Reuse Water Reservoirs Help Meet Nitrogen Total Maximum Daily Load: Do Floating Wetland Islands Help?

Rafael Vázquez-Burney, Jeffrey Harris, James Bays, Kerstin Kenty, and Ryan Messer

The methods, data analysis, and results of a performance assessment of floating wetland islands (FWIs) for nitrogen management of reclaimed waters in total maximum daily load (TMDL)-limited watersheds were studied to determine if FWIs could passively provide nitrogen reduction while reclaimed water is being stored in reclaimed water reservoirs before it is applied in the form of irrigation in TMDL-limited watersheds.

The Pasco County Master Reuse System (PCMRS) is a regional reclaimed water transmission and distribution system providing the sole wastewater effluent management mechanism for the Pasco County Utilities Services Branch with a service area that is partially within a TMDL-limited watershed. The Tampa Bay Nitrogen Management Consortium (TBNMC) developed total nitrogen (TN) load allocations for the TMDL for Tampa Bay. The allocated load for the PCMRS for the area contributing to Tampa Bay is 5.8 tons per year. Since the load was determined based on prior-year loading (2008), the County is already discharging its entire allocation to this basin during normal operations.

To approximate the efficacy of FWIs to reduce TN in the PCMRS, FWIs were constructed, operated, and monitored in a test cell receiving reclaimed water from the PCMRS subject to coverage by the FWIs. Reclaimed water was applied at rates consistent with practical reservoir residence time.

Water quality performance was assessed during the establishment period (first six months of grow-in), performance period (eight months immediately following grow-in), and the control period (three months after the FWIs were removed). The results indicate that FWIs installed in reclaimed water reservoirs affects the removal of TN. The test cell alone removed nitrogen and phosphorus, but the FWIs were found to enhance that removal capacity by decreasing suspended algal growth and increasing denitrification. The combined effect of the FWIs on the test cell has been a decrease in organic nitrogen and oxidized nitrogen in the test cell outflow.

By evaluating the difference between the performance and control periods, an incremental rate at which the FWIs removed TN from the test cell was calculated to be 0.9 pounds per sq ft (lb/ft^2) of island per year. The test cell included a total of 1,600 sq ft of FWIs, so the total rate of TN removal that can be attributed to FWIs is approximately 1,440 lb of TN per year. This estimated rate of removal may be applicable for systems receiving reclaimed water of similar characteristics and at similar rates. The implementation of FWIs is a relatively new application of natural treatment system technology. Just as time has allowed for integrative studies on treatment wetlands to confirm expectations of performance, FWIs application to ponds will require more analyses such as those conducted during this study to develop readily applied sizing criteria and removal rate constants. Because ponds differ in depth, size, and loads, each system needs to be assessed separately to fully understand the capacity for these FWIs to remove TN.

The purpose of this project is to quantify performance characteristics of FWIs for management of nitrogen, thereby expanding reclaimed water application opportunities in watersheds facing stringent nitrogen loading constraints.

The PCMRS is a regional reclaimed water distribution system providing the sole wastewater effluent management mechanism for Pasco County. This total reuse strategy is accomplished by the beneficial reuse of effluent from all wastewater treatment facilities (WWTF) in Pasco County via a combination of irrigation customers and rapid-rate infiltration basin systems. In addition, the PCMRS contains a 62-mil-gal (MG) storage pond (Lake Rita), an existing 100-MG reservoir at the Land O' Lakes WWTF, and is constructing an additional 500-MG reservoir.

The PCMRS discharges indirectly via irrigation infiltration to Hillsborough Bay, one of four segments that comprise the Tampa Bay Estuary. The 2012 Tampa Bay Reasonable Assurance Submittal, referred to as the RA Document (Tampa Bay Estuary Program, 2012), has been developed and accepted and includes a TN load limit for PCMRS discharges to the Hillsborough Bay Basin.

Approximately 30 percent of the reclaimed water produced by Pasco County is reused in the

Rafael Vázquez-Burney is project technologist, James Bays is technology fellow, Kerstin Kenty is project manager 2, and Ryan Messer is project engineer with CH2M HILL in Tampa. Jeffrey Harris is an environmental biologist with Pasco County Utilities Engineering in New Port Richey.

Hillsborough Bay drainage basin. This basin also represents the area where most of the future growth in reclaimed water customers is projected. Therefore, the County is interested in decreasing overall nitrogen in the PCMRS to satiate the irrigation demand associated with that growth, while keeping the nitrogen load within their allocation.

The nitrogen in the PCMRS flow is predominantly in the form of nitrate, which is amenable to biological treatment. The FWIs offer a technology for improvement of surface water quality in existing or constructed water bodies where the water is being stored and conveyed. The FWIs utilize emergent wetland species growing on a floating mat (Headley and Tanner, 2006). Because the County is investing in significant surface water storage infrastructure, passive reduction of nitrogen by FWIs in reclaimed water reservoirs could increase the capacity of a reclaimed water system by allowing for increased use of reclaimed water in areas where TN may be limited without the additional infrastructure investment.

