Lake Apopka: Reducing Excess Nutrients

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Using Wetlands to Reduce Lake Apopka's Excess Nutrients

Introduction

Wetlands, both natural and constructed, provide a range of ecosystem services. These services can include water quality improvement, recreational space, habitat, water storage, and flood control (Mitsch and Jørgensen 2004). Constructed wetlands, which are engineered ecosystems, rely on biology, chemistry, physics, hydrology, and the combinations of these processes and many others, to provide the desired service. For water quality improvement, constructed wetlands can transform and translocate nutrients, suspended materials, and contaminants due to the assemblage of soil, water, plants, detritus, and microbes (Kadlec and Knight 1996; Kadlec and Wallace 2008). Constructed wetlands use natural wetland biogeochemical processes like sedimentation, accretion, sorption, precipitation, and nutrient uptake by plants and microbes, which can be optimized to meet specific design and operation goal(s).

The St. Johns River Water Management District's restoration program for Lake Apopka, FL includes a range of management practices that both reduce the external nutrient loading to the lake and remove nutrients already in the lake. The marsh flow-way (Figure 1), a 310-hectare constructed wetland, is one project that contributes to the removal of nutrients and suspended material already in Lake Apopka.

Typically, constructed wetlands treat incoming water in a single pass, meaning the wetland has one chance to remove incoming nutrients and/or contaminants. In addition, treatment goals often include

