Chapter 6: Optimization Research for the Stormwater Treatment Areas

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SUMMARY

Research into optimization of the Stormwater Treatment Areas (STAs) has continued over the past year. The 2000 Everglades Consolidated Report (SFWMD, 2000) contained detailed analyses and information on the state of knowledge about the Everglades Nutrient Removal Project (ENRP) and STAs. This chapter updates ongoing research and summarizes new findings completed since last year's report.

The Everglades Forever Act (Act) requires the South Florida Water Management District (District) to conduct research and monitoring programs to optimize nutrient removal performance of the STAs. Information is derived from practical experience operating the STAs and analyzing performance data, from experiments in some of the 30 0.2-hectare test cells, from mesocosm experiments, from analysis of data available from other wetlands, and eventually through simulation of operational scenarios using a dynamic water quality model.

The primary focus of STA Optimization Research this year has been to assess the performance of the STA treatment cells, conduct controlled experiments in the test cells, perform marsh dry-out experiments in mesocosms, and improve the hydraulic performance of treatment Cell 4.

The highlights of events and research into STA optimization are listed below:

- **STA-1 West**:
  - The Everglades Nutrient Removal Project (ENRP) has been incorporated into the larger STA-1 West (STA-1W) with the addition of treatment Cells 5A and 5B. The effective treatment area of the enlarged STA is now 2,699 hectares (ha) (6,670 acres), a significant increase from the former 1,545 ha (3,819 acres).
  - Incorporating the ENRP into STA-1W has altered some of the previous hydrologic flow patterns. Because construction activities disrupted collection of critical inflow water quality and flow data, water and phosphorus budget updates are available only for treatment Cells 2, 3 and 4 this year, for which phosphorus (P) retention was higher than that of prior years. Mass removal of

total phosphorus (TP) in Cell 4 has averaged greater than 56 percent over 5 years.

- The eastern and western flow-ways differ significantly in TP retention even when accounting for differences in TP loading. These results may be due to differences in vegetation, hydraulic retention time, water depths, and/or seepage inflow into the eastern flow-way.
- Although treatment Cell 4 retains more TP relative to its size than the other treatment cells, a dye tracer study indicated that over half (51 percent) of the inflow water into treatment Cell 4 bypassed the vegetation. A series of earthen plugs was installed across the deeper canals to distribute flow more evenly and a follow-up study will determine the effectiveness of these structures.
- Peat accretion during the first four years of operation was 8.5 mm/year.

- **Test Cells**
  - Experiments to determine the effects of changing hydraulic loading rate and depth on treatment performance are in progress. Mean outflow TP concentrations increased as hydraulic loading rates increased, exceeding 0.050 mg/L (1 mg/L=1000 µg/L=1000 ppb) only when hydraulic loading rates surpassed 10 cm/d. At low TP, increased inflow concentrations did not produce higher exports of TP.
  - Cotton strip assays in the test cells determined that decomposition rates increased as phosphorus loads increased. At low TP concentrations, decomposition rates were not affected by loading rates.
- **Mesocosms**
  - Marsh dryout experiments are being conducted to determine the effects of extreme drought and subsequent soil oxidation on nutrient release and retention when the marsh is reflooded. Preliminary results suggest that while the dryout/reflooding cycle does produce TP influx into the water column, this release lasts about one month. Total phosphorus flux into the water column was less in tanks with emergent species present.

BACKGROUND AND ISSUES

EVERGLADES IMPACTS AND STORMWATER TREATMENT AREAS

The Everglades ecosystem has been degraded as a consequence of human activities. Impacts include land use changes such as urban and agricultural development, altered hydrology from regional flood-control efforts, and nutrient enrichment from agricultural and urban runoff and Lake Okeechobee water releases. Discussions of these impacts and their effects on the Everglades ecosystem are presented in the 1999 Everglades Interim Report (McCormick et al., 1999; Redfield et al., 1999; Sklar et al., 1999).

Everglades periphyton and plant communities are known to be extremely sensitive to phosphorus (P) availability. Excess P and changing hydrology are most responsible for negative ecological impacts occurring in the Everglades (Koch and Reddy, 1992; McCormick and O'Dell,

1996; McCormick et al., 1998). A reduction in total P (TP) input to this system is central to the District's Everglades restoration program. Part of the restoration program includes building STAs, a series of large treatment wetlands. Under the Act, the District must initiate a research and monitoring program to collect information necessary to optimize STA nutrient removal performance. Regional environmental issues and Act requirements pertaining to the STAs are discussed more fully in the Introduction (**Chapter 1)** of this Report.

STORMWATER TREATMENT AREA OPTIMIZATION RESEARCH PROGRAM

The STA Optimization Research and Monitoring Program mandated by the Act will assist the District to develop operational strategies to maximize STA performance independent of other technologies. The STA Optimization Research and Monitoring Program is described in greater detail in Chimney and Moustafa (1999) and Chimney et al. (2000). Information is being compiled from four distinct research efforts:

- Practical experience gained from operating the ENRP and analysis of its performance data
- Experiments conducted in the STA-1W test cells and mesocosms
- Analysis of data from other treatment wetlands, especially those located in South and Central Florida
- Simulation of nutrient removal under different operating scenarios using a dynamic water quality model.

CONSTRUCTION OF STA-1 WEST

The Everglades Nutrient Removal Project (ENRP) was a 1,545 hectares (ha) (3,819 acres) treatment wetland constructed by the District on land previously farmed for sugar cane, rice and vegetables (SFWMD, 1991). The ENRP served as a prototype STA (Chimney et al., 2000) and has been incorporated into the footprint of STA-1 West (STA-1W; **Figure 6-1**). The ENRP ceased to exist as a separate entity from both a regulatory and operations perspective with the issuance of the STA-1W NPDES [#FL0177962-001] and Everglades Forever Act [#503074709] operating permits in May 1999 and completion of key water control structures shortly thereafter. The operational and reporting requirements of FDEP operating permit #502232569 for the ENR Project have been superceded by these new permits.

Completion of treatment Cells 5A and 5B in STA-1W (**Figure 6-1**) increased the effective treatment area of this wetland from 1,545 ha to 2,699 ha (6,670 acres). Inflow now enters STA-1W through gates at the G302 weir. Some of this flow is diverted into treatment Cell 5A through a series of culverts in a dividing levee, while the remainder enters treatment Cells 1 through 4 through gates at the G303 structure. The G250 pump station has ceased handling combined inflow and seepage return waters and now handles seepage return exclusively. The levee separating the Buffer Cell and Treatment Cell 1 was degraded and these cells were combined into an enlarged Treatment Cell 1.

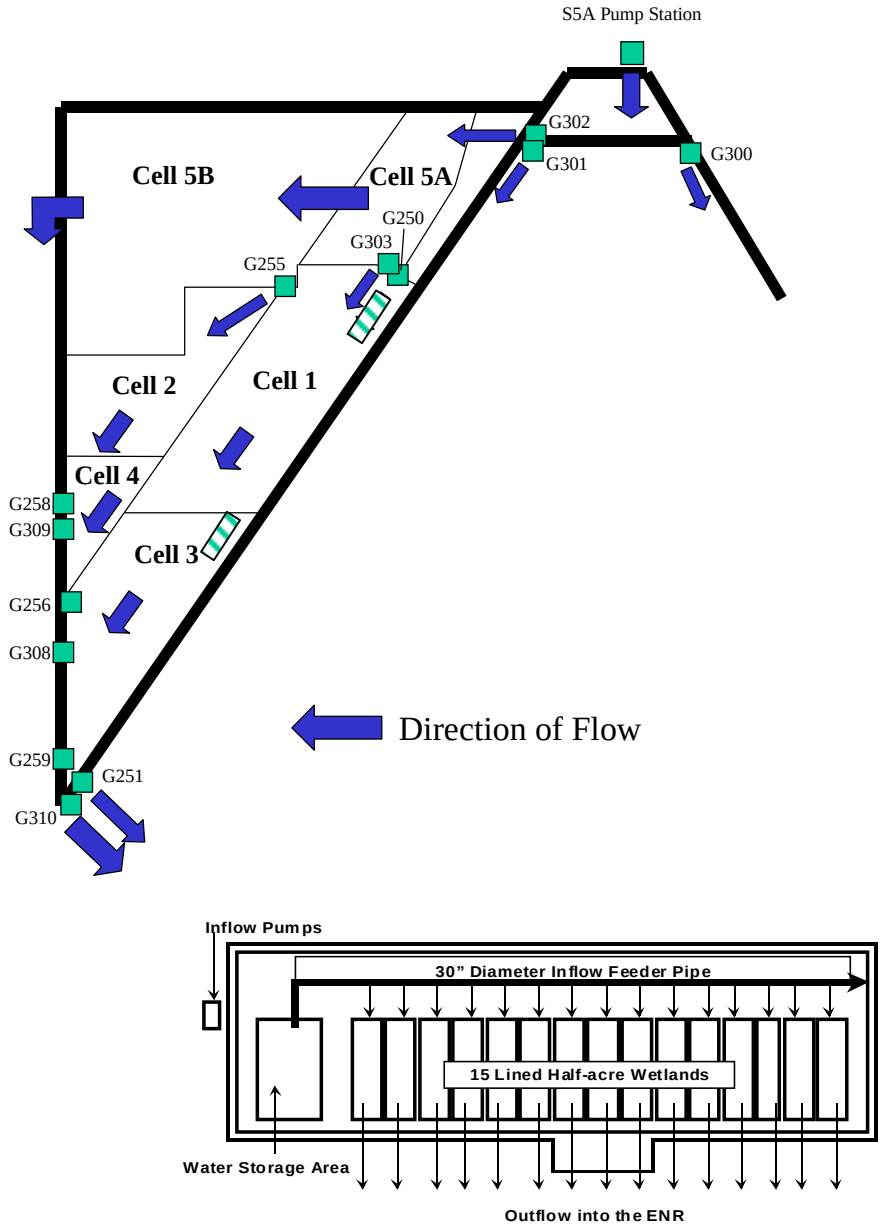

Figure 6-1. Stormwater Treatment Area 1-W and the test cells. Directional flow is illustrated for the existing and new water control structures in STA-1W and in the test cells. The north test cells are in Treatment Cell 1 and the south test cells are in Treatment Cell 3.

Outflow from treatment Cells 3 and 4 still exits the system through the G251 pump station. A new pump station (G310) was built to process all flow from treatment Cells 5A and 5B and excess water from treatment Cells 3 and 4 during large storm events. Water will be released from treatment Cells 3 and 4 through the G258, G259, G308 and G309 structures into the canal leading to G310.

CHAPTER OBJECTIVES

Detailed results from a number of individual studies that comprise the STA Optimization Research and Monitoring Program were presented and discussed at length in previous reports (Chimney and Moustafa, 1999; Chimney et al., 2000). The objectives of this chapter are to present new findings and analyses completed since last year's report and/or to provide an update to ongoing activities that have generated sufficient new information. The primary focus of STA Optimization Research this year has been to document the performance of the treatment cells, improve the performance of treatment Cell 4, and conduct controlled hydrologic experiments in the test cells.

HYDROLOGY AND PHOSPHORUS BUDGETS FOR TREATMENT CELLS

Water and phosphorus budgets were calculated in the past for the entire ENRP and individual interior cells (Chimney and Moustafa, 1999; Chimney et al., 2000; Nungesser and Chimney, 2000). Construction activities associated with building STA-1W (such as installation of G303 and modifications made to G250) resulted in a disruption of critical flow data needed to calculate these budgets. Stage recorders installed at G303, the new primary source of inflow to treatment Cells 1 through 4, had not been fully calibrated by the end of April 2000 and could not be used to calculate flow through this structure. While accurate flow measurements through G250 are available, they represent only part of the total inflow. As a result, water and phosphorus budgets could not be updated for the entire STA-1W nor for Treatment Cell 1. Because the Buffer Cell was incorporated into treatment Cell 1, no further budgets can be calculated for it. However, collection of accurate flow and water quality data continued in treatment Cells 2, 3 and 4 during this year (**Table 6-1**).

Table 6-1 reports the flow and total phosphorus budgets for treatment Cells 2, 3 and 4 for the 5-year period from 1 May 1995 through 30 April 2000. Except for seepage into and out of the treatment cells, the methods for calculating the water and nutrient budgets follow those defined in Chimney et al. (2000). Seepage losses from the treatment cells had relied on the assumption that the seepage return canal water was isolated from other seepage sources. However, construction has intermingled water from the new Treatment Cell 5 and has periodically interrupted water flow in the seepage return canal. Because there are no consistent data upon which to estimate seepage out of the cells for Water Year 1999-2000, we estimated it as the mean for the same month in previous years. Groundwater seepage into the treatment cells had relied upon stage gauges that were removed. A stage gauge located at the south end of the L-7 levee above the outflow pump G-251 was substituted. Alternative methods to estimate seepage will be explored for future water and nutrient budgets for STA-1W.

Table 6-1. STA-1W Water Budget and Phosphorus Budget data for Treatment Cells 2, 3, and 4 from May 1995 through April 2000. Data are unavailable for treatment Cell 1 and for the entire ENRP for water year 1999-2000 because of alterations from construction and installation of monitoring equipment. See text for details.

