Final Report:

Evaluation of Floating Wetland Islands (FWIs) as a Retrofit to Existing Stormwater Detention Basins

A 319(h) project sponsored by NCDENR – Division of Water Quality

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Executive Summary

The purpose of the project was to evaluate a retrofit of wet ponds, Floating Wetland Islands (FWIs) for potential widespread use in Nutrient-sensitive watersheds of Central North Carolina, namely Jordan Lake and Falls Lake. FWIs are a hydroponic system that when fully vegetated are essentially wetlands that float on the surface of open water. FWIs are a particularly attractive retrofit because they (1) do not require earth moving, (2) eliminate the need for additional land to be dedicated to treatment, and (3) will not detract from the required storage volume required for wet ponds (because they float).

To test whether FWIs provide a benefit for nutrient and TSS removal, two ponds in Durham, NC, were monitored, pre- and post-FWI installation. The distinguishing characteristic between the two ponds post-retrofit was the fraction of surface covered by FWI. The first (DOT pond) had 9% coverage by FWI, while the second (Museum Pond) had 18% of its surface area covered by FWI. It was important to test this range of coverage due to the cost of FWIs. At least 16 events were collected from each pond during each monitoring period.

FWIs tended to improve performance of both ponds, with the Museum pond having statistically significant improvement post-retrofit for both TP and TSS. It appears that fraction of FWI coverage matters. Root length was measured to be approximately 2 feet below the ponds, which has the benefit of stilling water flow, thereby increasing sedimentation. A very small fraction of N and P was also taken up by wetland plants, as measured in October 2011. The mean effluent concentrations of total nitrogen (TN) were reduced at one pond from 1.05 mg/L to 0.61 mg/L from pre- to post-retrofit, a dramatic improvement. Mean TP effluent concentrations were reduced at both wet ponds from pre- to post-retrofit (0.17 mg/L to 0.12 mg/L at the DOT pond 0.11 mg/L to 0.05 mg/L at the Museum pond). The post-retrofit concentrations are similar to those observed for bioretention cells.

Very importantly, both the pre- and post-FWI retrofit ponds performed well from a pollutant removal perspective. One pond had extremely low TN effluent concentrations (0.41 mg/L and 0.43 mg/L) during both pre- and post- FWI retrofit periods, respectively. These ponds regularly exceeded the assigned NCDENR pollutant removal credits for TN, TP, and TSS. In general, FWIs made good ponds work even better.

The authors took advantage of having these pond data and created a simple tool to predict effluent concentrations based upon the relative size of the pond to its watershed. While this study is not definitive, there are some “thumbnail” design standards that are offered to NCDENR:

1) More FWI coverage is better. Perhaps if NCDENR were to make 20% FWI coverage the threshold for which additional TN, TP, or TSS credit is offered, this would be somewhat conservative.
2) The amount of additional TN and TP credit to be awarded a pond that employs FWI should initially be minimal, perhaps a 5% “bonus.” To receive additional TN credit, perhaps the vegetated should be required to be harvested. That is, a pond with 20% FWI coverage would receive 30% TN removal credit rather than 25% for a standard pond.
3) Finally, NCSU fully supports NCDENR if their decision is to hold off assigning any benefits to FWIs until additional research (conducted elsewhere) is reported.

Introduction

Urban stormwater poses significant threats to waterways by more efficiently transporting anthropogenic pollutants. Additionally, loads of pollutants, such as nutrients, heavy metals, sediment, indicator organisms, and hydrocarbons, tend to be higher in urban areas than in rural areas. The added volume of stormwater that is conveyed from impervious surfaces causes stream bank erosion, degradation of aquatic habitat, and loss of real estate. Therefore, federal, state, and local legislation in the U.S. mandates the use of stormwater control measures (SCMs) to combat these negative consequences of urban growth.

Examples of SCMs include innovative stormwater practices, such as bioretention, permeable pavement, water harvesting, and infiltration devices, which are often integrated into Low Impact Development (LID) strategies. Since the passage of the Clean Water Act (1972), wet detention basins have been required to mitigate the increased peak flow rates observed post-construction. As such, there are many existing wet ponds across North Carolina. Further, because North Carolina has many nutrient-sensitive waters, ponds have been assigned credit to “remove” pollutants: 25% for total nitrogen (TN), 40% for total phosphorus (TP), and 85% for total suspended solids (TSS) (NCDENR, 2007). Considering their widespread use, a surprising lack of literature exists on the performance of wet ponds for removal of pollutants (Mallin et al. 2002; Jones and Hunt 2010; Hancock et al. 2010; Gallagher et al. 2011; Wium-Andersen 2011; DeLorenzo et al. 2012), especially for nutrient removal. One paper in the literature (Mallin et al. 2002) quantifies nutrient removal at three ponds in the North Carolina Coastal Plain. Of the three ponds, one showed promising removal of TN, one showed negligible removal of TN, and TN increased by 50% at the third pond. TP concentrations were reduced at two of the ponds, and increased at a third. Nutrient removal from past studies of wet detention basins has been uncertain, and is certainly less reliable than a media filter, such as bioretention (Hunt et al. 2008). Field evaluations of wet ponds have shown between 41-93 percent removal of TSS, with sediment removal a function of influent particle size distribution (Wu et al. 1996; Greb and Bannerman, 1997; Mallin et al. 2002; Hathaway et al. 2007).

With the passage of the Jordan Lake Rules (North Carolina Administrative Code, 2008) and similar rules in other watersheds in NC, nutrient reduction goals have been set with strict TN and TP load limits for new and existing development. Since existing developments often have limited space for retrofitting stormwater practices, methods to improve currently in-ground stormwater practices' performance for nutrient removal are crucial. One potential retrofit for reducing nutrients in wet detention ponds is the use of floating wetland islands (FWIs), also referred to as floating treatment wetlands (FTWs). FWIs function in a similar manner to hydroponic systems, where plants and microbes inhabit a floating mat and uptake nutrients as they grow. A laboratory study of FWIs (Tanner and Headley 2011) showed positive removal of Cu, Zn, and fine suspended particulates. A study using FWIs to treat raw domestic *wastewater* showed removal efficiencies of 22-42% for total ammoniacal nitrogen (TAN), TN, and TP (Van de Moortel et al. 2010). However, field studies have not been completed on FWIs and their performance as retrofits to *stormwater* wet ponds.

Research Goals

The goals of this research were threefold: (1) Examine the pollutant load reduction and effluent water quality from two existing wet detention ponds in Durham, NC; (2) examine the impact of the addition of floating wetland islands to the ponds on load reduction and effluent water quality;

and (3) determine ancillary benefits of floating wetland islands, including nutrient uptake by plants and benthic macroinvertebrate health.

Deliverables

1. Two conventional stormwater wet ponds will be monitored for 1 year.
   Two ponds, one treating a DOT interchange I-85 and US 15-501 (DOT pond) and a second treating a parking lot and maintenance facilities at the NC Museum of Life and Science (Museum Pond) were monitored from November 2008 to March 2010. Sixteen storms were analyzed during the pre-retrofit period for water quality.

2. Two demonstration ponds will be retrofitted with floating wetland islands.
   Nine percent of the DOT pond surface area was coved by floating wetland islands, and 18% of the Museum pond's surface was retrofit by islands. This occurred in March and April 2010.

3. The retrofitted floating island ponds will be monitored for 1 year.
   The FWI-retrofitted ponds were monitored from July 2010 through September 2011. During this period, 16 events were sampled at the DOT pond and 18 events were collected at the Museum Pond.

4. Two classroom training events for design professionals will highlight these retrofits. There will also be two site visits for design professionals made.
   Three classroom training events highlighting floating wetland islands were conducted in Raleigh (X2) and Lenoir. The workshops were held in June and August 2011. Additionally, during one of the installation days, several designers were invited and visited in March 2010.

5. A factsheet will be written detailing the use, design, and performance of the floating wetland ponds, provided the systems are shown to work. If the floating islands do not appear to function as intended, a short report will be made to the public discouraging the use of this particular retrofit. Either publication will be posted on the BAE Stormwater Website.
   This deliverable has not been completed. There will be two products however, that are in preparation that will fulfill this obligation. A version of this final report is to be submitted to the Journal of Environmental Engineering for publication. Additionally a factsheet is in the planning stages that will highlight many types of pond retrofits, including FWI's, creation of aquatic shelves, and upflow filters. NCSU is still conducting an upflow filter study (and will through this summer), which is the cause for this delay. The university will provide the factsheet to NCDENR as soon as it has been prepared and we apologize for the delay.

6. Guidance, in the form of a Stormwater BMP Design Manual addendum, will be given to NC DENR personnel upon completion of the project either (1) recommending the use of this BMP retrofit (with design guidelines and nutrient removal credit), or (2) discouraging the adoption of this product as a BMP retrofit.

This final report and journal article will be provided to NCDENR stormwater and wetlands unit. Faculty at NCSU will meet with NCDENR officials to discuss how to incorporate these findings into the future pond chapter. Some recommendations are provided in the Executive Summary.

7. A final project report.
   Submitted herein.

Description of Sites

Two existing wet detention ponds in Durham, NC were identified for monitoring during the summer of 2008. Sites were chosen because they had a single, piped inlet and an outlet structure that allowed for the installation of monitoring equipment. Both ponds were designed to treat the water quality volume and mitigate peak flow rates from the 1-yr, 2-yr, and 10-yr return period storm events, as required by the NC Department of Environment and Natural Resources (NCDENR), Division of Water Quality's (2007) *Stormwater Best Management Practices Design Manual* and/or the City of Durham. As such, they were designed to have a forebay, to treat the 2.5 cm event without overflow, to draw down to permanent pool elevation in 2 to 5 days, and to release outflow through a vegetative filter strip.

The first wet pond was installed by the NC Department of Transportation (hereafter referred to as "DOT pond") during the expansion of an interchange at US 15-501 and Interstate-85. The 13.07 ha drainage area consisted entirely of roadway and associated vegetated shoulders, and was 87.7% impervious (Table 1). The surface area of the pond at permanent pool elevation was 0.36 ha. The surface area of the forebay was 11.7% of the total surface area of the pond and the forebay was not vegetated. The pond had both a concrete box outlet structure and a rip-rap lined emergency spillway, which regulated overflow and conveyed emergency spillway flow, respectively (Figure 1a). Throughout the monitoring periods, the pond was frequented by 20 Canada geese, *Branta canadensis*.

The second wet pond was installed at the North Carolina Museum of Life and Science (hereafter referred to as "Museum pond") and drains a parking lot, a maintenance building, and a picnic area (Table 1). The drainage area was 2.37 ha and 54.3% impervious. The wet basin was 0.05 ha in surface area, and the surface area of the forebay was 18% of the total surface area of the basin. The forebay was vegetated with a dense mat of cattails (*Typha latifolia*). The pond had a concrete box outlet structure which regulated overflow, which doubled as an emergency spillway (Figure 1b). Both the DOT and museum ponds, respectively, had somewhat similar length to width ratios (2.84 and 2.4), forebay depths (0.83 m and 0.53 m) and depths at permanent pool (1.22 m and 0.93 m).

Table 1. Characteristics of two wet detention ponds examined in Durham, NC.

Attribute	DOT Pond	Museum Pond
Surface area (ha)	0.36	0.05
Drainage area (ha)	13.07	2.37
Hydraulic Loading (unitless)	36.4	47.4
Watershed Imperviousness (%)	87.7%	54.3%
Watershed Land Use	Interstate highway	Parking lot, maintenance building, picnic area
Forebay Area (m^2)	421	90
Average Forebay Depth (m)	0.83	0.53
Wet Pond Length (m)	91	36
Wet Pond Average Width (m)	32	15
Length to Width Ratio	2.84	2.4
Mean Depth at Permanent Pool Elevation (m)	1.22	0.93
Storage Volume at Permanent Pool Elevation (m^3)	3869	386
Brink of Overflow Storage Volume (m^3)	7993	1190
Brink of Emergency Spillway Storage Volume (m^3)	9625	NA

Figure 1a (left). Satellite imagery of DOT pond with twelve floating wetland islands.
Figure 1b (right). Satellite imagery of Museum pond with four floating wetland islands.
Photos: Google Earth.

