samples were first digested by adding 0.5 ml of 5.6N H_2SO_4 and 0.2 g NH_3SO_4 to 25 ml of sample and exposing the samples to a heated and pressurized environment for 30 minutes in an autoclave. Nitrate+nitrate, run on the Lachat QuikChem IV automated system, used the cadmium reduction method.

Results and Discussion

2003 results and 10-year comparisons

Water quality results for 2003 weekly and two-per-day sampling are summarized in Table 2 while percent change through the wetlands and statistical significance are summarized in Table 3. A comparison of percent change in water quality for each of the 6 basic water quality indices for the entire 10-year period that the experimental wetlands have been in operation is given in Figure 2. A similar 10-year illustration is given for total phosphorus (Figure 3) and nitrate+nirate (Figure 4).

In 2003 there were increases in water temperature, decreases in redox potential and conductivity compared to readings in 2002. There were no significant differences

Table 3. Water quality changes (+ indicates increase through wetland) and statistical significance at Olentangy River experimental wetlands, 1999-2003. W1 = planted wetland; W2 = unplanted wetland; In = inflow; Out = outflow.

Parameter and year	% change W1 (+ = increase; - = decrease)	% change W2	Paired t-test, p-value In v. Out W1	In v. Out W2	Out W1 v. Out W2
Temp 99	-1.1	-2.1	nd	nd	0.0070
Temp 00	+6.0	+5.1	0.0000	0.0134	0.0000
Temp 01	+5.6	+7.0	0.0000	0.0000	nd
Temp 02	-3.9	+2.9	0.267	0.0067	0.0314
Temp 03	+6.9	+10.8	0.0119	0.0003	nd
DO 99	+4.9	-1.2	nd	0.0438	0.0001
DO 00	+8.5	-5.0	0.0000	0.0010	0.0000
DO 01	+10.4	+8.1	0.0000	0.0000	nd
DO 02	+3.3	+1.0	nd	nd	nd
DO 03	+3.7	+1.6	0.0084	nd	nd
Cond 99	-4.2	-3.1	0.0002	nd	0.0014
Cond00	-7.2	-2.9	0.0000	0.0000	0.0000
Cond01	-8.5	-5.5	0.0000	0.0000	0.0001
Cond 02	-3.0	-3.1	nd	nd	nd
Cond 03	-11.2	-13.1	0.0000	0.0000	nd
pH 99	+ 1.7	+0.7	0.0001	0.0020	0.0001
pH 00	+2.7	+0.4	0.0000	0.0040	0.0000
pH01	+4.9	+3.2	0.0000	0.0000	0.0000
pH 02	+3.0	+1.1	0.0000	0.0000	0.0004
pH 03	+4.0	+4.1	0.0000	0.0000	nd
Redox 99	-6.3	-6.8	0.0001	0.0001	nd[1]
Redox 00	-5.1	-2.3	0.0000	0.0000	0.0000
Redox01	1.0	1.5	0.0000	0.0000	0.0000
Redox 02	-6.9	-6.5	0.0365	0.0602	nd
Redox 03	-6.0	-8.6	0.0207	0.0000	0.033
Turbidity 99	-24.3	-18.2	0.0001	0.0070	0.0044
Turbidity 00	-42.7	-35.2	0.0000	0.0000	0.02751
Turbidity01	-0.6	8.2	nd	nd	nd
Turbidity 02	+29.2	+31.9	0.0085	0.0177	nd
Turbidity 03	+25.4	-5.1	nd	nd	nd
Total P 99	-27	-40	0.0128	0.0001	nd
Total P 00	-47	-34	0.0000	0.0184	nd
Total P 01	-39	-26	0.0000	0.0001	0.0115
Total P 03	-13	-7	nd	nd	nd
SRP 99	-71	-75	0.0001	0.0001	nd
SRP 00	-77	-67	0.0000	0.0000	nd
SRP 01	-62	-59	0.0000	0.0000	nd
$NO_3 + NO_2$ 99	-30	-33	0.0001	0.0001	nd
$NO_3 + NO_2$ 00	-34	-44	0.0004	0.0000	nd
$NO_3 + NO_2$ 01	-35	-23	0.0001	0.0086	nd
$NO_3 + NO_2$ 03	-41	-44	0.0002	0.0000	nd