Sizing methods to determine the feasibility of FWIs to accomplish this objective are not well-established. A pilot experiment using FWIs was conducted in Hungary with additions of 5 mg/l of oxidized nitrogen; results indicated that the system removed 85 percent of the TN (Headley and Tanner, 2006). Another study that investigated the removal performance of nitrogen by FWIs (Borne et al., 2013) in nitrate-rich stormwater reported increased denitrification. The TN losses due to low dissolved oxygen and increased organic carbon availability in the root zone below the FWIs were compared to a control pond that did not include FWIs.

To approximate the efficacy of FWIs to reduce TN in the PCMRS, FWIs were constructed,

operated, and monitored in a test cell receiving reclaimed water from the PCMRS for a period of 18 months. Reclaimed water was applied at rates designed to create relatively short hydraulic residence times (HRT) consistent with actual reservoir residence time. The methods, results, and data analysis to assess whether FWIs could provide further nitrogen reduction in the PCMRS are discussed.

Project Implementation

To study the performance capabilities of FWIs, this project was implemented in a 4-acre-lined test cell at the Wesley Center Wastewater Treatment Facility (WWTF). This system included a temporary pipe that delivered reclaimed water flow from the PCMRS and an outflow spillway pipe that spilled to the WWTF's reject pond and returned water back to its headworks.

Installation

A total of 20 mats were purchased; each mat measured 8 ft by 10 ft. Total FWI surface area on the 4-acre test cell was 1,600 sq ft. The FWIs were interconnected with stainless steel cables and hardware to create the desired configuration. Because the test cell was lined, anchors could not be driven into the ground. Instead, weighted anchors were provided to rest on the bottom of the test cell to avoid liner damage during installation and operation.

Wetland Plant Species Selection

A variety of plants were selected for this study to assess growth rates and evaluate the ability of each species to adapt to the reclaimed water quality. Wetland plants were obtained mostly as potted plants and bare root to enhance planting success and accelerate growth. A seed mix was also obtained and used on two islands to compare with the 18 planted islands.

Table 1 provides a listing of plant species installed on the floating mats. Species were selected based on previous experience on FWIs applications and root/shoot growth characteristics.

Test Cell Operation

Operation of the test cell was an important aspect of the study because hydraulic characteristics could potentially affect nutrient concentrations and performance of the FWIs in terms of nutrient uptake. Reclaimed water was applied at rates designed to create an HRT consistent with the Land O' Lakes Storage Reservoir residence time.

Average HRT in the test cell was approximately 20 days; the operational volume in the test

Table 1. Floating Wetland Island Planted Species

Plant Species	Common Name	Plant Species	Common Name
Scirpus validus	Softstem bulrush	Paspalum vaginatum	Tussock paspalum
Scirpus californicus	Giant bulrush	Panicum hemitomon	Maidencane
Schoenoplectus americanus	Chairmaker's bulrush	Hydrocotyle umbellata	Marsh pennywort
Cladium jamaicense	Sawgrass	Panicum anceps	Beaked panicgrass
Spartina bakeri	Cordgrass	Panicum longifolium	Longleaf panicum
Ludwigia grandiflora	Primrose willow	Paspalum floridanum	Florida paspalum
Canna flacida	Golden cana	Juncus effusus	Soft rush
Tripsacum dactyloides	Fakahatchee grass	Vernonia gigantea	Giant ironweed
Paspalidium geminatum	Egyptian panicgrass	Eupatorium perfoliatum	Boneset

cell was approximately 5 MG. A temporary 4-in. line with a flow meter was installed on the west side of the test cell berm near the southwest berm corner to provide the test cell with continuous flow. Meter readings were recorded daily by WWTF operators. Reclaimed water flowed through the test cell and exited by spilling out via gravity through a pipe in the southeast corner that hydraulically connects the test cell to a twin pond. This pipe provided an adequate control elevation and eliminated the need to monitor the test cell stage.

Water Quality Sampling

Water quality monitoring was conducted biweekly from the beginning of the study with the intent of capturing the effect of plant establishment on the water column nitrogen concentrations, particularly as temperatures increased during the summer. This data supported the determination of removal rate constants, nitrogen species conversion, and temperature adjustment factors.

Ammonia nitrogen, oxidized nitrogen (nitrate plus nitrite), organic nitrogen (ON), and TN were monitored biweekly for the three distinct project phases: the grow-in period (July 2012 through December 2012), the performance period (January 2013 through August 2013), and the control period after the islands were removed (September 2013 through November 2013).

