Biogeochemical patterns of created riparian wetlands: Twelfth-year results (2005)

William J. Mitsch, Li Zhang, and Maria E. Hernandez

Schiermeier Olentangy River Wetland Research Park, Environmental Science Graduate Program and School of Environment and Natural Resources, The Ohio State University

Introduction

As part of a long-term, large-scale experiment on self-design, two wetland basins at The Olentangy River Wetland Research Park (ORWRP) 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 12 growing seasons by the end of 2005 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)—W1 plants developed, particularly around the perimeter, to about 13% macrophyte cover in August, compared to essentially no macrophyte cover in W2. 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)—W1 continued to develop in vegetation cover with about 39% cover. Unplanted W2, 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 three growing seasons.

• Year 4 (1997)—Macrophyte growth continued to increase in both wetlands with about 54% cover in W1 and 58% cover in W2.

• Year 5 (1998)—Macrophyte cover was similar in the two basins but W2 began to be dominated by highly productive *Typha spp*. while W1 still had a wider diversity of cover and was not dominated by *Typha spp*. In other words, W1 plant cover was now more diverse.

• Year 6 (1999)—W2 was dominated by *Typha* while W1 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.

• 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 in 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 W1 on November 2, 2003.

Year 11 (2004)—The pulsing experiment continued with pulses during the first week of February, March, April, May, and June. This year was the official pulsing year for

Table 1. Water quality sampling at Olentangy River Wetland experimental wetlands in 2005.

Sample frequency	# Sampling stations	Period in 2005	Equipment	Parameters measured
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	LACHAT QuikChem IV (Lab) Shimadzu 5050A TOC analyzer (Lab)	total phosphorus soluble reactive P $NO_3 + NO_2$ TKN TOC

a USDA-sponsored grant comparing results to 2005 non-pulsing conditions.

Year 12 (2005)—Pulses were discontinued in this year (except for a natural flood in January) and steady flow occurrred in the wetland all year. This year was the official steady-flow year for the USDA-sponsored grant.

This study reports water quality results for the 12th year (2005) of operation of the experimental wetlands at the ORWRP. 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 5–11 (Mitsch et al., 1999, 2000, 2001, 2002, 2004, 2005a; Mitsch and Zhang, 2003). Two undergraduate honors theses (Wehr, 1995; Vorwerk, 1997), four OSU Master's theses (Harter, 1999; Dilley, 2003; Nahlik, 2005; Tuttle, 2005), 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. Ten journal articles (Mitsch et al., 1998, 2005b, c; 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 the water quality function of these experimental wetlands.

Methods

A summary of the water quality monitoring protocol for the two experimental wetlands in 2005 is shown in Table 1. Weekly water sampling, started in late April 1994, continued through 2005. One 1000 ml sample was collected at each of the 7 sites. Water samples were taken to laboratories in the Heffner Wetland Research and Education Building where subsamples were filtered and frozen for later measurement of soluble reactive phosphorus. Unfiltered samples were preserved with concentrated H_2SO_4 (0.5 ml/100 mLlsample) and frozen for later analysis of total phosphorus, nitrate+nitrite (NO_3 + NO_2), TKN, and occasionally ammonia-nitrogen. A raw sample is also stored for TOC analysis. Sample preparation and preservation is usually completed within 48 hours of original collection.

Two-per-day water sampling, also initiated in 1994, continued through 2005 by the staff and students of the ORWRP at Ohio State University. Inflow of W1 (representing the inflow to both basins) and the outflows of W1 and W2 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.

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, TKN, and nitrate+nitrite are 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 methods employed the ascorbic acid and a molybdate color reagent method. Total phosphorus and TKN samples are first digested in a block digestor by adding 5 mL of a digestion solution made up of H_2SO_4 and K_2SO_4 to 20 mL of sample and exposing the samples to a heated environment for 1 hour at 160°C and continued digestion for 1.5 hours at 380°C. Nitrate+nitrate, run on the Lachat QuikChem IV automated system, used the cadmium reduction method. TKN, after digestion, is estimated by the salicylate and hypochlorite colorimetric method. TOC (total organic carbon) is estimated by a TOC analyzer (Shimadzu 5050A).