Materials and Methods

Data Collection

At the DOT pond, stormwater entered through a 152 cm reinforced concrete pipe (RCP) which was partially submerged at the permanent pool elevation. An ISCO 720 (Lincoln, Neb.) area velocity meter was fixed to the bottom of the pipe to collect flow data. These meters collect continuous velocity measurements based upon the Doppler Effect and continuous stage data using a pressure transducer. Since the cross-sectional area of the pipe was known, the meter could make measurements of flow rate. Similar area velocity flow measuring locations were installed at the outlet to the DOT pond (41 cm RCP), which was continuously submerged, and the inlet to the Museum basin (61 cm RCP), which was partially submerged at normal pool (Figures 2a and 2b). At the Museum pond, stage measurements were made in the freely-flowing 61 cm RCP outlet pipe using an ISCO 730 bubbler module (Figure 3). Stage measurements were converted to flow rate using Manning's Equation with known values for pipe slope, pipe roughness, and cross-sectional area (Manning 1891).

Flow measurements were taken on a 2-minute interval, which triggered automated samplers to collect flow-weighted, composite water quality samples (Figures 4a and 4b). At the DOT pond, ISCO Avalanche® refrigerated samplers were used, while at the Museum pond ISCO 6712 samplers were employed. Sample intake strainers were located in an area with well-mixed flow. A minimum of five aliquots was required to adequately represent the entire hydrograph (U.S. EPA 2002). Samples were stored in a 10L glass jar inside the sampler. Samples were taken to a U.S. EPA certified laboratory on ice within 24 hours of the cessation of rainfall. Storm events were characterized by a minimum antecedent dry period of 6 hours and had rainfall depths between 3 and 150 mm. Rainfall data were collected at each site using both a manual rain gauge and a recording, tipping bucket (Davis Rain Collector II) rain gauge (Figure 5). Hydrologic and rainfall data were analyzed using Flowlink® and Hoboware Pro® software, respectively.

Figure 2a (left). Spring ring monitoring assembly with sample intake, suction tubing, and area-velocity meter (submerged) at inlet of Museum pond.

Figure 2b (right). Installing monitoring equipment at the DOT pond inlet.

Figure 3. Spring ring monitoring assembly with sample intake, suction tubing, and bubbler assembly at outlet of Museum pond.



Figure 4a (left). Monitoring box containing ISCO 6712 sampler and deep cycle battery at Museum pond outlet.

Figure 4b (right). Avalanche sampler, deep cycle battery, and solar panel DOT pond outlet.


Figure 5. Rain gauge installation at the DOT pond.

Laboratory Analysis

Water quality samples were collected from samplers during an approximately 3-hr round-trip from Raleigh, NC. Sample collection took place within 24 hours of the end of the rain event. The composite samples were dispensed into 2 L pre-acidified plastic bottles for nutrient and TSS analysis. Upon collection, all samples were immediately placed on ice and chilled to <4°C. Samples were delivered to the City of Durham wastewater laboratory and were analyzed using EPA (U.S. EPA 1993) and Standard methods (Eaton et al. 1995) (Table 2). Laboratory analysis was performed for total Kjeldahl nitrogen (TKN), nitrate and nitrite ($NO_{2,3}$-N), total ammoniacal nitrogen (TAN), orthophosphate (ortho-P), TP, and TSS. Organic nitrogen (ON) was calculated as the difference between TKN and TAN. Particle bound phosphorus (PBP) was calculated by subtracting the ortho-P concentration from the TP concentration. Total nitrogen TN was calculated as the sum of TKN and $NO_{2,3}$-N.

Table 2. Analytical methods for water quality analysis.

Constituent	Laboratory Testing Methods	Preservation	Laboratory Reporting Limit (mg/L)
TAN	Std Method 4500-NH_3-D (Eaton et al. 1995)	H_2SO_4 (<2 pH), <4°C	0.05
TKN	Std Method 4500-N_{org} (Eaton et al. 1995)	H_2SO_4 (<2 pH), <4°C	0.3
$NO_{2,3}$-N	EPA method 300.0 revision 2.1 (U.S. EPA 1983)	H_2SO_4 (<2 pH), <4°C	0.1
TN	Calculated as $NO_{2\text{-}3}$-N + TKN	N/A	N/A
ON	Calculated as TKN – TAN	N/A	N/A
Ortho-P	Std Method 4500-P-E	H_2SO_4 (<2 pH), <4°C	0.03
PBP	Calculated as TP – Ortho-P	N/A	N/A
TP	Std Method 4500-P-E (Eaton et al. 1995)	H_2SO_4 (<2 pH), <4°C	0.03
TSS	Std Method 2540 D (Eaton et al. 1995)	<4°C	2.5

Floating Wetland Islands

Monitoring of the pre-retrofit wet detention basins was completed during the 14 month period spanning December 2008 through February 2010. During this time, sixteen paired samples were obtained from the inlet and outlet of the DOT pond. Sixteen paired samples were also collected at the inlet and outlet of the Museum pond.

In late March 2010, FWIs were installed as retrofits at both the Museum and DOT ponds. FWIs act as a hydroponic system, with the plants and microbes that inhabit the plant roots taking up nutrients from the stormwater. The surface vegetation improves the above-water ecosystem, while the roots provided submerged habitat. At the DOT pond, twelve floating wetland islands were installed, or a surface coverage of 9%. Four islands were installed at the Museum pond, or a surface coverage of 18%.

Each island had a surface area of approximately 23 m^2 and was 25 cm thick. The mats are constructed of extruded plastic woven together and float because of injected closed-cell foam that is internal to the island. The islands had pre-drilled holes on 20 cm centers that were 13 cm deep. These were filled half-full with peat moss, and planted with a mixture of *Carex stricta* (Tussock sedge), *Juncus effusus* (soft rush), *Spartina pectinata* (prairie cordgrass), *Acorus gramineus* (Japanese sweet flag), *Pontederia cordata* (pickerelweed), *Peltandra virginica* (arrow arum), *Andropogon gerardii* (big bluestem), and *Hibiscus moscheutos* (marsh hibiscus). A total of 3,550 plugs (2.5 cm diameter) were planted, or an average of 225 plants per island. Following planting, the islands were moved into the basin (Figure 6a). FWIs were affixed to the bottom of the ponds through the use of four cinder block anchors. Goose fencing was installed by the City of Durham at the DOT pond, because of a resident Canada goose population (Figure 6b). During and immediately following planting, North Carolina experienced a period of unseasonably hot and dry Spring weather; mortality of approximately 20% of the plants was observed. They were replaced during a second planting conducted the second week of April 2010. Plantings were allowed to mature from April through June 2010 before monitoring recommenced in July 2010.

Figure 6a (left). Launching a floating wetland island.
Figure 6b (right). Installing goose prevention fencing.

The post-retrofit monitoring period ended in September 2011. A total of sixteen and eighteen paired water quality samples were taken at the DOT pond and the Museum pond, respectively. During both the pre- and post-retrofit monitoring efforts, samples were relatively well distributed across all seasons, with between one and six storms sampled per season.

Wetland Island Plant Sampling and Analysis

Methods for plant sampling and analysis were adapted from Tanner and Headley (2011). The sampling was conducted at both sites, DOT and Museum. Juncus (*Juncus spp.*), Sedge (*Carex stricta*), Grass (*Sacciolepis striata*), and Hibiscus (*Hibiscus coccineus*) were the dominant species found at both sites. Pickerelweed (*Pontedaria cordata*) was dominant at the DOT pond, but not found at the Museum. Three samples of each species were somewhat randomly harvested from all the mats at each site in October 2011, when the plants wer nineteen months old. The samples were collected via boat and machete, and for root accessibility, the samples were harvested from the outer edge of each mat. The shoot base and root biomass which had grown into the mat were excluded from the analysis, similar to the methods in Tanner and Headley (2011).

Figure 7. Harvesting of the plant samples.

The samples were dried in a fan-circulated oven at 80°C for at least 48 hours. All biomass values reported are in dry weight. Biomass ratios were calculated as the quotient of above mat biomass to below mat biomass.

Figure 8a (left). Below mat biomass samples.
Figure 8b (right). Above mat biomass samples.

The dried tissue was ground and representative subsamples of both the above mat and below mat biomass were sent to the North Carolina State University Environmental and Agricultural Testing Service Laboratory to be analyzed for macronutrients. Nitrogen was measured by Dumas combustion, and phosphorus and potassium by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) using the Dry Ash Method (Munter et al., 1984).

Benthic Macroinvertebrate Sampling

Benthic macroinvertebrate samples were taken at both the DOT pond and Museum pond soon after installation of the floating wetland islands (July 16, 2010) to serve as a control. The ponds were revisited a year later (August 26, 2011) to reassess any potential increase in macroinvertebrate populations, such diversity or total number of specimens. At each site, four sweeps were conducted in the shallow water zone (near the bank) at randomized locations. Macroinvertebrates were collected by jabbing a D-frame sweep net into shallow water sediments and sweeping upward through the water column a distance of 1 m (Batzer et al. 2001). Specimens from all sweeps were live-sorted and identified to the family level. All specimens in the same family were composited for data analysis. Macroinvertebrate richness (number of different families present), Shannon's diversity index (H'), and relative abundance were determined for each site. The presence of fish in sweep net samples was also recorded as it may be an indicator of predation.

Statistical Analysis

The water quality data were statistically analyzed to compare paired influent and effluent concentrations and loads. Statistical tests were separately completed on pre-retrofit and post-retrofit data for each pond. The difference between each set of paired data was tested for normality using four goodness-of-fit tests (Shapiro-Wilk, Cramer-von Mises, Anderson-Darling, and Kolmorogov-Smirnov). If data were normal or log-normal, a paired t-test was performed. Otherwise, a Wilcoxon signed rank test was utilized.

To determine the effects of the floating islands on nutrient and sediment concentrations, statistical comparisons between the pre- and post-retrofit data sets were made. These tests were completed using Wilcoxon rank-sum tests to compare influent concentrations pre- and post-retrofit and effluent concentrations pre- and post- retrofit. A criterion of 95% confidence (α=0.05) was used for this research. Statistical analyses were performed using the SAS software version 9.1.3 (SAS Institute 2006). A value of one-half the detection limit was substituted for concentration data that were below the detection limit (Gilbert 1987). Each sampling event was considered a replicate for statistical purposes.

Results and Discussion

A summary of rainfall depths, sample collection type (nutrients, sediment, or both nutrients and sediment), and nutrient and sediment concentrations are presented in Appendices A-C, respectively. Pollutant loads were calculated for each storm for which water quality samples were collected (Appendix D). Cumulative probability plots, an alternative method for evaluating SCM performance, are presented in Appendix E. Raw data from the plant analysis are located in Appendix F. Finally, a pictorial view of FWI installation is provided in Appendix G.

Rainfall

During the pre-retrofit monitoring period, 79 and 74 storm events occurred at the DOT and Museum ponds, respectively. Of these, sixteen events were sampled for water quality analysis. Slightly fewer rain events took place during the post retrofit monitoring period, with 64 and 62 events, respectively, at the DOT and Museum ponds. Sixteen and eighteen of these were sampled for water quality analysis. Mean and median rainfall depths for sampled storm events were greater than those for all storm events during the monitoring period (Table 3).

Table 3. Rainfall summary statistics during the pre- and post-retrofit monitoring periods.

Statistic	**DOT Pond**				**Museum Pond**			
	Pre-Retrofit		Post-Retrofit		Pre-Retrofit		Post-Retrofit	
	All Storm Events	Events Sampled for Water Quality	All Storm Events	Events Sampled for Water Quality	All Storm Events	Events Sampled for Water Quality	All Storm Events	Events Sampled for Water Quality
Number	79	16	64	16	74	16	62	18
Mean Rainfall (mm)	17	29	19	21	17	31	21	27
Median Rainfall (mm)	10	19	11	22	10	24	12	18
Rainfall Depth Range (mm)	3 - 149	7 -149	3 -132	9 -132	3 - 143	6 -143	3 - 96	3 - 96

The range of rainfall depths was very similar between sampled and non-sampled storm events. The median monitored water quality storm event was between the 70th and 80th percentile storm rainfall depth calculated from 30 years of rainfall data at Raleigh-Durham International Airport (Bean 2005).