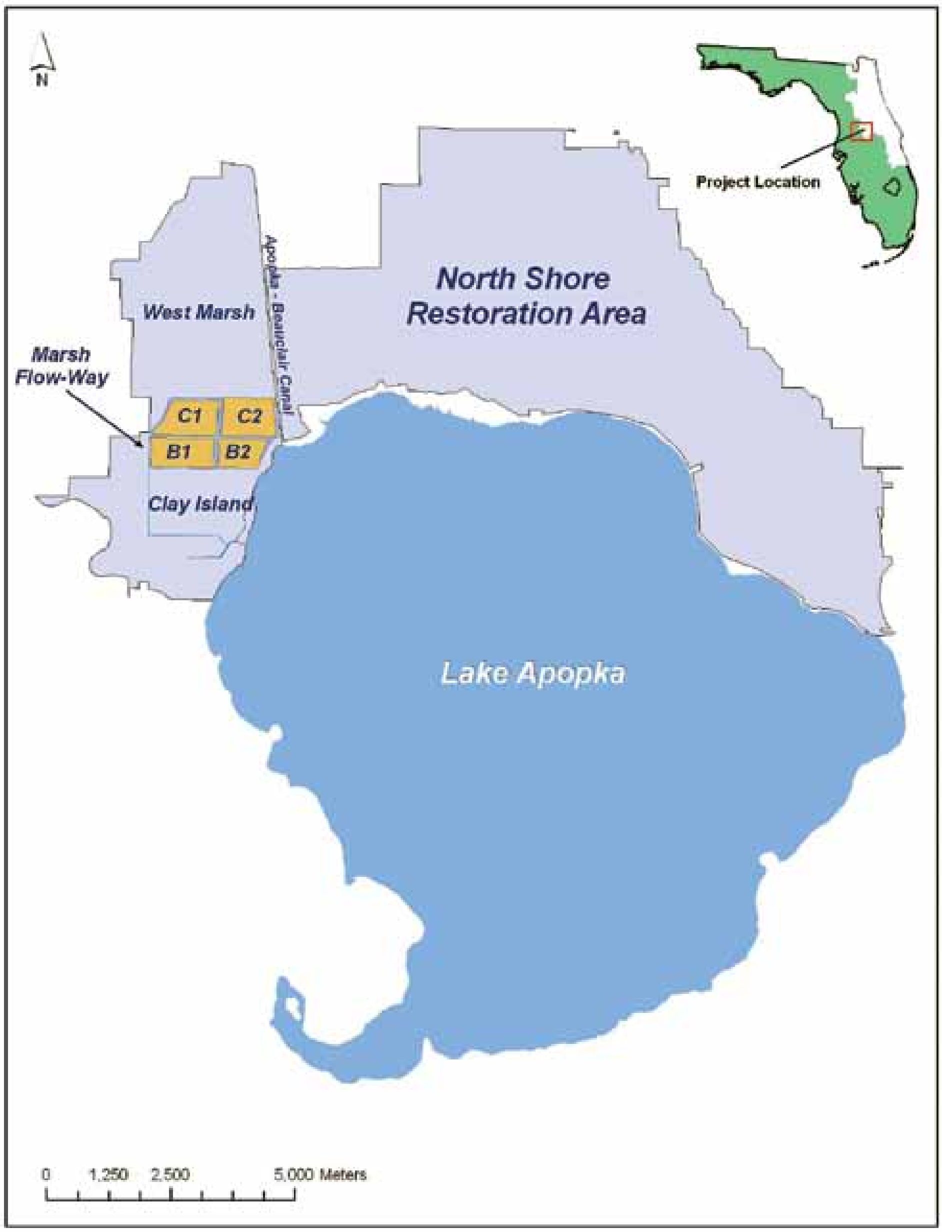

Figure 1. Location map of the marsh flow-way project in central Florida and its location in the Apopka watershed.

achieving a specific outflow water quality concentration. In single-pass wetlands, the goal is to maximize efficiency, which is the proportion of pollutant removed. As a recirculating wetland, the marsh flow-way operates quite differently. Rather than attempting to meet an outflow concentration, our goal is to maximize nutrient and suspended solid removal rates from incoming Lake Apopka water and recirculate the cleaner water back to the lake (Lowe et al. 1989). In physics, power is defined as the work done per unit time. As nutrient and suspended solid removal is the work of the treatment wetland, by analogy, we denote removal rate as the power of the treatment wetland. Therefore, to maximize power, the marsh flow-way is operated at high hydraulic loading rates (HLRs) relative to many constructed wetland systems within the U.S.

Our objectives for this article are to give a brief overview of system goals, description of the project, monitoring, management, and system performance for the first seven years of operation between 2003 and 2010.

