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FLOATING WETLAND ISLANDS AS A METHOD OF NITROGEN MASS REDUCTION: RESULTS OF A 1-YEAR TEST

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ABSTRACT

Floating wetland islands (FWIs) were tested in Pasco County Florida as a method of reducing total nitrogen (TN) in reclaimed water during reservoir storage. The Pasco County Master Reuse System (PCMRS) is a regional reclaimed water transmission and distribution system providing wastewater effluent disposal for the county. Total daily mass loading from reclaimed water is limited by nitrogen content in the PCMRS watershed. To test TN reduction efficacy, twenty FWIs were constructed, installed, and monitored in a lined pond receiving PCMRS reclaimed water. A total of 149 m² of FWIs were installed, distributed as a connected network covering 1,122 m², or 7 percent of pond area. Pond hydraulic residence time averaged 15.7 days.

Treatment performance was assessed during three consecutive periods: establishment (first 6 months of grow-in), performance (8 months immediately following grow-in), and control (3 months after the FWIs were removed from the pond). The FWIs enhanced pond nitrogen removal capacity by 32 percent. The primary effect of the FWIs was to decrease organic nitrogen in the pond outflow. By evaluating the difference between the performance and control periods, an incremental TN removal rate for the FWIs was calculated to be 4.2 kg N/m² FWI per year.

KEY WORDS: floating wetland islands, vegetated mats, floating treatment wetlands, reclaimed water, water reuse, TMDL, total nitrogen, nitrogen allocation

INTRODUCTION

The Pasco County Master Reuse System (PCMRS) is a regional reclaimed water distribution system providing the sole wastewater effluent management mechanism for Pasco County Florida. 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 includes a 235 Megaliter (ML) storage pond (Lake Rita), an existing 379 ML reservoir at the Land O' Lakes WWTF, and an additional 1,893 ML reservoir under construction.

The Tampa Bay Nitrogen Management Consortium has developed total maximum daily loads for Tampa Bay. The PCMRS operates in the Hillsborough Bay watershed, a tributary to Tampa Bay. The 2012 Tampa Bay Reasonable Assurance Submittal (Tampa Bay Estuary Program, 2012) includes a total nitrogen (TN) load limit for PCMRS discharges to the Hillsborough Bay Basin. The allocated basin load is 5.3 tons per year. Since the load was determined based on prior year loading (2008), the County already discharges its allocation during normal operations. The nitrogen in the PCMRS flow is predominantly in the form of nitrate.

Approximately 30 percent of the reclaimed water produced by Pasco County is reused in the Hillsborough Bay drainage basin. This basin also represents the area where most of the future growth in reclaimed water customers is projected. Because the County is constructing large reclaimed water storage reservoirs, installing FWIs for passive reduction of nitrogen could enable greater use of reclaimed water in nitrogen-limited areas.

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4 Floating wetland islands (FWIs) offer a technology for improvement of surface water quality in
5 existing or constructed water bodies where the water is being stored and conveyed. FWIs utilize
6 emergent wetland species growing on a consolidated floating mat (Headley and Tanner, 2006).
7 Dodkins and Mendzil (2014) reviewed the literature and concluded that FWIs improve
8 phosphorus removal by 2 to 55% and nitrogen removal by 12 to 42% relative to controls. A pilot
9 experiment using FWIs in Hungary with additions of 5 mg/l of oxidized nitrogen showed an 85
10 percent reduction of TN (Headley and Tanner, 2006). Van de Moortel et al. (2010) reported that
11 floating mats significantly increased TN reduction in combined sewer overflows by an average
12 of 33% relative to controls. Chang et al. (2013) reported a net increase in TN reduction in
13 stormwater attributable to floating treatment wetlands. Borne et al. (2013a) attributed enhanced
14 denitrification in nitrate-rich stormwater to low dissolved oxygen and increased organic carbon
15 availability in the root zone below the FWIs when compared to a control pond without FWIs.
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18 To investigate the efficacy of FWIs in reducing TN, FWIs were constructed and monitored in a
19 pond receiving reclaimed water from the PCMRS for a period of 18 months. Reclaimed water
20 was applied at rates designed to create relatively short hydraulic residence times (HRT)
21 consistent with actual reservoir residence times.
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24 **METHODS AND MATERIALS**