WATER BUDGET

	Inflow Water Load			Outflow Water Load			Remainder		ΔS
Sources of Flow	hm^3	cm/day	%	hm^3	cm/day	%	hm^3	%	hm^3
Treatment Cell 2 - 05/01/95 to 04/30/2000									
G255	449.0	7.44	94.2	--	--	--	--	--	--
Rainfall	27.8	0.46	5.8	--	--	--	--	--	--
G254	--	--	--	418.1	6.92	79.0	--	--	--
Seepage	--	--	--	85.7	1.42	16.2	--	--	--
Evapotranspiration	--	--	--	25.6	0.42	4.8	--	--	--
TOTALS	476.8	7.9	100.0	529.4	8.8	100.0	-52.6	-11.0	0.22
Treatment Cell 3 - 05/01/95 to 04/30/2000									
G253	342.3	5.79	84.5	--	--	--	--	--	--
Rainfall	27.2	0.46	6.7	--	--	--	--	--	--
L-7 Surficial Seepage	12.4	0.21	3.1	--	--	--	--	--	--
L-7 Deep Seepage	23.4	0.40	5.8	--	--	--	--	--	--
G251-G256	--	--	--	310.6	5.26	85.2	--	--	--
Seepage	--	--	--	28.3	0.48	7.8	--	--	--
Evapotranspiration	--	--	--	25.5	0.43	7.0	--	--	--
TOTALS	405.3	6.9	100.0	364.4	6.2	100.0	40.9	10.1	-0.29
Treatment Cell 4 - 05/01/95 to 04/30/2000									
G254	418.1	19.46	97.7	--	--	--	--	--	--
Rainfall	9.8	0.46	2.3	--	--	--	--	--	--
G256	--	--	--	387.6	18.04	90.4	--	--	--
G258	--	--	--	0.1	0.00	0.0	--	--	--
Seepage	--	--	--	32.1	1.49	7.5	--	--	--
Evapotranspiration	--	--	--	9.1	0.42	2.1	--	--	--
TOTALS	427.9	19.9	100.0	428.9	20.0	100.0	-1.0	-0.2	0.14

PHOSPHORUS BUDGET

	Inflow TP Load			Outflow TP Load			TP Retained		
TP Sources	kg	$g/m^2/yr$	%	kg	$g/m^2/yr$	%	kg	$g/m^2/yr$	%[2]
Treatment Cell 2 - 05/01/95 to 04/30/2000									
G255	38,611	2.34	98.4	--	--	--	--	--	--
Rainfall	400	0.02	1.0	--	--	--	--	--	--
Dry Deposition	214	0.01	0.5	--	--	--	--	--	--
G254	--	--	--	18,978	1.15	97.5	--	--	--
Seepage	--	--	--	496	0.03	2.5	--	--	--
TOTALS	39,225	2.37	100.0	19,474	1.18	100.0	19,751	1.19	50.4
Treatment Cell 3 - 05/01/95 to 04/30/2000									
G253	11,421	0.71	88.7	--	--	--	--	--	--
Rainfall	391	0.02	3.0	--	--	--	--	--	--
Surficial Seepage	136	0.01	1.1	--	--	--	--	--	--
Groundwater Seepage	725	0.04	5.6						
Dry Deposition	209	0.01	1.6	--	--	--	--	--	--
G251-G256	--	--	--	8,697	0.54	98.8	--	--	--
Seepage	--	--	--	109	0.01	1.2	--	--	--
TOTALS	12,882	0.80	100.0	8,806	0.54	100.0	4,076	0.25	31.6
Treatment Cell 4 - 05/01/95 to 04/30/2000									
G254	18,978	3.23	98.9	--	--	--	--	--	--
Rainfall	141	0.02	0.7	--	--	--	--	--	--
Dry Deposition	76	0.01	0.4	--	--	--	--	--	--
G256	--	--	--	8,304	1.41	98.7	--	--	--
Seepage	--	--	--	107	0.02	1.3	--	--	--
TOTALS	19,195	3.26	100.0	8,411	1.43	100.0	10,784	1.83	56.2

[2] Percent TP retained calculated relative to the amount of TP that entered only that individual cell.

One of the estimated inflows to the ENRP in the water budgets is seepage from Water Conservation Area 1 (the Arthur R. Marshall Loxahatchee National Wildlife Refuge). In 1997, the USGS conducted extensive field monitoring of groundwater seepage into and out of the ENRP from a series of wells installed along three transects positioned across treatment Cells 1, 2, 3 and 4 in 1997 (Harvey et al., 2000). Results from this study supported the seepage rates used in our water budgets (Guardo and Prymas, 1998) in both magnitude and temporal pattern.

Inflow volumes for Treatment Cells 2 and 4 were consistent with those for prior years (Chimney et al., 2000, Table 6-5). However, flow-weighted inflow TP concentrations were higher than previous years (**Figure 6-2)**, particularly in Treatment Cell 2 where TP concentrations surpassed any previous monthly values during 1999-2000. Inflow TP loading into Cell 2 had averaged 0.47 $g/m^2/yr$ over the previous four years in 1999; in 2000, it increased nearly five-fold to 2.37 $g/m^2/yr$. For Cell 4, it was much higher as well, 3.26 $g/m^2/yr$ in 1999-2000, compared to 2.34 $g/m^2/yr$ for the prior four years (Chimney et al., 2000):

	Area loading ($g/m^2/yr$		Area retention ($g/m^2/yr$)		Retention (%)	
	1995-1999	1995-2000	1995-1999	1995-2000	1995-1999	1995-2000
Cell 2	0.47	2.37	0.65	1.19	36.4%	50.4%
Cell 3	0.71	0.80	0.11	0.25	16.1%	31.6%
Cell 4	2.34	3.26	1.10	1.83	46.9%	56.2%

Total phosphorus retention (the difference between inflow and outflow mass loadings) for Treatment Cells 2, 3 and 4 was much higher than that of prior years. TP retention in Cell 2 nearly doubled to 1.19 $g/m^2/yr$ from 0.65 $g/m^2/yr$ (Chimney et al., 2000) and for Treatment Cell 4 retention averaged 1.83 $g/m^2/yr$ versus 1.10 $g/m^2/yr$. Retention for Cell 3 was similar to previous years, although its performance exceeds that of prior years (**Figure 6-2**). TP retention in Cell 2 increased dramatically and its value of 50.4 percent approached that of Cell 4 (56.2 percent) (**Table 6-1**).

With an overall TP retention rate of 56.2 percent, Cell 4 continued to outperform other treatment cells, though Cell 2 performance increased dramatically as well (**Table 6-1, Figure 6-2**). The two western flow-way cells retained a total of more than 30,500 kg of TP over the project period. Treatment Cell 3 retained the least amount of TP based both on mass and on areal efficiency of TP removal, but its performance improved over this last year, as well. It should be noted that Cell 3 was the least loaded at a third to a quarter of the levels of Cells 2 and 4, and its retention is therefore lower.

Wetland ecosystem behavior often varies with vegetation, hydrology, nutrients, area, shape, water depth, and other differences. Retention rates of TP (as a percent of inflow mass) in the treatment cells have varied over time (**Figure 6-3**). Each water year has seen highly variable retention rates. Cell 2 has retained 42 to 58 percent of inflow TP consistently since 1995. Cell 3 performance has improved over the last two years. The performance of Cell 4 has improved over the project period, and has maintained consistently high retention rates. This cell has been managed differently than the other three, maintained as open water and submerged aquatic vegetation; it is smaller in size, and is operated with shorter hydraulic residence times.

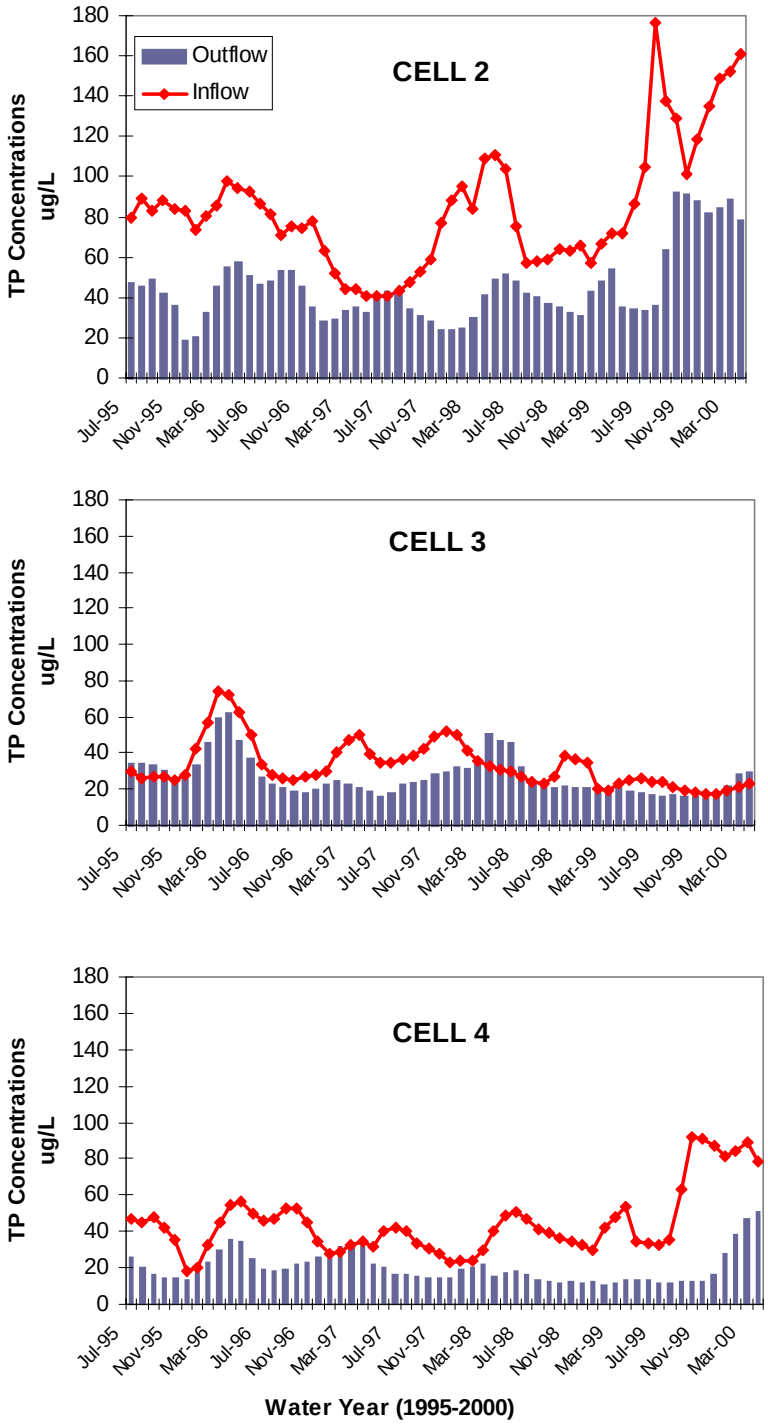

Figure 6-2. Monthly flow-weighted TP concentrations for Treatment Cells 2, 3, and 4 for the period of record (1995-2000).

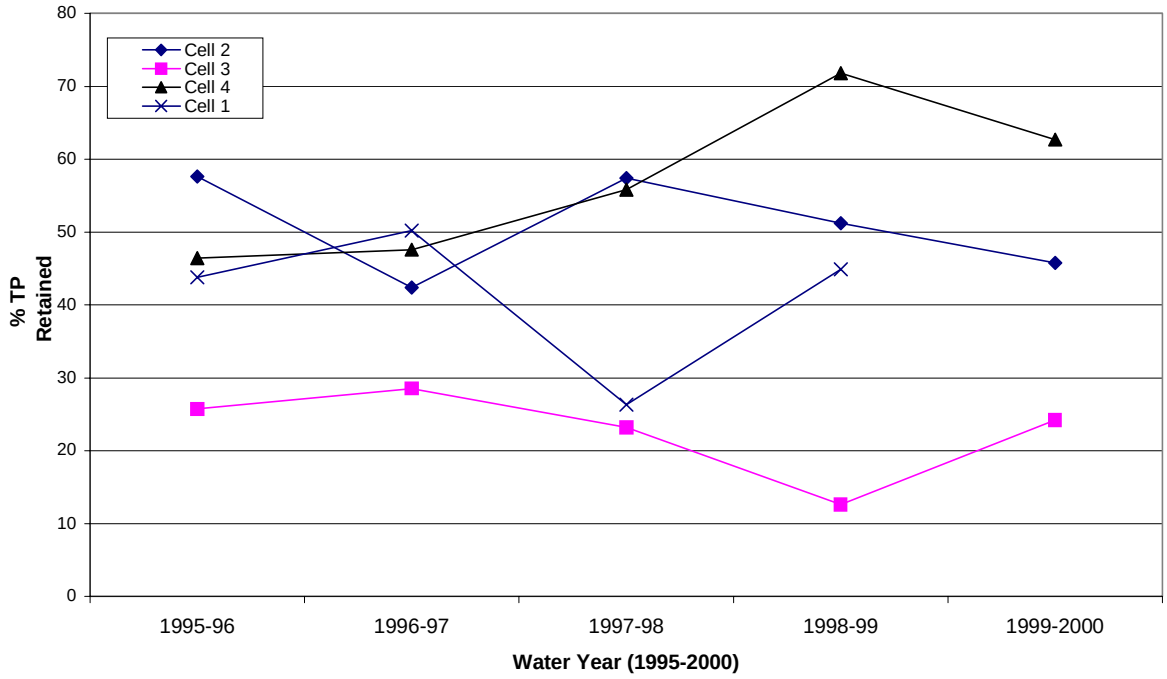

Figure 6-3. Annual TP retention rates for treatment wetlands in STA-1W as a percent of the inflow TP mass.

With the intent of improving its performance even further, a detailed analysis of hydrologic conditions in Cell 4 was performed. Under the supervision of District staff, DB Environmental Laboratories (2000; **App. A8-1**) conducted a lithium tracer study to determine flow patterns in Cell 4 to quantify short-circuiting which may reduce nutrient removal performance. The dye tracer study results showed that about 51 percent of the inflow water bypassed the submerged aquatic vegetation (SAV) and rapidly moved down existing borrow canal areas. Earthen plugs were constructed in the spring of 2000 to redistribute flow and reduce short-circuiting. A second tracer study will be conducted during the upcoming water year to determine the effectiveness of these modifications. Future analyses will determine whether these modifications improved Cell 4 performance.

Treatment cell data from 1995 through 1999 have been analyzed to determine not only how the treatment cells are performing, but also whether their performances differ once physical differences are accounted for. Differences between cells include nutrient retention rates (**Table 6-1**), size, depth, area, hydraulic residence time, vegetation types and coverage (**Table 6-2**), and other factors. In an attempt to discern what effect these factors have on TP retention, we looked at TP load reduction relative to cell size and TP inflow characteristics (Nungesser and Chimney, 2000).

Table 6-2. Vegetation development in STA-1W Cells 1, 2, 3, and 4, and the Buffer Cell from May 1995 through April 1999. Units are hectares covered by vegetation type determined through aerial imagery and field validation.