[1] nd = no significant difference at $\alpha = 0.05$

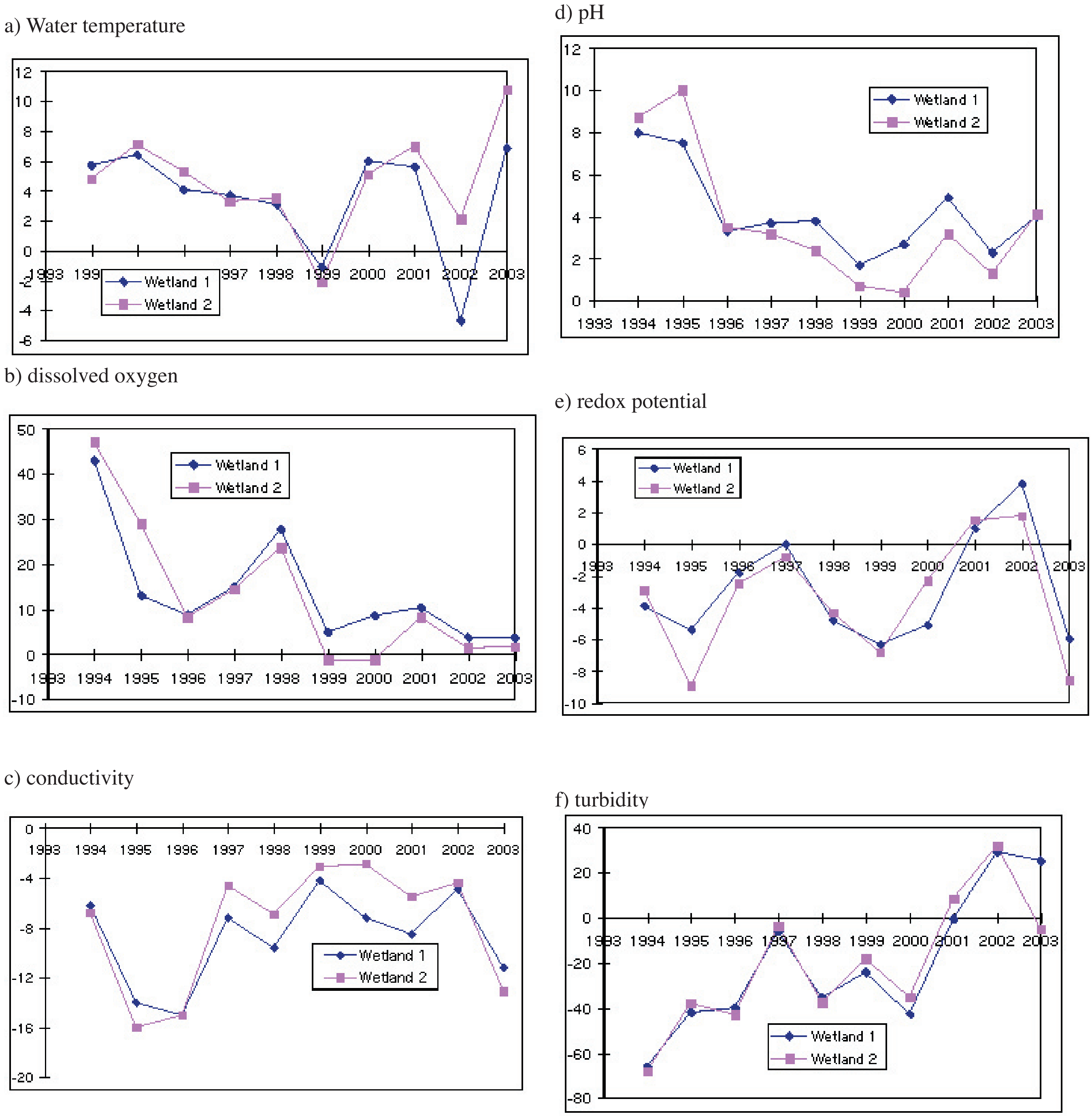

Figure 2. Changes in water quality 1994-2003 in experimental wetland basins. Values are expressed as percent change from inflow to outlfow.