Results and Discussion

Water quality results for 2005 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 for the past three years. A comparison of percent change in water quality for each of the six basic water quality indices for the entire 12-year period that the experimental wetlands have been in operation is given in Figure 1 and the 12-year pattern of nutrient removal is summarized in Figure 2.

Table 3 summarizes conditions for the three-year pulsing experiment. 2003 and 2004 had hydrologic pulses while 2005 had steady-flow conditions. 2004 represented the second year in which hydrologic pulsing was purposefully applied to the experimental wetlands to determine the effects of flood pulsing on ecosystem function.

In 2005 there were increases in water temperature, dissolved oxygen, and pH, and decreases in redox potential and conductivity through both wetlands (Table 3). This is similar to the patterns for these three parameters as in 2004. In 2005, there were significant differences between the two wetlands for all six two-per-day water quality parameters (temperature, dissovled oxygen, conductivity, pH, redox, and turbidity. Dissolved oxygen, pH and turbidity were statistically different in the outflows of the two wetlands in 2004. In the previous year (2003) only redox potential was different between the two wetlands. It appears that the two wetlands are diverging in biogeochemical function over the past three years although it is difficult to attribute that difference to the planting experiment in 1994.

There have been no significant differences between the two wetlands for nitrogen, phosphorus or carbon species measured over the three-year pulsing experiment (Figure 2). The wetlands retained more phosphorus in 2005 (28–30%) compared to the pulsing years when 7–24% was retained (Table 3). Especially in 2004, total phosphorus retention in the pulsing wetlands was low. Inflow total phosphorus concentration averaged 170 μg-PL^{-1} while outflows were 149

Table 2. Summary of water quality measurements at Olentangy River experimental wetlands, 1996 through 2005. 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)
	2004	179±22 (54)	170±19 (48)	126±9 (43)	130±10 (40)	149±12 (49)	130±10 (47)	151±17 (51)
	2005	94±9 (47)	100±10 (39)	74±8 (39)	77±7 (41)	70±8 (46)	72±8 (46)	73±8 (46)
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)
	2004	24±4 (54)	21±3 (49)	15±2 (43)	13±2 (43)	10±1 (49)	11±2 (50)	10±2 (48)
	2005	34±10 (43)	19±3 (37)	20±5 (31)	15±4 (32)	14±2 (36)	15±3 (40)	22±6 (35)
$NO_3 + NO_2$, 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)
	2004	2.27±0.25 (43)	2.38±0.30 (40)	2.14±0.31 (33)	2.22±0.31 (34)	1.71±0.17 (41)	1.69±0.18 (42)	1.89±0.21 (37)
	2005	2.80±0.45 (45)	2.22±0.31 (38)	1.63±0.26 (40)	1.97±0.43 (40)	1.71±0.26 (44)	1.66±0.25 (45)	1.65±0.25 (43)
TKN, mg-N/L	2004	0.62±0.05 (51)	0.57±0.04 (48)	0.75±0.05 (40)	0.71±0.05 (41)	0.79±0.06 (50)	0.93±0.15 (50)	0.73±0.05 (50)
	2005	0.93±0.09 (46)	0.88±0.12 (40)	1.04±0.23 (38)	1.16±0.17 (40)	0.87±0.08 (46)	0.92±0.12 (46)	0.93±0.09 (45)
TOC, mg-C/L	2004	6.9±0.7 (56)	6.5±0.8 (51)	5.9±0.6 (44)	5.7±0.6 (42)	7.0±0.8 (53)	6.9±0.7 (50)	7.2±0.9 (52)
	2005	9.1±1.2 (46)	6.8±1.0 (39)	7.4±1.0 (39)	8.3±1.1 (40)	8.6±1.2 (46)	8.1±1.3 (44)	9.0±1.3 (46)
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)	
	2004		31±2 (324)			37±2 (325)	35±2 (313)	
	2005		34±2 (345)			32±2 (361)	42±3 (357)	
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)	
	2004		10.2±0.2 (326)			12.3±0.3 (321)	13.1±0.4 (317)	
	2005		10.1±0.2 (348)			12.2±0.4 (361)	13.2±0.4 (359)	
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)	