Date	05/95	11/95	04/96	11/96	05/97	10/97	04/98	11/98	04/99
BUFFER CELL									
cattail		23.6	22.4	21.7	22.8	23.6	24.1	23.4	23.5
floating spp.		17.8	15.3	19.6	20.6	24.3	22.1	22.0	24.3
other emergent spp.		7.7	8.3	8.7	8.4	4.5	5.3	4.8	4.5
open H2O/sub. veg.		4.7	8.0	3.9	1.9	1.4	2.3	3.6	1.3
TOTAL		53.7	53.9	54.0	53.7	53.7	53.8	53.7	53.7
CELL 1									
cattail	227.6	211.2	193.5	176.0	183.8	183.8	179.8	161.3	152.9
floating spp.	21.4	51.1	29.0	65.1	21.0	24.5	16.1	26.5	28.7
other emergent spp.	80.7	80.1	82.5	84.8	87.3	85.8	85.3	101.7	115.0
open H2O/sub. veg.	194.3	183.0	219.0	199.0	233.0	230.3	243.0	235.5	228.0
TOTAL	524.0	525.4	524.0	524.8	525.2	524.3	524.2	525.0	524.6
CELL 2									
cattail	335.3	341.9	336.7	316.4	312.5	269.9	230.0	189.9	190.1
floating spp.	1.8	29.6	21.8	42.4	39.1	33.2	33.8	26.7	43.9
other emergent spp.	15.6	8.9	11.0	10.0	10.5	5.6	5.5	4.1	9.5
open H2O/sub. veg.	58.4	32.3	44.5	46.0	52.3	105.6	145.1	193.7	170.9
TOTAL	411.2	412.7	413.9	414.7	414.4	414.4	414.3	414.4	414.3
CELL 3									
cattail	99.7	126.7	137.2	153.3	164.2	171.1	178.9	188.7	192.4
floating spp.	0.2	2.7	2.6	8.0	5.8	3.3	1.5	5.8	3.9
other emergent spp.	197.2	188.3	187.2	185.0	178.9	179.4	175.5	167.3	169.2
open H2O/sub. veg.	105.5	85.2	79.0	60.7	57.7	52.4	49.7	45.0	41.0
TOTAL	402.6	402.9	405.9	407.0	406.6	406.2	405.7	406.7	406.4
CELL 4									
cattail	1.9	3.1	3.7	5.0	5.2	5.1	5.0	6.4	7.0
floating spp.	0.0	2.1	1.2	3.2	2.3	1.1	0.5	0.4	1.2
other emergent spp.	5.4	0.7	0.6	1.6	2.2	2.1	1.9	1.4	1.1
open H2O/sub. veg.	140.0	141.6	141.1	137.0	137.2	138.4	139.5	138.4	137.4

To account for loading differences among cells, we weighted TP load reduction by the area of the treatment cell. Because the treatment cells were loaded differently, performance among these cells was evaluated statistically in a one-way analysis of covariance (ANCOVA) of unit-area TP load reduction, using inflow TP as a covariate. All data were log transformed prior to analysis. The ANCOVA model tested for homogeneity of slopes among treatment cells. The comparison of 3-month moving averages was followed by a *post hoc* least squares mean test using SAS (Proc GLM, SAS Institute Inc. Cary, NC) to discriminate among treatment cells.

The ANCOVA of TP retention detected significant differences among treatment cells (**Table 6-3**). The least squares means test declared all cells to be statistically different from each other with the exception of Cells 2 and 3. The regression model resulting from the ANCOVA accounted for almost all the variance in TP retention (R^2=0.9978). The inverse relationship between smaller size and higher removal efficiency is at first counterintuitive, although similar findings have been reported for other treatment wetlands (Li, 2000). These results may be produced by differences between flow-ways in hydraulic residence time (HRT), operating depths, vegetation characteristics, and/or the influence of seepage into the eastern flow-way from Water Conservation Area 1 (WCA-1).

A previous analysis (Chimney et al., 2000) compared three-month rolling average TP settling rates with TP loading rates, hydraulic loading rates, water depth, and nominal hydraulic residence time (Figures 6-27 through 6-34 in Chimney et al., 2000). The settling rates were positively correlated with the first three factors and negatively with nominal hydraulic residence time except in the Buffer Cell and treatment Cell 3. Flow-weighted outflow TP concentrations were positively correlated with TP and hydraulic loading rates and negatively correlated with nominal hydraulic residence time. Flow-weighted outflow TP was positively correlated with water depth in the Buffer Cell and treatment Cell 3, negative for treatment Cell 4, and not significant for the treatment Cells 1 and 2.

Results of the ANCOVA and the correlation analyses suggest that management strategies involving manipulation of water depth, HRT, vegetation type, and nutrient loading may alter phosphorus retention in the STAs. Further analysis of data from the District's STA Optimization Research Program will help clarify these relationships.

Table 6-3. Summary of analysis of covariance of total phosphorus retained with total phosphorus loading (3-month moving unit-area values) in the interior cells of STA-1W from May 1995 through April 1999. All data were log transformed prior to analysis.

Source	DF	Sum of Squares	Mean Square	F value	*P* > F
Model	9	548.5	60.9	10506.4	<0.0001
Treatment Cells	4	2.1	0.5	90.7	<0.0001
TP Load	1	131.4	131.4	22652.8	<0.0001
Cells*TP Load	4	<0.1	<0.1	1.83	0.1236
Error	210	1.2	<0.1		
Corrected Total	219	549.7		R^2 = 0.9978	

Least Squares Means

Grouping[a]	Mean[b]	Cell
A	1.2323	Buffer
B	0.2066	4
C	-0.8338	3
C	-0.8328	2
D	-1.0913	1

[a]Treatment Cell Means with the same letter are not significantly different.
[b]Treatment Cell Means have been adjusted for the covariate, TP load

VEGETATION AND PEAT ACCRETION

Spatial and temporal changes in the composition of the vegetation community in the ENRP was monitored through a combination of aerial overflight imagery and field verification (Chimney et al., 2000). Fourteen overflights were conducted from October 1993 through April 1999. Although a total of 20 different vegetation types was identified, the data presented here are summarized into four major categories: cattail, open water/submerged aquatic vegetation, floating macrophytes and other emergent macrophytes. Vegetation mapping of the ENRP was a condition of the expired FDEP operating permit and has been discontinued. One more overflight to construct a base map of STA-1W is required by the NPDES operating permit, but no further regular overflights are scheduled. A discussion of vegetation changes is provided in Chimney et al. (2000).

The composition of the vegetation community in Cells 1, 3 and 4 changed little over the past two years (**Table 6-2**). However, the vegetation in Cell 2 has shifted markedly since 1997 from dominance by cattails to expansion of open water and submerged aquatic vegetation (SAV). Water levels were 10 to 30 cm deeper during this time, and these levels may have promoted loss of cattail and expansion of open water and submerged vegetation.

The annual peat accretion rate was measured at a number of locations throughout the ENRP using feldspar horizon markers from mid-1995 through mid-1999 at a series of sites in the wetland to provide a clear demarcation of post-operation sediment accumulation. Field and laboratory methodologies are detailed in Chimney et al. (2000). Median accretion for the entire ENRP (**Figure 6-4**) appeared to slow markedly during the first three years of monitoring (34.5, 19.6 and 8.1 mm/yr, respectively) but remained relatively constant from year 3 to year 4 (8.5 mm/yr). These changes are attributed to two possible factors: (1) compaction of material deposited during the first years of operation and/or (2) a real decrease in production of plant detritus as the vegetation community shifted from rapid accumulation of new biomass during plant colonization and subsequent production of detritus to the maintenance of existing biomass as the community matured.

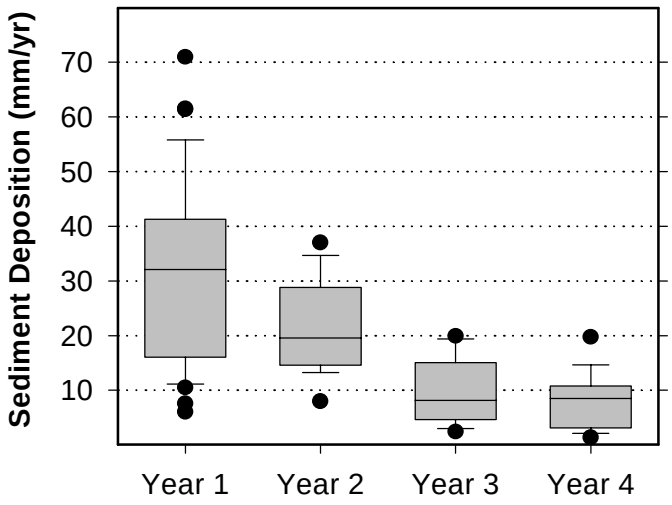

Figure 6-4. Annualized sediment deposition in the STA-1W treatment cells.

STA-1W TEST CELL RESEARCH

The District is conducting experiments in the test cells to determine hydrologic conditions that affect STA performance. The size, vegetation diversity, and hydrologic complexity of the treatment cells within an STA render them difficult to conduct controlled experiments. The test cells were designed and constructed to provide sites for controlled research experiments. These experiments include management strategies that maximize TP removal efficiencies as well as those that may cause noncompliance in the STAs. The STA-1W test cells are shallow, rectangular wetlands, approximately 0.2 ha in size. They are arranged into two groups of 15 cells, half located in the north and half in the south STA-1W (Newman and Lynch, 2000; **Figure 6-1**). Ten test cells are in use for STA Optimization research experiments, six at the north and four at the south. Vegetation in the test cells consists primarily of dense stands of Typha species (cattails) with incidental populations of submerged aquatic vegetation (SAV) and periphyton communities (Chimney et al., 2000). The remaining wetlands are being used for Advanced Treatment Technology (Chapter 8) and Marsh Dry Out research projects. The hydrology, calibration, experimental design, and preliminary water quality evaluation were detailed in Chimney et al. (2000).

Experiments were designed to determine system response to various hydrologic conditions at the north and south test cells. The hydraulic loading rates (HLR) and water depths are altered, with two test cells at each location acting as controls. The HLR experiments measure the effect of decreasing and increasing HLR, thereby increasing and decreasing hydraulic residence time, respectively, on TP removal efficiencies. The depth experiments will maintain a constant inflow rate while altering depth. The two control test cells at both the north and south sites are operated at a mean HLR of 2.7 cm/d and a nominal depth of 0.6 m, which approximates the average design conditions for the STAs (Walker, 1991). While the depth is held constant, the HLR for two north test cells and one south test cell are incrementally decreased by 50 percent, thereby increasing

hydraulic residence time. Each 15 week period, the initial value of 2.7 cm/d is decreased incrementally to approximately 0.3 cm/day (low HLR experiments). Concurrently, the HLR in the remaining north and south test cells are being incrementally increased by 50 percent every 15 weeks to approximately 20 cm/d (high HLR experiments) (**Table 6-4**). Following completion of the HLR experiments, all cells will be returned to a HLR of 2.7 cm/d, after which minimum and maximum water depth experiments and pulsing HLR experiments will be examined concurrently for a period of one year. At this time, only two of three HLR experiments (Exp. 1N and Exp. 2N, described in **Table 6-4**) were completed at the north site and one of three (Exp. 1S) was completed at the south. The remaining HLR and depth experiments will be completed by the end of October 2001. To determine actual HRT, lithium tracer experiments are being conducted in five test cells at different HLRs. Results will be reported in next year's Consolidated Report.

Table 6-4. Implementation dates, mean hydraulic loading rates, and nominal depths for the Optimization research at the STA-1W test cells (**Figure 6-1**).

Exp. #	*North Test Cells*	*South Test Cells*	*HLR (cm/d)*			*Depth (m)*
			Low	*Control*	*High*	
1	May 19, 1999	November 2, 1999	1.27	2.7	4.92	0.6
2	September 1, 1999	February 14, 2000	0.72	2.7	10.72	0.6
3	February 14, 2000	July 3, 2000	0.27	2.7	19.04	0.6
4	October 2, 2000	October 18, 2000	-	2.7	-	0.15
5	October 2, 2000	October 18, 2000	-	Pulsed	-	0.6
6	April 1, 2001	April 12, 2001	-	2.7	-	1.2
7	April 1, 2001	April 12, 2001		Pulsed		0.6

Weekly grab and/or composite water samples were taken at the storage cell outlet (representing inflow water) and at the outflow from each test cell. Water samples were collected around mid-day from the test cells and analyzed for 30 parameters (**Table 6-5**) in accordance with the District's Comprehensive Quality Assurance Plan (SFWMD, 1998). When values were less than the method detection limits, they were reported and used in calculations at the detection limit value. Organic nitrogen, particulate P, and dissolved organic phosphorus were calculated from the means of measured parameters. Mean particulate phosphorus (PP) was calculated as the difference between mean TP and mean total dissolved phosphorus (TDP). Mean dissolved organic phosphorus (DOP) was calculated according to District guidelines as the difference between TDP and soluble reactive phosphorus (SRP). However, it is recognized that SRP represents an estimate of the dissolved inorganic phosphorus (DIP) and a small fraction of any condensed phosphate present may be hydrolyzed during the analytical procedure (APHA, 1989). The glossary of this Report provides a complete listing of the forms of phosphorous measured in water and sediment samples. Total organic nitrogen was calculated as the difference between total Kjeldahl nitrogen (TKN) and ammonia nitrogen (NH_4-N). While the means and standard errors for mass and concentration values of all parameters are reported in the Appendix (**Tables A6-1** through **A6-4**), only phosphorus and nitrogen are discussed in the following subsections.

Table 6-5. Physical and chemical parameters monitored at inflow and outflow stations located at the STA-1W test cells.

Total phosphorus	Dissolved oxygen	Total suspended solids
Total dissolved phosphorus	Temperature	Total dissolved solids
Soluble reactive phosphorus	pH	Total organic carbon
Total nitrogen	Specific conductance	Dissolved organic carbon
Total Kjeldahl nitrogen	Stage	Total inorganic carbon
Total Dissolved Kjeldahl nitrogen	Flow	Alkalinity
Ammonia nitrogen	Aluminum	Calcium
Nitrate-nitrite nitrogen	Iron Potassium	Potassium
Silica	Magnesium	Sodium
Sulfate	Manganese	Zinc
Chloride	Molybdenum	

RESULTS

North Site Experiments (Exp. 1N and Exp. 2N)

Mean inflow TP concentrations at the north site were 0.077 and 0.104 mg/L during Exp. 1N and Exp. 2N, respectively (**Table 6-6**). Mean outflow TP concentrations were lower than mean inflow, and exceeded the interim Phase 1 target of 0.050 mg/L only for the highest HLR tested (**Figure 6-5)**. At low HLR, mean outflow TP values were significantly lower than mean outflow TP values produced by the high HLR trials. Generally, outflow TP concentrations increased as HLR increased.

Mean north site inflow total dissolved phosphorus (TDP) concentrations during Exp. 1N and Exp. 2N were 0.044 mg/L and 0.065 mg/L, respectively. Mean outflow TDP values were lower than inflow (**Table 6-6**). For the low and control trials, TDP mean outflow concentrations were similar but increased for high HLR trials (**Figure 6-5**).

Table 6-6. Mean inflow and outflow phosphorus and nitrogen concentrations and (standard errors) for STA-1W optimization experiments at the north and south test cells.

