In: Proceedings of 8th Biennial Conference (2005) on Stormwater Research and Watershed Management, pp. 175 – 184. Southwest Florida Water Management District, Brooksville, FL.

Evaluation of a Floating Wetland for Improving Water Quality in an Urban Lake

Thomas A. DeBusk[1], *Rick Baird*[2], *David Haselow*[3] and *Tom Goffinet*[3]

[1]DB Environmental, Inc., Rockledge, FL, [2]Orange County Environmental Protection Division, Orlando, FL, [3]Azurea, Inc., Rockledge, FL

Abstract

Stands of littoral vegetation are thought to improve water quality in ponds and lakes. The effectiveness of fringing vegetation plantings, however, can be constrained by many factors, including steep shorelines that provide limited littoral area, and poor hydraulic exchange between the vegetated littoral zone and the bulk water column. In this study, we evaluated the water treatment effectiveness of a floating wetland, deployed near the center of a 1.6 hectare hypereutrophic urban lake. The wetland vegetation was contained within a floating boom 18 meters in diameter, which was equipped with a flexible fabric skirt that extended from the water's surface to the sediments. This effectively isolated a parcel of water, 262 m^2 and 2.75m deep, from the lake's water column. A solar-powered pump was deployed to provide a semi-continuous water exchange from the lake's water column into the compartment at a rate of approximately 100 m^3/day. At this exchange rate, a volume of water equal to the lake's entire water column passed through the wetland compartment in 10.5 months.

The floating wetland was deployed in August 2003, and performance was monitored from November 2003 through October 2004. The wetland effectively removed particulate matter, reducing total suspended solids and turbidity by 67% and 50%, respectively. Chlorophyll *a* levels were reduced by 65% during passage through the system, suggesting the bulk of the removed particles were phytoplankton.

Because of internal cycling of phosphorus (P) within the wetland compartment, we assumed little net P removal would be achieved by the wetland under steady-state conditions. We therefore injected alum once monthly beneath the floating mat to stabilize P in the accumulating wetland sediments. Based on weekly measurements, P removal in the system from November 2003 through October 2004 averaged 50%, with mean inflow concentrations reduced from 0.168 to 0.084 mg TP/L. Total nitrogen (N) removal in the system averaged 40%. On a mass basis, the system removed 25.6 kg N and 2.81 kg P/yr. The floating wetland was heavily utilized by birds, which probably contributed to an observed net export in coliform bacteria, and also may have reduced system nutrient removal effectiveness.

Data from this, and prior studies, suggest that the floating wetland can be an effective nutrient control technology, particularly for small urban lakes, wet detention ponds and agricultural impoundments with water column TP concentrations in excess of approximately 0.100 mg/L.

Introduction

Emergent macrophytes commonly are planted in the littoral regions of ponds, lakes and wet detention ponds to improve water quality (USEPA 1999a; USEPA 1999b). Not all water bodies, however, are amenable for littoral plantings. In some cases, the system bathymetry is such that there is limited littoral shelf available for emergent macrophyte beds. In other systems, particularly wet detention ponds, water stages can vary markedly, thereby either flooding the littoral vegetation during high stages, or stranding the macrophytes on dry soil during low stages. Even in water bodies with fairly consistent stage conditions, hydraulic exchange between the vegetated littoral region and the bulk water column may be limited. Finally, in some water bodies, shoreline property owners object to littoral plantings for aesthetic reasons, or over concerns that the vegetation could harbor dangerous wildlife.

Because of these potential limitations to the use of littoral macrophytes, we tested an alternative approach to improving water quality, in which we deployed macrophyte vegetation in the center of a small urban lake. This floating wetland was equipped with a solar powered pump to effect water exchange between the wetland and the bulk water column of the lake. Because the wetland was equipped with discrete inflow and outflow ports, it was possible to measure the pollutant removal effectiveness of the wetland based on concentration and mass load reductions. The goals of this study were: to characterize pollutant load reductions by the floating wetland; to compare these load reductions to the estimated external pollutant loads from the lake's watershed; and, to determine under what conditions the floating wetland can be a useful tool for enhancing lake/pond water quality.