continued

	2003	11.8±0.5 (215)	12.6±0.6 (199)	13.1±0.6 (217)
	2004	13.8±0.4 (345)	15.1±0.5 (342)	15.7±0.5 (338
	2005)	14.6±0.5 (381)	15.3±0.5 (381)	15.5±0.5
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)
	2004	552±7 (335)	498±8 (315)	478±9 (317)
	2005	571±8 (363(	551±9 (377)	536±7 (377)
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)
	2004	7.67±0.03 (345)	8.04±0.05 (342)	8.10±0.04 (337)
	2005	8.12±0.03 (342)	8.48±0.04 (360)	8.54±0.04 (358)
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)
	2004	158±8 (337)	143±8 (330)	143±7 (327)
	2005	265±3 (354)	245±3 (369)	241±3 (367)

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

Table 3. Water quality changes from inflow to outflow within and between the experimental wetlands, and statistical significance, 2003–2005. 2003 and 2004 were hydrologic pulsing years; 2005 was steady flow year. W1 = planted wetland; W2 = unplanted wetland; In = inflow; Out = outflow; nd = no significant difference at $\alpha = 0.05$

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 03	+6.9	+10.8	0.0119	0.0003	nd
Temp 04	+9.2	+13.9	0.0000	0.0000	nd
Temp 05	+4.6	+6.3	0.0000	0.0000	0.0000
DO 03	+3.7	+1.6	0.0084	nd	nd
DO 04	+19.6	+27.7	0.0000	0.0023	0.0068
DO 05	+20.9	+31.0	0.0000	0.0000	0.017
Cond 03	-11.2	-13.1	0.0000	0.0000	nd
Cond 04	-9.9	-13.5	0.0000	0.0000	nd
Cond 05	-3.5	-6.2	0.0099	0.0000	0.02
pH 03	+4.0	+4.1	0.0000	0.0000	nd
pH 04	+4.8	+5.5	0.0000	0.0000	0.0021
ph 05	+4.5	+5.2	0.0000	0.0000	0.0000
Redox 03	-6.0	-8.6	0.0207	0.0000	0.033
Redox 04	-9.2	-9.2	0.0000	0.0000	nd
Redox 05	-7.6	-9.4	0.0000	0.0000	0.006
Turbidity 03	+25.4	-5.1	nd	nd	nd
Turbidity 04	+21.5	+13.2	nd	nd	0.0034
Turbidity 05	-5.9	+22.5	0.0254	0.0135	0.0000
Total P 03	-13	-7	nd	nd	nd
Total P 04	-12	-24	nd	0.0064	nd
Total P 05	-30	-28	0.0005	0.0112	nd
SRP 04	-51	-47	0.0002	0.0005	nd
SRP 05	-24	-20	nd	nd	nd
$NO_3 + NO_2$ 03	-41	-44	0.0002	0.0000	nd
$NO_3 + NO_2$ 04	-28	-29	0.0073	0.0066	nd
$NO_3 + NO_2$ 05	-23	-25	0.0002	0.0000	nd
TKN 04	+38	+63	0.0038	0.0243	nd
TKN 05	-0.3	-5	nd	nd	nd
TOC 04	+8	+7	nd	nd	nd
TOC 05	-27	-19	nd	nd	nd