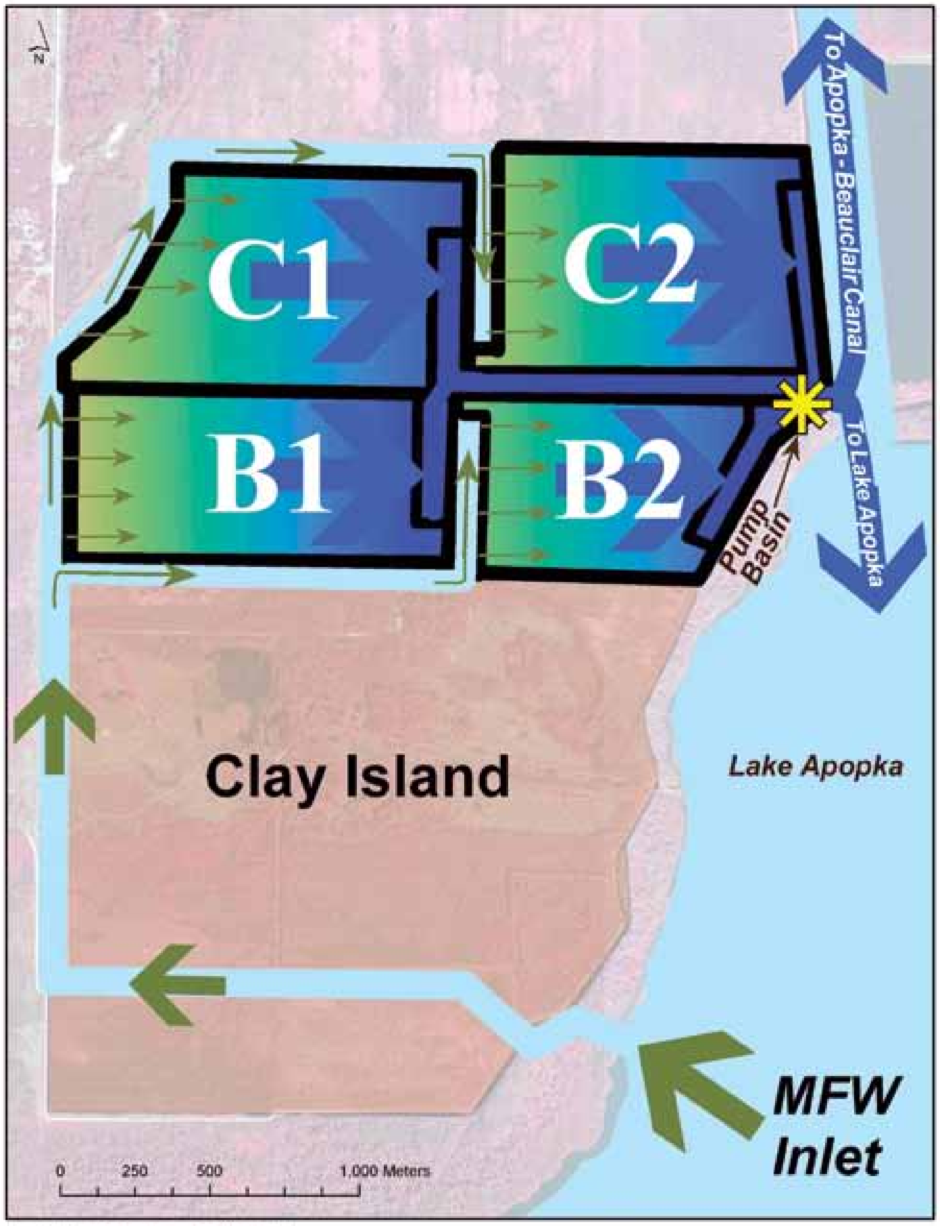

Figure 2. Schematic of water flow through the four treatment wetland cells (B1, B2, C1, and C2) of the marsh flow-way at Lake Apopka.

Materials and Methods

Site Layout and Description

The marsh flow-way is located in the northwest corner of Lake Apopka and consists of four independent treatment cells (B1, B2, C1, and C2). The cells receive Lake Apopka water via gravity flow through a series of canals and gated culverts (Figure 2). Once in the cell, water flows west to east through the wetland. Water passes through open water areas, emergent vegetated areas and over small lateral ditches, which are perpendicular to flow. Water exits each cell over riser board structures, and all outflows are routed to a pump basin via a canal. Once in the pump basin, water is pumped back to the lake (Figure 3).

Each year, during November and/or December, aerial photographs were taken of the site and used to interpret and classify dominant vegetation communities. Based on the interpreted imagery for six years (2003-2008) 65 percent of the marsh flow-way was shallow herbaceous marsh and 18 percent was shrub swamp. The remainder (17 percent) was shallow open water.

Site Monitoring

The marsh flow-way began operation in November 2003, and we report data up until November 2010. During this time, water levels were measured daily and flows were estimated using weir flow equations.

Typically, inflow and outflow water was sampled weekly and analyzed for a range of parameters according to standard methods. A total of 20-23 parameters were analyzed, including total phosphorus (TP), total dissolved phosphorus (TDP), dissolved reactive phosphorus (PO_4-D), total suspended solids (TSS), ammonium, nitrate+nitrite, and total Kjeldahl nitrogen.

Cell maintenance includes cell drawdown, vegetation mowing, ditch cleaning, vegetation planting, installation of silt fences and wattles, and use of alum to mitigate P release during reflooding. During maintenance of C2, finger levees were constructed to reduce hydrologic short-circuits. In B cells, maintenance occurred between March 2007 and January 2008, whereas maintenance in C cells was undertaken between May 2008 and October 2009. During maintenance, various individual cells were offline.

Figure 3. Plume of treated marsh flow-way water (clear water) being returned to Lake Apopka.
Photo by Jim Peterson.