Study Site

Lake June is a 1.6 hectare (ha) lake located in the Holden Heights neighborhood, Orange County, Florida. The lake has a 37 ha commercial and residential drainage basin. Bathymetric surveys performed by the Orange County Environmental Protection Division depicted a mean water depth of 2 meters, and maximum muck depth of up to 0.5m. This survey also revealed that the lake has a steep shoreline, with little littoral shelf. Estimated water volume of Lake June is 32,000 m^3. The lake discharges over a weir into a drainage well, which effectively controls maximum stage. Previous water analyses characterized the lake as hypereutrophic, with total nitrogen (N) concentrations of 2.0 mg/L, total phosphorus (P) concentrations of 0.24 mg/L, and chlorophyll *a* values of 92 mg/m^3. At the time of deployment of the floating wetland, the dominant macrophyte vegetation type in the lake was water hyacinth (*Eichhornia crassipes*), which covered approximately 10% of the lake's surface.

Materials and Methods

The floating wetland was contained within a circular floating boom 18 meters in diameter, which was equipped with a weighted, flexible fabric skirt that extended from the water's surface to the sediments, effectively isolating a parcel of water beneath the vegetation from

In: Proceedings of 8th Biennial Conference (2005) on Stormwater Research and Watershed Management, pp. 175 – 184. Southwest Florida Water Management District, Brooksville, FL.

the lake's water column (Fig. 1). This isolated water parcel was $262m^2$ in surface area and 2.75 m deep. To initiate development of a floating vegetative mat, we first encircled a portion of the water hyacinths in the lake into the floating boom. Other plants were added within the floating boom to create a more diverse wetland, including plants in the genera *Hydrocotyle*, *Bidens*, *Sagittaria*, and *Pontederia*. The remaining water hyacinths in the lake were killed with a herbicide. No vegetation harvesting from the wetland was performed during the study.

A solar-powered pump was deployed within the floating wetland to provide a semi-continuous water exchange from the lake's water column into the compartment at a rate of approximately 100 m^3/day (Fig. 1). This provided a hydraulic retention time (HRT) within the compartment of 7 days. At this exchange rate, a volume of water equal to the lake's entire water column would pass through the wetland compartment in 10.5 months. Fishing line was deployed to discourage birds from landing on the solar collectors and the edge of the floating boom. No attempt was made to discourage birds from feeding or roosting within the vegetation itself.

Figure 1. The floating wetland deployed in Lake June. The photo on the right depicts a closer view of the solar panels and vegetation.

At the initiation of the study, we assumed that P removal, based solely on the accrual of P in sediments produced by the wetland vegetation, would not be significant relative to the P removal needs of the lake. We therefore enhanced P removal of the floating wetland by chemically stabilizing P in the organic detritus that was deposited in the underlying sediments. This was accomplished by means of a monthly injection of alum beneath the wetland, at a dose of 12.5 mg Al/L as aluminum sulfate (alum). This alum concentration was selected based on results of jar tests, which demonstrated formation of a moderate to rapidly settling floc at this dose. Chemical analyses also revealed that the lake is poorly buffered, so we also injected $NaHCO_3$ immediately before injecting alum. Other than initial jar tests, no further attempts were made to optimize aluminum dose or form of compound during this study.

Wetland inflow and outflow monitoring was performed from November 2003 through October 2004. The wetland inflow sample was collected from the lake (0.2m depth) just outside of the floating wetland barrier. The wetland outflow sample was collected from one of three locations. Prior to March 2004, outflow total P (TP) samples were collected from just inside the wetland enclosure, adjacent to the submerged outflow port. Outflow samples for other analyses (see below) were collected using a long length of polyethylene tube running from the shoreline to the submerged outflow port of the wetland. After several months of collecting samples through this tube, we determined that they were being contaminated with fine particulate matter dislodged by the suction of the sampling pump. In March 2004 we corrected this problem by adjusting the wetland outflow pipe so it discharged above the waters surface. After this time, all outflow samples, for TP and other parameters, were collected as a grab sample from this location.