Pre-Retrofit Results

Effluent Concentrations

The existing DOT wet detention basin performed well for TN, TP, and TSS reduction during the fourteen month pre-retrofit monitoring period. The inlet concentrations (Table 4) at the DOT pond were representative of previous studies on transportation runoff in North Carolina (Wu et al. 1998; Winston et al. 2012). Mean concentration reductions for TN, TP, and TSS at the DOT pond were 36%, 36%, and 92%. The TN reduction compared favorably to the credit that NCDENR provides to wet ponds (25%). Statistically significant reductions were observed between influent and effluent concentration at the DOT pond for NO_{2-3}-N, PBP, and TSS. The variability in concentration (as determined by the standard deviation) was reduced by more than 50% when comparing the effluent to influent concentrations for all pollutants except TAN.

McNett et al. (2010) correlated benthic macroinvertebrate health to in-stream pollutant concentrations for the three ecoregions in North Carolina (Mountain, Piedmont, and Coastal Plain). The benthic health was rated on a scale from excellent to poor. Excellent and good water quality supported intolerant macroinvertebrate species, including mayflies and caddisflies. Median effluent concentrations for TN, TP, and TSS for the DOT pond were 0.65 mg/L, 0.13 mg/L, and 26 mg/L. This corresponded to excellent water quality for TN and fair water quality for TP. The target of 25 mg/L established for TSS by Barrett et al. (2004) was just exceeded.

The Museum pond had lower mean influent concentrations for TN and TSS than the DOT pond (Table 4), perhaps due to differences in watershed composition (parking lot vis-à-vis interstate highway). The mean TN and TP concentrations were very near those from for eight asphalt parking lots in North Carolina [mean TN (1.57 mg/L) and TP (0.19 mg/L)] reported by Passeport and Hunt (2009). Mean concentration reductions for TN, TP, and TSS at the Museum pond were

59%, 57%, and 89%, all of which were statistically significant. Additionally, TKN, TAN, ON, and PBP concentrations were all statistically reduced in the Museum wet pond. TN and TP reductions for this pond easily exceed the North Carolina credit for wet ponds (25% TN and 40% TP). The treatment provided by the wet pond reduced the variability in effluent concentration when compared against influent concentration variability.

Median TN, TP, and TSS effluent concentrations for the Museum pond were 0.40 mg/L, 0.11 mg/L, and 14 mg/L, respectively. This corresponded to excellent water quality levels for TN and good water quality for TP. Additionally, effluent concentrations met the 25 mg/L TSS threshold. Before retrofitting with floating wetland islands, the ponds were performing better than expected, meeting or exceeding most effluent concentration targets as well as the NCDENR pollutant removal credit for wet ponds.

Table 4. Pre-retrofit monitoring period water quality results.

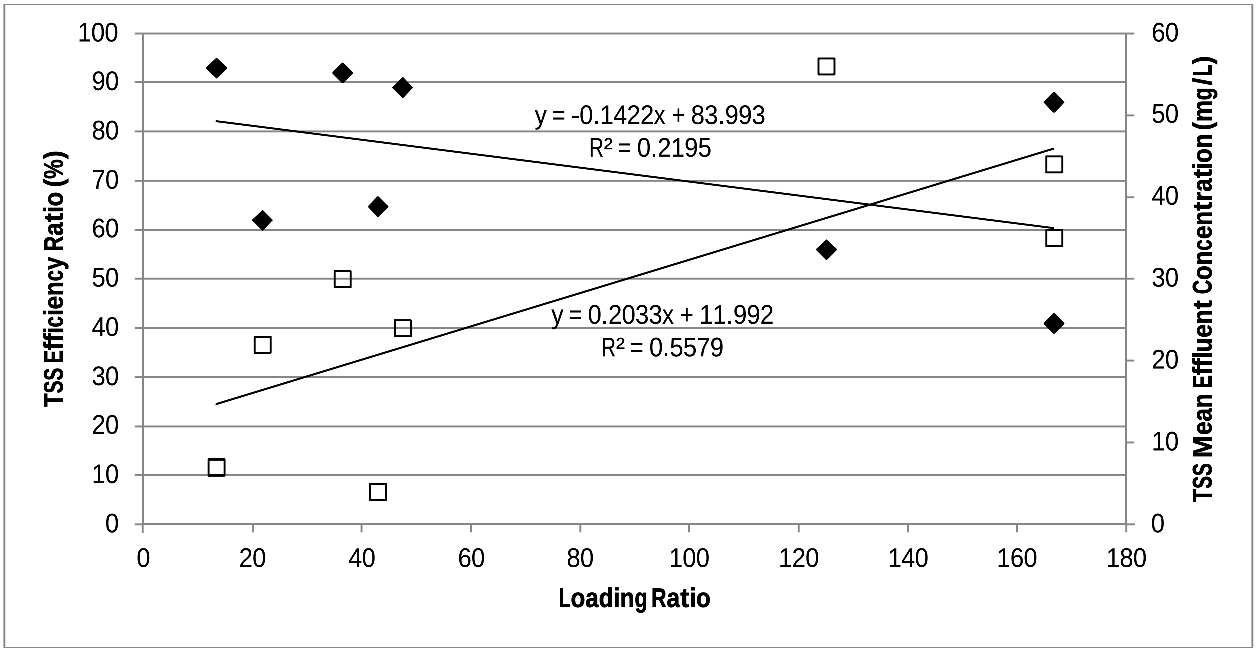
Sampling Location	Statistic	TKN (mg/L)	NO_{2-3}-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)
DOT Inlet	Median	0.80	0.15	1.05	0.03	0.98	0.06	0.06	0.15	215
	Mean (Standard Deviation)	1.43 (2.21)	0.20 (0.17)	1.64 (2.21)	0.12 (0.23)	1.50 (2.04)	0.14 (0.21)	0.13 (0.15)	0.26 (0.33)	354 (365)
DOT Outlet	Median	0.60	0.05	0.65	0.07	0.63	0.09	0.04	0.13	26
	Mean (Standard Deviation)	0.97 (0.98)	0.08 (0.04)	1.05 (0.97)	0.11 (0.18)	0.93 (0.85)	0.12 (0.10)	0.05 (0.02)	0.17 (0.11)	230 (20)
Museum Inlet	Median	0.70	0.05	0.80	0.04	0.75	0.09	0.05	0.18	77
	Mean (Standard Deviation)	0.88 (0.78)	0.12 (0.16)	1.01 (0.81)	0.10 (0.13)	0.89 (0.79)	0.13 (0.11)	0.13 (0.14)	0.26 (0.20)	216 (249)
Museum Outlet	Median	0.35	0.05	0.40	0.03	0.34	0.07	0.03	0.11	14
	Mean (Standard Deviation)	0.35 (0.17)	0.06 (0.04)	0.41 (0.19)	0.05 (0.05)	0.34 (0.17)	0.07 (0.05)	0.04 (0.02)	0.11 (0.05)	24 (30)

Note: Shaded cells of similar color show a statistically significant difference between influent and effluent concentrations.

Effect of Loading Ratio on Pond Performance

The performance of wet detention ponds, or any SCM, as a function of design variables is critical to both design engineers and the regulatory community. Sedimentation, which removes TSS from stormwater, is the primary pollutant removal mechanism in wet ponds. Barrett et al. (2008) found a significant relationship between influent and effluent TSS concentrations for wet ponds (data from the International Stormwater BMP Database). A critical design variable for any SCM is hydraulic loading ratio, or the ratio of catchment area to SCM surface area, which determines the amount of land that must be dedicated to stormwater treatment. A relatively good relationship between hydraulic loading and percent TSS removal was reported by Wu et al. (1996) for three wet ponds in Charlotte, NC. Data from Wu et al. (1996), Greb and Bannerman (1997), Mallin et al. (2002), Hathaway et al. (2007), and the DOT and Museum ponds (pre-retrofit) were utilized to project pond efficiency for TSS removal against hydraulic loading (Figure 9). A total of eight ponds with loading ratios from 13 to 167 were used in the analysis. In general, an inverse relationship exists between hydraulic loading ratio and TSS removal efficiency. However, this relationship is not nearly as clear-cut ($R^2 = 0.22$) as what was shown in Wu et al. (1996), perhaps owing to the fact that different climatic conditions and influent concentrations existed across the eight ponds. Design factors, such as hydraulic retention time, presence or absence of littoral shelves, and depth at normal pool, may also have impcted these results.

Recent research (McNett et al. 2010) has suggested that meeting a target effluent concentration might be preferable to percent reductions. Effluent concentration metrics for SCMs were expected to be a better indicator of performance because they account for regional water quality and “irreducible” concentrations. TSS mean effluent concentrations from the eight ponds were regressed against loading ratio in Figure 9. They ranged in magnitude from 4 mg/L to 56 mg/L with higher effluent concentrations resulting from greater loading ratios. A line of best fit was able to explain 56% of the variability in the data, which is considered reasonably good considering these were eight field monitored ponds located in two states and various ecoregions. While past research has shown that TSS efficiency ratio varies as a function of loading ratio, the review of available peer-reviewed studies conducted here showed a much stronger relationship with TSS mean effluent concentration.



Note: Diamonds represent TSS efficiency ratio data, while hollow squares represent TSS effluent concentration data.

Figure 9. Stormwater pond performance for TSS as a function of loading ratio.

Post-Retrofit Results

Mean pollutant concentrations for the fourteen month post-retrofit monitoring period are presented in Table 5. During the post-retrofit period, the DOT pond significantly reduced concentrations of TKN, NO_{2-3}-N, TN, ON, OP, TP and TSS. Mean concentration reductions were 48%, 39%, and 78%, respectively for TN, TP, and TSS. The NC TN reduction credit for wet ponds of 25% was exceeded but the TP and TSS credits (40% and 85%) were not met during the post-retrofit monitoring period. Median effluent concentrations of TN, TP, and TSS were 0.60 mg/L, 0.13 mg/L, and 18 mg/L, respectively. This corresponded to excellent water quality for TN and fair water quality for TP. The pond met the target 25 mg/L TSS concentration. The variability of effluent concentrations tended to be less for the effluent for TP and TSS during the post-retrofit monitoring period; this was not the case for nitrogen species.

At the Museum site, concentrations of all nine analytes were significantly reduced between the inlet and outlet of the wet pond. While reductions in some of the nitrogen species had been inconsistent at the DOT pond during both monitoring periods and the Museum pond during the pre-retrofit period, three large outliers for TKN (range 7.2-15.3 mg/L) and TAN (range 3.4-12.3

mg/L) at the inlet probably aided in significant reduction of these species. They also resulted in the large differences between mean and median nitrogen species values (Table 5). The influent TP concentration was also much higher than any other monitoring period-pond combination, suggesting that fertilizer use in the watershed occurred. Mean concentration reductions for TN, TP, and TSS were 88%, 88% and 95%, respectively. These nutrient reductions were clearly skewed by elevated influent concentrations. Median effluent concentrations for TN, TP, and TSS were 0.45 mg/L, 0.04 mg/L, and 6 mg/L, respectively. These values corresponded to excellent water quality for both TN and TP. The pond also easily met the 25 mg/L TSS target effluent concentration.

Table 5. Post-retrofit monitoring period water quality results.

Sampling Location	**Statistic**	**TKN (mg/L)**	**NO_{2-3}-N (mg/L)**	**TN (mg/L)**	**TAN (mg/L)**	**ON (mg/L)**	**OP (mg/L)**	**PBP (mg/L)**	**TP (mg/L)**	**TSS (mg/L)**
DOT Inlet	Median	0.80	0.35	1.25	0.03	0.78	0.11	0.05	0.18	100
	Mean (Standard Deviation)	0.84 (0.30)	0.34 (0.21)	1.17 (0.34)	0.11 (0.14)	0.72 (0.29)	0.12 (0.08)	0.07 (0.06)	0.19 (0.10)	101 (70)
DOT Outlet	Median	0.55	0.05	0.60	0.03	0.53	0.06	0.04	0.13	18
	Mean (Standard Deviation)	0.55 (0.34)	0.06 (0.02)	0.61 (0.34)	0.05 (0.04)	0.50 (0.34)	0.07 (0.06)	0.05 (0.04)	0.12 (0.07)	22 (19)
Museum Inlet	Median	1.15	0.20	1.25	0.24	0.79	0.09	0.09	0.18	67
	Mean (Standard Deviation)	3.32 (4.72)	0.17 (0.11)	3.49 (4.70)	1.60 (3.15)	1.72 (2.25)	0.24 (0.34)	0.17 (0.19)	0.41 (0.52)	252 (551)
Museum Outlet	Median	0.40	0.05	0.45	0.03	0.38	0.02	0.02	0.04	6
	Mean (Standard Deviation)	0.37 (0.25)	0.06 (0.04)	0.43 (0.26)	0.04 (0.02)	0.33 (0.24)	0.02 (0.01)	0.03 (0.05)	0.05 (0.05)	13 (17)

Note: Shaded cells of similar color show a statistically significant difference between influent and effluent concentrations.