25 Twenty FWIs were constructed and established within an existing 1.6-hectare (ha) plastic-lined
26 pond at the Wesley Center WWTF. Reclaimed water from the PCMRS was delivered to the pond
27 through a temporary pipe. Pond overflow spilled to the WWTF's adjacent reject pond, which
28 was then pumped back to the WWTF headworks.
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31 **Installation**

32 The FWIs were BioHavenTM floating mats purchased from Martin Ecosystems Inc., Baton
33 Rouge, LA (www.martinecosystems.com). Each mat measured 2.4 m x 3.0 m. The surface area
34 of FWIs totaled 149 m². The FWIs were interconnected with stainless steel cables through PVC
35 pipes and distributed in a network of FWIs covering a total area of 1,122 m², or 7 percent of the
36 total pond area (Figure 1). Weighted anchors resting on the pond bottom held the FWIs in their
37 target configuration after initial installation. The pond bottom sloped from approximately 1
38 meter deep near the west end to 2 m deep near the east end. The FWIs were located near the
39 outfall where the pond bottom is approximately 1.5 meters deep.
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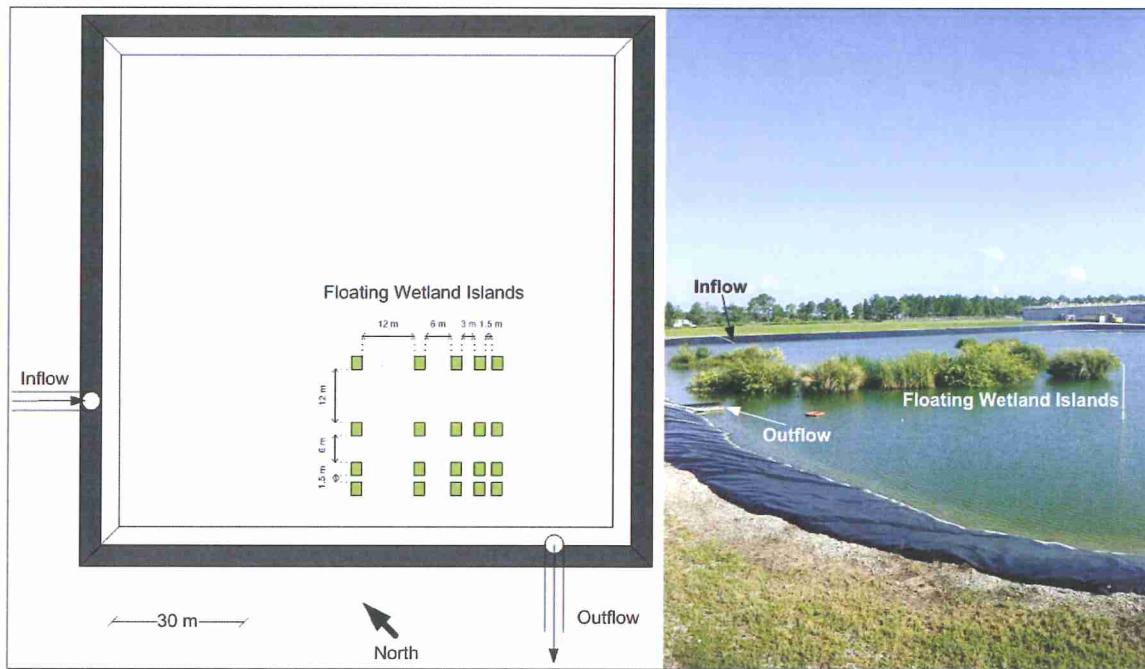


Figure 1. Placement of Floating Wetland Islands and Typical View, showing relation of islands and pond outlet.

Wetland Plant Species Selection

Wetland plants comprising 18 local species were obtained as potted plants and bare root propagules from local commercial nurseries. A local seed mix was applied to two islands to compare with the 18 planted islands.