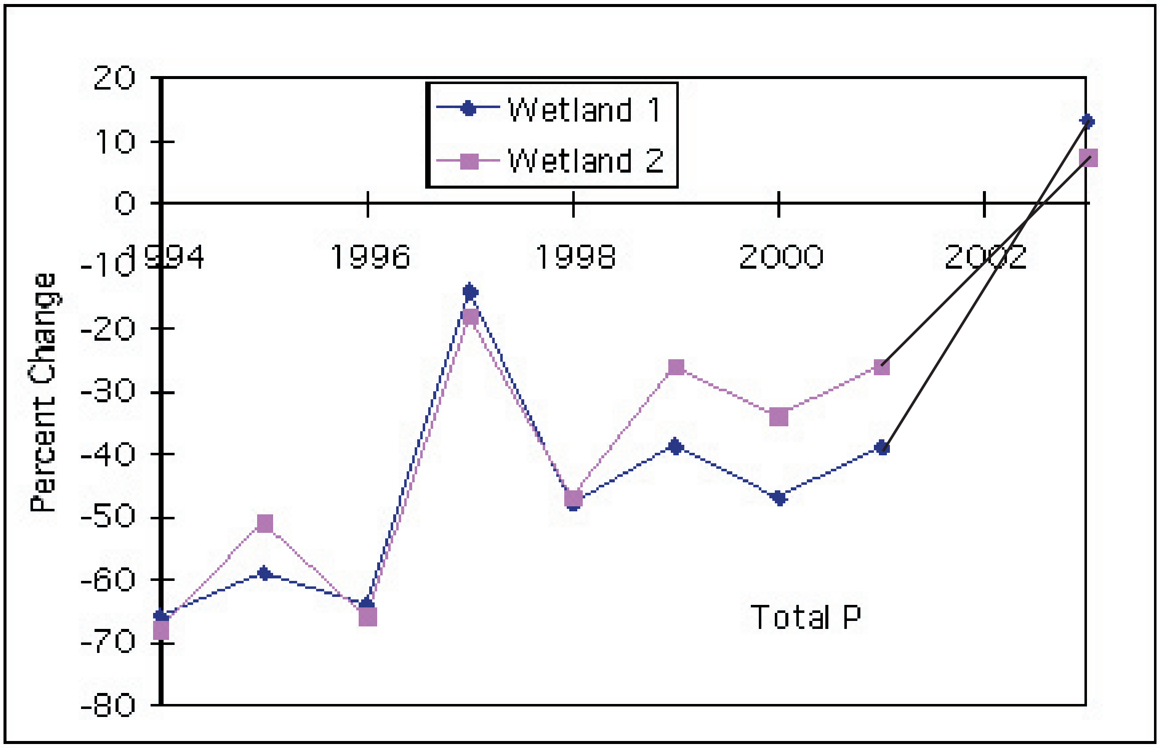

Figure 3. Changes in total phosphorus for 1994-2003 in experimental wetland basins. Values are expressed as percent change from inflow to outlfow. No data were collected in 2002.