Tissue Sample Collection

Tissue analysis of the planted vegetation was performed to quantify plant nutrient uptake during the study period. The fraction of plant nutrient uptake compared to the inflow and outflow concentrations was important to understand for the overall balance of nutrient concentrations within the test cell. Plants were harvested and assessed as whole plant biomass. During FWIs installation, two random sampling sites (slotted well screens) were installed in each of the three planting zones on each FWI for a total of six tissue sampling sites per FWI. During each sam-

pling event, at least one sample was collected from all islands. The plant species for tissue sampling were selected randomly.

Plant tissue samples collected quarterly were analyzed for dry weight and percent TN. Quarterly samples were collected during September 2012, November 2012, April 2013, and August 2013. Root length, shoot length, and media depth (island matrix) were measured upon collection. Plant samples were packaged in coolers and shipped to the University of Florida Wetland Biogeochemistry Laboratory for analysis.

Lithium Chloride Tracer Study

Understanding the hydraulics of the FWIs test cell is important to the successful operation and nutrient removal. It has been established that there is a distribution of HRT in treatment wetlands (Kadlec and Wallace 2009). To characterize wetland hydraulics, tracer studies were conducted using conservative inorganic compounds such as lithium or bromine, or fluorescent dyes, to track and quantify the rate of movement of individual water parcels through specific cells.

After 11 months of island establishment, a tracer study was performed involving a one-time slug application of lithium chloride (LiCl) at the test cell influent pipe. Lithium ion (Li) was monitored at the test cell outfall in order to determine the time and concentrations of the exiting tracer. Detection of Li well above the background Li concentration at the test cell outfall aided in determining important flow behaviors such as HRT, average flow-weighted velocity, and the presence of significant flow path short circuiting.

Floating Wetland Islands Removal and Relocation

The FWIs were removed from the test cell at the Wesley Center WWTF on Aug. 27 and 28, 2013. The FWIs were fully grown and saturated with water at the completion of the study. The FWIs were relocated and permanently installed at the Lake Rita reclaimed water storage facility.

Hydrologic Evaluation of the Test Cell

To assess treatment performance, the test cell hydrology was evaluated. Recorded flows and test cell stage-storage relationships were used to complete a daily water balance of the test cell. In addition, a tracer study was performed to determine the hydraulic characteristics of the system. These analyses were used to establish the basis for evaluation of treatment performance.

Water Balance

The purpose of the water balance is to determine the HRT for the test cell. Measured flow to the test cell, precipitation records, and evaporation were used to calculate daily test cell outflow. The average HRT was determined to be 25 days. The daily nominal HRT varied between 5.6 days and 158 days due to extreme rain events and periods when the flow to the test cell was turned off for reasons outside of the control of this study.

To determine hydraulic characteristics of the test cell, the tracer response curve was analyzed for common hydraulic parameters, including the number of tanks in series, dimensionless variance, wetland dispersion number, Peclet number (Pe), and volumetric efficiency.

A gamma distribution was used to solve for the number of tanks, N, and the mean HRT by minimizing the sum of squared differences between the residence-time distribution (RTD) and the field data in a modeling analysis. The value N represents the degree of mixing and the dimensionless variance characterizes the spread of the tracer response curve about the mean of the distribution. The variance occurs by mixing of water or by the velocity distribution during passage. It is important to note that although gamma distri-

butions describe tanks-in-series (TIS) mixing, they do not imply the existence of turbulent flow (Kadlec and Wallace, 2009), since a gamma distribution may be observed in unmixed systems with several travel paths and different velocities. As N becomes very large, the gamma distribution might indicate a plug-flow reactor (PFR)-type system. An N of 1.0 in theory indicates a completely mixed flow reactor (CMFR)-type system.

For the test cell, N was determined to be 1.0, representing a realistic application of a CMFR. The wetland dispersion number calculated for this system was 8.0, which is atypical of normal treatment wetland systems; typical values for the wetland dispersion range from 0.07 to 0.33.

An average daily inflow rate and an estimated water volume were used to estimate the nominal HRT of the system of 25 days. The mean HRT for the test cell, calculated using a first-order gamma distribution analysis, as recommended in Kadlec and Wallace (2009), is 15.7 days. The nominal HRT calculated based on the volume of the test cell and the field-estimated mean HRT varies by 25 percent.

The early response and the long-descending limb of the tracer response curve indicate the presence of both short circuits and the existence of areas with reduced hydraulic connection.

The Pe describes the dispersion as a dimensionless parameter, where Pe = 0 represents a CSTR-type flow, and Pe = ∞ represents a PFR-type flow. For free surface wetlands, reported values range from Pe = 5 to 20 (Kadlec and Knight, 1996). The Pe for the test cell was 0.13, which indicates significant short-circuiting of flow through the system.

Finally, the volumetric efficiency was calculated by dividing the actual HRT by the nominal HRT. For the test cell, this ratio was less than 1, which means that the actual HRT was shorter than expected. This also indicates short-circuiting.