In addition to TP, soluble reactive P (SRP) and pH were measured weekly, and the following parameters were measured every 4 – 6 weeks: nitrate-nitrogen (N), ammonia-N, total kjeldahl N, chlorophyll *a*, total suspended solids (TSS), turbidity, sulfate, total aluminum (TAl), dissolved oxygen (DO), fecal coliforms (FC) and total coliforms (TC). All laboratory analyses were performed using USEPA-approved procedures, including appropriate quality assurance/quality control protocols.

In order to characterize the floating wetland sediments, during January 2005 we retrieved four 7.6 cm diameter sediment cores from within the wetland enclosure, and an additional four cores from an open water area in the lake. These cores were visually inspected for presence and depth of organic matter and alum floc accretion.

Results

The floating wetland was initially deployed in August 2003, at which time it exhibited approximately 40% vegetation cover. The macrophyte standing crop increased throughout the fall of 2003, and attained 100% cover in March 2004.

Lake nutrient concentrations varied widely during the study, from 0.084 to 0.379 mg /L for TP and 0.76 to 1.25 mg/L for TN (Table 1). We observed no obvious increasing or decreasing trend in lake water TP concentrations during the year-long evaluation: maximum and minimum lake water TP levels were observed in April and August 2004, respectively (Fig. 2). The floating wetland exhibited effective nutrient removal, removing 50% of the inflow TP and 40% of the inflow TN. Despite widely varying lake TP concentrations, the outflow from the floating wetland was relatively consistent, averaging 0.084 mg/L and ranging from 0.054 to 0.130 mg/L (Fig. 2). Neither the wetland inflow (= lake water) nor wetland outflow contained substantial amounts of soluble reactive P (Table 1). Wetland outflow TN concentrations averaged 1.08 mg/L, and ranged from 0.76 to 1.25 mg/L (Table 1).

Table 1. Summary of the water quality treatment performance of the Lake June floating wetland. Total P and soluble reactive P were measured approximately every week for one year. Other constituents were measured every 4 – 6 weeks for six months.

	Wetland Inflow (Lake)		**Wetland Outflow**	
total phosphorus (mg/L)	0.168	(0.084 – 0.379)	0.084	(0.054 – 0.130)
soluble reactive phosphorus (mg/L)	0.006	(<0.002 – 0.027)	0.008	(<0.002 – 0.029)
total nitrogen (mg/L)	1.80	(1.36 – 2.17)	1.08	(0.76 – 1.25)
chlorophyll *a* (mg/m^3)	78	(34 – 123)	26	(15 – 35)
total suspended solids (mg/L)	17	(6 – 26)	6	(2 – 10)
Turbidity (NTU)	12	(8 – 18)	6	(4 – 11)
total aluminum (mg/L)	0.161	(0.057 – 0.260)	0.142	(0.060 – 0.260)
Sulfate (mg/L)	18.1	(10 – 21)	20.9	(12 – 44)
dissolved oxygen (mg/L)	9.6	(6.3 – 15)	1.2	(0.17 – 3.6)
total coliform (CFU)	339	(100 – 840)	3057	(400 – 6800)
fecal coliform (CFU)	193	(20 – 550)	1051	(280 – 1800)