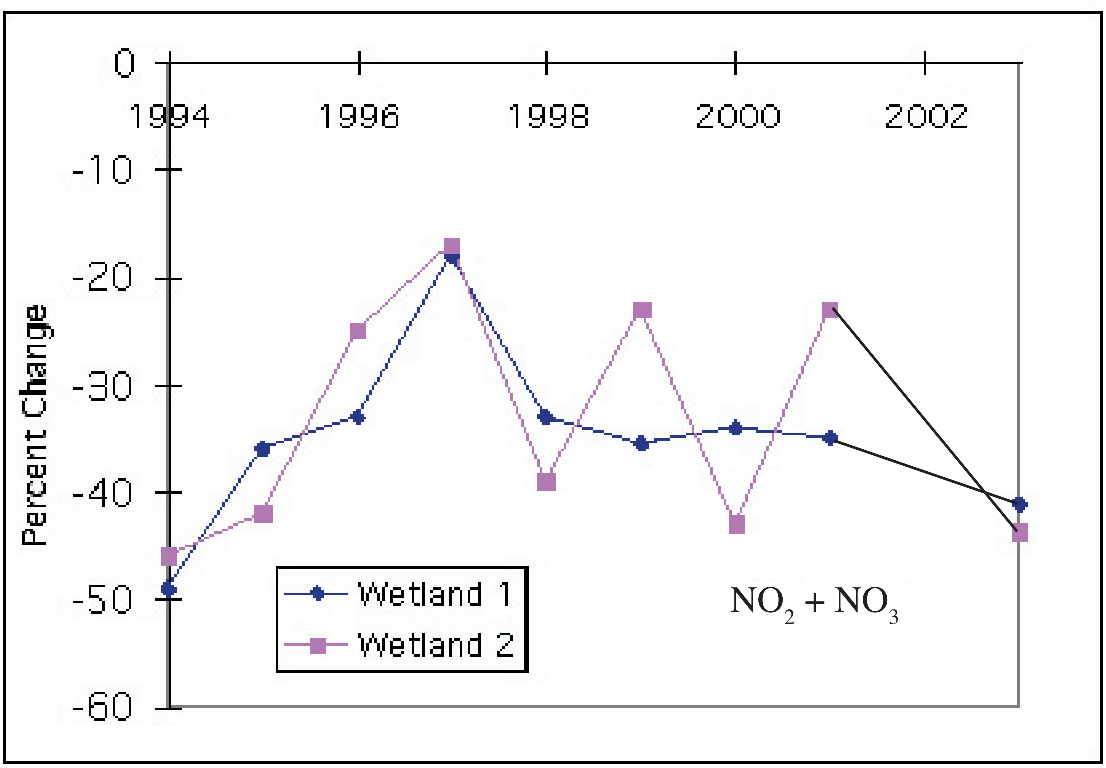

Figure 4. Changes in nitrate+nitrite-nitrogen for 1994-2003 in experimental wetland basins. Values are expressed as percent change from inflow to outlfow. No data were collected in 2002.

in water quality parameters between the two wetlands for 7 of the 8 measured parameters in 2003. Only redox potential was statistically different in the outflows of the two wetlands. Wetland 1 was a net exporter of suspended materials (turbidity) and Wetland 2 reduced turbidity by only 5%.

The wetlands continued to show a pattern started in 2000 of retaining less phosphorus each year. In 2003, inflow total phosphorus concentration averaged 121 μg-P/L while outflows were 137 and 130 μg-P/L for Wetlands 1 and 2 respectively. For the first year since the wetlands were created, they were exporting phosphorus. The wetlands continued to retain nitrate-nitrogen with a 41% decrease in Wetland 1 and a 44% decrease in Wetland 2. All of these water quality measurements include both flood pulse and normal flow conditions.

Pulsing conditions

The year 2003 represented the first year in which hydrologic pulsing was purposefully applied to the expermental wetlands to determine the effects of this pulsing on ecosystem function. During pulsing conditions, Wetland 1 retained only 6.5% of total phosphorus (Table 4) by concentration while Wetland 2 exported total phosphorus with a retention of -11.6%. During non-pulsing periods, conditions were only slightly better, Wetland 1 retained 8.1% and Wetland 2 0.5% of total phosphorus by concentration (Table 4). Nitrate-nitrogen patterns during non-pulsing and pulsing periods appeared to be similar (Table 5). The two wetlands retained 21 and 32% of nitrate-nitrogen by concentration during pulses and 21 and 39% during non-pulse periods.

Patterns of phosphorus and nitrate mass retention as a function of inflow rates are shown in Figures 5 and 6. These graphics combine data from the two experimental wetlands. Several data points at low flows and high flows showed export of total phosphorus with a weak polynomial relationship that suggests maximum phosphorus retention at about 15 cm/day inflow (equivalent to 275 gpm). Below that point, phosphorus might be retained but there is low flow so retention is flow-limited. Above that point, retention is low because of low retention time even though flow is high. The pattern of nitrate-nitrogen mass retention vs. hydraulic loading rate for non-growing season data only had a similar regression coefficient for a second-order trend line (Figure 6) but the pattern was exactly the opposite. Retention was lowest in the range of 10-15 cm/day (180-275 gpm) with higher retenion at low-flow conditions that approach stagnation and at high pulses that may have been utilizing more of the wetland basins. When summer data are included in this graphic, no trendline is possible because of high denitrification in the summer, no matter what the flow.

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Table 4. Total phosphorus during pulsing and non-pulsing periods in experimental wetlands in 2003.

Period	Flow, gpm Wetland 1	Flow, gpm Wetland 2	Phosphorus, μg-P/L inflow	outflow Wetland 1	outflow Wetland 2
PULSES					
Jan 3, 2003	380	380	141	141	116
Feb 1-5, 2003	484	464	133	149	259
Mar 5, 2003	495	417	410	231	354
May 4-6, 2003	476	553	167	317	252
Jun 2-4, 2003	417	446	49	4	17
Ave±std err (#)	450±22 (5)	452±29 (5)	180±60 (5)	168±50 (5)	200±60 (5)
% reduction				6.5	-11.6
NON-PULSES					
Jan 8-27, 2003	84	64	137	153	123
Feb 10-24, 2003	104	75	221	312	250
Mar 7-10, 2003	249	209	292	162	182
Apr 23-30, 2003	74	61	98	89	189
Jun 11- Jul 30, 2003	79	91	67	75	45
Nov 5-12, 2003	247	215	58	11	79
Ave±std err (#)	139±35 (6)	119±30 (6)	145±38 (6)	134±42 (6)	145±31 (6)
% reduction				8.1	0.5

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Table 5. Nitrate+nitrite nitrogen during pulsing and non-pulsing periods in experimental wetlands in 2003.