Results and Discussion

Hydrology

Hydraulic loading rate (HLR) increased each year up until 2006. After 2006, mean HLR decreased, with recent years somewhat similar to each other (Table 1). The maintenance of wetlands cells in 2007 through 2009 contributed to the variability and low median HLR during these years. Maintenance was undertaken to mitigate the onset of reduced system performance for nitrogen (N) and P removal. Reduced effectiveness was concomitant with the occurrence of hydraulic short-circuits within cells, and there was a change from emergent vegetation to increased coverage by floating vegetation mats. We believe that these floating mats occur because of increasing water depths in cells.

During the complete period of record (POR), the mean HLR was 36 m/yr, which resulted in about 40 percent of the lake's volume being treated per year (Figure 4). This HLR is high relative to HLRs in many other constructed wetlands in Florida and the U.S., which can range between 10-20 m/yr. The marsh flow-way was operated at a high HLR, since one of the main design and operational goals was to maximize power (Lowe et al. 1989). One way to increase power is to increase HLR, thus treating more lake water. Previous studies report that increasing the HLR and/or nutrient loading rate contributes to increased removal rates (Reddy et al. 2009).

Another factor that makes the marsh flow-way different from other constructed wetlands is the site location. The marsh flow-way is located on land that was historically used for agricultural row crops (prior to this, it was part of the lake's floodplain wetland); therefore, these organic soils received many years (~40-50 years) of fertilizer applications. It was found from previous on-site studies that the legacy of nutrient loads in soils contributed to a release of soluble nutrients, specifically P, from soil to overlying water (Coveney et al. 2002). We anticipated that increasing HLR, thereby reducing hydraulic residence times within the flow-way, would help mitigate P release from soil. We also applied alum residual, a water treatment by-product, to the soils at a rate of 22 wet metric tons per hectare (~ 47 kg Al ha^{-1}) to mitigate the release of P from the soil prior to reflooding.

Total Suspended Solids and Accretion Rates

The marsh flow-way retained large amounts of total suspended solids (TSSs) from incoming Lake Apopka water. The TSS power or removal rate varied between 3 and 20 metric tons of TSS per day (Figure 5). The primary biogeochemical process involved in removing TSS from water is sedimentation. We observed greatest power during 2007 and 2008 (Figure 5). After 2008, power decreased, as incoming TSS concentrations decreased. The HLR was also lower than preceding years, as maintenance was undertaken on C cells during 2008 and 2009.

The seven-year median areal power was 1.4 kg m^2/yr, and the median removal

Table 1. Total Suspended Solids, Total Phosphorus and Total Nitrogen Removed (g/m2/yr) by the Marsh Flow-way at Lake Apopka, FL Between November 2003 and November 2010.*

Parameter	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*
	g/m2/y							
TSS	257	1,396	926	1,859	2,104	2,339	1,035	1,133
TP	-1.9	0.5	0.4	1.6	1.6	1.8	0.4	0.9
TN	6	40	22	35	41	39	13	26

TSS = Total suspended solids; TP = Total phosphorus; TN = Total nitrogen.

*Values are yearly medians. Positive values are removal and negative values are release. Values for partial years 2003 and 2010 were annualized for comparative purposes.