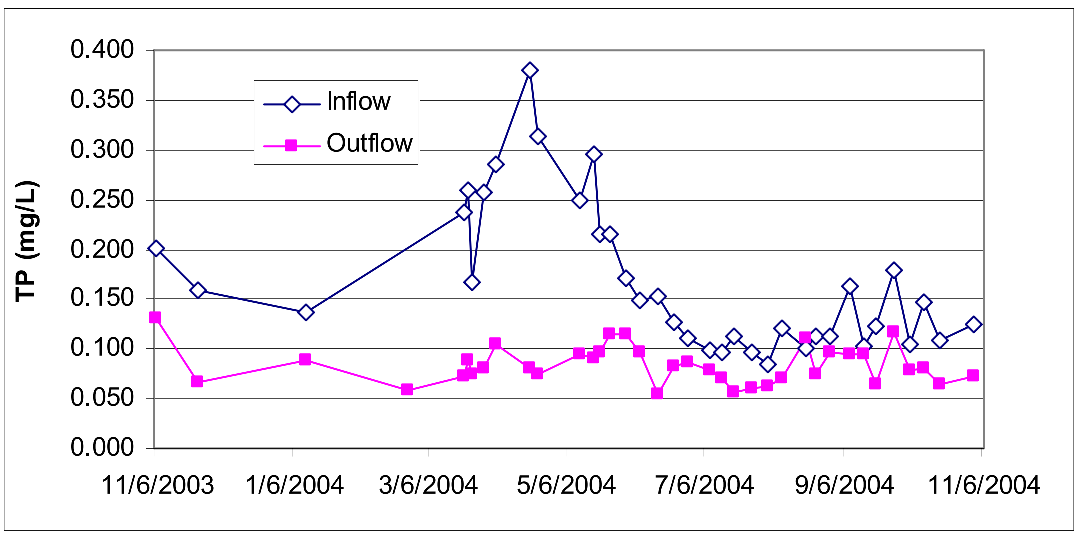

Figure 2. Inflow (= lake water) and outflow TP concentrations from the floating wetland in Lake June.

The floating wetland was effective at removing particulate matter, providing a 65, 50 and 67% reduction of total suspended solids, turbidity and chlorophyll *a*, respectively (Table 1; Fig. 3). Visual inspection of the water samples, coupled with chlorophyll *a* analyses, suggest that phytoplankton comprised the bulk of the particulate matter in the relatively turbid wetland inflow samples (Table 1). By contrast, the outflow from the floating wetland was quite clear. Despite the observed reduction in particles, fecal and total coliform levels in the wetland outflow were approximately an order of magnitude higher than inflow values (Table 1).

Although the monthly injection of alum into the water beneath the floating wetland vegetation undoubtedly enhanced water column pollutant removal, we observed no clear temporal relationship between wetland outflow TP levels and the timing of alum applications. For example, Figure 4 depicts wetland outflow TP concentrations just prior to, and for 22 days following the March 2004 alum addition. Despite the periodic use of alum, mean total aluminum levels in the wetland outflow were slightly lower than those of the influent lake water (Table 1). Outflow sulfate levels, by contrast, were slightly higher in the wetland outflow than in the inflow waters (Table 1).

Daytime wetland inflow (= lake water) DO concentrations typically were high, averaging 9.6 mg/L. Wetland outflow DO levels were markedly lower, with mean values of 1.2 mg/L. Mean wetland inflow and outflow pH levels were 7.1 and 6.3, respectively.

Three hurricanes passed near Lake June during August and September 2004. None of the wetland infrastructure, including the solar-powered pumping system, sustained any damage from the storms. Some of the wetland foliage, however, was shredded by the strong winds, particularly from the August storm (Hurricane Charley).

At each weekly site visit, we noted that the floating wetland was frequented by several bird species (cormorants, herons, egrets, anhingas, gallinules), some of which used the wetland as a perch, and others which fed within the wetland vegetation itself.

The sediment cores collected from the lake and within the wetland enclosure suggested a large, historical accumulation of organic material. The depth of unconsolidated and consolidated floc varied widely both within and outside of the enclosure, ranging from 0.2 to 0.4 m. No evidence of an alum floc was found in any of the cores collected from within the enclosure.