Period	Flow, gpm Wetland 1	Flow, gpm Wetland 2	Nitrate+nitrite, mg-N/L inflow	outflow Wetland 1	outflow Wetland 2
Jan 3, 2003	380	380	8.8	7.25	6.98
Feb 1-5, 2003	484	464	4.23	3.47	3.51
Mar 5, 2003	495	417	2.58	2.55	2.49
May 4-6, 2003	476	553	4.36	2.60	2.50
Jun 2-4, 2003	417	446	4.25	3.24	2.59
Ave±std err (#)	450±22 (5)	452±29 (5)	4.84±1.04 (5)	3.82±0.88 (5)	3.62±0.86 (5)
% reduction				21.1	32.2
NON-PULSES					
Jan 8-27, 2003	84	64	6.743	7.098	6.452
Feb 10-24, 2003	104	75	3.345	3.350	3.225
Mar 7-10, 2003	249	209	2.75	2.1	2.18
Apr 16-30, 2003	74	61	3.280	2.330	2.220
May 7-28, 2003	140	96		2.629	1.221
Jun 11-Jul 30, 2003	119	88	3.469	0.380	0.463
Nov 5-12, 2003	247	215	1.705	1.775	1.865
Mean	145±28 (7)	115±25 (7)	3.55±0.69 (6)	2.81±0.79 (7)	2.52±0.73 (7)
% reduction				20.8	39.0

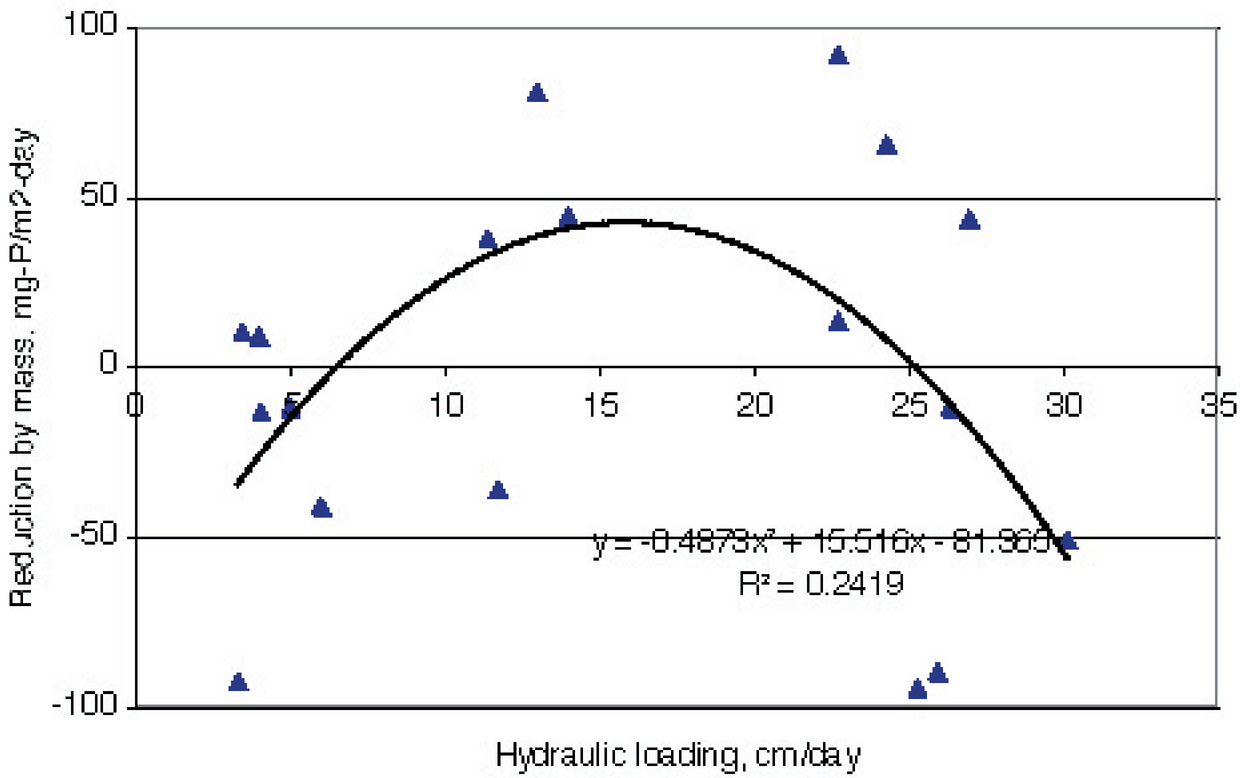

Figure 5. Reduction in total phosphorus mass as a function of hydraulic loading rate for experimental wetlands in 2003