	Inflow (mg/L)	*Outflow (mg/L)*		
		Low	***Control***	***High***
Exp. 1N				
TP	0.077 (0.0100)	0.030 (0.0030)	0.035 (0.0047)	0.040 (0.0048)
SRP	0.030 (0.0061)	0.006 (0.0003)	0.0063 (0.0039)	0.007(0.0005)
TDP	0.044 (0.0082)	0.016 (0.0008)	0.016 (0.0007)	0.020 (0.0023)
TKN	2.655 (0.2700)	1.577 (0.0730)	1.657 (0.0920)	2.002 (0.0980)
NH_4	0.421 (0.0760)	0.061 (0.0060)	0.033 (0.0040)	0.052 (0.0070)
NO_2-NO_3	0.045 (0.034)	0.011 (0.003)	0.010 (0.005)	0.008 (0.001)
Exp. 2N				
TP	0.104 (0.0244)	0.030.4 (0.0031)	0.047 (0.0072)	0.057 (0.0086)
SRP	0.029 (0.0039)	0.005 (0.0002)	0.005 (0.0005)	0.006 (0.0006)
TDP	0.065 (0.0083)	0.022 (0.0015)	0.022 (0.0018)	0.028 (0.0021)
TKN	2.837 (0.1460)	1.888 (0.0710)	2.129 (0.0780)	2.379 (0.0650)
NH_4	0.405 (0.059)	0.112 (0.0200)	0.072 (0.0140)	0.111 (0.0140)
NO_2-NO_3	0.006 (0.001)	0.006 (0.0008)	0.004 (0.0001)	0.004 (0.0002)
Exp. 1S				
TP	0.029 (0.006)	0.028 (0.004)	0.034 (0.0050)	0.033 (0.0090)
SRP	0.0053 (0.0004)	0.004 (0.0002)	0.006 (0.0006)	0.005 (0.0003)
TDP	0.0178 (0.0029)	0.016 (0.0025)	0.021 (0.0028)	0.028 (0.0048)
TKN	1.994 (0.046)	1.822 (0.080)	1.897 (0.0360)	1.951 (0.0600)
NH_4	0.087 (0.008)	0.040 (0.005)	0.045 (0.0040)	0.049 (0.0060)
NO_2-NO_3	0.074 (0.009)	0.005 (0.0003)	0.005 (0.0004)	0.007 (0.002)

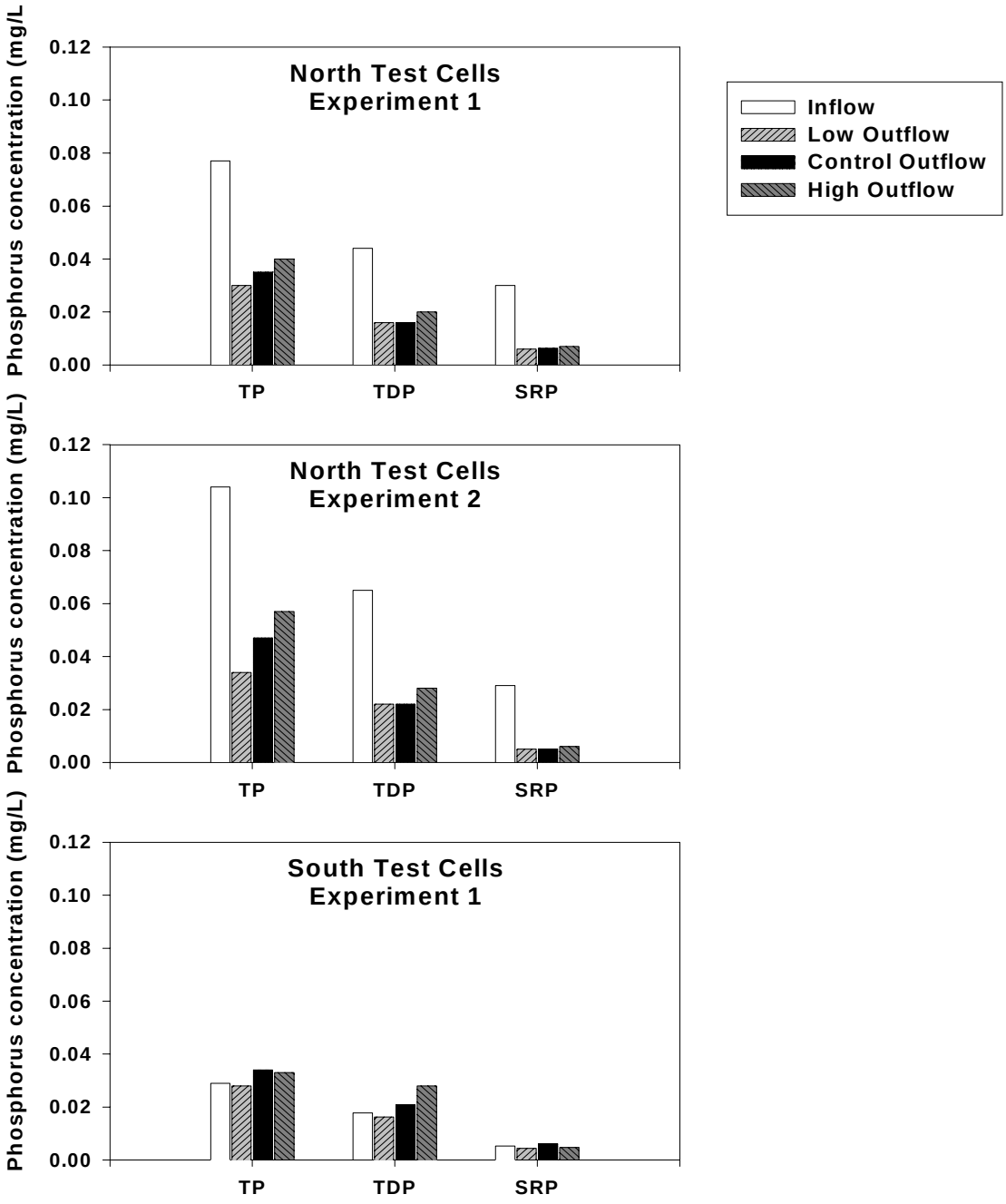

Figure 6-5. Mean total phosphorus, total dissolved phosphorus, and soluble reactive phosphorus for the inflow and outflow for the controls, low, and high HLR experiments in the STA-1W test cells.

Mean inflow soluble reactive phosphorus (SRP) concentrations were 0.030 mg/L and 0.029 mg/L during Exp. 1N and Exp. 2N, respectively (**Table 6-6**). All experimental trials produced mean SRP outflow concentrations ranging from 0.005 mg/L to 0.007 mg/L and were not affected by changes in HLR (**Figure 6-5**). During both HLR experiments, 25 to 81 percent of outflow SRP values were below the method detection limit (0.004 mg/L).

While nutrients can be categorized into four main fractions (dissolved and particulate inorganics and dissolved and particulate organics), we aggregated the particulate constituents into one category. Therefore, TP is comprised of dissolved inorganic phosphorus (DIP, also referred to as SRP), dissolved organic phosphorus (DOP), and particulate phosphorus (PP). Inflow TP concentration characteristics differed between Exp. 1 and Exp. 2 at the north site (**Figure 6-6**). During Exp. 1N, inflow TP concentration consisted of approximately 40 percent each of DIP and PP with DOP the remainder. In Exp. 2N, inflow concentrations consisted of approximately equal proportions of P species.

Although inflow TP species characteristics differed from Exp. 1N to Exp. 2N, outflow characteristics were similar. Generally, DIP<DOP<PP except at the lowest HLR tested, when concentrations of DOP exceeded PP (**Figure 6-6**). Additionally, Exp. 1N outflow concentrations of DOP and PP increased as HLR increased for control and high HLR relative to inflow. During Exp. 2N, only PP outflow concentrations changed relative to HLR. As previously mentioned, DIP was unaffected by changes in HLR and remained close to minimum detection levels for all HLR.

Mean outflow nitrogen concentrations ranged from 1.588 mg/L to 2.383 mg/L, less than mean inflow concentrations of approximately 2.77 mg/L (**Figure 6-7**). Mean total nitrogen (TN) outflow concentrations generally increased as loading rate increased, although this trend was more pronounced during Exp. 2N. Organic nitrogen was the predominant form of nitrogen at both inflow and outflow sites, with inorganic nitrogen preferentially being taken up within the wetlands (**Figure 6-7**). Within an experimental trial, mean outflow organic nitrogen concentrations generally increased as the HLR increased, ranging from 1.505 mg/L to 2.264 mg/L. Mean outflow inorganic nitrogen concentrations did not change in response to changes in HLR, representing less than 10 percent of the outflow nitrogen concentration for all experimental trials.

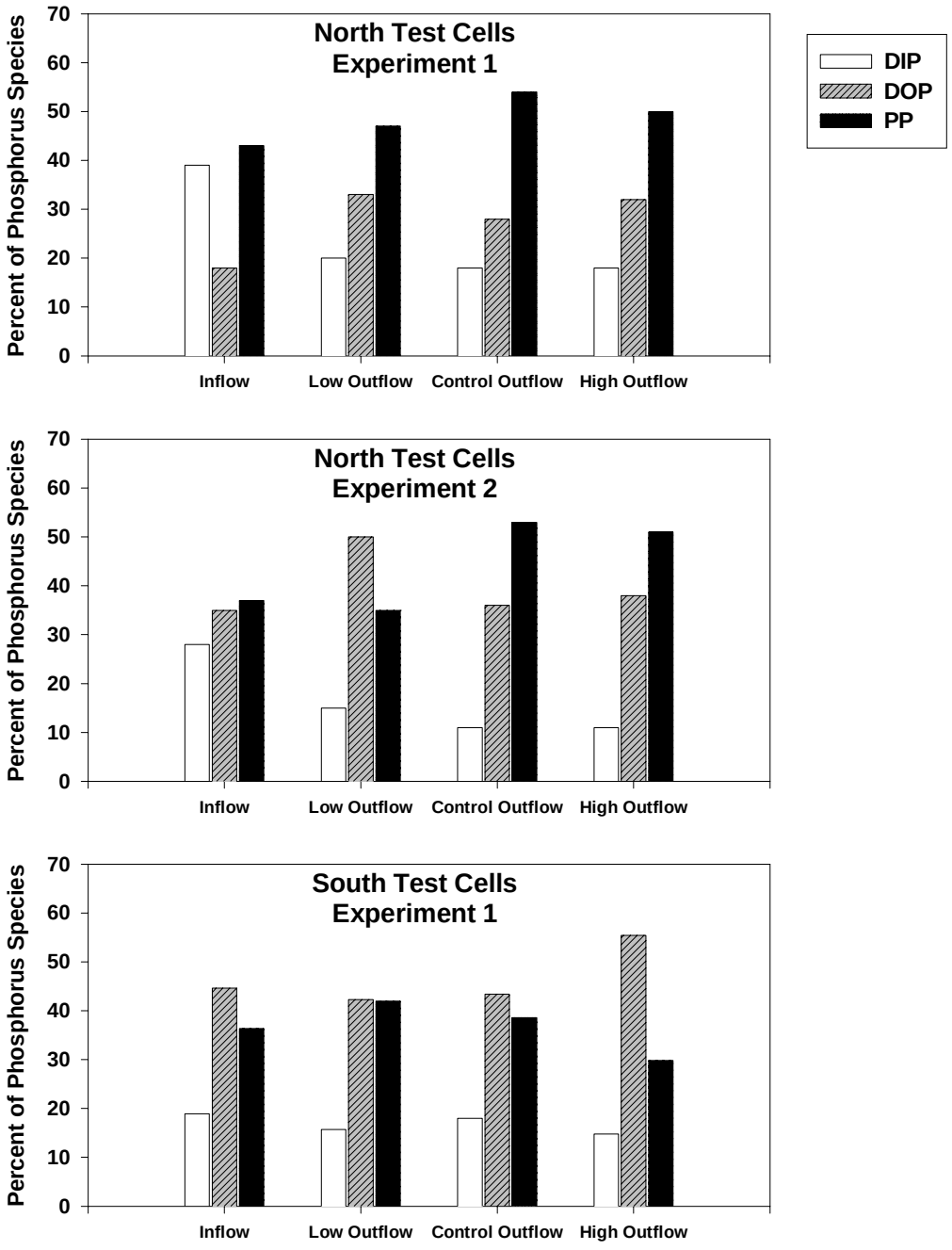

Figure 6-6. Phosphorus constituents (mean percent dissolved inorganic, dissolved organic, and particulate phosphorus) for the inflow and outflow in the STA-1W test cells.

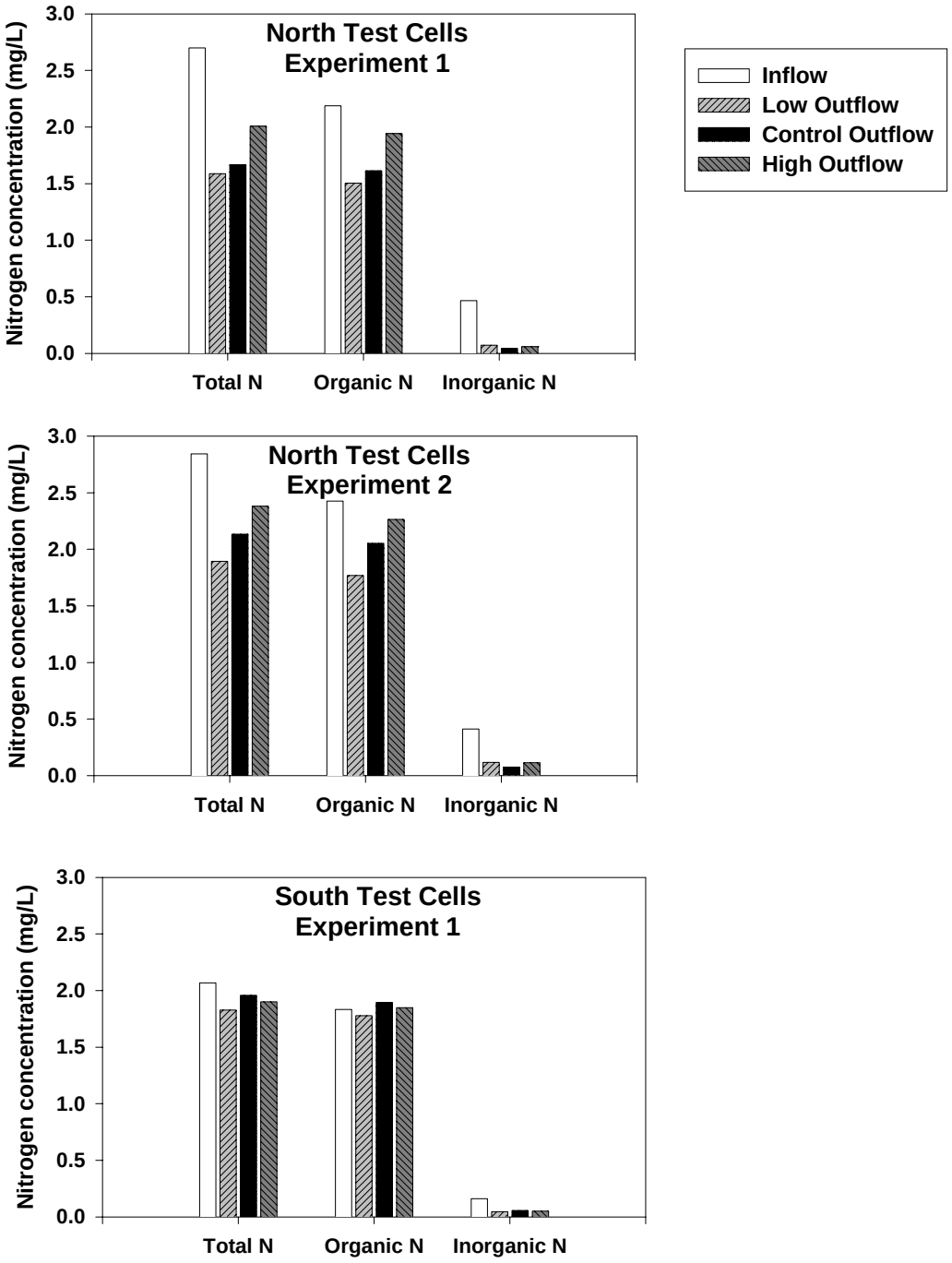

Figure 6-7. Mean nitrogen constituents for the HLR test cell experiments. Mean concentrations for total N, organic N, and inorganic N for inflow and outflow inflow and outflow for the controls, low, medium, high HLR experiments in the STA-1W test cells.