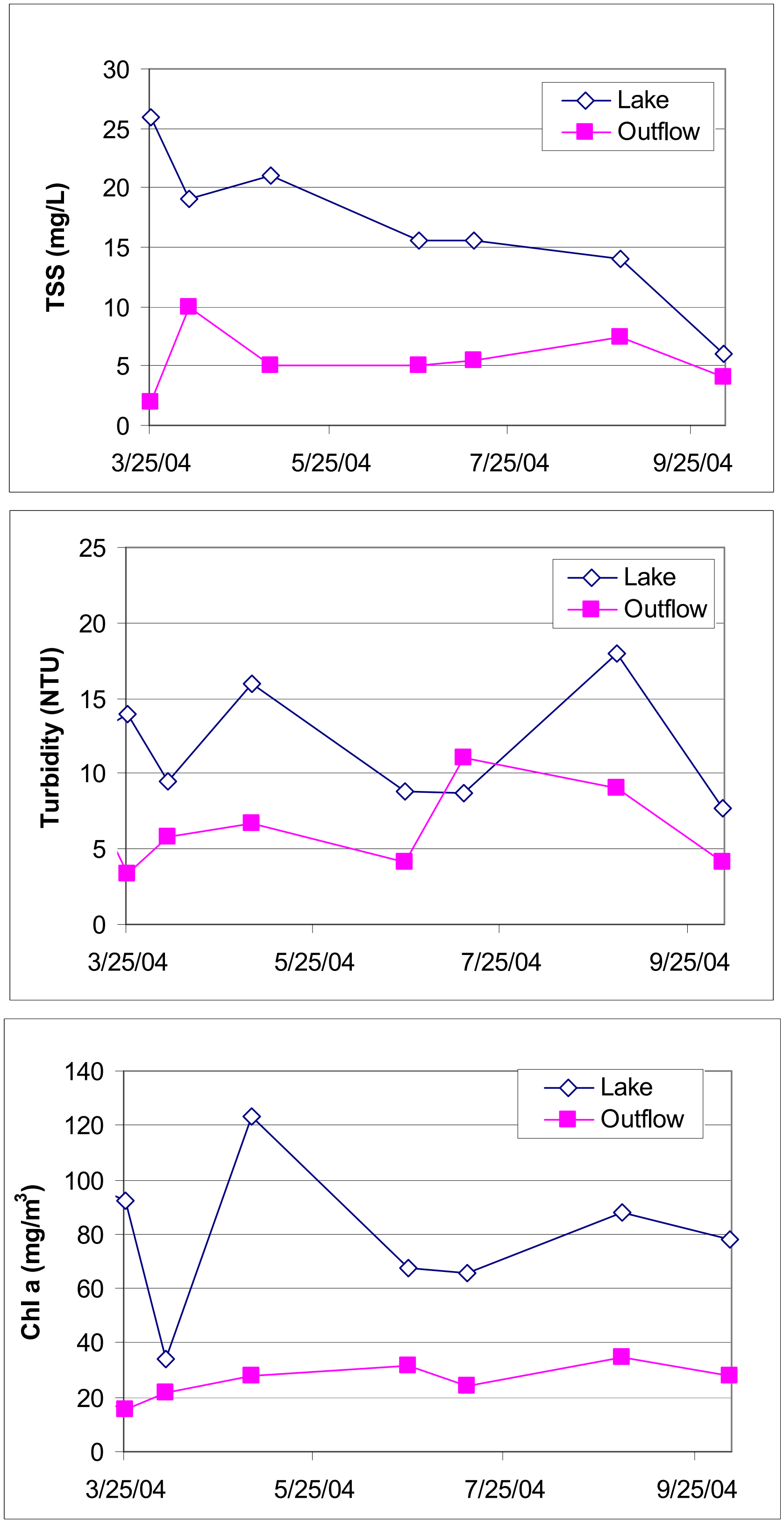

Figure 3. Removal of particulate matter, represented by total suspended solids, turbidity and chlorophyll *a*, in the floating wetland.