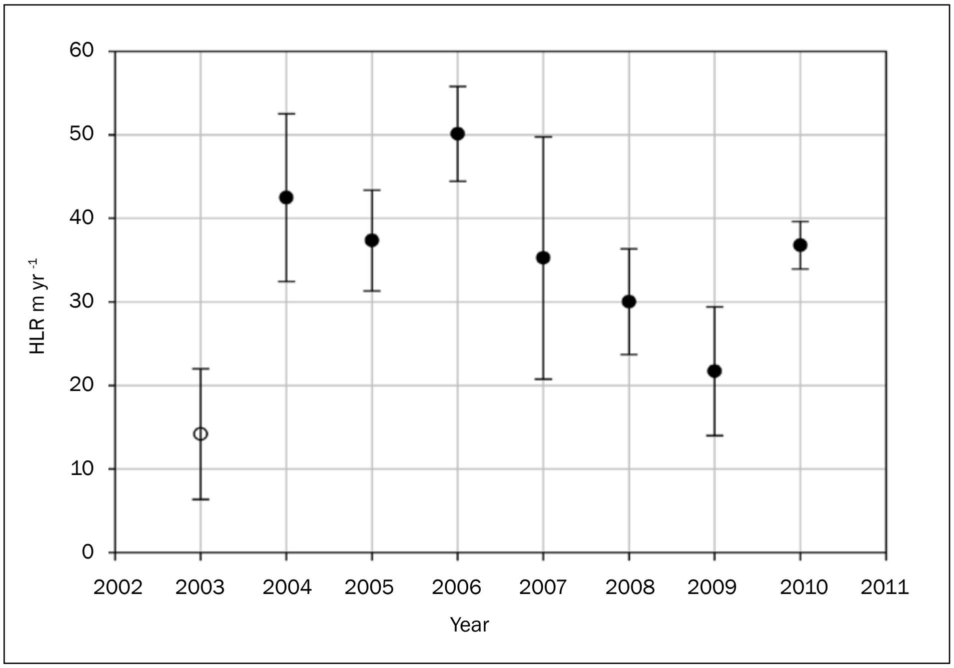

Figure 4. Hydraulic loading rate (HLR) m/yr to the marsh flow-way between November 2003 and November 2010. Values represent mean ± one standard deviation.

efficiency for that timescale was 92 percent. Suspended solids removal is important since approximately 90 percent of the nutrients in lake water were in particulate forms (Figure 7).

We estimated that accretion rates of flocculent sediment in the wetland were 2 ± 1 cm/yr for B cells and 3 ± 1 cm/yr for C cells up until maintenance was undertaken in both B and C during 2007 and 2008/2009, respectively. To estimate this, we used TSS retained by individual treatment cells up until the time of maintenance, individual treatment cell area, bulk density and percent solids of collected sediment samples prior to maintenance. In a previous pilot-scale study at Lake Apopka, it was found that flocculent sediment consolidated about seven-fold during treatment cell drawdown.

Phosphorus

During the initial start-up period, which lasted about three to four months, the system released P (Figure 6), mostly in dissolved form. This was anticipated from previous findings and probably resulted from release of dissolved P from flooded soil, and release from decomposing terrestrial vegetation (Coveney et al. 2002). After the start-up period, TP power increased to a maximum of 17 kg/d (2008).

Typically, performance was better during cooler months (October through May) relative to warmer months (June through September). During the period of record (POR), areal power ranged between 0.5 and 1.8 g of TP m^2/yr (Table 1), whereas the median was 0.9 g m^2/yr. Efficiency based on mass removal was 28 percent, similar to the project design goal of 30 percent.

During the POR, about 90 percent of the incoming P mass was in a particulate form, whereas PO_4-D and dissolve organic phosphorus (DOP) each accounted for about 5 percent of TP (Figure 7). The relative proportion of these fractions changed as lake water passed through the wetland. In the outflow water, which was recirculated back to Lake Apopka, particulate phosphorus (PP) was about 60 percent of the total P mass (Figure 7), while PO_4-D and DOP each made up about 2 percent.

Nitrogen

The yearly trend in total nitrogen (TN) power was similar to both TSS and TP. Yearly rates were variable ranging between about 11 and 350 kg/d (Figure 8). Total N power or removal rate was highest in 2007 and 2008 (Figure 8 and Table 1) and lowest in 2003 and 2009. Power was also seasonally dependent, a pattern probably caused by the effects of water temperature and dissolved oxygen content in wetland waters and underlying soils – both of which affect nitrification and denitrification rates. Nitrogen removal was best during cooler periods (October through May, ~ 35 g m^2/yr), while during warmer periods (June through September) performance dropped to 19.5 g N m^2/yr. For the seven years of operation, the median areal power was 28.9 g m^2/yr, while efficiency was 24 percent.

Conclusions and Management Implications

The performance of the marsh flow-way at Lake Apopka during the first seven years of operation shows that this constructed wetland was effective in removing nutrients and suspended material from eutrophic Lake Apopka water. Relative to most other constructed wetlands, the goals, operation, and management of the marsh flow-way are different. Because the flow-way is a recirculating system, it is operated at high HLRs to maximize power, even if this causes declines in efficiency. Power grows with HLR because rate of nutrient and suspended material removal increases with HLR, while the rate of release of dissolved nutrients from soils and accumulated sediments does not.