Monitoring Results

Nitrogen Water Quality Monitoring Results

To determine the performance of the FWIs in the test cell, water quality parameters were monitored biweekly through the duration of the study. Water samples were collected at the test cell inflow and outflow and analyzed for TN, oxidized nitrogen, ammonia nitrogen, and ON to assess total nitrogen treatment performance for each period and to understand the nitrogen conversion dynamics within the test cell.

Figure 1 presents TN concentrations for the test cell inflow and outflow over the duration of the study. During the study, inflow TN concentrations averaged 6.1 mg/L and ranged from 3.4 to 9.6 mg/L. Based on inflow and outflow TN concentrations, TN was reduced by 54 percent on average during the grow-in period, 70 percent on average during the performance period, and 30 percent during the control period when the FWIs were not present. These data show a clear difference in performance between the performance period and the control period, suggesting that the FWIs had an effect in the treatment performance of the test cell.

Nitrogen species conversion and nitrogen dynamics can be explored by comparing inflow and outflow concentrations of each nitrogen species. Figure 2 presents oxidized nitrogen concentrations for the test cell inflow and outflow over the duration of the study. During the study, inflow oxidized nitrogen concentrations averaged 5.3 mg/L and ranged from 2.8 to 7.8 mg/L. This represents approximately 87 percent of the TN entering the test cell. In general, the outflow concentrations were less than 1.5 mg/L, with most concentrations below the detection limit during all the monitoring periods.

These results for oxidized nitrogen together with TN performance suggest that during the performance period, oxidized nitrogen was being removed from the system more readily than during the control period, whereas during the control period, oxidized nitrogen was just being converted to other forms of nitrogen. The other nitrogen species were assessed to understand the conversion of nitrogen species within the test cell.

Ammonia concentrations were not observed at significant levels in the inflow nor in the outflow of the test cell. In general, ammonia concentrations were found to be either below the detection limits of the analytical method or between the detection limit and the practical quantitative limit. Based on the water quality results for ammonia, nitrogen species conversions involving ammonia were considered negligible in the test cell.
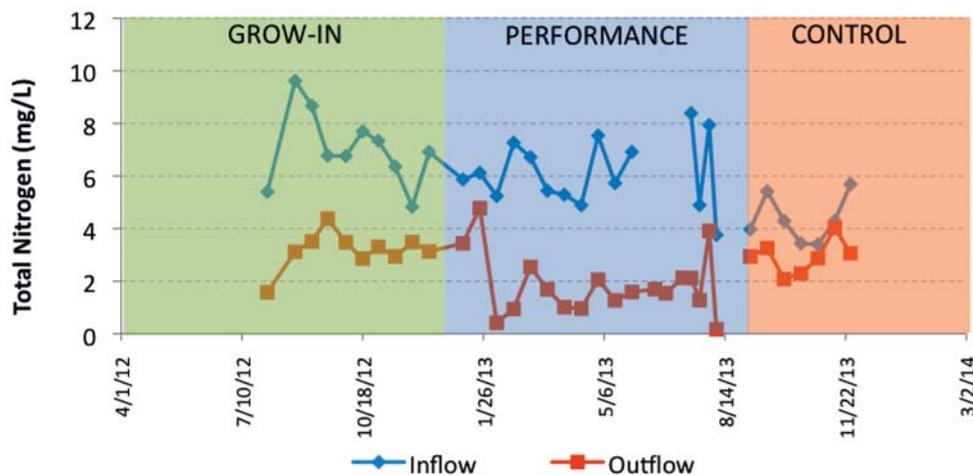
Figure 1. Total Nitrogen Concentrations

Figure 3 presents organic nitrogen concentrations for the test cell inflow and outflow over the duration of the study. During the study, inflow organic nitrogen concentrations averaged 0.6 mg/L and ranged from nondetect to 1.8 mg/L. This parameter represents approximately 10 percent of the TN entering the test cell. In general, the outflow concentrations were significantly above the inflow concentrations, with average organic nitrogen concentrations of 2.2 mg/L that ranged from 0.4 to 4.0 mg/L. Inflow organic nitrogen less than outflow of organic nitrogen demonstrates the conversion of inorganic nitrogen to organic nitrogen. The dominant inflow nitrogen form throughout the study was oxidized nitrogen, while the dominant outflow nitrogen form was organic nitrogen. Average outflow organic nitrogen concentrations for the grow-in period, performance period, and control periods were 3.0 mg/L, 1.4 mg/L, and 2.8 mg/L, respectively.

The data suggest that the FWIs affected the rate of conversion of oxidized nitrogen to organic nitrogen after the grow-in period. The FWIs increased processes that resulted in removal of total nitrogen and did not just convert nitrogen to other forms.

Figure 2. Oxidized Nitrogen Concentrations

Figure 3. Organic Nitrogen Concentrations

Tissue Sampling Results

Tissue samples were collected quarterly and analyzed for total dry weight and TN. Total estimated mass per island was calculated by averaging the plant samples collected from each zone, multiplying the average for each zone by the number of plugs they contain, and then summing the totals for each zone together. Average TN sample concentration was used to estimate the mass of TN removed that can be attributed to plant uptake. Based on these estimates it is estimated that approximately 2.2 kg of TN was bound up in plant tissue mass, which accounts for only 0.2 percent of the TN removed.