Comparisons Between Pre- and Post-Retrofit Results

Effluent Concentrations

Influent concentrations for the post-retrofit period at the DOT pond were similar to or less than influent concentrations for the pre-retrofit period. Since lower influent concentrations are more difficult to reduce {see irreducible concentration theory [Strecker et al. (2001)]}. Statistical tests were run to compare influent concentrations pre- and post-retrofit at this pond; only NO_{2-3}-N concentrations were significantly higher in the post-retrofit period. This meant that direct comparison of the effluent concentrations at this pond was reasonable. Mean effluent concentrations at the DOT pond were 0.44 mg/L, 0.05 mg/L, and 8 mg/L lower for TN, TP, and TSS, respectively when comparing the post-retrofit period to the pre-retrofit period. These results suggest that plant uptake and microbial respiration processes resulted in lower pollutant concentrations (and therefore loads) entering surface waters. While mean concentrations of key pollutants were reduced, statistical tests to compare effluent concentrations during pre- and post-retrofit periods resulted in no significantly different data sets. While the islands appeared to aid in reducing effluent concentrations at the DOT pond, the reductions were not statistically significant, potentially suggesting that greater than 9% floating island coverage is needed.

Additionally, an invasive aquatic weed (Creeping Water Primrose, *Ludwigia hexapetala*) inhabited the DOT pond both pre- and post-retrofit which may have affected the results. During the summer (at maximum primrose coverage), roughly 25% of the surface area of the pond was covered by primrose pre-retrofit. The floating islands acted as footholds for the primrose, and 12 months after installation (during summer) about 60% of the pond surface was covered with primrose (Figure 10). This is a potential confounding factor for the results from this pond.

Figure 10. Presence of Primrose around banks and floating wetland islands
(photo on August 8, 2011)

Mean influent concentrations of TN and TP at the Museum pond were 3.4 and 1.6 times higher, respectively, during the post-retrofit period when compared to the pre-retrofit period. These augmented nutrient concentrations suggested greater use of fertilizer in the watershed; however, this could not be confirmed with maintenance crews. Mean influent TSS concentrations were also modestly (16%) higher during the post-retrofit period. Statistical tests revealed differences in TN and TAN influent concentration between pre- and post-retrofit monitoring periods. Since influent concentrations of nitrogen species were divergent, comparisons between the two data sets were more difficult. With that caveat, mean effluent concentrations from the post-retrofit Museum pond were 0.02 mg/L higher for TN (essentially unchanged), 0.06 mg/L lower for TP, and 11 mg/L lower for TSS when compared to the pre-retrofit period. The improvements in TP and TSS effluent concentrations (which were statistically significant) suggest greater sedimentation perhaps due to increased hydraulic resistance imparted by the islands themselves and their root mats. Additionally, a significant improvement in OP was observed at the Museum pond, suggesting that plant uptake occurred. The significant reductions in OP, TP, and TSS at the Museum site (when comparing pre- to post-retrofit periods) seemed to suggest that the 18% coverage provided better treatment of stormwater by the FWIs.

Efficiency Ratio

Another metric which may be used to evaluate BMP performance is an efficiency ratio (ER), which is defined as:

ER = (influent concentration – effluent concentration)/influent concentration

To compare pre- and post-retrofit monitoring periods, efficiency ratios for the two ponds were calculated (Table 6). In all cases except TSS at the DOT pond, efficiency ratios for TN, TP, and TSS improved after installation of the floating wetland islands. These results suggest that the addition of the FWIs does expand upon the unit processes which occur in a wet detention pond, providing further treatment of stormwater. Conclusions when using the ER metric must be tempered since this method is sensitive to changes in influent concentration. This was especially the case for TN and TP at the Museum pond during the post-retrofit monitoring period, where higher influent concentrations were observed.

Table 6. Efficiency ratios for pre- and post-retrofit monitoring periods.

Sampling Location	Efficiency Ratio		
	TN	TP	TSS
DOT Pre Retrofit	0.36	0.36	0.92
DOT Post Retrofit	0.48	0.39	0.78
Museum Pre Retrofit	0.59	0.57	0.89
Museum Post Retrofit	0.88	0.88	0.95

Pollutant Load Performance

Pollutant loads, which are a product of event mean concentration and flow volume for each storm event, are an excellent indicator of SCM performance since they account for concentration improvements and infiltration and/or evapotranspiration. Pollutant loads were calculated on a storm event basis and were normalized based on drainage area and rainfall depth (Table 7). Pre- and post- retrofit pollutant load of TSS for the DOT and Museum ponds, respectively, was reduced by 95%, 72%, 82%, and 93%. Summing the four data sets, the two ponds contributed to an overall TSS load removal of 90%, which exceeded the credit awarded in NC by 5%. Effluent loads of TSS were higher at the DOT pond and lower at the Museum pond during the post-retrofit period when compared to the pre-retrofit period. Since the primary mechanism of pollutant removal in ponds is through settling of particulate matter, it was not surprising that PBP loads were reduced by greater than 42% during all monitoring periods. Load-based removal of all pollutants occurred for all combinations of monitoring period, site, and analyte except for OP, which tended to move through the ponds without treatment during the pre-retrofit period. OP loads were reduced (29% and 82%) by the two ponds during the post-retrofit period.

Load reduction of TP varied from 15% to 76%. For both ponds, the post-retrofit period had higher percent load reductions and lower effluent loads of TP than the pre-retrofit period. For TN, load reduction for the two ponds varied from 35% to 78%, with both ponds performing better for load reduction in the post-retrofit period. However, the influent loads of TN in the post-retrofit period at the Museum pond were elevated by a factor of 3.9 when compared to the pre-retrofit monitoring period. Since it is necessarily easier to reduce a greater load of pollutants, the results from this pond for TN must be footnoted. The large influent loads of TN during the post-retrofit period probably were the cause for the increased effluent load of TN from this pond when comparing the post-retrofit to the pre-retrofit period. Effluent loads of TN were lower in the post-retrofit period at the Museum site.

Table 7. Pollutant loads (kg/ha/yr) for the DOT and Museum ponds
both pre- and post-retrofit.

DOT Pond Pollutant Load (kg/ha/yr)									
Monitoring Location	**TKN**	**$NO_{2\text{-}3}$-N**	**TN**	**TAN**	**ON**	**OP**	**PBP**	**TP**	**TSS**
Inlet Pre-Retrofit	8.5	1.2	9.6	1.7	8.0	0.7	0.8	1.5	4418
Outlet Pre-Retrofit	5.3	0.7	6.0	0.7	5.3	0.9	0.4	1.3	215
Inlet Post-Retrofit	7.4	2.5	9.9	0.7	6.7	1.1	0.7	1.8	842
Outlet Post-Retrofit	4.7	0.5	5.2	0.4	4.3	0.8	0.4	1.2	236
Museum Pond Pollutant Load (kg/ha/yr)									
Monitoring Location	**TKN**	**$NO_{2\text{-}3}$-N**	**TN**	**TAN**	**ON**	**OP**	**PBP**	**TP**	**TSS**
Inlet Pre-Retrofit	3.4	0.6	3.9	0.5	3.4	0.7	1.2	2.0	1210
Outlet Pre-Retrofit	2.1	0.4	2.5	0.3	2.2	0.7	0.3	1.0	213
Inlet Post-Retrofit	14.5	0.9	15.3	5.5	9.0	0.9	0.8	1.7	1532
Outlet Post-Retrofit	3.0	0.3	3.4	0.3	2.8	0.2	0.3	0.4	101

Turnover Volume Analysis

In theory, a stormwater pond works as a plug flow device which, when a storm event occurs, releases cleaner water while detaining the first flush (runoff from 25.4 mm of precipitation). To test this theory, an analysis of turnover volume versus effluent concentrations was completed. Turnover volume is defined as the ratio of influent stormwater volume to pond storage volume. We hypothesize that with greater turnover volumes, higher effluent pollutant concentrations will be produced by the wet ponds. To test this theory, the Pearson Correlation Coefficient with a Fisher Correction was calculated between turnover volume and the three major pollutants of concern in NC: TN, TP, and TSS. Since there were four data sets (two sites, pre- and post-retrofit), a total of 12 correlation coefficient's were calculated, with statistical significance calculated at an $\alpha = 0.05$.

Of the 12 combinations of effluent concentration and turnover volume, none of the combinations had a correlation coefficient that was large enough to be considered statistically significant. This suggests that pollutant effluent concentration was not related to turnover volume. Perhaps this can be explained by the fact that when turnover volume was less than unity (1.0), the ponds captured the majority of the dirty influent, releasing relatively clean effluent. When turnover volume was greater than unity, the effects of mixing and the capture of the first flush also resulted in relatively clean effluent concentrations. Turnover volume, whether small or large, had no impact on effluent concentrations leaving the ponds.

Wetland Plant Study Results

The mean plant biomass values for both sites are illustrated in Figure 11. It was observed that the above mat biomass was greater than the below mat biomass for all species except Sedge. Sedge was found to have large, wooly root systems (roughly 0.75 meters in length) in comparison to the other species. It was the only species with a biomass ratio less than 1.0 at both sites (Figure 11). All other plant species had biomass ratios greater than 1.0. The maximum biomass ratio was 6.3 (hibiscus) at the DOT pond and 2.7 (grass) at the Museum pond. At the DOT pond, hibiscus had the largest total mean plant biomass, followed by sedge. The museum site, which had much greater canopy cover from surrounding trees, had lower mean above and below mat biomass for all species sampled when compared against the DOT pond. No trees were present at the DOT pond. Sunlight is clearly an important factor in biomass accumulation on FWIs. The plant with the largest mean plant biomass at the Museum pond was sedge.

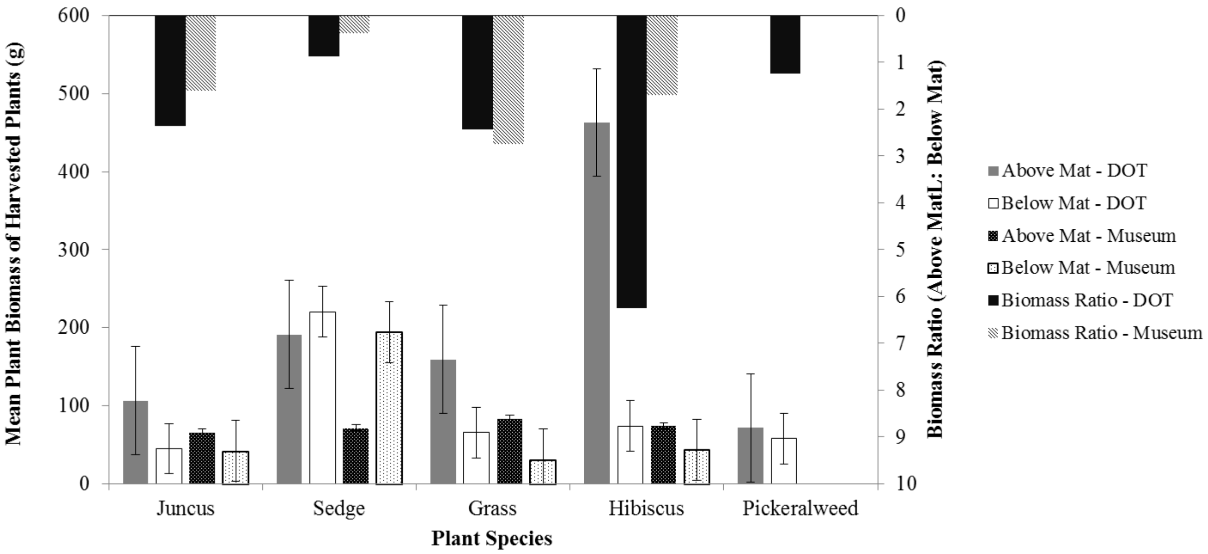
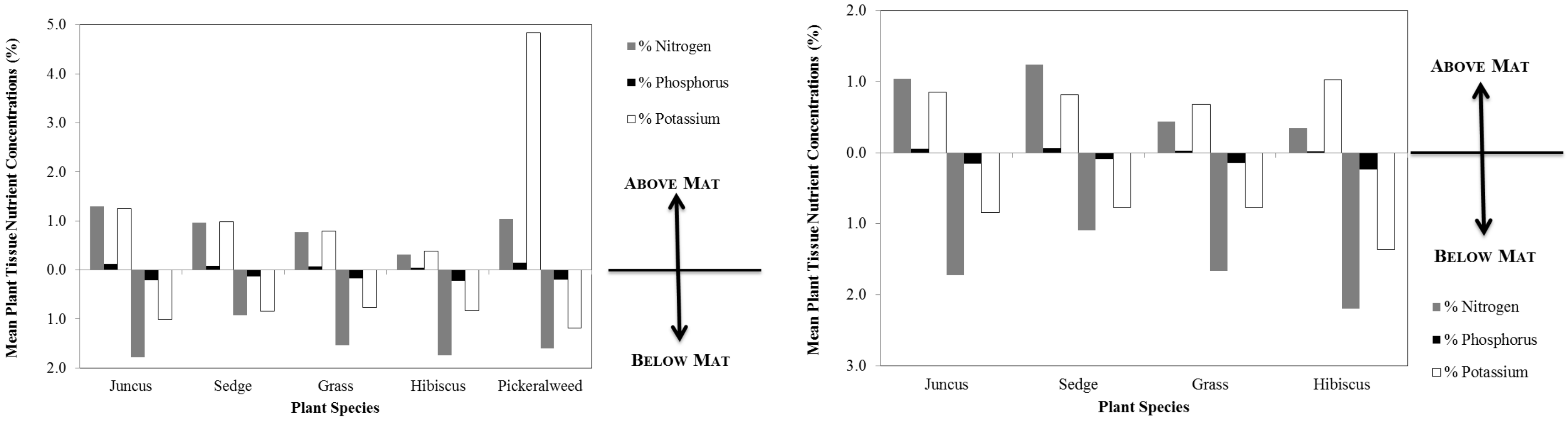