Operating at these high HLRs may have implications for emergent vegetation management, as we observed that following high HLR years, there was a greater occurrence of floating vegetation mats and hydraulic short circuits. During the POR, we undertook maintenance once in each cell.

In a broader context, Lake Apopka water quality has improved since 1995 (1989-1994 was the baseline period used for TMDL development). Annual average TP concentrations in Lake Apopka water during marsh flow-way operating periods (2004 through 2009) averaged 43 percent lower than baseline, algal chlorophyll declined 35 percent, and Secchi transparency improved by 53 percent.

We anticipate that the marsh flow-way will continue to remove nutrients and suspended material into the future. However, it will become more difficult for the system to remove nutrients and suspended material at similar rates, as concentrations in lake water decline. The

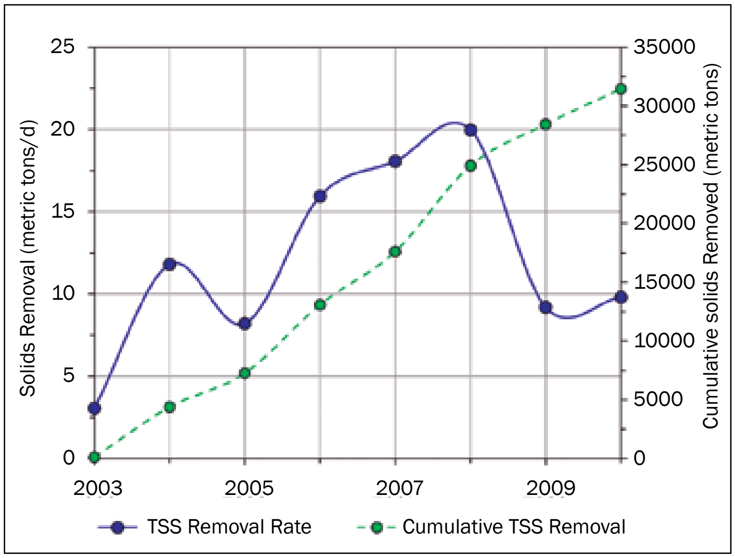

Figure 5. Total suspended solids removal rate (metric tons/d) by the marsh flow-way between November 2003 and November 2010 (solid line) and the cumulative amount (metric tons) of total suspended solids retained by the marsh flow-way (dashed line).

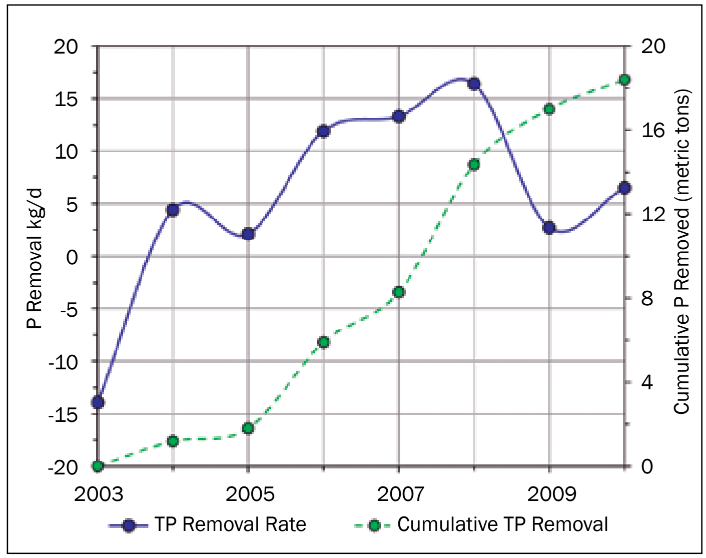

Figure 6. Total phosphorus removal rate (kg/d) by the marsh flow-way between November 2003 and November 2010 (solid) and the cumulative amount (metric tons) of total phosphorus retained by the marsh flow-way (dashed line).

system will require dynamic management in response to these improving conditions. This may entail operating better performing cells, while not operating and/or maintaining other cells during certain periods, increasing HLRs to increase nutrient and suspended solid loads, and adaptively managing within-cell water depth and hydroperiod.