Algal Productivity and Deposits

Throughout the study, algae flourished on the test cell, leaving deposits that are known as "calcified cyanobacteria." Cyanobacteria calcify when water conditions favor calcium carbonate precipitation and when photosynthesis is able to occur on the algae (Riding, 2011). The lack of photosynthesis in deeper waters of the test cell explains why the calcification only occurred in the shallower parts of the test cell. The highest line of calcification was a reliable high-water-level indicator for this study.

Calcified deposits on the test cell liner were sampled at the end of this study. Ten samples with a surface area of 4 sq ft were taken. Groups of two samples were taken at increments of 30 ft inward of the west berm. Within these groups, the first sample was taken between 75 to 100 ft north of the first sample in the previous sample group. The second sample was taken at varying distances north or south of the first sample. Samples were analyzed for wet weight and TN. The total estimated amount of TN accumulated in the calcified deposits was 96 kg.

Nitrogen Mass Balance and Transformations

The test cell nitrogen cycle, performance of each nitrogen species, and the potential for FWIs to reduce TN concentrations within reclaimed water storage facilities were assessed. Figure 4 shows the principal components of the nitrogen cycle in the test cell with the FWIs.

The various forms of nitrogen in aquatic systems are continually involved in a process of transformation from inorganic to organic compounds and back from organic to inorganic (Kadlec and Wallace 2009). Some of these processes are microbially mediated, requiring energy (typically derived from an organic carbon source), and others release energy, which is used by organisms for growth and survival. Most of the chemical changes are controlled through the
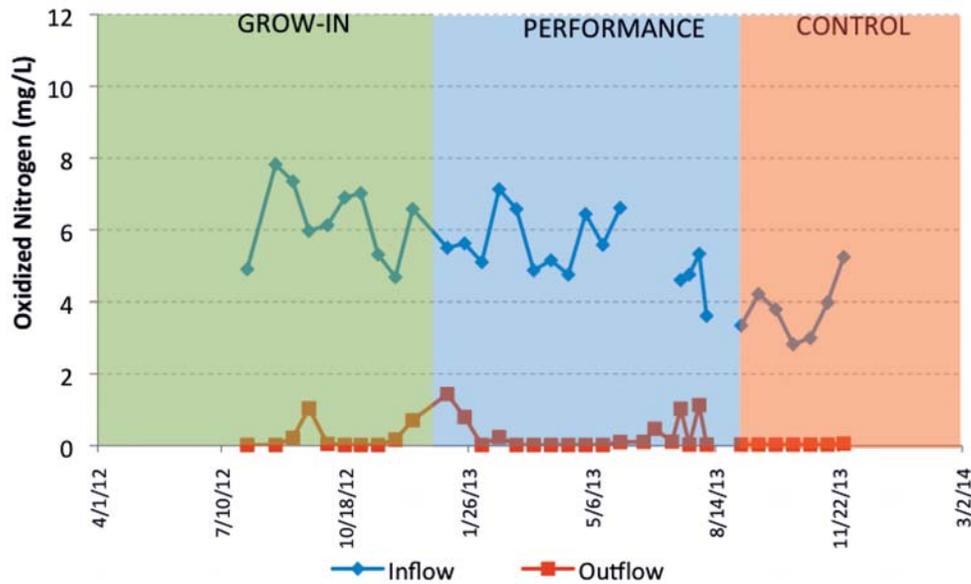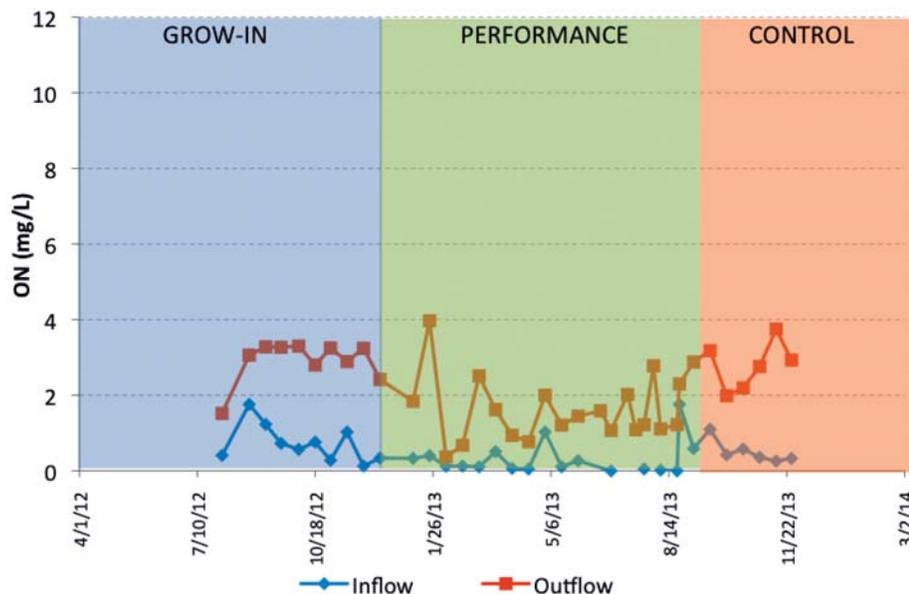
production of enzymes and catalysts by the living organisms they benefit. Principal processes transform nitrogen from one form to another. The processes assessed include ammonification, nitrification, denitrification, plan uptake, algal assimilation, and burial. A detailed understanding of these nitrogen transfer and transformation processes is important for understanding treatment performance of storage facilities with and without FWIs.