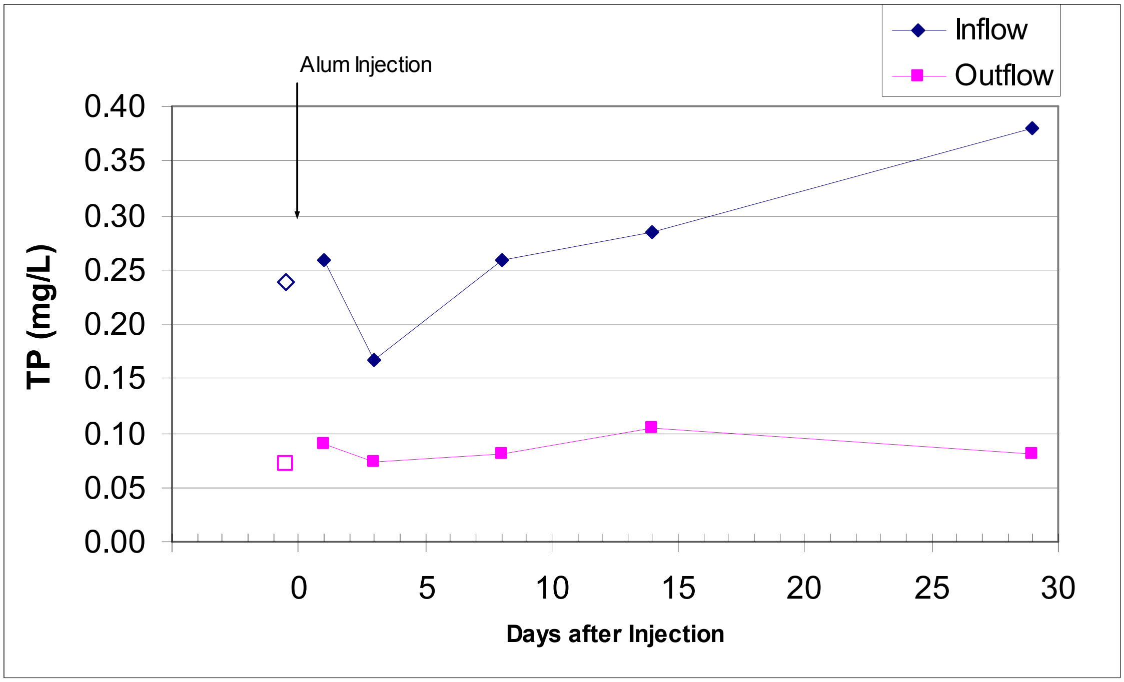

Figure 4. Effect of the April 2004 alum injection on TP removal performance of the floating wetland. Open symbols represent the floating wetland inflow and outflow TP concentrations just prior to the alum injection.

Discussion

The Lake June floating wetland provided effective removal of N, P and particulate matter. Other effects on water quality, such as the low outflow DO levels and slightly acidic pH conditions, are typical of outflows from densely vegetated wetlands (DeBusk and DeBusk 2001). Despite the periodic injection of alum, marked increases in aluminum and sulfate were not observed in the wetland outflow. Similarly, we found no visual evidence of an alum floc in the underlying sediments. This was probably due to two factors. First, the alum floc likely was diluted by a continuous input of organic matter. This material consisted primarily of phytoplankton from the wetland inflow (= lake water) that settled in the dark water column below the mat, as well as detritus produced by the overlying macrophytes. Second, because the lake's original organic floc layer was quite fluid, activity by burrowing organisms could readily have mixed the alum floc with previously deposited sediments.

The order of magnitude increase in coliforms that we observed during the water's passage through the wetland was probably caused by the widespread use of the wetland by birds. Additionally, the birds almost certainly contributed substantial loads of N and P to the wetland. It is probable that the removal effectiveness for most constituents would be improved by utilizing fishing line or netting to discourage all bird activity within the wetland.

Regardless of the inflow (= lake water) TP concentration, which attained levels as high as 0.38 mg/L, the floating wetland generally produced outflow TP levels in the range of 0.05 to 0.10 mg TP/L. It is unknown whether lower TP levels could be achieved in the absence of bird activity. However, without further data, it appears that this system would provide only minimal benefits if deployed in a lake or pond with ambient water column TP levels substantially below 0.100 mg/L.

Our prior experience with this floating wetland concept suggested that a system sized at approximately 2% of the area of the overall water body could significantly reduce the mass of key pollutants that contribute to impaired water quality. In the present study, the floating wetland comprised 1.6% of Lake June's surface area. Based on an average estimated flow rate of 100m^3/day through the wetland, the Lake June floating wetland removed a total mass of 25.6 kg N and 2.81 kg P/yr from the lake water column.