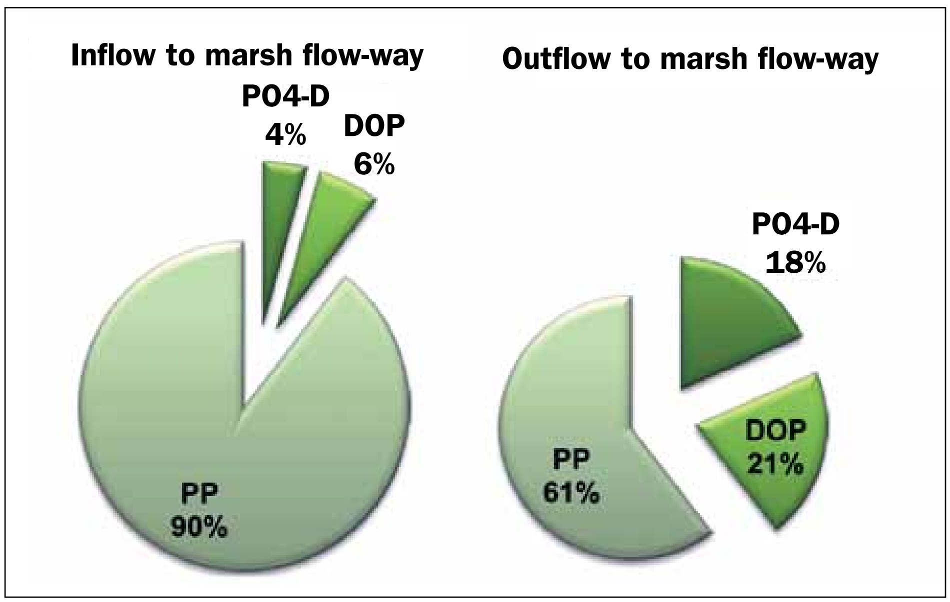

Figure 7. The relative proportions of phosphorus fractions in Lake Apopka water that flow into the marsh flow-way and treated marsh flow-way water that returns to Lake Apopka. PP = particulate phosphorus, DOP = dissolved organic phosphorus and PO_4-D = dissolved reactive phosphorus.

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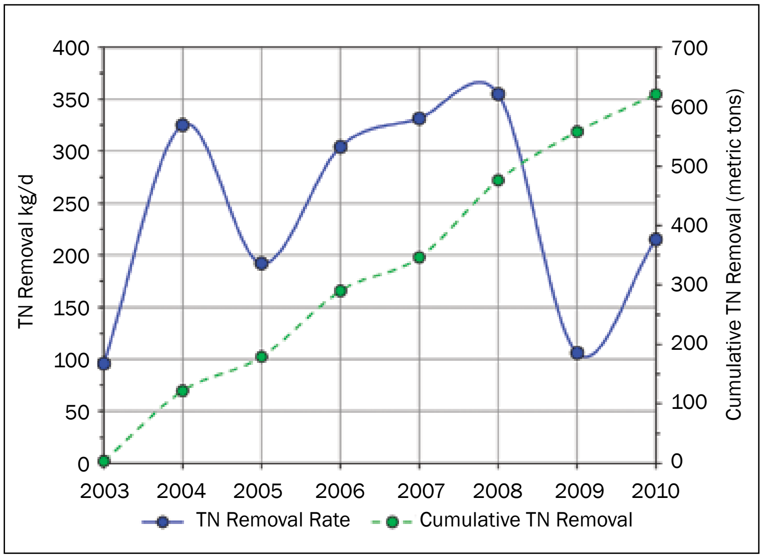

Figure 8. Total nitrogen removal rate (kg/d) by the marsh flow-way between November 2003 and November 2010 (solid line) and the cumulative amount (metric tons) of total nitrogen retained by the marsh flow-way (dashed line).

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