A nitrogen mass balance was estimated for the performance and control periods. The nitrogen mass balance consists of quantification of the fate of nitrogen within the test cell, the nitrogen fluxes and nitrogen species conversions based on the water balance, and water quality monitoring done during the study.

Figure 5 presents the nitrogen mass balance during the performance period. During this period, the percent mass removal is estimated to be 61 percent, with 56 percent estimated as loss in the form of elemental nitrogen to the atmosphere (denitrification). Approximately 87 percent of the test cell inflow nitrogen is composed of oxidized nitrogen. Based on the tissue samples gathered and the liner biofilm samples, it is estimated that approximately 4.3 g N/m2/yr is lost to system storage. This corresponds to 4.2 g N/m2/yr bound in the calcified cyanobacteria and 0.1 g N/m2/yr bound in the plant tissue. During the establishment period, system storage corresponds to 5 percent of TN lost. Plant uptake during this period is attributed to only 0.2 percent of the TN removed.

Figure 6 presents the nitrogen mass balance during the control period. During this period, the percent mass removal is estimated to be 32 percent, with 24 percent estimated as loss of nitrogen gas to the atmosphere (gasification or denitrification). At a greater rate than in the previous periods, algal uptake (algal biomass) was responsible for converting the nitrate to organic nitrogen, which is then exported in the test cell outflow. Approximately 96 percent of the nitrogen in the test cell outflow was composed of organic nitrogen. During the control period, a significantly greater loss of approximately 24 percent less nitrogen to the atmosphere was estimated when compared to the performance period. By removing the FWIs, the mass balance suggests that the ability of the system to denitrify and convert oxidized nitrogen to organic nitrogen is greatly reduced, and the majority of the nitrogen is exported in the outflow stream.