Pond Operation

The pond volume totaled approximately 19 ML. A temporary 10-cm diameter pipe with a flow meter was installed on the west side of the pond near the southwest berm corner to provide continuous flow. Meter readings were recorded daily by WWTF operators. The fixed-elevation outflow pipe provided continuous water level control and eliminated the need to monitor the pond stage. Recorded flows and pond stage-storage relationships were used to complete a daily water balance of the pond.

Water Quality Sampling

Water samples were collected biweekly at the pond inflow and outflow and analyzed for ammonia nitrogen, oxidized nitrogen (nitrate plus nitrite), organic nitrogen (ON), and TN for 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). Laboratory analysis was performed according to Standard Methods SM-4500 (APHA 2000) by the Pasco County Environmental Laboratory, which is certified by the Florida Department of Health Laboratory Certification Program in accordance with the National Environmental Laboratory Accreditation Conference.

Tissue Sample Collection

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4 Tissue analysis of the planted vegetation was performed to quantify plant nutrient uptake during
5 the study period. Plants were harvested quarterly and analyzed for dry weight and percent TN.
6 During FWI installation, six tissue sampling sites were placed evenly throughout each FWI.
7 During each sampling event, at least one sample was collected from all islands. Plants for tissue
8 sampling were selected randomly.
9

10 Samples were collected in September 2012, November 2012, April 2013, and August 2013. Root
11 length, shoot length, and media depth (island matrix) were measured upon collection. Plant
12 samples were packaged in coolers and shipped to the University of Florida Wetland
13 Biogeochemistry Laboratory, Gainesville FL for analysis in accordance with Standard Methods
14 (APHA 2000).
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16 A total of six sites were prepared before planting for tissue samples. These included the use of a
17 small section of 75-cm polyvinyl well screen installed through the mat for easy removal. Sites
18 were planted randomly and in the same way as the rest of the mat. One sample from each island
19 was collected quarterly from the pre-prepared sampling sites. The root zone of each sample was
20 washed to remove all soil, packaged, and sent to the University of Florida Wetland
21 Biogeochemistry Laboratory for analysis of TN. The minimum detection limit (MDL) and
22 practical quantitation limit (PQL) for TN were 0.23 mg/kg, and 0.27 mg/kg, respectively.
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24 Ten samples of calcified algal deposits were taken at the study conclusion, each with a surface
25 area of 0.37 square meter. Groups of two samples were taken at 9 m increments inward of the
26 west berm. Within these groups, the first sample was taken between 23 to 30 meters north of the
27 first sample in the previous sample group. The second sample was taken at varying distances
28 north or south of the first sample. Samples were analyzed for wet weight and TN.
29

30 **Lithium Chloride Tracer Study**

31 After 11 months of island establishment, a tracer study was performed involving a one-time slug
32 application of lithium chloride (LiCl) at the pond influent pipe. Lithium ion (Li) was monitored
33 at the pond outfall in order to determine the time and concentrations of exiting tracer.
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35 **Floating Wetland Islands Removal and Relocation**

36 The FWIs were removed from the pond at the Wesley Center WWTF on August 27 and 28,
37 2013. The FWIs were fully grown and saturated with water at the completion of the study. The
38 FWIs were relocated and permanently installed at the Lake Rita reclaimed water storage facility.
39