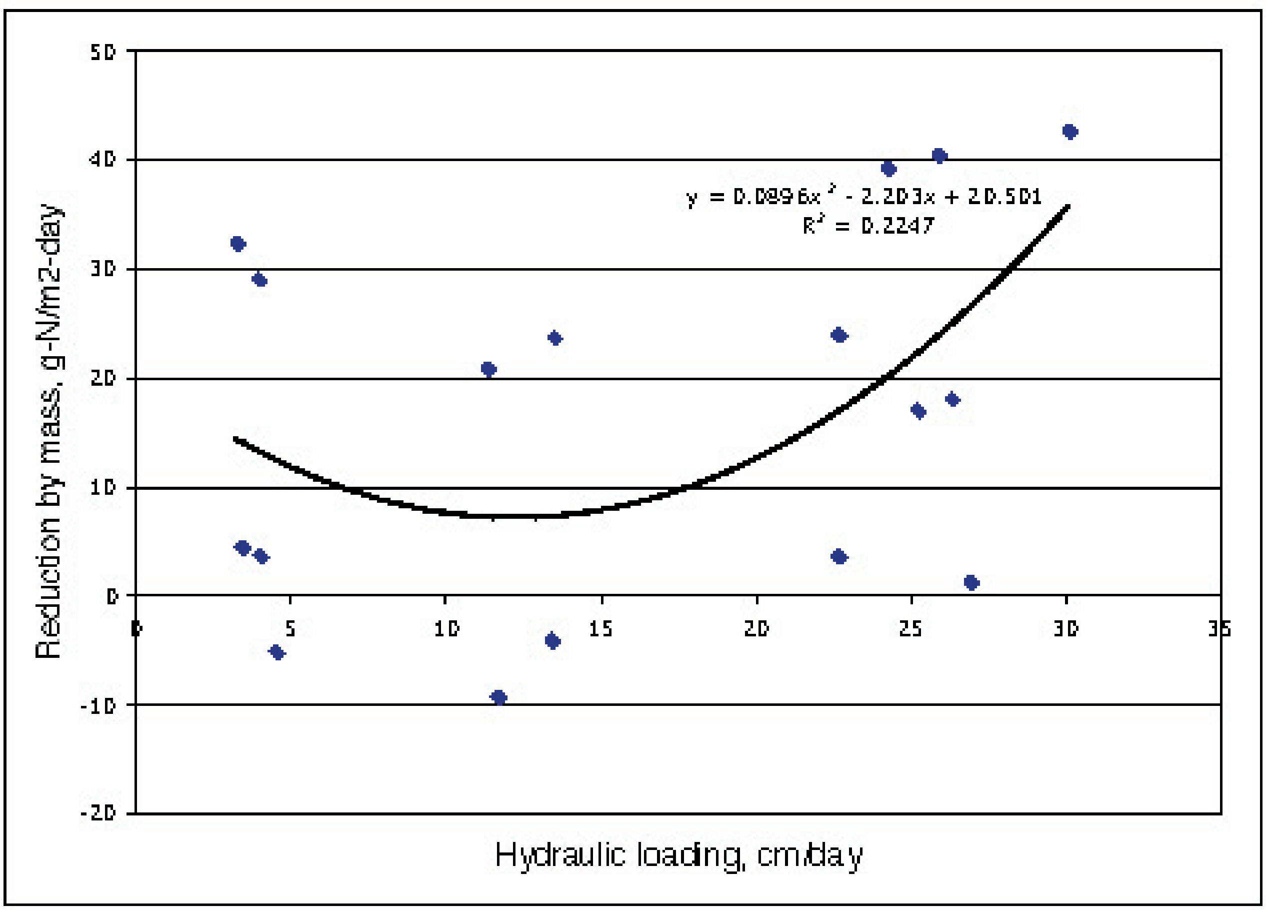

Figure 6. Reduction in nitrate+nitrite mass as a function of hydraulic loading rate for experimental wetlands in 2003 for non-growing season data only.

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