Figure 11. Side-by-side comparison of the mean plant biomass values of the harvested plants at the DOT and Museum sites. The error bars indicate standard error.

Overall the plant nutrient concentrations follow the same patterns for each species at both sites (Figure 12). Generally, nitrogen and potassium concentrations were much greater in magnitude than the phosphorus concentrations for each species. At both sites, N and P concentrations above the mat were less than or equal to 1% of plant biomass, while they were between 1-2% for the below mat biomass. With the exception of sedge at the Museum site, the below mat nutrient concentrations were greater than the above mat concentrations. The above mat potassium concentration (nearly 5%) for Pickerelweed at the DOT site was a substantial outlier.



(a) DOT site

(b) Museum site

Figure 12. Mean plant tissue macro-nutrient concentrations recorded in the above and below mat biomass for the (a) DOT and (b) Museum sites. Values below the x-axis indicate concentrations of the below mat biomass.

The total concentrations of macronutrients for each species were tabulated in Table 8. *Juncus* had the highest nitrogen concentrations at both ponds with 3.1% and 2.8%. Pickerelweed contained the most potassium at the DOT pond (not found at the Museum pond) with a total concentration of 6.0%; where hibiscus contained the most at the Museum pond with 2.4%. Phosphorus concentration did not specifically vary by plant species.

Table 8. Mean total (above + below) plant tissue macro-nutrient concentrations for each species at both sites

Plant Species	**Nitrogen (%)**	**Phosphorus (%)**	**Potassium (%)**
DOT Site			
Juncus	3.1	0.3	2.3
Sedge	1.9	0.2	1.8
Grass	2.3	0.2	1.6
Hibiscus	2.0	0.3	1.2
Pickeralweed	2.6	0.3	6.0
Museum Site			
Juncus	2.8	0.2	1.7
Sedge	2.3	0.2	1.6
Grass	2.1	0.2	1.4
Hibiscus	2.5	0.3	2.4

Benthic Macroinvertebrate Sampling Results

At the DOT pond, the pre-retrofit sampling of benthic macroinvertebrates was successful in identified 66 total specimens (Table 9). During post-retrofit sampling, a total of only 20 specimens were found, a decrease of 67%. Macroinvertebrate richness decreased from 10 to 5 from pre- to post-retrofit. Additionally, the diversity of the macroinvertebrate community was greater during the pre-retrofit period (Shannon's H' of 1.56 pre-retrofit and 1.16 post-retrofit). These H' values were much less than those reported as the average of 20 wet ponds in North Carolina, 1.97 (Moore and Hunt 2012). There may be two reasons for this apparent decline in macroinvertebrate community health: (1) the proliferation of Primrose in the pond, which may have provided shelter for small fish and other predators, and (2) the presence of mosquitofish (*Gambusia*) in the pond. During the pre-retrofit sampling, the presence of *Gambusia* was not noted; however, during post-retrofit sampling, they were found in three of the four sweep nets performed.

At the Museum pond, a 29% decline in total specimens occurred from pre- to post-retrofit, with 185 and 131 specimens, respectively (Table 9). Concurrently, richness of the macroinvertebrate population decreased from 15 to 10. The diversity of the macroinvertebrate community was greater during the pre-retrofit period (Shannon's H' of 2.31 pre-retrofit and 1.84 post-retrofit). The pre-retrofit diversity exceeded the average Shannon's H of 1.97 for 20 ponds in NC, while the post-retrofit diversity dipped below this value (Moore and Hunt 2012). This decline in macroinvertebrate richness and diversity was more challenging to explain, as no obvious changes in vegetation or fish population occurred at this pond. However, these results should be extrapolated on in future research. It is acknowledged that **sampling around the floating wetland islands was not undertaken**, and that these may provide further habitat for benthic macroinvertebrates.

Table 9. Benthic macroinvertebrate sampling results for the Museum and DOT ponds.

Family	DOT pond				Museum Pond			
	Pre-Retrofit		Post-Retrofit		Pre-Retrofit		Post-Retrofit	
	Number	Proportion of Total	Number	Proportion of Total	Number	Proportion of Total	Number	Proportion of Total
Ashnidae	-	-	-	-	11	0.06	-	-
Beatidae	1	0.02	-	-	11	0.06	6	0.05
Chironomidae	1	0.02	1	0.05	6	0.03	4	0.03
Coenagrionidae	32	0.48	-	-	12	0.06	-	-
Corixidae	1	0.02	-	-	6	0.03	-	-
Culicidae	4	0.06	7	0.35	8	0.04	34	0.26
Dysticidae	-	-	-	-	4	0.02	-	-
Gerridae	-	-	1	0.05	-	-	16	0.12
Haliplidae	-	-	-	-	-	-	1	0.01
Hirudinidae	-	-	-	-	1	0.01	-	-
Hydrophilidae	-	-	-	-	2	0.01	-	-
Libellulidae	5	0.08	1	0.05	34	0.18	6	0.05
Naucoridae	-	-	-	-	-	-	1	0.01
Nepidae	-	-	-	-	6	0.03	23	0.18
Notonectidae	-	-	-	-	37	0.20	36	0.27
Oligochaetae	-	-	-	-	31	0.17	-	-
Pyralidae	2	0.03	-	-	-	-	-	-
Pysidae	3	0.05	-	-	1	0.01	-	-
Tipulidae	1	0.02	-	-	-	-	-	-
Veliidae	16	0.24	-	-	15	0.08	-	-
Zygoptera	-	-	10	0.50	-	-	4	0.03

Outcomes and Conclusions

Two wet detention ponds in Durham, NC, were evaluated for pollutant concentrations and load improvement for fourteen months prior to and after retrofitting with floating wetland islands. The following conclusions can be drawn from this study:

1. The pre-retrofit wet detention ponds performed favorably, reducing TN, TP, and TSS mean concentrations by 36% and 59%, 36% and 57%, and 92% and 89%, respectively. These concentration reductions compared well to previous field research on wet detention. Additionally, the ponds met or exceeded the NC pollutant removal credit of 25% TN, 40% TP, and 85% TSS without consideration for potential load reduction through evapotranspiration.

2. During the pre-retrofit period, the DOT pond significantly reduced concentrations of $NO_{2\text{-}3}$-N, PBP, and TSS. The Museum pond significantly reduced TKN, TN, TAN, ON, PBP, TP, and TSS concentrations. Capture of TSS and sediment-bound pollutants was the dominant removal mechanism.

3. Data were mined from six wet ponds in the literature and were combined with the two pre-retrofit data sets. A negative linear relationship existed between hydraulic loading ratio and TSS removal efficiency. However, a much stronger positive linear relationship existed between loading ratio and mean effluent TSS concentrations. During engineering design, this relationship could be used as a predictor of effluent concentrations from wet ponds.

4. During the post-retrofit monitoring period, the DOT pond significantly reduced concentrations of seven of nine analytes studied (all except TAN and PBP), while the Museum pond with FWIs significantly reduced concentrations of all pollutants studied. Mean effluent concentrations were 0.44 mg/L, 0.05 mg/L, and 8 mg/L for TN, TP, and TSS, respectively, at the DOT pond during the post-retrofit period. Similar results were observed for TP (0.06 mg/L) and TSS (11 mg/L) at the Museum pond. Efficiency ratios improved during the post-retrofit vis-à-vis pre-retrofit period for TN and TP at both ponds and TSS at the Museum pond. When compared against the pre-retrofit period, these results would suggest that a larger number of unit processes were provided during the post-retrofit period, presumably due to the addition of the floating wetland

islands. The addition of the floating wetland islands also appeared to reduce variability in effluent concentrations.

5. Statistical comparisons between pre- and post-retrofit effluent concentrations showed no significant improvement in concentrations at the DOT site. At the museum site, OP, TP, and TSS effluent concentrations were significantly lower in the post-retrofit period. This suggested (1) that the benefit to pond performance with the addition of floating islands was modest and (2) that the Museum pond, which had 18% surface area coverage, performed better than the DOT site, which had 9% surface area coverage.

6. Pollutant load reductions occurred for every pollutant studied except OP. Sediment load reductions in the pond were between 72-95% for the two ponds. In most cases, the post-retrofit was lower than the pre-retrofit effluent load, suggesting treatment by the floating wetland islands.

7. The differences in wetland plant biomass values between the two sites can be attributed to the amount of sunlight received. The shaded Museum site had were overall less than those of the DOT site which had full sunlight throughout the day.

8. Overall, the plant nutrient concentrations follow the same patterns for each species at both sites. Nitrogen and potassium concentrations were much greater than the phosphorus concentrations for each species. The concentrations of all nutrients were greater in the below mat biomass in comparison to the above mat biomass.

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Budget

Line Item	**319h Allocated Funds**	**Match**	**Notes**
Personnel (Salary + Fringe)	$42,357	$3,337	Shawn Kennedy & RJ Winston (NCSU-paid.
Supplies and Materials	$42,208	$49,500 (City of Durham)	Purchase of FWI, Appurtenances and Plants
Mileage/ Motor Pool	$1809		RT NCSU-Durham
Chemical Analysis		$9,000	Provided by City of Durham
Equipment		$10,000	Provided by City of Durham
Forfeited Overhead/Other		$14,941	17.3% difference in OH from 27.3% NCSU requests & 10% 319 pays
Subtotal	$86,364	$86778	
10% Overhead	$8,636	$577	For match. Only applies to NCSU salary
Total	$95,000	$87,355	

Appendix A: Rainfall Data.

Table A.1. Rainfall data recorded during pre-retrofit monitoring period at the DOT site.

Event Number	Date	Rainfall Depth (in)	Rainfall Depth (mm)
1	12/22/2008	0.9	22.9
2	3/16/2009	2.26	57.4
3	5/26/2009	0.78	19.8
4	6/10/2009	4.55	115.6
5	7/14/2009	1.11	28.2
6	7/21/2009	0.3	7.6
7	7/24/2009	0.59	15.0
8	8/6/2009	0.68	17.3
9	8/21/2009	0.7	17.8
10	10/26/2009	0.44	11.2
11	11/2/2009	1.11	28.2
12	11/13/2009	5.88	149.4
13	11/20/2009	0.59	15.0
14	11/24/2009	1.33	33.8
15	2/23/2010	0.4	10.2
16	2/25/2010	0.28	7.1

Table A.2. Rainfall data recorded during post-retrofit monitoring period at the DOT site.