South Site Experiments (Exp. 1S)

Only one experiment was completed for the south test cells during this reporting period. The mean inflow TP concentration for the HLR experiments was 0.029 mg/L, lower than mean inflow concentrations at the north site and below the interim Phase 1 target of 0.050 mg/L (**Table 6-6)**. No affect was seen in this treatment (**Figure 6-5**). Approximately 62 percent of the total P at the inflow was in the dissolved phase. Mean TDP outflow concentrations were approximately the same as inflow levels for the low flow experiment. These concentrations generally increased as HLR increased. Mean SRP concentrations at the inflow and outflow were similar. More than half of the inflow and outflow values were less than or equal to the minimum detection limit of 0.004 mg/L. Inflow and outflow TN concentrations were similar (**Figure 6-7**) at the south test cells. As observed at the north site, organic nitrogen was the predominant form of nitrogen, comprising more than 90 percent of the TN.

Mass

For the Water Year 1999-2000, separate water balances were calculated for each test cell. Balances were calculated only when data were available for a full year. The balance is based on daily inflows, outflow and change in storage capacity using the general water mass balance equation:

$$I - O + RO - ET = \Delta S + r \quad (1)$$

where:

I = inflow water volume to the test cell (m^3)

O = outflow water volume from the test cell (m^3)

RO = runoff water volume to the test cell (m^3)

ET = evapotranspiration (m^3)

ΔS = change in storage capacity within the test cell (m^3), and

r = residuals of the water budget (m^3).

A calibrated tipper bucket was used to verify the inflows for each HLR (Chimney et al., 2000). For the north test cells, the residuals (which include unmeasured components and measurement error) ranged from 16.27 to -15.87 percent during water year 1999-2000 (**Table 6-7**). Surveys of various lake and wetland water balance studies showed that it is not uncommon for residuals to range from 10 to 20 percent in either direction (Winter, 1981).

Table 6-7. Water balance at STA-1W north test cells from May 1, 1999 to April 30, 2000.

Test Cell Number	Inflow (m^3)	Outflow (m^3)	Residuals (%)
TC 07N Low	8418	9130	-8.45
TC 08N Low	8119	8224	-1.29
TC 05N Control	25,331	22,479	11.26
TC 10N Control	26,953	31,230	-15.87
TC 06N High	93,572	78,347	16.27
TC 09N High	88,890	76,395	14.06

Higher inflow HLR resulted in more phosphorus mass exported from the test cells than treatments with lower HLR. At the north site, an average 0.68 g $P/m^2/yr$ and 2.12 g $P/m^2/yr$ were exported from the high HLR experimental cells and 0.14 g $P/m^2/yr$ and 0.12 g $P/m^2/yr$ were exported from the low HLR experimental cells (**Figure 6-8**). Similar trends were noted at the south site. However, low inflow concentrations produced a smaller phosphorus mass export from the south than wetlands operating at similar HLR in the north site. Mass TP retention at the north site ranged between 30 and 52 percent with retention during low load experiments slightly higher than for high load experiments (**Figure 6-9**). At the south site, only the low HLR wetland retained TP. Both the control and high HLR wetlands experienced a small net export of TP mass.

At higher HLR, the TP mass exported from the system was generally related to changes in the inflow TP concentration (ranging between 0.04 mg-P/L and 0.20 mg-P/L). Total phosphorus export peaked when influent TP concentrations spiked (**Figure 6-10**). However, at low HLR, the TP mass exported was independent of influent TP concentrations. These results indicate that these test cells were able to process all TP regardless of influent TP concentrations at low HLR.

The north and south sites differed not only in inflow TP concentrations but also in the wetlands' responses to changes in HLR. Early results suggest that this response difference can be attributed to the lower mass loading at the south site. Preliminary north site results indicate that outflow TP concentration increased with increasing HLR. A mean HLR of 10.72 cm/d produced an outflow concentration just above the interim target of 50 ppb. At the south site, increased HLR had no direct effect on outflow TP concentration levels and these wetland systems were operating at steady state for TP concentration. Further support of these findings was provided at the north site when TP mass export increased only when TP inflow concentrations spiked at higher TP loading levels. At lower TP loadings, TP mass export was unaffected by increased TP inflow concentrations.

SRP responded differently than TP. While soluble reactive phosphorus made up a greater portion of the inflow TP at the north site than at the south, mean outflow SRP concentration values at all sites during all experiments were very close to the method detection limit. These low values indicate SRP limitation within these systems, and even at extremely low residence times, wetland plants and animals are able to utilize almost all available phosphorus.

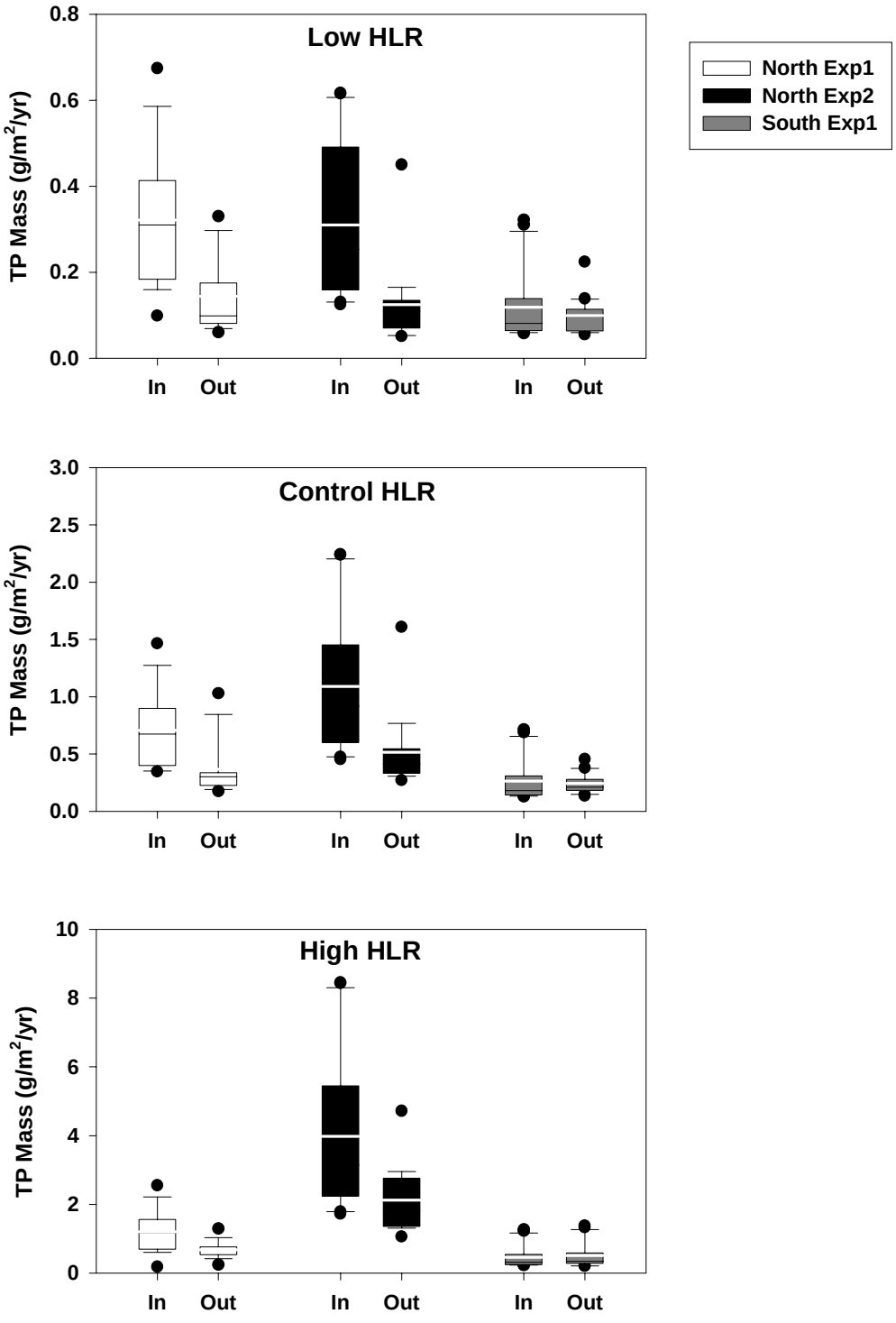

Figure 6-8. Mean total phosphorus mass for the inflow and outflow during the low, control, and high HLR experiments in the STA-1W test cells.

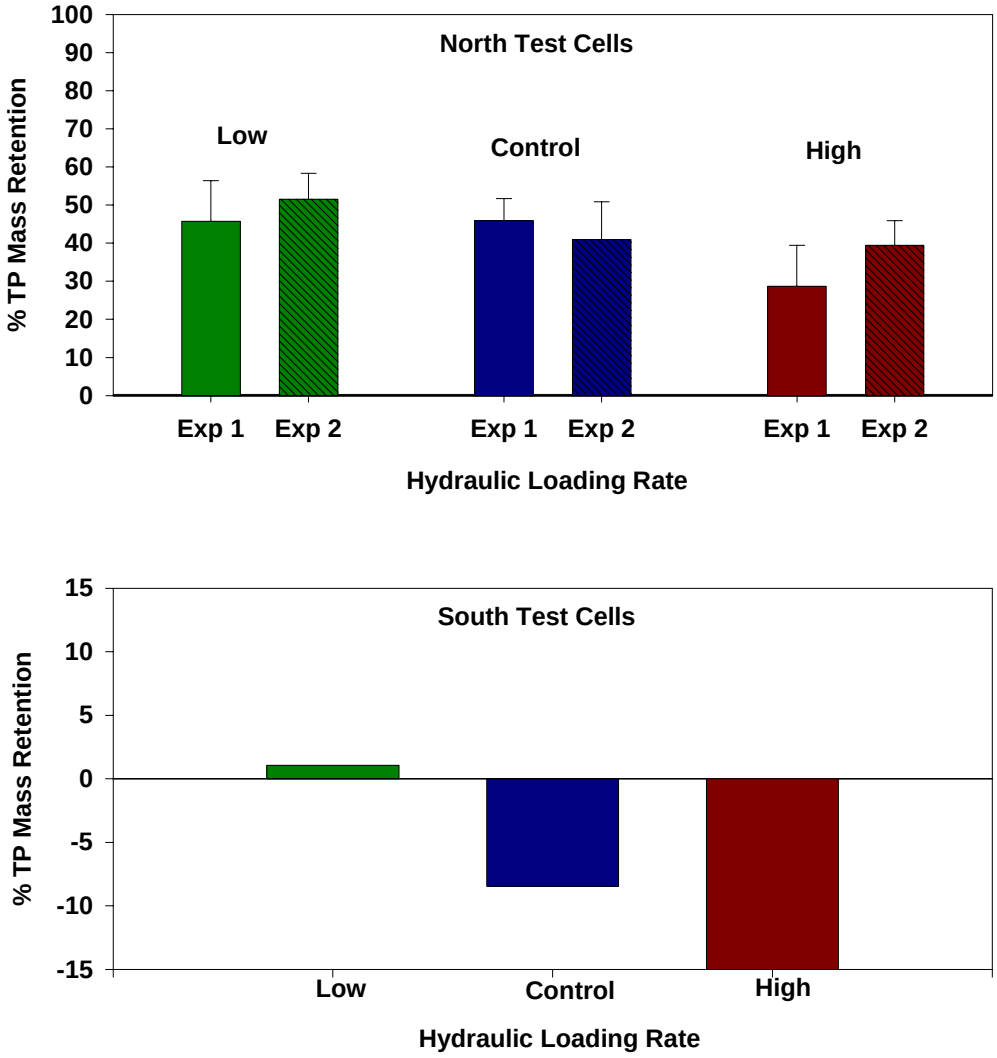

Figure 6-9. Mean percent mass retention for total phosphorus during the low, control, and high HLR experiments in the STA-1W test cells.

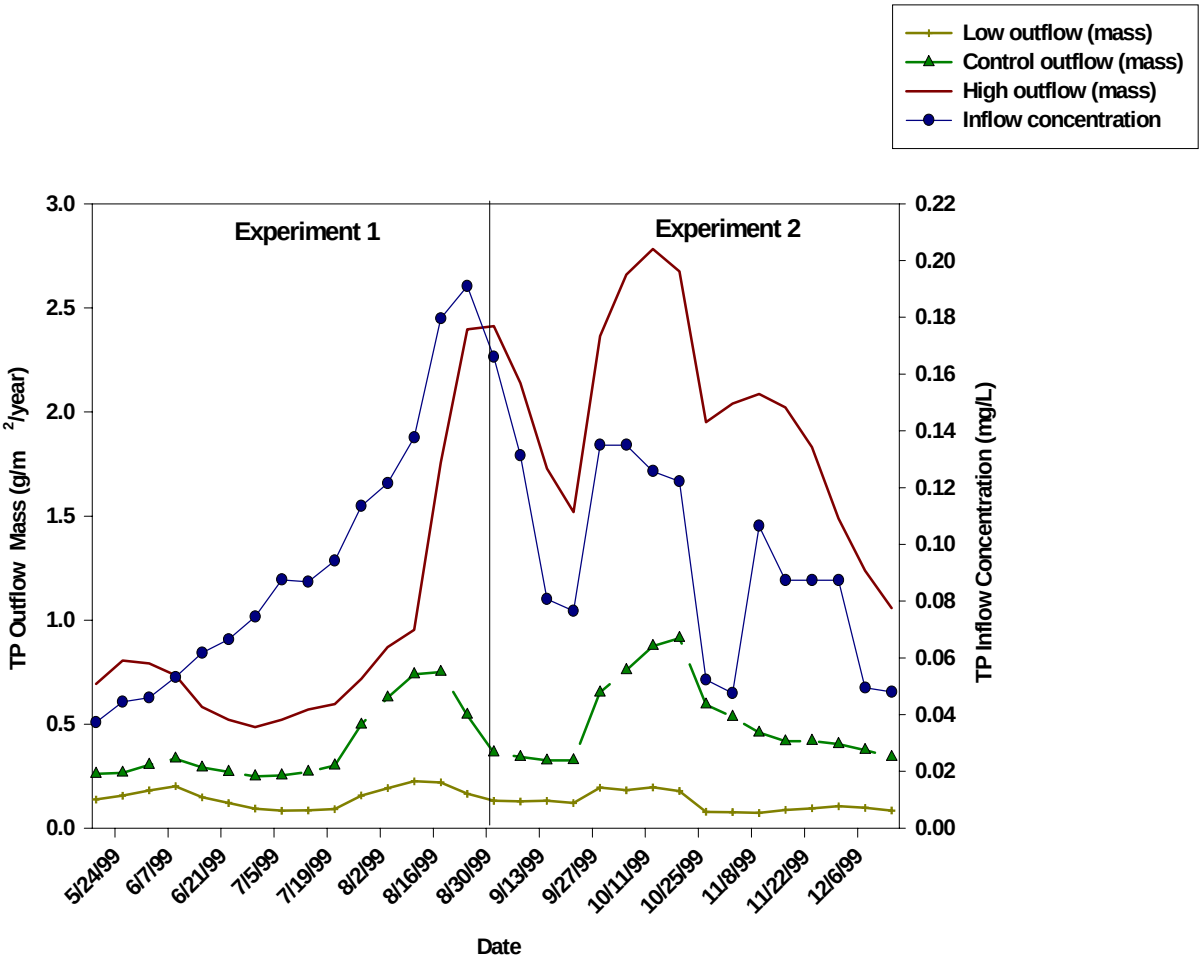

Figure 6-10. Mean total phosphorus inflow concentration and outflow mass during the low, control, and high HLR experiments at the north test cells.