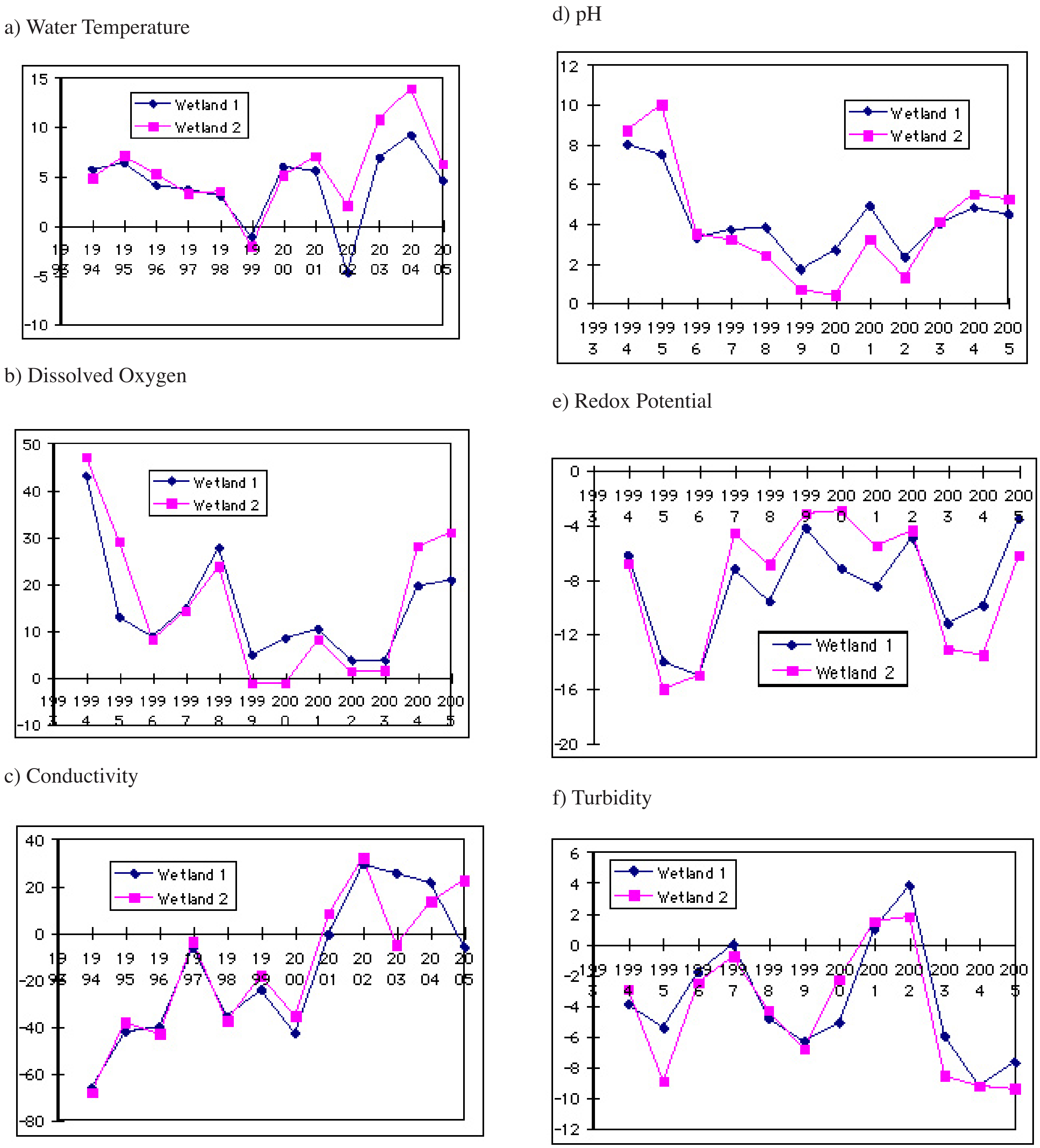

Figure 1. Changes in water quality, 1994–2005, in experimental wetland basins. Values are expressed as percent change from inflow to outlfow.