Event Number	Date	Rainfall Depth (in)	Rainfall Depth (mm)
17	07/14/10	1.92	48.8
18	07/28/10	1.63	41.4
19	08/06/10	0.67	17.0
20	08/25/10	0.35	8.9
21	09/28/10	2.6	66.0
22	10/15/10	1.39	35.3
23	02/07/11	1.3	33.0
24	03/01/11	0.86	21.8
25	03/07/11	0.45	11.4
26	03/10/11	0.42	10.7
27	03/28/11	0.58	14.7
28	08/29/11	0.52	13.2
29	08/30/11	0.39	9.9
30	09/07/11	5.2	132.1

31	09/22/11	0.84	21.3
32	09/26/11	0.9	22.9

Table A.3. Rainfall data recorded during pre-retrofit monitoring period at the Museum site.

Event Number	Date	Rainfall Depth (in)	Rainfall Depth (mm)
1	12/12/2008	1.76	44.7
2	12/22/2008	0.9	22.9
3	3/16/2009	2.31	58.7
4	6/10/2009	6.2	157.5
5	6/17/2009	0.57	14.5
6	7/14/2009	0.98	24.9
7	7/21/2009	0.51	13.0
8	8/6/2009	1.78	45.2
9	8/21/2009	0.51	13.0
10	10/26/2009	0.55	14.0
11	11/2/2009	1.25	31.8
12	11/13/2009	5.63	143.0
13	11/20/2009	0.47	11.9
14	11/24/2009	1.37	34.8
15	2/23/2010	0.38	9.7
16	2/25/2010	0.25	6.4

Table A.4. Rainfall data recorded during post-retrofit monitoring period at the Museum site.

Event Number	Date	Rainfall Depth (in)	Rainfall Depth (mm)
17	07/14/10	1.92	48.8
18	07/28/10	2.21	56.1
19	08/06/10	0.6	15.2
20	08/25/10	0.46	11.7
21	09/28/10	2.34	59.4
22	10/15/10	1.1	27.9
23	10/26/10	0.87	22.1
24	02/07/11	1.38	35.1
25	03/01/11	0.85	21.6
26	03/07/11	0.45	11.4
27	03/10/11	0.46	11.7
28	03/28/11	0.59	15.0

29	04/06/11	0.41	10.4
30	08/30/11	0.29	7.4
31	09/07/11	3.78	96.0
32	09/22/11	0.49	12.4
33	09/26/11	0.86	21.8
34	09/28/11	0.3	7.6

Appendix B: Sampled Storm Events.

Table B.1. Summary of sampled storm events at DOT site.

Event Number	Date	Pre- or Post-Retrofit	Constituents Sampled Basin Inlet	Constituents Sampled Basin Outlet
1	12/22/2008	Pre	P, TSS	P, TSS
2	3/16/2009		N, P, TSS	N, P, TSS
3	5/26/2009		N, P, TSS	N, P
4	6/10/2009		N, P, TSS	N, P, TSS
5	7/14/2009		N, P, TSS	N, P, TSS
6	7/21/2009		N, P, TSS	N, P, TSS
7	7/24/2009		N, P, TSS	N, P, TSS
8	8/6/2009		N, P, TSS	N, P, TSS
9	8/21/2009		N, P, TSS	N, P, TSS
10	10/26/2009		N, P, TSS	N, P, TSS
11	11/2/2009		N, P, TSS	N, P, TSS
12	11/13/2009		N, P, TSS	N, P, TSS
13	11/20/2009		N, P, TSS	N, P, TSS
14	11/24/2009		N, P, TSS	N, P, TSS
15	2/23/2010		N, P, TSS	N, P, TSS
16	2/25/2010		N, P	N, P
17	07/14/10	Post	N, P, TSS	N, P, TSS
18	07/28/10		N, P, TSS	N, P, TSS
19	08/06/10		N, P, TSS	N, P, TSS
20	08/25/10		N, P	N, P
21	09/28/10		N, P, TSS	N, P, TSS
22	10/15/10		N, P, TSS	N, P, TSS
23	02/07/11		N, P, TSS	N, P, TSS
24	03/01/11		N, P, TSS	N, P, TSS
25	03/07/11		N, P, TSS	N, P, TSS
26	03/10/11		N, P, TSS	N, P, TSS

27	03/28/11		N, P, TSS	N, P, TSS
28	08/29/11		N, P, TSS	N, P, TSS
29	08/30/11		N, P, TSS	N, P, TSS
30	09/07/11		N, P, TSS	N, P, TSS
31	09/22/11		N, P, TSS	N, P, TSS
32	09/26/11		N, P, TSS	N, P, TSS

Table B.2. Summary of sampled storm events at Museum site.

Event Number	**Date**	**Pre- or Post-Retrofit**	**Constituents Sampled Basin Inlet**	**Constituents Sampled Basin Outlet**
1	12/12/2008	Pre	N, P, TSS	N, P, TSS
2	12/22/2008		N, P, TSS	N, P, TSS
3	3/16/2009		N, P, TSS	N, P, TSS
4	6/10/2009		N, P, TSS	N, P, TSS
5	6/17/2009		N, P, TSS	N, P, TSS
6	7/14/2009		N, P, TSS	N, P, TSS
7	7/21/2009		N, P, TSS	N, P, TSS
8	8/6/2009		N, P, TSS	N, P, TSS
9	8/21/2009		N, P, TSS	N, P, TSS
10	10/26/2009		N, P, TSS	N, P, TSS
11	11/2/2009		N, P, TSS	N, P, TSS
12	11/13/2009		N, P, TSS	N, P, TSS
13	11/20/2009		N, P, TSS	N, P, TSS
14	11/24/2009		N, P, TSS	N, P, TSS
15	2/23/2010		N, P, TSS	N, P, TSS
16	2/25/2010		N, P	N, P
17	07/14/10	Post	N, P, TSS	N, P, TSS
18	07/28/10		N, P, TSS	N, P, TSS
19	08/06/10		N, P, TSS	N, P, TSS
20	08/25/10		N, P	N, P
21	09/28/10		N, P, TSS	N, P, TSS
22	10/15/10		N, P, TSS	N, P, TSS
23	10/26/10		N, P, TSS	N, P, TSS
24	02/07/11		N, P, TSS	N, P, TSS
25	03/01/11		N, P, TSS	N, P, TSS
26	03/07/11		N, P, TSS	N, P, TSS
27	03/10/11		N, P, TSS	N, P, TSS

28	03/28/11		N, P, TSS	N, P, TSS
29	04/06/11		N, P, TSS	N, P, TSS
30	08/30/11		N, P, TSS	N, P, TSS
31	09/07/11		N, P, TSS	N, P, TSS
32	09/22/11		N, P, TSS	N, P, TSS
33	09/26/11		N, P, TSS	N, P, TSS
34	09/28/11		N, P, TSS	N, P, TSS

Appendix C: Nutrient and Sediment Concentrations.

Table C.1. Pre-retrofit nutrient and sediment concentrations at the DOT basin inlet.

Storm No.	Sample Site	Date	TKN (mg/L)	NO_{2-3}-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)
1	Inlet	12/22/2008	No data	0.05	No data	0.11	No data	0.04	0.26	0.30	188
2	Inlet	3/16/2009	1.60	0.20	1.80	0.03	1.78	0.05	0.17	0.22	810
3	Inlet	5/26/2009	3.20	0.50	3.70	0.03	3.68	0.21	0.30	0.51	736
4	Inlet	6/10/2009	0.40	0.05	0.45	0.63	-0.18	0.06	0.06	0.12	1079
5	Inlet	7/14/2009	0.50	0.60	1.10	0.03	1.08	0.06	0.32	0.38	221
6	Inlet	7/21/2009	0.50	0.10	0.60	0.03	0.58	0.06	0.05	0.11	18
7	Inlet	7/24/2009	0.30	0.40	0.70	0.03	0.68	0.30	0.05	0.35	112
8	Inlet	8/6/2009	0.40	0.20	0.60	0.03	0.58	0.04	0.02	0.06	38
9	Inlet	8/21/2009	0.60	0.05	0.65	0.03	0.63	0.10	0.06	0.16	17
10	Inlet	10/26/2009	1.10	0.20	1.30	0.07	1.23	0.08	0.03	0.11	225
11	Inlet	11/2/2009	0.80	0.10	0.90	0.03	0.88	0.06	0.04	0.10	135
12	Inlet	11/13/2009	1.00	0.05	1.05	0.03	1.03	0.06	0.03	0.09	215
13	Inlet	11/20/2009	1.40	0.30	1.70	0.06	1.64	0.06	0.02	0.08	759
14	Inlet	11/24/2009	0.30	0.05	0.35	0.06	0.29	0.10	0.03	0.13	66
15	Inlet	2/23/2010	8.98	0.10	9.08	0.80	8.18	0.88	0.55	1.43	833
16	Inlet	2/25/2010	1.00	0.30	1.30	0.03	0.98	0.09	0.09	0.18	No data

Table C.2. Pre-retrofit nutrient and sediment concentrations at the DOT basin outlet.

Storm No.	Sample Site	Date	TKN (mg/L)	NO_{2-3}-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)
1	Outlet	12/22/2008	No data	0.10	No data	0.21	No data	0.03	0.04	0.07	17
2	Outlet	3/16/2009	0.05	0.20	0.25	0.03	0.22	0.02	0.07	0.08	49
3	Outlet	5/26/2009	1.10	0.05	1.15	0.03	1.13	0.05	0.11	0.16	No data
4	Outlet	6/10/2009	0.30	0.05	0.35	0.15	0.20	0.15	0.04	0.19	22
5	Outlet	7/14/2009	1.50	0.05	1.55	0.11	1.44	0.27	0.05	0.32	34
6	Outlet	7/21/2009	0.60	0.05	0.65	0.03	0.63	0.21	0.03	0.24	10
7	Outlet	7/24/2009	0.70	0.10	0.80	0.06	0.74	0.22	0.06	0.28	38
8	Outlet	8/6/2009	1.10	0.05	1.15	0.09	1.06	0.07	0.04	0.11	29
9	Outlet	8/21/2009	3.40	0.05	3.45	0.15	3.30	0.09	0.04	0.13	45
10	Outlet	10/26/2009	1.10	0.05	1.15	0.07	1.08	0.09	0.04	0.13	31
11	Outlet	11/2/2009	0.50	0.10	0.60	0.03	0.58	0.07	0.04	0.11	20
12	Outlet	11/13/2009	0.60	0.05	0.65	0.03	0.63	0.08	0.03	0.11	16
13	Outlet	11/20/2009	0.30	0.10	0.40	0.09	0.31	0.08	0.03	0.11	14

14	Outlet	11/24/2009	0.20	0.10	0.30	0.05	0.25	0.09	0.02	0.11	14
15	Outlet	2/23/2010	3.00	0.10	3.10	0.74	2.26	0.39	0.08	0.47	85
16	Outlet	2/25/2010	0.50	0.05	0.55	0.03	0.48	0.07	0.05	0.12	*

Table C.3. Post-retrofit nutrient and sediment concentrations at the DOT basin inlet.

Storm No.	Sample Site	Date	TKN (mg/L)	$NO_{2\text{-}3}$-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)
17	Inlet	7/14/2010	0.83	0.30	1.13	0.08	0.75	0.11	0.14	0.25	155
18	Inlet	7/28/2010	0.79	0.40	1.19	0.13	0.66	0.05	0.22	0.27	142
19	Inlet	8/6/2010	0.60	0.40	1.00	0.19	0.41	0.14	0.04	0.18	55
20	Inlet	8/25/2010	1.00	0.30	1.30	0.03	0.98	0.09	0.09	0.18	No data
21	Inlet	9/28/2010	1.20	0.40	1.60	0.03	1.18	0.21	0.16	0.37	215
22	Inlet	10/15/2010	1.10	0.40	1.50	0.32	0.78	0.17	0.10	0.27	144
23	Inlet	2/7/2011	0.40	0.90	1.30	0.03	0.38	0.02	0.05	0.06	36
24	Inlet	3/1/2011	0.15	0.20	0.35	0.03	0.13	0.07	0.03	0.10	128
25	Inlet	3/7/2011	0.80	0.40	1.20	0.03	0.78	0.08	0.09	0.17	137
26	Inlet	3/10/2011	1.00	0.40	1.40	0.49	0.51	0.05	0.05	0.10	32
27	Inlet	3/28/2011	0.80	0.60	1.40	0.03	0.78	0.14	0.03	0.17	61
28	Inlet	8/29/2011	0.8	0.05	0.85	0.03	0.78	0.03	0.01	0.04	9
29	Inlet	8/30/2011	1.2	0.30	1.50	0.0	1.18	0.22	0.03	0.25	100
30	Inlet	9/7/2011	0.8	0.05	0.85	0.03	0.78	0.11	0.01	0.12	10
31	Inlet	9/22/2011	1.3	0.20	1.50	0.27	1.03	0.31	0.03	0.34	227
32	Inlet	9/26/2011	0.6	0.10	0.70	0.06	0.54	0.13	0.05	0.18	69

Table C.4. Post-retrofit nutrient and sediment concentrations at the DOT basin outlet.