40 **RESULTS**

41 **Pond Hydraulic Characteristics**

42 The nominal hydraulic residence time (nHRT) averaged 25 days based upon an average daily
43 inflow rate and an estimated pond volume at the operating water depth. The nHRT varied from
44 5.6 days after extreme rain events to 158 days during short periods when the flow to the pond
45 was halted for operational reasons outside of the control of this study.
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47 To characterize pond hydraulics, the tracer response curve was analyzed for the number of tanks
48 in series (N), dimensionless variance, wetland dispersion number, Peclet number, and volumetric
49 efficiency. Residence time distribution was analyzed as a first-order gamma distribution to
50 determine N and mean residence time as described in Kadlec and Wallace (2009).
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4 The pond N was determined to be 1.04, just greater than 1, the value for a continuously stirred
5 tank reactor (CSTR). The wetland dispersion number was 8.0. Highly sensitive to N values in
6 this range, pond dispersion values are typically higher, indicating rapid lateral and reverse
7 dispersion as inflow water enters the lined pond, in contrast to wetlands, which typically range
8 much lower from 0.07 to 0.33 and are consistent with laminar flow (Kadlec and Wallace 2009).
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11 The measured HRT for the pond averaged 15.7 days. The volumetric efficiency, calculated by
12 dividing the actual HRT by the nominal HRT, was 0.63, meaning that the actual HRT was less
13 than expected, presumably through preferential flow. The tracer response curve showed tracer
14 exiting the pond within 4 hours after application, along with a long descending limb, indicating
15 the presence of both short-circuits and “dead” zones. The presence of algae and floatable debris
16 in the northeast and northwest pond corners indicated stagnant water in these areas. A Peclet
17 number (Pe) of 0 represents a CSTR, and $Pe = \infty$ represents a plug-flow reactor. Reported values
18 for free water surface wetlands range from $Pe = 5$ to 20 (Kadlec and Knight, 1996). The Pe for
19 the test cell was 0.13, which indicates significant short-circuiting.
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22 With a duration of 90 days, the control period was approximately equivalent to six measured
23 HRTs. Given the general understanding that three residence times is considered sufficient to
24 characterize a tracer impulse (Kadlec and Wallace 2009), the data collected during the control
25 period represent the pond conditions with no lingering effect from the islands.
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28 **Plant Growth Response**

29 In September 2012, five months after planting, plant shoot length averaged 94 cm (range 30 to
30 157 cm) and root length averaged 28 cm (range 10 to 46 cm). In August 2013, just before the
31 islands were removed, root and shoot lengths were remeasured. Shoot length averaged 132 cm
32 (range 9 to 238 cm) and root length averaged 38 cm (range 6 to 305 cm).
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35 **Nitrogen Water Quality Monitoring Results**

36 Inflow TN averaged 6.1 mg/L and ranged from 3.4 to 9.6 mg/L (Figure 2). Average (± 1 standard
37 error) and range of TN concentration reductions were 54 ± 5 % (range 43% to 69%) during the
38 grow-in period, 67 ± 7 % (range 31% to 83%) during the performance period, and 25 ± 12 percent
39 (range 6% to 35%) during the control period.
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42 Oxidized nitrogen (nitrite+nitrate) inflow concentrations for the pond averaged 5.3 mg/L and
43 ranged from 2.8 to 7.8 mg/L (Figure 3). In general, the outflow concentrations were less than
44 1.5 mg/L, with most measurements below detection during all monitoring periods.
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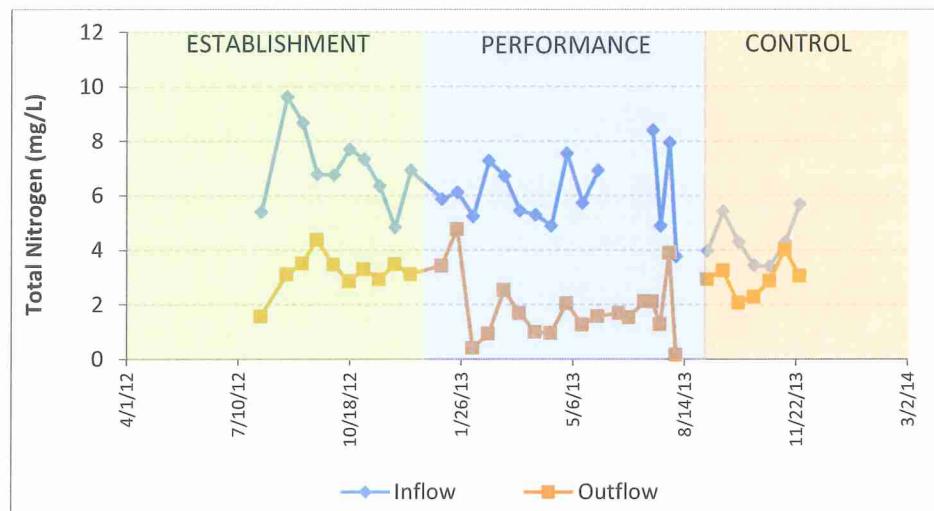


Figure 2 Total Nitrogen

Ammonia concentrations were either below the detection limits of the analytical method or between the detection limit and the practical quantitative limit. Based on the results for ammonia, nitrogen species conversions involving ammonia were considered negligible.