DECOMPOSITION STUDIES

Decomposition of plant cellulose is an important component of nutrient cycling in wetlands and can provide a significant nutrient source to the system (Harrison et al., 1988). Factors affecting the rates at which plant material is broken down include temperature, pH, dissolved oxygen, and nutrient availability. Cotton strip assays are a good indicator of natural cellulose decomposition rates (Maltby, 1985). Cotton strip assays were used to determine the effects of nutrient concentration and hydraulic loading rate on cellulose mineralization within the test cells.

Cotton strip assays were performed using a technique similar to Maltby (1985). A stainless steel frame supporting three 12-cm by 30-cm strips was inserted 15 cm deep into the soil for one week. Half the cotton strip was in the sediment and half was in the water column to compare decomposition environments in these media. Four replicate strips were located within emergent and submerged vegetation at the inflow and outflow regions. Upon removal, the strips were cut into 2-cm increments, 10-cm above the soil surface and 10-cm below the soil surface. The strips were frayed by hand until a single thread could be removed intact along the length of the cut edge to assure a constant cotton strip width to avoid bias from weak or torn threads. Each strip was soaked in water and blotted dry to remove excess water and simulate 100 percent humidity. Tensile strength of these strips was measured using a Chatillon TCD-200 tensiometer equipped with a digital force gauge (DFIS 200, Chatillon, Greensboro, NC). The tensiometer applied force to the strip until it tore. Tensile strengths were adjusted to correct for the loss in tensile strength of a field control strip. The data were linearized and expressed as annual cotton rotting rates (CRR) over time, calculated as:

$$CR = \sqrt[3]{(y_o - y)/y} \quad (2)$$

$$CRR = (CR/t)*365 \quad (3)$$

where CR = rottenness

y_0 = mean tensile strength of control strip

y = mean tensile strength of the test strip at a given depth

t = duration of burial.

Cotton strip assays were used to compare sediment and water column cellulose decay rates over various HLR, nutrient regimes, and vegetation types. Varying HLR at higher nutrient loads (north test cells) appeared to have greater influence on CRR than at lower nutrient loads (south test cells). These differences suggest that decomposition rates increased as phosphorus loads increased, while at lower nutrient loads, decomposition rates were not affected (**Figure 6-11**). No differences were detected between HLR treatments for pH and dissolved oxygen, which may affect decomposition rates. Additionally, decomposition rates within *Typha* communities (41.3/ yr) were similar to those found within submerged aquatic vegetation communities (30.6/yr). Preliminary results indicate that CRR responded to a high HLR but not to a low HLR, suggesting that low nutrient concentrations may limit microbial activity or that higher concentrations stimulate activity. Similar studies in the Everglades system also have noted an increase in cellulose decomposition with an increase in nutrient loading (Maltby, 1985). The use of cotton strip decomposition may prove to be a sensitive bioindicator for soil health and biological activity (Pankhurst et al., 1995; Smith et al., 1993).

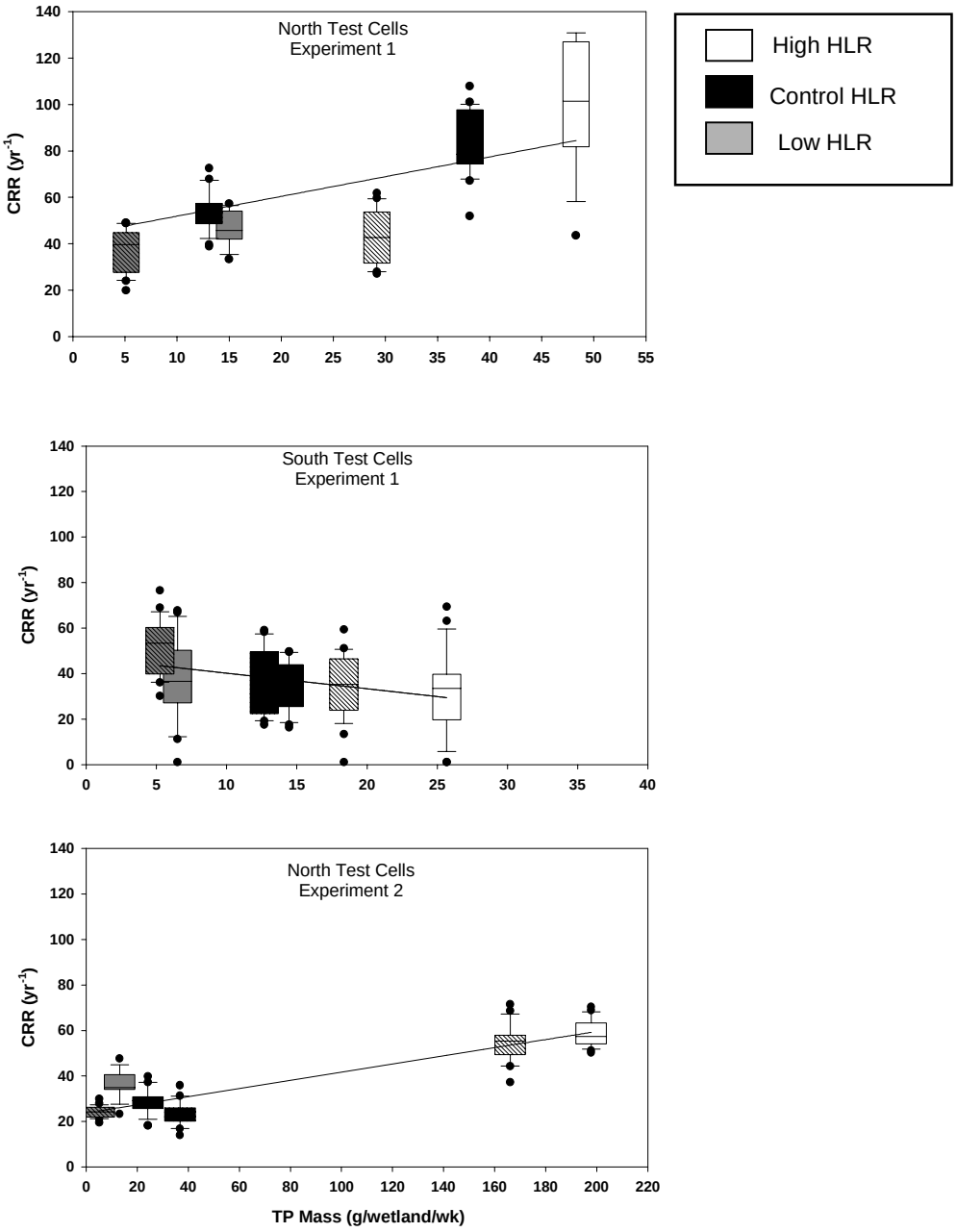

Figure 6-11. Comparison of cotton rotting rates (CRR) and total phosphorus loads of the varying hydraulic loading rates (HLR) for each experiment at the north and south STA-1W test cells.

ONGOING RESEARCH

The primary objective of the test cell experiments is to define the limits of operation for the STAs for TP outflow concentration. Research into the effects of HLR will continue in addition to new experiments on the effects of pulsed HLR and high and low depths on TP outflow concentrations. Data will be analyzed for the other 29 water quality parameters to discern patterns related to HLR that may affect downstream water quality. Two studies on periphyton and macroinvertebrates in the test cells began in February 2000 and concluded in June 2000. These studies were designed to provide a broad overview of community structure and biomass estimates in the test cells and to examine any changes in this structure due to dry out. Results will be presented in next year's report. Lithium tracer studies are being conducted this year to determine actual flow paths and hydraulic residence times in five test cells at different HLRs.

MARSH DRYOUT STUDY

While design and operational guidelines of STAs require normal water levels of 15 to 135 cm, extreme drought conditions may dry out part or all of an STA. Some STAs, including the STA-1W, are composed of highly organic peat soils. If these peat soils are dried and oxidized for prolonged periods, they may release nutrients into the water column upon reflooding. This loss results from factors controlling oxidation within the soils, including composition of organic material, sediment temperature, seasonal variability, and duration of dry-out (Reddy, 1983; Olila et al., 1997). The District is conducting research in mesocosms to quantify the effects of phosphorus loading, duration of dry-out periods, season of dry-out (wet and dry seasons), and the presence or absence of macrophytes on the rate of phosphorus flux from the sediments to the overlying water column. Results of these experiments indicate a time-limited flux that is greater in the absence of macrophytes.

METHODS

The mesocosms used for the Marsh Dry-Out Study (MDOS) consisted of 24 fiberglass-lined plywood tanks measuring 5.9 m long by 1.0 m wide by 1.0 m deep. Each mesocosm contained 30 cm of peat soil overlaid with 40 cm of STA-1W water and was open at the top. A flow-through system operating at an average hydraulic loading rate of 2.61 cm/d resulted in a nominal hydraulic retention time of 15.4 days. Mesocosms were located at two sites within STA-1W, 12 at the North Advanced Treatment Technology (ATT) Site using post-BMP water with high P inflow concentrations, and 12 at the South ATT Site using post-STA water with reduced P concentrations. Dry-out involved draining water in the tank and then eliminating all supplemental water sources except for rainfall. The MDOS experimental design is described in greater detail in Chimney et al. (2000).

At both north and south sites, mesocosms were divided into four treatment types, providing replication in triplicate for each treatment. Treatments were based on the presence or absence of vegetation and flooding regime types (**Table 6-8**). Tanks representing emergent vegetation were planted with cattail (*Typha* spp.). Additional species grew in these tanks, including muskgrass (*Chara* spp.), smartweed (*Polygonum* spp.), torpedo grass (*Panicum repens*; L.), southern naiad (*Najas guadalupensis;* Spreng.) small duckweed (*Lemna valdiviana*; Philippi), water fern (*Salvinia minima*; Baker.), and floating and benthic algae. Non-planted tanks developed communities dominated by *Chara* spp. and floating, benthic, and epiphytic algae. During dry-out, both emergent and non-emergent tanks grew several species of grass, including para grass (*Brachiaria mutica*; Forsk. Stapf), *Cyperus* spp., *Amaranthus* spp., and several unidentified species of grasses and sedges.

Table 6-8. Mesocosm treatment types based on the presence or absence of vegetation and flooding regime. For treatment number, "C" represents control, "D" represents dry out tanks, "N" represents non-planted tanks, and "P" represents planted tanks.

Tank Number			*Treatment Type*			
North ATT Site	South ATT Site	Treatment Number	Vegetation		Flooding Regime	
			Planted	Non-Planted	Continuously	Intermittently
31	231	C – P	✔		✔	
12	212	C – N		✔	✔	
43	243	D – P	✔			✔
24	224	D – N		✔		✔
25	225	D – N		✔		✔
46	246	D – P	✔			✔
37	237	C – P	✔		✔	
18	218	C – N		✔	✔	
19	219	C – N		✔	✔	
310	2310	C – P	✔		✔	
211	2211	D – N		✔		✔
412	2412	D – P	✔			✔

Results only from the northern sites were available during the period of this report. South site experiments are presently underway. At the north, water samples were collected from both tank inflow and outflow. Parameters collected for the MDOS include TP, total dissolved phosphorus (TDP), SRP, ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total kjeldahl nitrogen (TKN), total organic carbon (TOC), alkalinity, calcium (Ca), magnesium (Mg), iron (Fe), sulfate (SO_4), and total suspended solids (TSS). For treatment number, "C" represents control, "D" represents dry out tanks, "N" represents non-planted tanks, and "P" represents planted tanks. A detailed description of MDOS water quality and sampling methods appear in Chimney et al. (2000). Intermittently flooded tanks (dry-out tanks) were dried out three times, twice during the dry season from April to May in 1999 and 2000, and once during the wet season from September to October 1999. Controls were continuously flooded for the duration of the experiment.

Weekly water quality data for the first year of study (1 March 1999 through 30 March 2000) were averaged for each phase of the MDOS. Currently, there are five phases: three continuously flooded (startup and interim phase) and two dry out phases (dry season and wet season reflooding). Each dry-out phase occurred over four weeks with no flow followed by reflooding to 40 cm depths. Reflooding occurred over a four-hour period, and then the tanks remained flooded for one week until normal flow-through resumed. The end of the dryout phase was determined to occur when average outflow TP concentrations returned to control levels for that vegetation type. Average concentrations (mg/L) with standard error and mass (mg/d) for all values are listed in **Appendix A6-5**. Second year data, starting April 2000, are not yet available for analysis. Decomposition rates within mesocosm tanks were measured using cotton strip assays and leaf litter bags. Cotton strips assays (CSA) were used to assess the effect of community structure and re-flooding events on cellulose decomposition rates within the water and soil column, while leaf litter bags were used to determine the effect of dry-out on whole plant decomposition.

Two types of cotton strip assays were performed to characterize the water/sediment interface and the water column. The water column study consisted of suspending three 20 cm long cotton strips for 2 weeks after the wet season reflood near the surface of the water column at both inflow and outflow of each treatment. For the water/sediment analysis, stainless steel frames with three attached 12-cm by 30-cm strips were inserted into the soil to a depth of 15 cm for one week at various periods throughout the experiment. Collection and analysis methods of both studies follow the methods outlined for test cell CSA analysis presented earlier in this chapter. Two-cm interval results from the water/sediment interface study were averaged for the water and soil column, while all water column study intervals were averaged together to provide one value.