Storm No.	Sample Site	Date	TKN (mg/L)	$NO_{2\text{-}3}$-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)
17	Outlet	07/14/10	0.70	0.10	0.80	0.03	0.68	0.06	0.12	0.18	31
18	Outlet	07/28/10	0.94	0.05	0.99	0.12	0.82	0.22	0.06	0.28	79
19	Outlet	08/06/10	0.50	0.05	0.55	0.03	0.48	0.11	0.03	0.14	15
20	Outlet	08/25/10	0.50	0.05	0.55	0.03	0.48	0.07	0.05	0.12	No data
21	Outlet	09/28/10	0.15	0.05	0.20	0.03	0.13	0.09	0.04	0.13	11
22	Outlet	10/15/10	0.15	0.10	0.25	0.07	0.08	0.02	0.05	0.06	9
23	Outlet	02/07/11	0.60	0.05	0.65	0.03	0.58	0.02	0.05	0.06	21
24	Outlet	03/01/11	0.15	0.05	0.20	0.03	0.13	0.02	0.00	0.02	18
25	Outlet	03/07/11	0.40	0.05	0.45	0.11	0.29	0.02	0.05	0.06	18
26	Outlet	03/10/11	0.15	0.05	0.20	0.03	0.13	0.02	0.05	0.06	12
27	Outlet	03/28/11	1.40	0.05	1.45	0.05	1.35	0.02	0.17	0.18	26
28	Outlet	08/29/11	0.80	0.05	0.85	0.03	0.78	0.13	0.04	0.17	35
29	Outlet	08/30/11	0.70	0.05	0.75	0.03	0.68	0.02	0.04	0.05	4
30	Outlet	09/07/11	0.60	0.05	0.65	0.03	0.58	0.11	0.02	0.13	33
31	Outlet	09/22/11	0.80	0.05	0.85	0.14	0.66	0.12	0.03	0.15	18
32	Outlet	09/26/11	0.30	0.05	0.35	0.03	0.28	0.06	0.03	0.09	3

Table C.5. Pre-retrofit nutrient and sediment concentrations at the Museum basin inlet.

Storm No.	Sample Site	Date	TKN (mg/L)	$NO_{2\text{-}3}$-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)

1	Inlet	12/12/2008	1.10	0.05	1.15	0.23	0.92	0.19	0.49	0.68	354
2	Inlet	12/22/2008	0.15	0.05	0.20	0.22	-0.02	0.08	0.36	0.44	455
3	Inlet	3/16/2009	0.10	0.05	0.15	0.03	0.13	0.07	0.26	0.33	821
4	Inlet	6/10/2009	0.15	0.05	0.20	0.06	0.14	0.09	0.28	0.37	26
5	Inlet	6/17/2009	1.00	0.60	1.60	0.50	1.10	0.08	0.04	0.12	51
6	Inlet	7/14/2009	0.70	0.40	1.10	0.03	1.08	0.20	0.05	0.25	77
7	Inlet	7/21/2009	1.50	0.20	1.70	0.15	1.55	0.46	0.20	0.66	389
8	Inlet	8/6/2009	1.00	0.20	1.20	0.16	1.04	0.06	0.02	0.08	268
9	Inlet	8/21/2009	0.30	0.05	0.35	0.07	0.28	0.10	0.04	0.14	5
10	Inlet	10/26/2009	2.90	0.05	2.95	0.03	2.93	0.17	0.02	0.19	596
11	Inlet	11/2/2009	0.60	0.05	0.65	0.03	0.63	0.12	0.05	0.17	32
12	Inlet	11/13/2009	0.40	0.05	0.45	0.03	0.43	0.09	0.04	0.13	57
13	Inlet	11/20/2009	0.80	0.05	0.85	0.03	0.83	0.05	0.03	0.08	58
14	Inlet	11/24/2009	0.50	0.05	0.55	0.03	0.53	0.07	0.03	0.10	26
15	Inlet	2/23/2010	2.34	0.10	2.44	0.12	2.22	0.25	0.12	0.37	170
16	Inlet	2/25/2010	0.70	0.05	0.75	0.03	0.68	0.02	0.07	0.08	No Data

Table C.6. Pre-retrofit nutrient and sediment concentrations at the Museum basin outlet.

Storm No.	Sample Site	Date	TKN (mg/L)	NO_{2-3}-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)
1	Outlet	12/12/2008	0.50	0.10	0.60	0.22	0.38	0.19	0.01	0.20	64
2	Outlet	12/22/2008	0.15	0.05	0.20	0.13	0.07	0.07	0.02	0.09	14
3	Outlet	3/16/2009	0.15	0.10	0.25	0.03	0.23	0.05	0.10	0.15	117
4	Outlet	6/10/2009	0.15	0.05	0.20	0.03	0.18	0.13	0.04	0.17	31
5	Outlet	6/17/2009	0.40	0.05	0.45	0.09	0.36	0.10	0.05	0.15	27
6	Outlet	7/14/2009	0.50	0.05	0.55	0.03	0.53	0.02	0.04	0.05	11
7	Outlet	7/21/2009	0.30	0.05	0.35	0.03	0.33	0.02	0.03	0.04	5
8	Outlet	8/6/2009	0.15	0.05	0.20	0.03	0.18	0.06	0.02	0.08	14
9	Outlet	8/21/2009	0.30	0.05	0.35	0.03	0.33	0.08	0.03	0.11	11
10	Outlet	10/26/2009	0.40	0.05	0.45	0.03	0.43	0.09	0.06	0.15	10
11	Outlet	11/2/2009	0.30	0.05	0.35	0.03	0.33	0.09	0.04	0.13	3
12	Outlet	11/13/2009	0.40	0.05	0.45	0.03	0.43	0.07	0.03	0.10	5
13	Outlet	11/20/2009	0.50	0.05	0.55	0.05	0.50	0.06	0.06	0.12	6
14	Outlet	11/24/2009	0.60	0.05	0.65	0.03	0.63	0.09	0.02	0.11	29
15	Outlet	2/23/2010	0.13	0.05	0.18	0.05	0.08	0.04	0.01	0.05	20
16	Outlet	2/25/2010	0.60	0.20	0.80	0.03	0.58	0.02	0.08	0.09	No Data

Table C.7. Post-retrofit nutrient and sediment concentrations at the Museum basin inlet.

Storm No.	Sample Site	Date	TKN (mg/L)	NO_{2-3}-N (mg/L)	TN (mg/L)	TAN (mg/L)	ON (mg/L)	OP (mg/L)	PBP (mg/L)	TP (mg/L)	TSS (mg/L)
17	Inlet	07/14/10	0.64	0.20	0.84	0.13	0.51	0.02	0.08	0.09	145
18	Inlet	07/28/10	0.62	0.30	0.92	0.06	0.56	0.09	0.14	0.23	97
19	Inlet	08/06/10	0.40	0.30	0.70	0.15	0.25	0.07	0.03	0.10	27
20	Inlet	08/25/10	0.70	0.05	0.75	0.03	0.68	0.02	0.07	0.08	No data
21	Inlet	09/28/10	1.40	0.05	1.45	0.20	1.20	0.02	0.03	0.04	55
22	Inlet	10/15/10	1.50	0.20	1.70	0.27	1.23	0.11	0.12	0.23	113

23	Inlet	10/26/10	1.00	0.05	1.05	0.03	0.98	0.08	0.15	0.23	46
24	Inlet	02/07/11	15.00	0.20	15.20	6.26	8.74	0.77	0.51	1.28	2215
25	Inlet	03/01/11	3.30	0.20	3.50	3.25	0.05	0.08	0.29	0.37	105
26	Inlet	03/07/11	6.10	0.05	6.15	3.43	2.67	0.50	0.37	0.87	124
27	Inlet	03/10/11	15.30	0.10	15.40	12.30	3.00	1.10	0.68	1.78	61
28	Inlet	03/28/11	2.70	0.20	2.90	0.38	2.32	0.14	0.07	0.21	38
29	Inlet	04/06/11	7.20	0.10	7.30	1.33	5.87	0.95	0.28	1.23	966
30	Inlet	08/30/11	1.30	0.40	1.70	0.50	0.80	0.12	0.03	0.15	33
31	Inlet	09/07/11	0.80	0.05	0.85	0.03	0.78	0.05	0.10	0.15	107
32	Inlet	09/22/11	0.70	0.20	0.90	0.09	0.61	0.07	0.02	0.09	40
33	Inlet	09/26/11	0.40	0.05	0.45	0.11	0.29	0.08	0.03	0.11	52
34	Inlet	09/28/11	0.70	0.30	1.00	0.28	0.42	0.11	0.01	0.12	67

Table C.8. Post-retrofit nutrient and sediment concentrations at the Museum basin outlet.

17	Outlet	07/14/10	0.80	0.05	0.85	0.06	0.74	0.02	0.21	0.22	67
18	Outlet	07/28/10	0.72	0.05	0.77	0.05	0.67	0.04	0.04	0.08	21
19	Outlet	08/06/10	0.40	0.05	0.45	0.03	0.38	0.02	0.00	0.02	6
20	Outlet	08/25/10	0.60	0.20	0.80	0.03	0.58	0.02	0.08	0.09	No data
21	Outlet	09/28/10	0.50	0.05	0.55	0.07	0.43	0.02	0.03	0.04	8
22	Outlet	10/15/10	0.15	0.05	0.20	0.03	0.13	0.02	0.03	0.04	4
23	Outlet	10/26/10	0.20	0.05	0.25	0.03	0.18	0.03	0.02	0.05	4
24	Outlet	02/07/11	0.20	0.05	0.25	0.06	0.14	0.02	0.00	0.02	3
25	Outlet	03/01/11	0.15	0.05	0.20	0.03	0.13	0.02	0.00	0.02	17
26	Outlet	03/07/11	0.15	0.05	0.20	0.08	0.07	0.02	0.02	0.03	6
27	Outlet	03/10/11	0.15	0.05	0.20	0.05	0.10	0.02	0.03	0.04	6
28	Outlet	03/28/11	0.40	0.05	0.45	0.03	0.38	0.02	0.00	0.02	3
29	Outlet	04/06/11	0.50	0.05	0.55	0.03	0.48	0.02	0.03	0.04	44
30	Outlet	08/30/11	0.60	0.05	0.65	0.03	0.58	0.02	0.02	0.03	4
31	Outlet	09/07/11	0.60	0.05	0.65	0.03	0.58	0.04	0.02	0.06	11
32	Outlet	09/22/11	0.50	0.05	0.55	0.03	0.48	0.02	0.03	0.04	4
33	Outlet	09/26/11	0.02	0.05	0.07	0.03	-0.01	0.02	0.00	0.02	3
34	Outlet	09/28/11	0.02	0.05	0.07	0.03	-0.01	0.02	0.00	0.02	3

Appendix D: Nutrient and Sediment Loads.