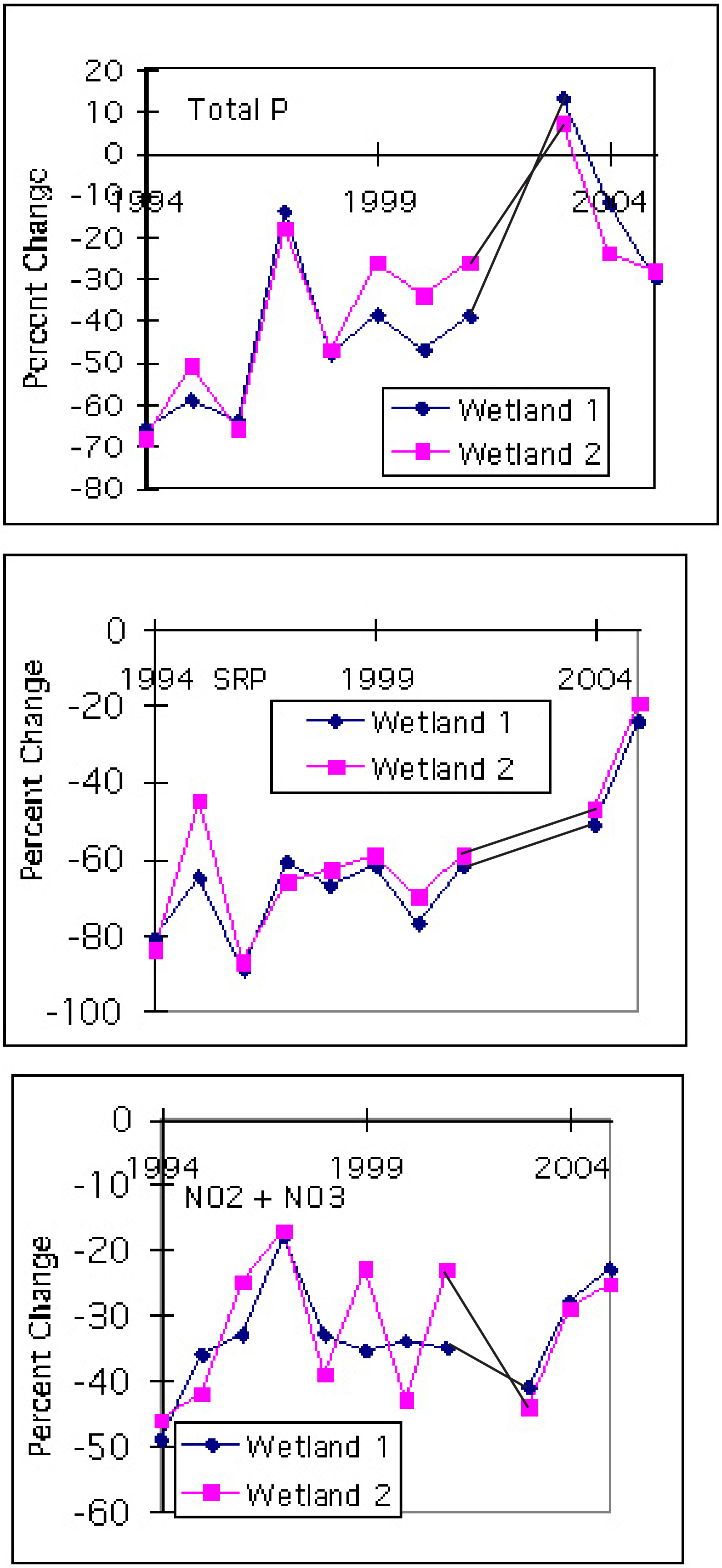

Figure 2. Changes in water quality, 1994–2005, in experimental wetland basins for total phosphorus, soluble reactive phosphorus (SRP), and nitrate + nitrite - nitrogen. Values are expressed as percent change from inflow to outlfow.

and 130 μg-P L^{-1} for W1 and W2 respectively. The wetlands continued to retain nitrate–nitrogen with a 23% decrease in W1 and a 25% decrease in W2. Soluble reactive phosphorus was retained less in the steady-flow year (20–24%) than in the pulsing year (47–51%).

Total organic carbon (TOC) has been measured for only the last 2 years (2004 and 2005). During the pulsing year, the wetland appeared to show a slight export of organic carbon. During the steady flow year (2005), the wetland retained 19–27% of TOC despite the fact that aquatic primary productivity was much higher in 2005 (Tuttle, 2005). Total Kjeldahl nitrogen (TKN), which is essentially a measure of total organic nitrogen (ammonium-nitrogen is below the level of detection), was exported (38–63% increase) in the pulsing year 2004 but was essentially unchanged (0.3–5% decrease) through the wetlands in steady-flow 2005.

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