To determine the effect of the wet season dry out on whole plant decomposition rates, leaf litter bags were used. Four plant species, three submerged (*Ceratophyllum demersum, N. guadalupensis, Chara spp.*) and one emergent (*Typha spp.*) species, were obtained from the STA-1W, air dried to a constant weight, and cut into one to four cm strips. Approximately two grams of the cut plant strips were placed into two-mm fiberglass 10 x 10 cm mesh bags and closed with nylon threading. Leaf litter bags were tied together in triplicates and laid on top of the soil. Bags with *Typha* spp. were placed in the planted tanks and left for 1, 4, 12, and 48 weeks. Bags containing submerged vegetation were placed in both non-planted and planted tanks (since submerged vegetation occurs in both treatments) and were left for 1, 2, 3, 4, and 8 weeks. For each time period, decomposed leaf litter was collected by removing a set of bags and immediately placing them on ice within a labeled plastic bag. Leaf litter material was oven dried at 60°C for 48 hours until a constant weight was obtained. Average species decomposition rates were determined by taking the difference of the constant dry weight of the litter bag contents from the original dried weight of the litter bag contents.

RESULTS

During the first year of study, inflow TP concentrations of all tanks averaged 0.108 mg/L, while outflow TP concentrations of the north site control tanks averaged 0.022 and 0.020 mg/L for planted and non-planted tanks, respectively. Phosphorus species in the control tanks consisted of an average of 30 percent soluble reactive phosphorus (SRP), 38 percent particulate phosphorus (PP), and 32 percent DOP. Reflooding of organic soils in non-planted and planted mesocosms during both dry and wet seasons resulted in an average 4- to 7-fold increase of outflow total phosphorus (TP) concentrations relative to controls. This increase in water column TP resembles that found by Olila et al. (1997) where reflooding of dried organic soils in the Lake Apopka marsh produced a ten-fold increase following a dry-out period of three to six weeks.

Outflow TP concentration in non-planted tanks was greater relative to planted tanks, ranging from 0.017 to 0.412 mg/L overall. Average dry season TP outflow concentrations for non-planted tanks were 0.125 mg/L, and wet season outflow concentrations averaged 0.065 mg/L. Total phosphorus outflow concentrations in the planted tanks ranged from 0.017 to 0.108 mg/L overall, with average dry season TP concentrations of 0.074 mg/L, and a wet season outflow concentration of 0.048 mg/L (**Figure 6-12**). Furthermore, non-planted mesocosms released a higher percentage of PP than planted tanks compared to controls during both dry and wet season reflooding (**Table 6-9**). These results suggest that vegetation type may play a significant role in phosphorus release after dryout and reflooding. The leaf litter study indicated that *Typha spp.* decayed more slowly than the submerged and periphyton species, retaining 30 percent more of its dry weight biomass than the submerged species and periphyton (*C. demersum, N.s guadalupensis, Chara* spp.) (**Figure 6-13**). Therefore, an increase in particulates could be due to the rapid physical breakdown of *Chara*.

During the wet and dry season dry-out periods, soil moisture and environmental conditions such as presence of standing water, cellulose decomposition rates, and vegetation type varied considerably. During wet season dry-out, soils within both planted and non-planted treatments remained moist and mostly anoxic (redox -100 to 300 mv). During the dry season, soils were completely aerobic and, in most cases, cracked from the absence of moisture (**Figure 6-14**). During the dry season, outflow TP concentrations after reflood averaged 54 and 92 percent higher than during the wet season for planted and non-planted tanks, respectively. Percent SRP during the dry season increased from 53 to 83 percent relative to controls. During the wet season, percent SRP either remained the same or decreased relative to controls in the planted and non-planted tanks, respectively (**Table 6-9**). Olila et al. (1997) found that oxidation of newly accreted peat material resulted in conversion of organic P into labile P (the readily useable form), which is readily released into the water column. Since SRP percentage increased after reflooding only during the dry season, soil oxidation may have converted phosphorus from organic to labile inorganic forms, contributing to the release of SRP into the water column. Decomposition keeps labile phosphorus forms relatively stable under anaerobic conditions (Reddy et al., 1999). The differences in soil oxidation levels in dry and wet seasons may cause the differences in SRP levels observed in the mesocosms.

Table 6-9. Total phosphorus concentrations and percent of phosphorus species based on season reflood and treatment type. For treatment number, "C" represents control, "D" represents dry out tanks, "N" represents non-planted tanks, and "P" represents planted tanks in the STA-1W mesocosm experiments.

Treatment	Reflood Average Concentration of		Percent of Total Phosphorus During Reflood					
	TP (mg L^{-1}) (SE)		PP		DOP		SRP	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
[C - N]	0.018 (0.001)	0.026 (0.001)	24.1	46.8	47.4	26.2	28.5	27.0
[D - N]	0.125 (0.022)	0.065 (0.006)	37.7	61.6	18.9	18.7	43.4	19.7
[C - P]	0.018 (0.001)	0.018 (0.001)	31.6	38.1	41.7	23.1	26.6	38.8
[D- P]	0.074 (0.005)	0.048 (0.005)	24.0	36.4	27.4	25.4	48.6	38.2

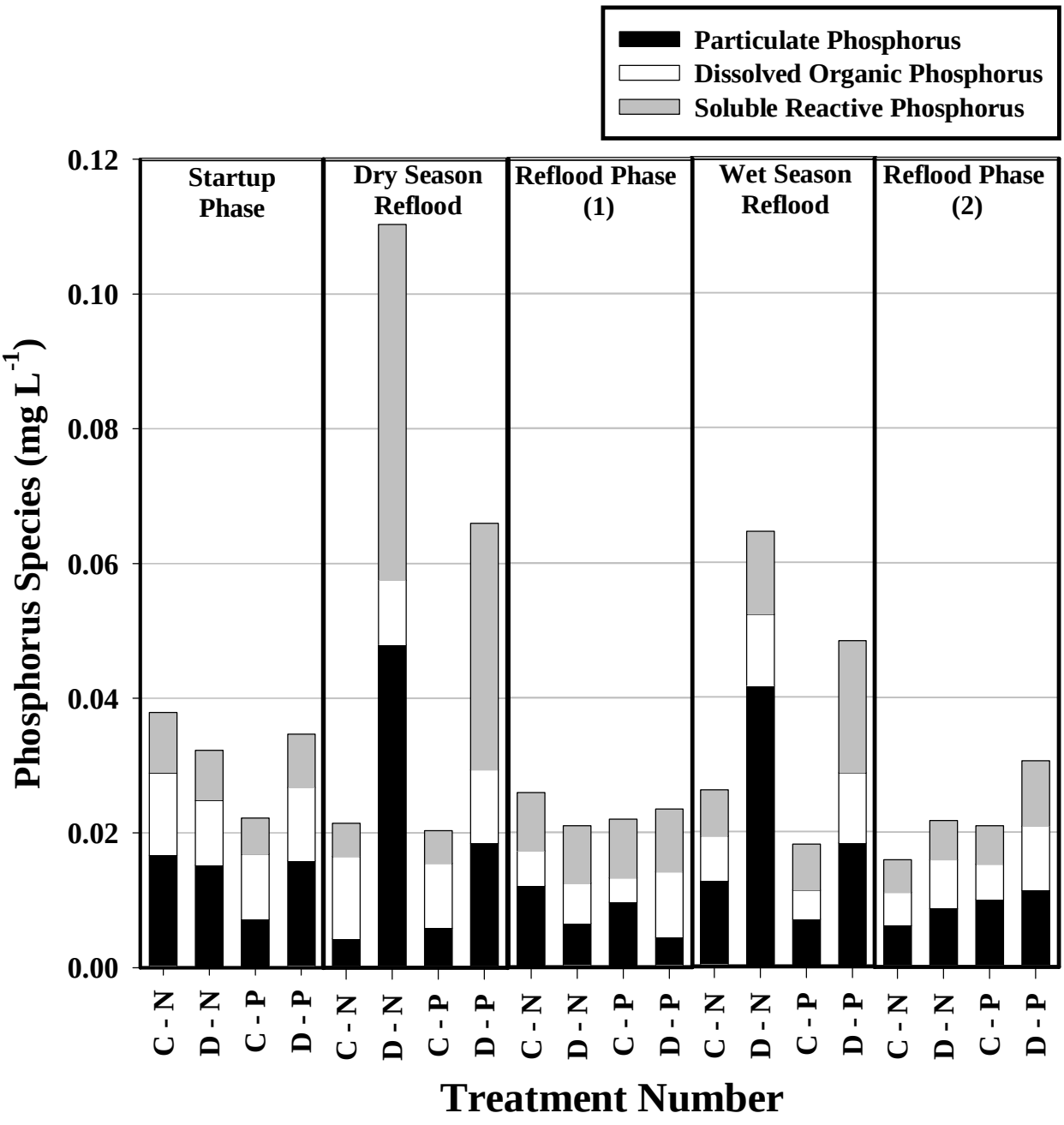

Figure 6-12. Mean concentration of phosphorus species at high phosphorus loading rates during the first year of research. Stabilization phase (3/5- 4/1), Dry Season Reflood (4/8 – 6/10), Interim Phase 1 (6/17 – 8/26), Wet Season Reflood (9/2 – 10/28), and Interim Phase 2 (11/4 – 2/28). For treatment number, "C" represents control, "D" represents dry out tanks, "N" represents non-planted tanks, and "P" represents planted tanks in the STA-1W mesocosm experiments.

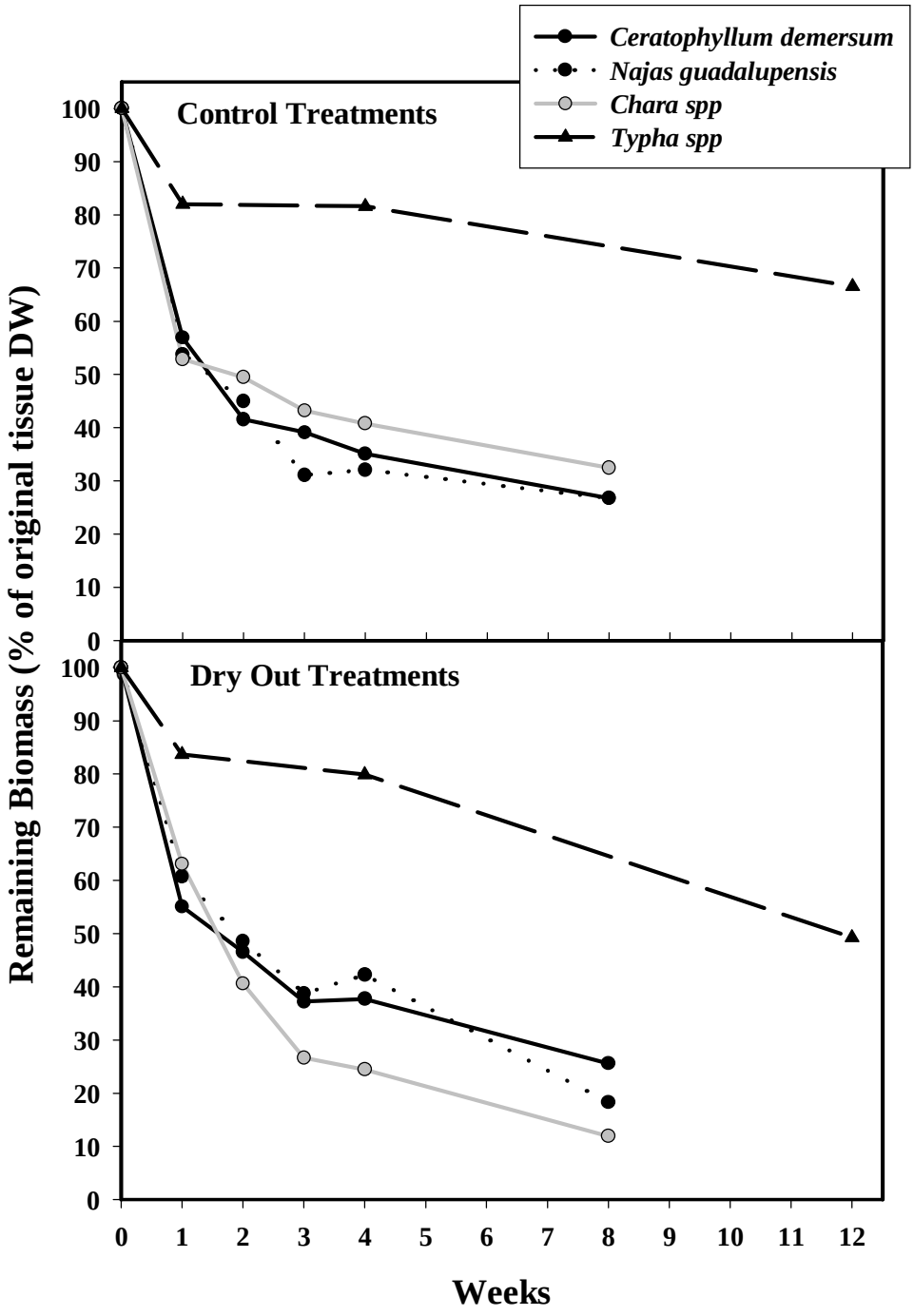

Figure 6-13. Percent mass loss (dry weight) using leaf litter bags of three submerged species (*Ceratophyllum dermersum*, *Najas guadalupensis*, and *Chera spp.*) and one emergent species (*Typha* spp.) over a period of 12 weeks in the STA-1W mesocosm experiments. Collection of submerged species ended on the eighth week.