Approximately 87 percent of the inflow nitrogen form throughout the study was oxidized nitrogen, while the dominant outflow nitrogen form was organic nitrogen (ON). Inflow ON concentrations averaged 0.6 mg/L and ranged from non-detect to 1.8 mg/L (Figure 4). Outflow ON concentrations were significantly greater, averaging 2.2 mg/L and ranging from 0.4 to 4.0 mg/L. The difference between inflow and outflow ON indicates the conversion of inorganic nitrogen to ON. Average (± 1 standard error) outflow ON concentrations for the grow-in period, performance period, and control periods were 3.0 ± 0.2 mg/L, 1.5 ± 0.3 mg/L, and 2.9 ± 0.4 mg/L, respectively.

This difference in pond performance is not related to differences in season or system hydraulics. During this time, monthly average temperatures showed similar ranges for the performance (19.2-29.2°C) and control (21.8-30.7°C) periods, and average period temperatures were not statistically significantly different ($p=0.28$). The decreased concentration of organic nitrogen in the pond outflow during the performance period and the subsequent increase after the removal of the islands points to reduction in algal growth in the presence of the islands.

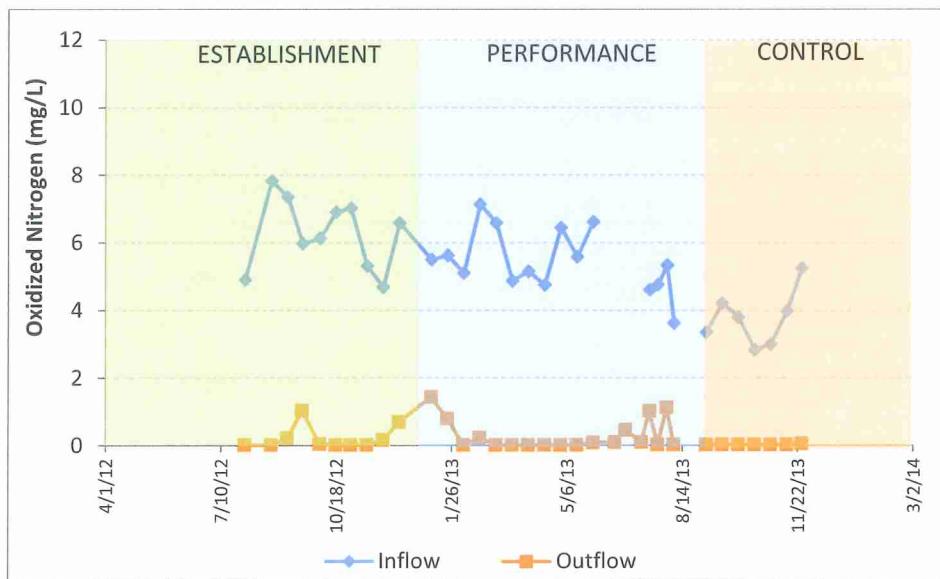
Tissue Sampling Results

Total estimated vegetation mass per island was calculated by averaging the plant samples collected for each event, multiplying the average by the number of plugs per FWI, 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, approximately 2.2 kg of TN was estimated to be bound up in plant tissue mass, which accounts for 0.2 percent of the TN removed.