Based on the liner cyanobacteria samples, approximately 4.2 g N/m2/yr is lost to system storage. Because the islands were removed during this period, plant uptake is removed from this mass balance. During the establishment period, system storage corresponds to 7 percent of TN lost.
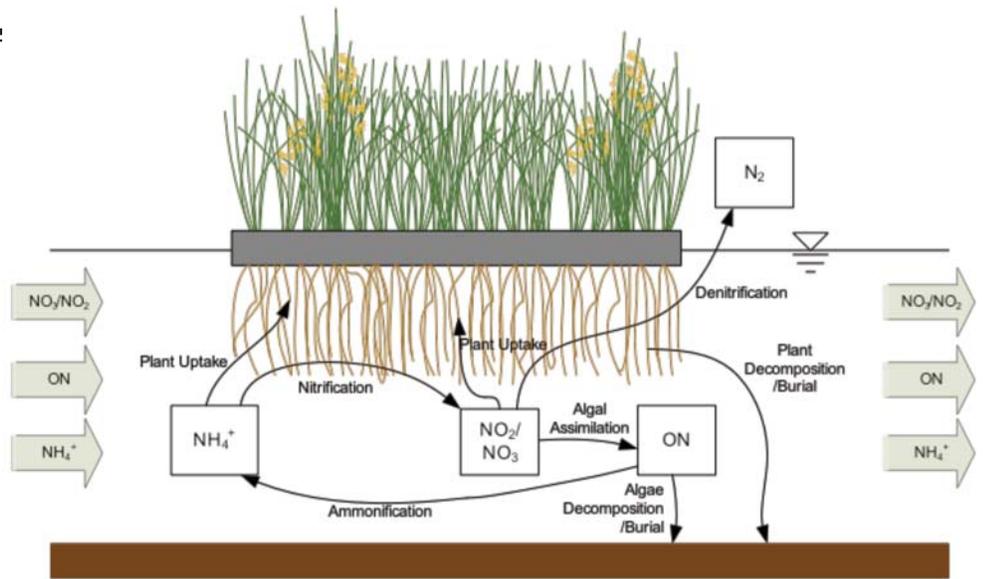
Figure 4. Simplified Nitrogen Cycle for the Floating Wetland Islands Test Cell
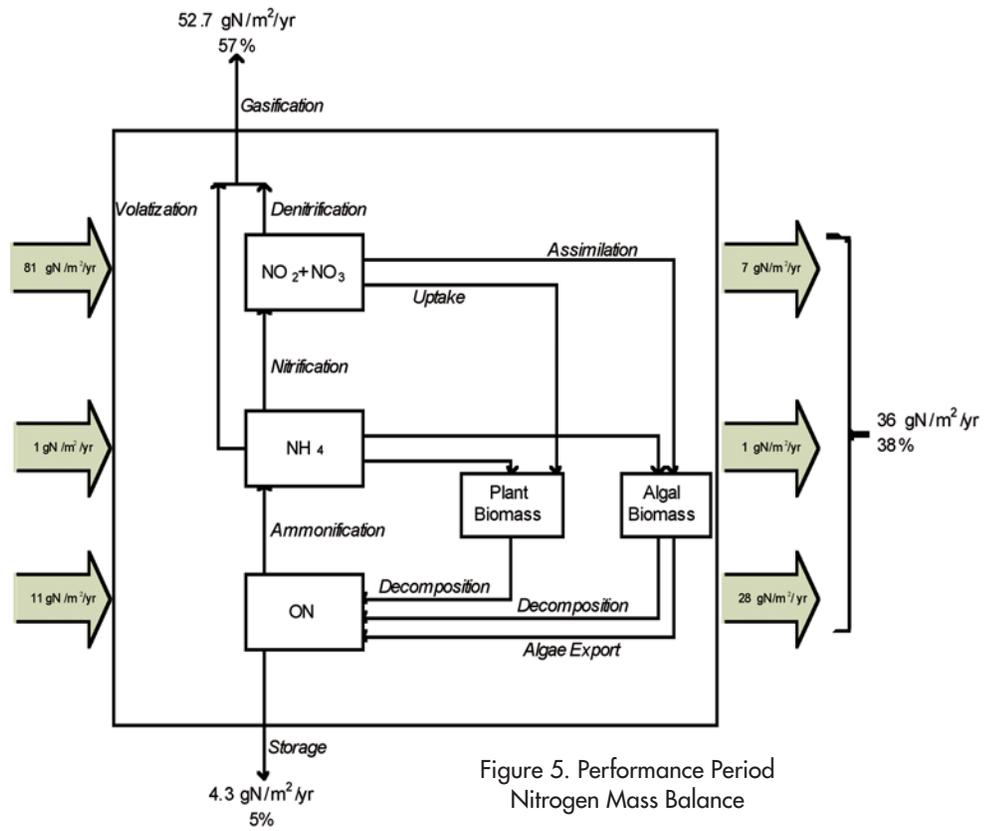
Figure 5. Performance Period Nitrogen Mass Balance

When comparing the mass reduction of the two periods, the mass removal that can be attributed to the FWIs can be estimated. A unit rate of denitrification of the performance period was estimated to compare to the control period. By comparing the denitrification rates of the control period with the performance period, a total mass of 630 kgN/yr can be attributed to the FWIs. This corresponds to a mass removal rate of approximately 0.4 kgN/yr (0.9 lb/yr) per sq ft of floating island. Plant uptake contributed to approximately 0.2 percent of this removal rate.

Treatment Model Calibration and Performance Assessment

Nitrogen removal in the test cell can occur

through three main processes: denitrification, plant uptake, and burial. The P-k-C* model (Kadlec and Wallace, 2009) was used to evaluate the monthly treatment of the nitrogen species in the test cell (Table 2). First-order removal rates were fitted to the measured species concentrations in the inflow and outflow of the test cell for each period.

Calculated treatment rate constants for nitrate are higher during the control period than during the performance period, indicating that the effect of the FWIs may be a decrease in nitrate removal rates.

The water quality results suggest that each period has a different background concentration for organic nitrogen. For the establishment, performance, and control periods, background concentrations for organic nitrogen of 3.3, 1.4, and 3.6 mg/L, respectively, were fitted based on the achievable outflow concentrations for each period. The increased background concentrations for organic nitrogen during the establishment and control periods, when FWIs were not established or not present, suggests that algal activity is increased. The data suggest that the FWIs had a significant effect on algal activity within the test cell.

Based on TN observations in the inflow and outflow of the test cell and calibration of rate constants and background concentrations, it appears that the FWIs had an effect on TN removal. Rate constants calculated during the performance period are within the range of typical treatment wetland performance. Removal of the FWIs and observations during the control period indicated that treatment performance for TN was reduced. During the performance period, a TN treatment efficiency of 61 percent was observed, compared to 30 percent treatment efficiency during the control period. When accounting for the effects of temperature, approximately 63 percent of the TN treatment observed during the study can be attributed to the presence of FWIs.