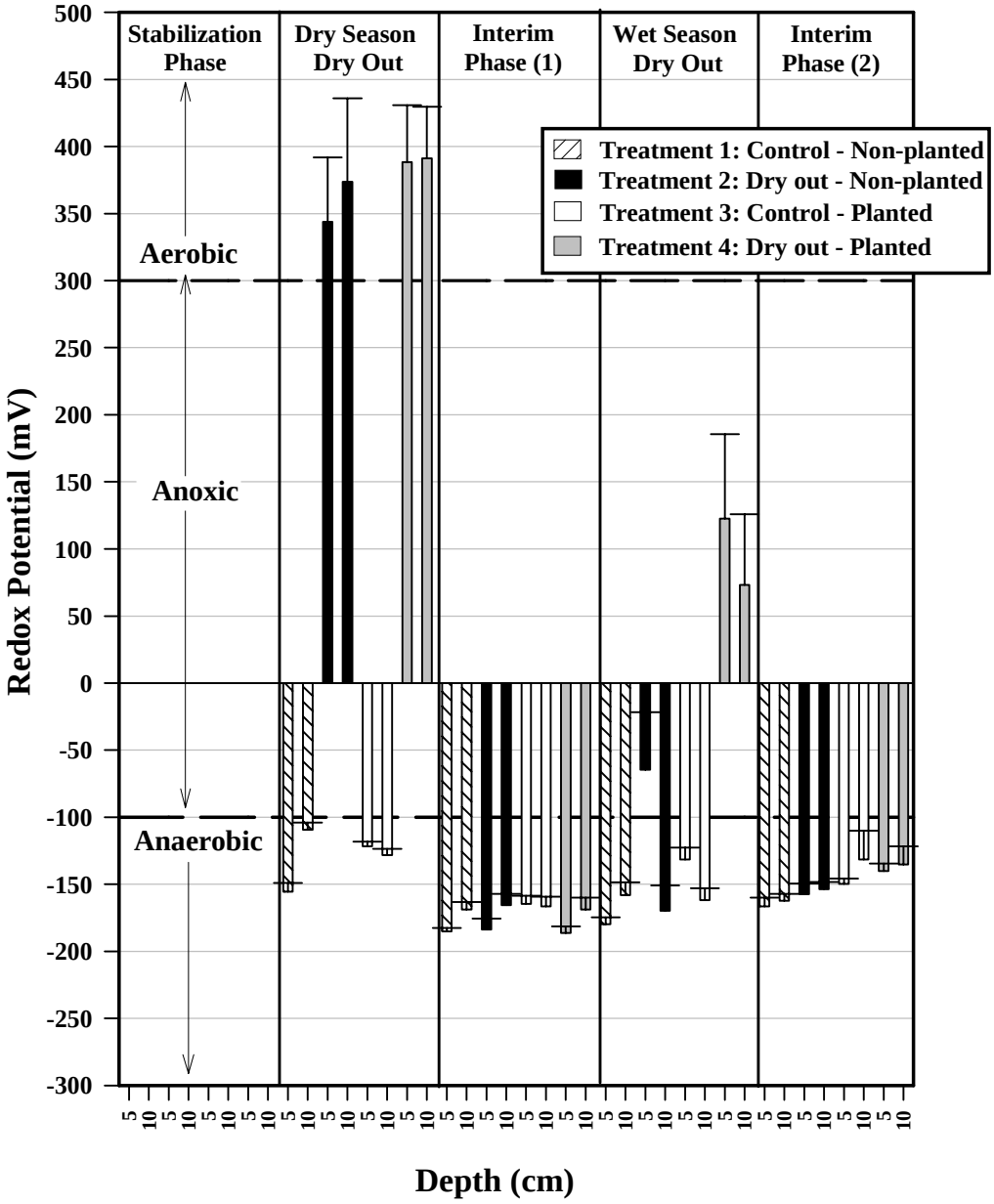

Figure 6-14. Corrected redox values of all treatments for soil depths of 5 and 10 cm in both control and dry-out tanks in the STA-1W mesocosm experiments.

Re-flooding events affect not only nutrient availability, but also communities of decomposers, in turn affecting decay rates of organic material and potentially reducing P retention. During the first year of study, soils of non-planted tanks had higher average CRR than planted tanks. Overall, CRR decreased in dry soils in both planted and non-planted tanks relative to controls. However, the wet season dry-out differed the least in cellulose decomposition rates (**Figure 6-14**). Preliminary results suggest that dry season dry-out produced soils that were completely oxidized and lacked moisture, possibly resulting in a decline in cellulose decomposers. During the wet season, soils remained relatively anoxic and moist, producing a favorable environment for decomposers and increasing CRR relative to the dry season.

While water/sediment cotton strip assays did not appear to be affected by dry-out within the water column after reflood, the floating frame study revealed that decomposition rates within the water column did increase after reflood (**Figure 6-15**). Water column microbial communities could respond differently to dry-out/reflood scenarios compared to communities ten centimeters above or below the soil/water interface.

Decomposer communities in the lower water column could be influenced by those communities in the soil, which decreased during dry-out, resulting in a lower CRR (**Figure 6-16**). Additionally, inflow decomposition rates in all treatments were greater than outflow in the water column. These results are similar to those in the Everglades study performed by Maltby (1985), which determined that cellulose decomposition rates within the water column increased with the addition of phosphorus and nitrogen, and decomposition rates generally decreased downstream from the nutrient source.

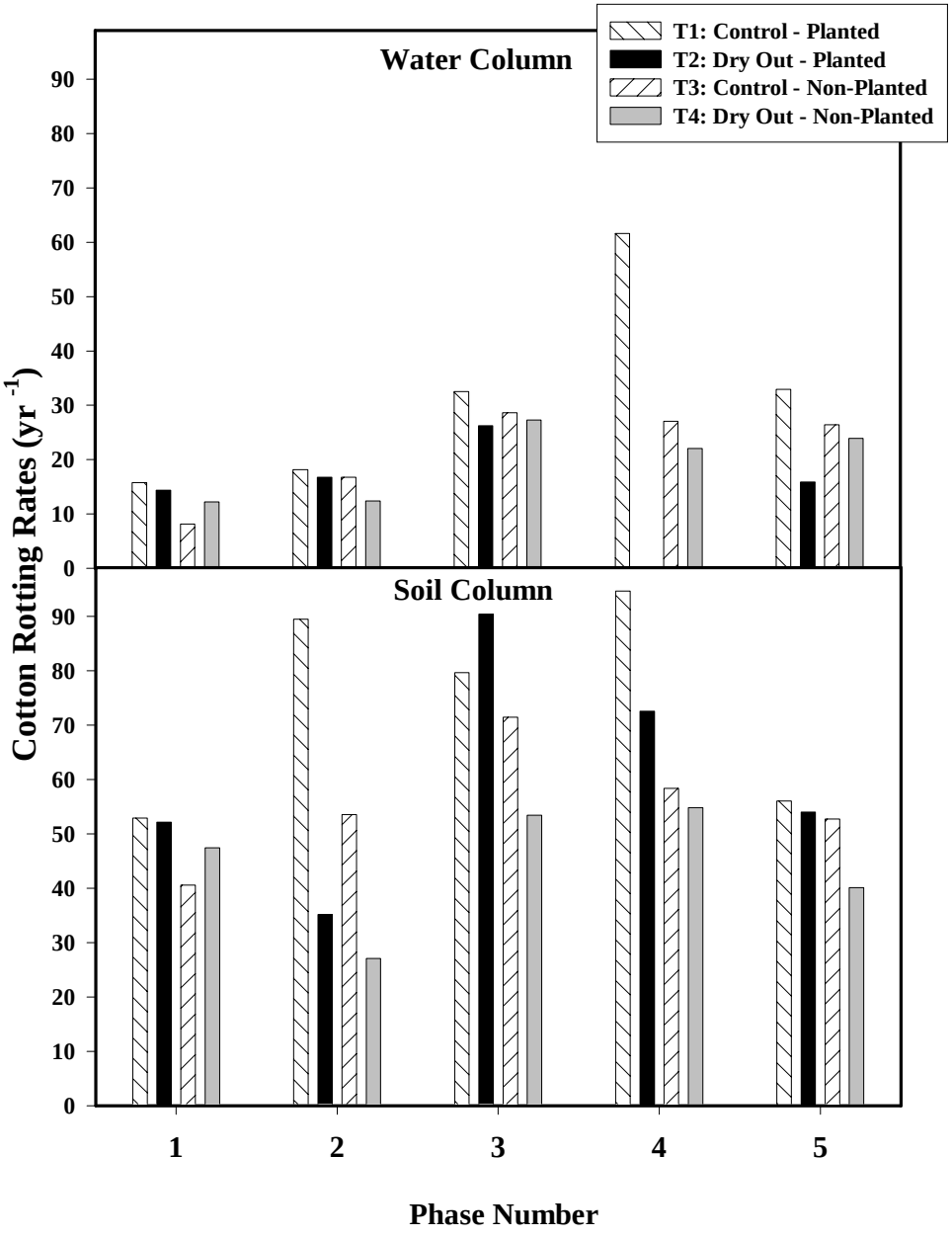

Figure 6-15. Cotton rotting rates in Marsh Dry-Out STA-1W mesocosms. Phase 1: Startup period, Phase 2: Dry Season Dry Out, Phase 3: Interim Phase (1), Phase 4: Wet Season Dry Out, Phase 5: Interim Phase (2).

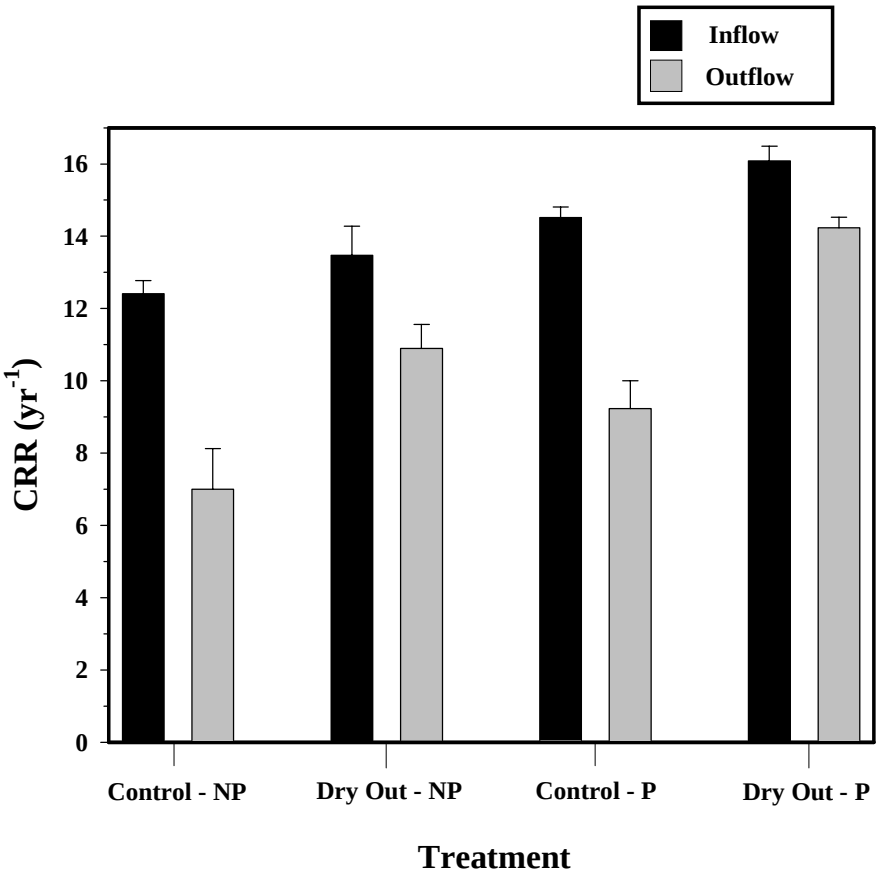

Figure 6-16. Cotton rotting rates in the water column of the inflow and outflow of four different treatment types in the STA-1W mesocosm experiments.

CONCLUSIONS

Nutrient retention of organic soils following dry-out and reflooding appears to depend on the extent of soil oxidation and vegetation type within a wetland system. Both planted and non-planted tanks produced a nutrient flux into the water column following reflooding during both dry and wet seasons. The highest nutrient releases occurred in non-planted tanks during the dry season dry-out/reflooding cycle. Preliminary results suggest that complete oxidation of organic soils under plant communities that rapidly decompose, such as a submerged aquatic/algae community, released more P into the water column when reflooded than those planted with emergent vegetation.

RESEARCH LINKAGE TO STA MANAGEMENT

District goals include assuring that management and operational strategies maximize nutrient reduction in the STAs. The research conducted on STA Optimization focuses on understanding the dynamics of shallow, subtropical wetlands and the conditions that improve or reduce nutrient removal efficiencies.

- Results from STA-1W have validated the premise that treatment wetlands constructed on former agricultural land can effectively reduce TP levels in EAA runoff and achieve outflow concentrations less than the interim target level of 50 ppb.
- The cumulative TP settling rate calculated for the ENR Project suggests that the settling rate used to design the STAs was conservative and should provide an adequate margin of safety to accommodate any decrease in treatment performance that may occur as these systems mature over time.
- Analysis of nutrient data from Treatment Cell 4 in STA-1W indicated that this cell out-performed the other treatment cells in STA-1W. This information has guided the District to focus on the cultivation of a submerged aquatic vegetation community in the lower reaches of the other STAs to enhance their treatment performance.
- Test cell research has identified an upper range of hydraulic loading rates in cattail-dominated peat-based wetlands that exceeds the ability of these systems to effectively remove P from flow-through waters. Additional experiments are currently investigating the role of water depth and inflow pulsing to further clarify the limits of treatment efficiency in these wetlands.

CHAPTER CONCLUSIONS

After five years of operation, STA-1W is performing at levels well below the targeted 50 ppb. Individually, Cells 2, 3 and 4 retain 31 to 56 percent of TP mass entering each treatment cell. Even though Cell 4 is the smallest of the treatment wetlands, it is most efficient in spite of a 51 percent short-circuiting in its water flow. Mixing is expected to increase its efficiency with the installation of earthen plugs, but results of these alterations will not be known until next year. One hypothesis is that the management of Cell 4 is responsible for its success in retaining TP, particularly regarding vegetation, HRT, and operating depth. The western flow-way retains three times more TP than the eastern flow-way when loading rates and size differences are included in the analysis.

Preliminary test cell experiments at the north site indicate that mean outflow TP and TN generally increased as inflow HLR increased. Mean outflow TP was less than the mean inflow values, but exceeded the Phase 1 target of 0.050 mg/L only at the highest HLR tested. Mean total outflow TN and organic N concentrations generally increased as hydraulic loading rates increased. Inorganic nitrogen was preferentially taken up in the wetlands. Removal efficiencies were greater at lower hydraulic loading rates in the north test cells when the inflow concentrations were higher. At the low inflow concentrations of the south test cells, HLR had little effect on outflow concentrations. Decomposition experiments revealed that low nutrient

concentrations may limit decay, or that an increase in TP loading seemed to increase decay rates in these wetlands.

The Marsh Dry-Out Study at the north site in STA-1W indicated that nutrient release in these mesocosms during reflooding after a dry-out period is time-limited to approximately one month. Vegetation seems to play a role in that non-planted tanks release more TP into the water column during the reflood than tanks planted with cattails. Soil dryness during dry-out also appeared to increase TP release into the water column.

FUTURE DIRECTIONS

Over the next water year, much of the present research, including monitoring internal water quality and flow stations in STA-1W, will continue. Construction on the new structures should be completed this year, so it is expected that next year's report will include performance data for all treatment cells. Analysis of prior years' performance in these treatment cells will continue and focus on other water quality parameters in addition to TP. In the test cells, research will continue on the effects of hydraulic loading rates, depth, and pulsing on TP concentrations. The Marsh Dry-Out studies will continue, and similar research in STA-6 is projected.

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