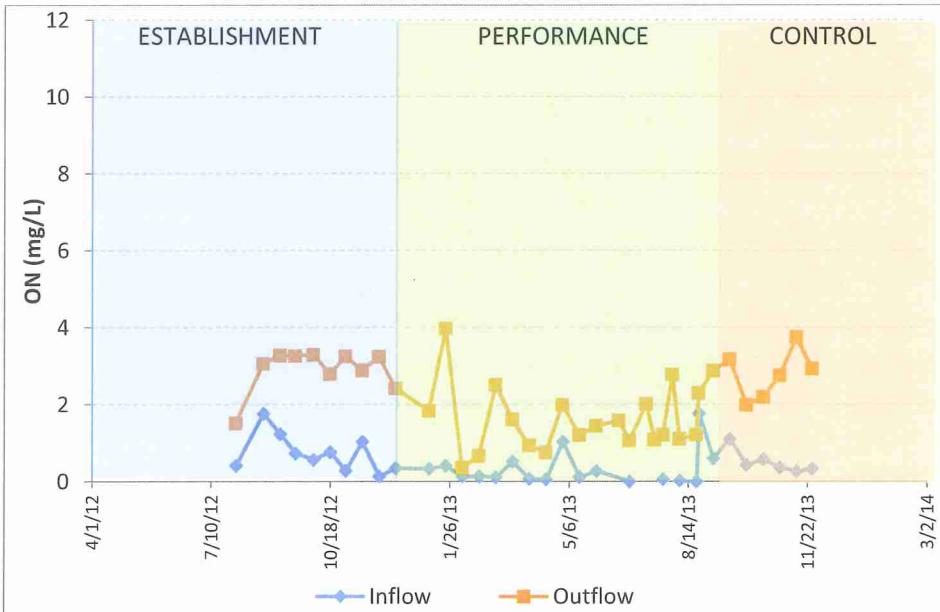
Algal Productivity and Deposits

Throughout the study, algae flourished in the pond and left calcified deposits. Cyanobacterial calcium carbonate precipitates when pH increases in response to photosynthesis (Riding, 2011).