If the above mass removal values are adjusted for the lake's surface area (16,000 m^2), then the floating wetland provided a 0.18 gP/m^2-yr reduction for P, and 1.6 gN/m^2-yr reduction for N. Under certain lake loading conditions, these removal rates can contribute significantly to improving water quality. For example, in a study of north-central Florida lakes, Shannon and Brezonik (1971) noted that eutrophic lakes exhibited an estimated average P supply of 0.30 gP/m^2-yr, and hypereutrophic lakes had an average P supply of about 0.45 gP/m^2-yr. These data suggest that under appropriate loading conditions, the mass load reduction afforded by the floating wetland is adequate to effect an improvement in trophic state.

Many lakes and ponds, by contrast, have loads far in excess of those noted above. Our estimates suggest that Lake June, with a 37.2 ha drainage basin, is one of these. We used the following assumptions to estimate hydraulic, N and P loadings to the lake from the drainage basin. We assumed 80% of the basin was single-family residential, and 20% was a commercial land use. Rainfall runoff from a single-family residential land use is thought to contain 0.43 mg TP/L, with the 28% impervious surface providing a runoff coefficient of 0.373. For commercial land uses, with 98% impervious surface and a runoff coefficient of 0.887, the TP concentration of runoff is estimated to be 0.43 mg TP/L (Harper 1994). Combining these values with the observed 177 cm rainfall depth, a calculated rough estimate of annual external loading to Lake June suggests that the system may have received as much as 310,000 m^3 of runoff, with a nutrient loading of 770 kg N and 105 kg P/yr. If these rates indeed are correct, then the lake volume (32,000m^3) was exchanged approximately 9.5 times during the study with external runoff, and the mass of N and P removed by the floating wetland would need to be markedly higher to improve lake water quality.

For dramatically overloaded systems such as Lake June, it is clear that either multiple floating wetlands, or one larger floating wetland, would need to be deployed in the lake to effect an improvement in lake water quality. In sizing the wetland, it is important to note that floating wetlands also appear effective at treating waters with much higher TP concentrations than those of Lake June. We tested a floating wetland, with a similar operational cycle (ca. 7 day HRT, alum dosing once/monthly), in a pond with ambient TP concentrations of 1.0 mg TP/L. Mass removal rates for this system were eight-fold higher than those of the Lake June system. This is a common phenomenon for both biological (e.g., wetland) and chemical-addition treatment systems, where the pollutant removal effectiveness on a mass basis is usually high at high inflow pollutant concentrations, and then declines as inflow pollutant levels decrease (Kadlec and Knight 1996).

In conclusion, these data suggest that floating wetlands will be most effective, on a mass removal per unit area basis, when deployed in eutrophic and hypereutrophic systems such as golf course ponds, urban lakes with large drainage basins, agricultural impoundments, polluted detention ponds that feed into cleaner water bodies, and even portions or lobes of lakes that receive high external nutrient loads. Discouragement of bird activity will probably enhance nutrient removal, and may even lead to effective treatment of microbiological constituents.

Acknowledgement

This effort was funded by a ReNEW grant from Orange County, Florida.

Literature Cited

Brezonik, P.L. and E.E. Shannon. 1971. Trophic State of Lakes in North Central Florida. Water Resources Research Center Publication #13, Dept. Environmental Engineering Sciences, University of Florida, Gainesville, FL.

DeBusk, T.A. and W.F. DeBusk. 2001. Wetlands for water treatment. In: D.M. Kent, Ed, Applied Wetlands Science and Technology. Lewis Publishers, Boca Raton, FL.

Harper, H. H. 1994. Stormwater Loading Rate Parameters for Central and South Florida. Report for Tampa Bay SWIM Program. Environmental Research and Design, Orlando, FL.

Kadlec, R.H. and R.L. Knight. 1996. Treatment Wetlands. Lewis Publishers, Boca Raton, FL.

U.S. Environmental Protection Agency, 1999a. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012. Office of Water, Washington, D.C.

U.S. Environmental Protection Agency, 1999b. Storm water technology fact sheet: Wet detention ponds. EPA-832-F-99-048. Office of Water, Washington, D.C.