Conclusions

The results from this study indicate that FWIs installed in reclaimed water reservoirs may aid in the removal of total nitrogen within the system. These systems may be capable of enhancing TN removal capacity by limiting suspended algae activity and enhancing denitrification. The result is robust removal of oxidized nitrogen and decreased levels of organic nitrogen in the test cell outflow, which lead to decreased levels of TN.

Increased performance was observed during the performance period when compared to the control period. The test cell achieved 61 percent mass removal efficiency of TN during the performance period while the FWIs were established, and only 30 percent mass removal efficiency of TN during the control period while there were no FWIs in the test cell. The rate at which the FWIs were found to remove TN from the test cell was 0.9 lb/ft^2 of island per year. The test cell included a total of 1,600 sq ft of FWI, so the total rate of removal of TN that can be attributed to FWIs is approximately 1,440 lb (almost 0.75 ton) of TN per year. This rate of removal may be applicable for systems receiving reclaimed water of similar characteristics and at similar rates. However, because ponds can differ in depth, size, and loads, each system must be assessed to understand the capacity for FWIs to remove TN.

References

- Borne, K.E. et al., 2013. Stormwater Nitrogen Removal Performance of a Floating Treatment Wetland. Water Science and Technology. 68 7: 1657-1667.
- Headley, T.R., and Tanner, C.C., 2006. "Application of Floating Wetlands for Enhanced Stormwater Treatment: A Review." Prepared for Auckland Regional Council, New Zealand.
- Kadlec, R.H., and Wallace, S., 2009. Treatment Wetlands. CRC Press, Boca Raton, Fla.
- Riding, R. 2011. Calcified cyanobacteria. In J. Reitner and V. Thiel (eds), Encyclopedia of Geobiology. Encyclopedia of Earth Science Series, Springer, Heidelberg, pp. 211-223.
- Tampa Bay Estuary Program, 2012. 2012 Tampa Bay Reasonable Assurance Submittal. Accessed via the internet at: http://www.tbeptech.org/index.php?option=com_content&view=category&id=29&Itemid=54&limitstart=10. ⬙
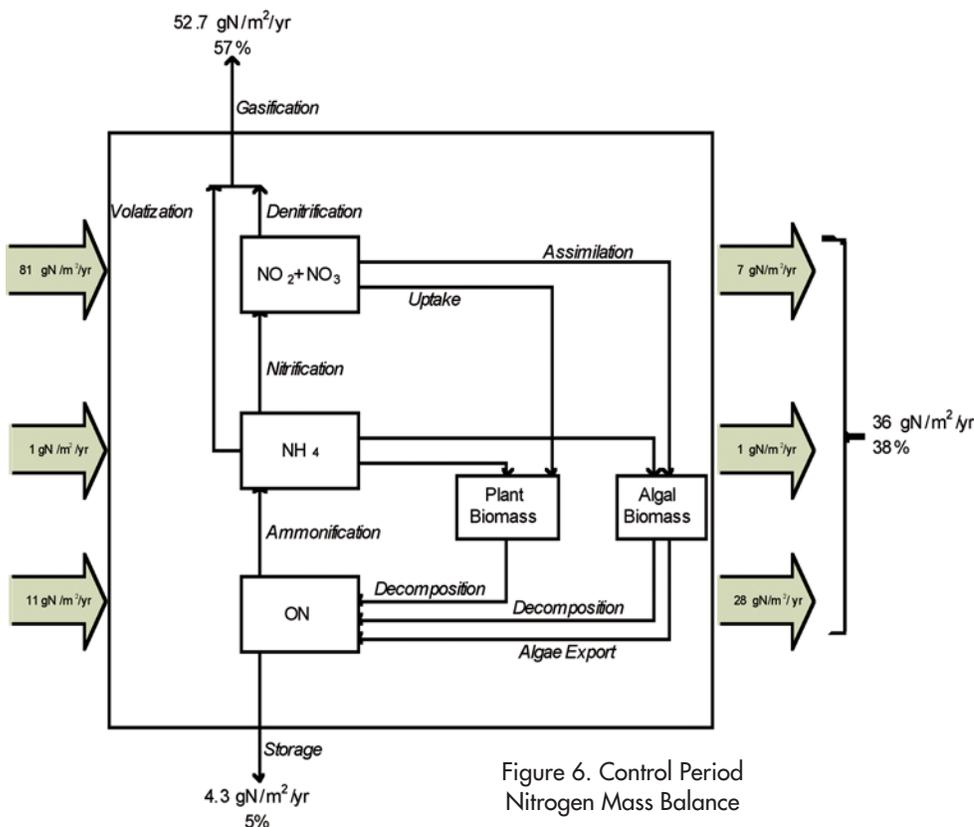
Figure 6. Control Period Nitrogen Mass Balance

Table 2. Summary of Nitrogen Species Areal Rate Constants (m/yr)

	Establishment Period	Performance Period	Control Period
$k_{NO3/NO2}$	120	181	287
k_{ON}	52	17	19
k_{TN}	14.4	37.9	4.6