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4 Algal deposits were limited to shallower depths of the pond. The highest line of calcification was
5 a reliable high-water level indicator for this study.
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28 Figure 3 Oxidized Nitrogen
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54 Figure 4 Organic Nitrogen
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58 Calcified deposits on the pond liner were sampled at the end of the study were estimated to have
59 accumulated a total of 96 kg TN over the course of the study.
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4 **Nitrogen Mass Balance and Transformation**
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6 The pond nitrogen cycle, performance of each nitrogen species, and the potential for FWIs to
7 reduce TN concentrations within reclaimed water storage facilities was assessed. Figure 5 shows
8 the principal components of the nitrogen cycle in the pond with the FWIs. Principal processes
9 transforming nitrogen in aquatic systems including ammonification, nitrification, denitrification,
10 plant uptake, algal assimilation and burial. A nitrogen mass balance was estimated for the
11 performance and control periods by quantifying pond input and output, the storage in plant and
12 cyanobacterial biomass, and estimating the denitrification rates based on the water balance and
13 water quality monitoring.
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15 During the performance period, 61 percent of the nitrogen mass was removed, of which 56
16 percent was estimated as loss by denitrification (Figure 5L). Based on the biomass samples,
17 system storage was estimated to be approximately $4.3 \text{ g N/m}^2 \text{ yr}$, corresponding to 4.2 g
18 $\text{N/m}^2 \text{ yr}$ in calcified cyanobacteria and $0.1 \text{ g N/m}^2 \text{ yr}$ in plant tissue. During the establishment
19 period, system storage corresponded to 5 percent of TN lost. Only 0.2 percent of the TN
20 removed during this period was attributed to plant uptake and storage, a calculable but negligible
21 amount.
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23 In the control period, nitrogen mass removal was $13.9 \text{ g N/m}^2 \text{ yr}$, a 30 percent reduction, of
24 which 23 percent was estimated to be gasification or denitrification (Figure 5R). Based on the
25 liner cyanobacteria samples, approximately $4.2 \text{ g N/m}^2 \text{ yr}$ accumulated in system storage.
26 Because the islands were removed during this period, plant uptake is removed from the mass
27 balance. During the establishment period, system storage corresponded to 7 percent of TN
28 removed.
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30 Almost all (96 percent) of the nitrogen in the pond outflow was composed of ON, indicating that
31 algal uptake was responsible for converting the remaining nitrate to ON in algal biomass, which
32 was then exported in the pond outflow. By removing the FWIs, the mass balance suggests that
33 the ability for the system to denitrify and convert oxidized nitrogen to ON in the absence of
34 FWIs was reduced, and the majority of the nitrogen was exported as algal solids in the outflow.
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36 By comparing the denitrification rates of the control period with the performance period, a total
37 mass reduction of 630 kgN/yr can be attributed to the FWIs. This corresponds to a mass removal
38 rate of $4.2 \text{ kgN/m}^2 \text{ FWI mat*yr}$. This value is greater than 90 percent of the range of TN removal
39 rates observed for free water surface treatment wetlands (Kadlec and Wallace 2009). When
40 calculated for the area defined FWIs and intermediate open areas ($1,122 \text{ m}^2$), the removal rate is
41 $562 \text{ gN/m}^2 \text{ FWI area *yr}$, corresponding to the 80th percentile of treatment wetlands (Kadlec and
42 Wallace, 2009). The greater reduction of organic nitrogen (in the form of algal solids) during the
43 performance period may be related to attachment of suspended solids to root surface areas, as
44 noted by Borne et al. (2013b). Enhanced denitrification may also be attributed to the FWIs, given
45 the greater oxygen depletion in FTWs, particularly in the presence of plants (Tanner and Headley
46 (2011).
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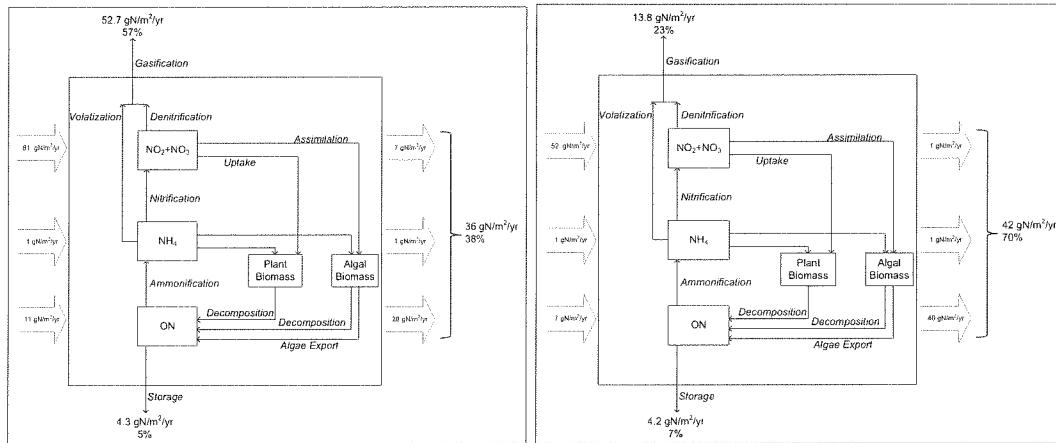


Figure 5. Nitrogen Mass Balances for Performance (L) and Control (R) Periods

CONCLUSIONS

The results from this study indicate that the TN mass removal efficiency of the reclaimed water pond was 61 percent during the performance period with FWIs present compared to 30 percent mass removal efficiency during the control period with the FWIs removed. Based upon the difference in TN performance during the performance and control periods, the FWIs accounted for 32 percent more reduction of TN. Relatively high TN removal rates of $4.2 \text{ kg/m}^2 \text{ FWI mat}^* \text{yr}$ or $562 \text{ gN/m}^2 \text{ FWI area}^* \text{yr}$ were estimated. Tracer test results suggest that performance might be improved if a pond were designed for greater hydraulic efficiency.

These results suggest that the removal of TN in reclaimed water reservoirs may be enhanced by FWIs. The FWIs may be capable of enhancing pond TN removal by limiting algae activity and enhancing denitrification. Similar studies are recommended for FWI pond applications to develop general sizing criteria and removal rate constants. Ponds differ in depth, size and loads and must be assessed uniquely to understand the capacity for FWIs to enhance TN removal.

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