Table D.1. Nutrient and sediment loads for the pre-retrofit DOT pond inlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	NO_{2-3}-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
1	12/22/2008	0.9	No Data	0.01	No Data	0.02	No Data	0.01	0.04	0.05	29
2	3/16/2009	2.26	0.76	0.09	0.85	0.01	0.84	0.02	0.08	0.10	384
3	5/26/2009	0.78	0.41	0.06	0.48	0.00	0.48	0.03	0.04	0.07	95
4	6/10/2009	4.55	0.41	0.05	0.47	0.65	-0.19	0.06	0.06	0.12	1118
5	7/14/2009	1.11	0.10	0.12	0.22	0.01	0.22	0.01	0.07	0.08	45
6	7/21/2009	0.3	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.00	1
7	7/24/2009	0.59	0.03	0.04	0.06	0.00	0.06	0.03	0.00	0.03	10
8	8/6/2009	0.68	0.04	0.02	0.06	0.00	0.06	0.00	0.00	0.01	4
9	8/21/2009	0.7	0.07	0.01	0.07	0.00	0.07	0.01	0.01	0.02	2
10	10/26/2009	0.44	0.06	0.01	0.08	0.00	0.07	0.00	0.00	0.01	13
11	11/2/2009	1.11	0.16	0.02	0.18	0.01	0.18	0.01	0.01	0.02	27
12	11/13/2009	5.88	1.37	0.07	1.44	0.03	1.40	0.08	0.04	0.12	294
13	11/20/2009	0.59	0.12	0.03	0.15	0.01	0.15	0.01	0.00	0.01	68
14	11/24/2009	1.33	0.08	0.01	0.09	0.02	0.07	0.03	0.01	0.03	17
15	2/23/2010	0.4	0.46	0.01	0.47	0.04	0.42	0.05	0.03	0.07	43
16	2/25/2010	0.28	0.03	0.01	0.04	0.00	0.03	0.00	0.00	0.01	No Data

Table D.2. Nutrient and sediment loads for the pre-retrofit DOT pond outlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	NO_{2-3}-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
1	12/22/2008	0.9	No Data	0.02	No Data	0.03	No Data	0.00	0.01	0.01	3
2	3/16/2009	2.26	0.02	0.09	0.12	0.01	0.10	0.01	0.03	0.04	23
3	5/26/2009	0.78	0.14	0.01	0.15	0.00	0.15	0.01	0.01	0.02	No Data
4	6/10/2009	4.55	0.31	0.05	0.36	0.16	0.21	0.16	0.04	0.20	23
5	7/14/2009	1.11	0.30	0.01	0.31	0.02	0.29	0.05	0.01	0.07	7
6	7/21/2009	0.3	0.02	0.00	0.02	0.00	0.02	0.01	0.00	0.01	0

7	7/24/2009	0.59	0.06	0.01	0.07	0.01	0.07	0.02	0.01	0.02	3
8	8/6/2009	0.68	0.12	0.01	0.12	0.01	0.11	0.01	0.00	0.01	3
9	8/21/2009	0.7	0.38	0.01	0.39	0.02	0.37	0.01	0.00	0.01	5
10	10/26/2009	0.44	0.06	0.00	0.07	0.00	0.06	0.01	0.00	0.01	2
11	11/2/2009	1.11	0.10	0.02	0.12	0.01	0.12	0.01	0.01	0.02	4
12	11/13/2009	5.88	0.82	0.07	0.89	0.03	0.86	0.11	0.04	0.15	22
13	11/20/2009	0.59	0.03	0.01	0.04	0.01	0.03	0.01	0.00	0.01	1
14	11/24/2009	1.33	0.05	0.03	0.08	0.01	0.06	0.02	0.01	0.03	4
15	2/23/2010	0.4	0.15	0.01	0.16	0.04	0.12	0.02	0.00	0.02	4
16	2/25/2010	0.28	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.00	No Data

Table D.3. Nutrient and sediment loads for the post-retrofit DOT pond inlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	$NO_{2\text{-}3}$-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
17	7/14/2010	1.92	0.32	0.12	0.44	0.03	0.29	0.04	0.05	0.10	61
18	7/28/2010	1.63	0.25	0.13	0.38	0.04	0.21	0.02	0.07	0.09	46
19	8/6/2010	0.67	0.06	0.04	0.11	0.02	0.04	0.01	0.00	0.02	6
20	8/25/2010	0.35	0.04	0.01	0.05	0.00	0.04	0.00	0.00	0.01	No Data
21	9/28/2010	2.6	0.67	0.22	0.89	0.01	0.65	0.12	0.09	0.21	120
22	10/15/2010	1.39	0.29	0.11	0.40	0.09	0.21	0.05	0.03	0.07	39
23	2/7/2011	1.3	0.10	0.22	0.32	0.01	0.09	0.00	0.01	0.01	9
24	3/1/2011	0.86	0.02	0.03	0.05	0.00	0.02	0.01	0.00	0.01	19
25	3/7/2011	0.45	0.05	0.02	0.07	0.00	0.05	0.00	0.01	0.01	8
26	3/10/2011	0.42	0.06	0.02	0.08	0.03	0.03	0.00	0.00	0.01	2
27	3/28/2011	0.58	0.07	0.05	0.12	0.00	0.07	0.01	0.00	0.01	5
28	8/29/2011	0.52	0.06	0.00	0.06	0.00	0.06	0.00	0.00	0.00	1
29	8/30/2011	0.39	0.06	0.01	0.07	0.00	0.06	0.01	0.00	0.01	5
30	9/7/2011	5.2	0.96	0.06	1.02	0.03	0.93	0.13	0.01	0.14	12
31	9/22/2011	0.84	0.19	0.03	0.21	0.04	0.15	0.04	0.00	0.05	32
32	9/26/2011	0.9	0.09	0.02	0.11	0.01	0.08	0.02	0.01	0.03	11

Table D.4. Nutrient and sediment loads for the post-retrofit DOT pond outlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	NO_{2-3}-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
17	07/14/10	1.92	0.28	0.04	0.31	0.01	0.27	0.02	0.05	0.07	12
18	07/28/10	1.63	0.31	0.02	0.32	0.04	0.27	0.07	0.02	0.09	26
19	08/06/10	0.67	0.05	0.01	0.06	0.00	0.05	0.01	0.00	0.01	2
20	08/25/10	0.35	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.01	No Data
21	09/28/10	2.6	0.08	0.03	0.11	0.01	0.07	0.05	0.02	0.07	6
22	10/15/10	1.39	0.04	0.03	0.07	0.02	0.02	0.00	0.01	0.02	2
23	02/07/11	1.3	0.15	0.01	0.16	0.01	0.14	0.00	0.01	0.01	5
24	03/01/11	0.86	0.02	0.01	0.03	0.00	0.02	0.00	0.00	0.00	3
25	03/07/11	0.45	0.02	0.00	0.03	0.01	0.02	0.00	0.00	0.00	1
26	03/10/11	0.42	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	1
27	03/28/11	0.58	0.12	0.00	0.13	0.00	0.12	0.00	0.01	0.02	2
28	08/29/11	0.52	0.06	0.00	0.06	0.00	0.06	0.01	0.00	0.01	3
29	08/30/11	0.39	0.03	0.00	0.04	0.00	0.03	0.00	0.00	0.00	0
30	09/07/11	5.2	0.72	0.06	0.78	0.03	0.69	0.13	0.02	0.16	40
31	09/22/11	0.84	0.11	0.01	0.12	0.02	0.09	0.02	0.00	0.02	3
32	09/26/11	0.9	0.05	0.01	0.05	0.00	0.04	0.01	0.00	0.01	0

Table D.5. Nutrient and sediment loads for the pre-retrofit Museum pond inlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	NO_{2-3}-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
1	12/12/2008	1.76	0.28	0.01	0.30	0.06	0.24	0.05	0.13	0.17	91
2	12/22/2008	0.9	0.02	0.01	0.02	0.02	0.00	0.01	0.04	0.04	46
3	3/16/2009	2.31	0.04	0.02	0.06	0.01	0.05	0.03	0.10	0.12	303
4	6/10/2009	6.2	0.19	0.06	0.25	0.08	0.18	0.11	0.35	0.47	33
5	6/17/2009	0.57	0.05	0.03	0.08	0.03	0.06	0.00	0.00	0.01	3
6	7/14/2009	0.98	0.08	0.05	0.13	0.00	0.12	0.02	0.01	0.03	9
7	7/21/2009	0.51	0.07	0.01	0.08	0.01	0.07	0.02	0.01	0.03	18
8	8/6/2009	1.78	0.26	0.05	0.31	0.04	0.27	0.02	0.01	0.02	70
9	8/21/2009	0.51	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.01	0
10	10/26/2009	0.55	0.15	0.00	0.15	0.00	0.15	0.01	0.00	0.01	30

11	11/2/2009	1.25	0.10	0.01	0.10	0.00	0.10	0.02	0.01	0.03	5
12	11/13/2009	5.63	0.45	0.06	0.51	0.03	0.48	0.10	0.05	0.15	64
13	11/20/2009	0.47	0.03	0.00	0.03	0.00	0.03	0.00	0.00	0.00	2
14	11/24/2009	1.37	0.09	0.01	0.10	0.00	0.10	0.01	0.01	0.02	5
15	2/23/2010	0.38	0.07	0.00	0.07	0.00	0.07	0.01	0.00	0.01	5
16	2/25/2010	0.25	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	No data

Table D.6. Nutrient and sediment loads for the pre-retrofit Museum pond outlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	$NO_{2\text{-}3}$-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
1	12/12/2008	1.76	0.13	0.03	0.15	0.06	0.10	0.05	0.00	0.05	16.42
2	12/22/2008	0.9	0.02	0.01	0.02	0.01	0.01	0.01	0.00	0.01	1.41
3	3/16/2009	2.31	0.06	0.04	0.09	0.01	0.08	0.02	0.04	0.06	43.18
4	6/10/2009	6.2	0.19	0.06	0.25	0.03	0.22	0.16	0.05	0.22	39.24
5	6/17/2009	0.57	0.02	0.00	0.02	0.00	0.02	0.01	0.00	0.01	1.42
6	7/14/2009	0.98	0.06	0.01	0.06	0.00	0.06	0.00	0.00	0.01	1.25
7	7/21/2009	0.51	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.23
8	8/6/2009	1.78	0.04	0.01	0.05	0.01	0.05	0.02	0.01	0.02	3.65
9	8/21/2009	0.51	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.50
10	10/26/2009	0.55	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.01	0.50
11	11/2/2009	1.25	0.05	0.01	0.06	0.00	0.05	0.01	0.01	0.02	0.48
12	11/13/2009	5.63	0.45	0.06	0.51	0.03	0.48	0.08	0.03	0.11	5.65
13	11/20/2009	0.47	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.24
14	11/24/2009	1.37	0.11	0.01	0.12	0.00	0.11	0.02	0.00	0.02	5.28
15	2/23/2010	0.38	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.61
16	2/25/2010	0.25	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	No Data

Table D.7. Nutrient and sediment loads for the post-retrofit Museum pond inlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	$NO_{2\text{-}3}$-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
17	07/14/10	1.92	0.19	0.06	0.24	0.04	0.15	0.00	0.02	0.03	42

18	07/28/10	2.21	0.22	0.10	0.32	0.02	0.19	0.03	0.05	0.08	34
19	08/06/10	0.6	0.02	0.02	0.04	0.01	0.01	0.00	0.00	0.01	2
20	08/25/10	0.46	0.03	0.00	0.03	0.00	0.03	0.00	0.00	0.00	No Data
21	09/28/10	2.34	0.53	0.02	0.54	0.08	0.45	0.01	0.01	0.02	21
22	10/15/10	1.1	0.20	0.03	0.23	0.04	0.16	0.01	0.02	0.03	15
23	10/26/10	0.87	0.10	0.00	0.10	0.00	0.09	0.01	0.01	0.02	4
24	02/07/11	1.38	2.76	0.04	2.79	1.15	1.61	0.14	0.09	0.24	407
25	03/01/11	0.85	0.31	0.02	0.33	0.30	0.00	0.01	0.03	0.03	10
26	03/07/11	0.45	0.23	0.00	0.23	0.13	0.10	0.02	0.01	0.03	5
27	03/10/11	0.46	0.60	0.00	0.60	0.48	0.12	0.04	0.03	0.07	2
28	03/28/11	0.59	0.15	0.01	0.16	0.02	0.13	0.01	0.00	0.01	2
29	04/06/11	0.41	0.24	0.00	0.24	0.04	0.20	0.03	0.01	0.04	32
30	08/30/11	0.29	0.03	0.01	0.04	0.01	0.02	0.00	0.00	0.00	1
31	09/07/11	3.78	0.56	0.03	0.59	0.02	0.54	0.03	0.07	0.10	74
32	09/22/11	0.49	0.03	0.01	0.04	0.00	0.03	0.00	0.00	0.00	2
33	09/26/11	0.86	0.04	0.00	0.04	0.01	0.03	0.01	0.00	0.01	5
34	09/28/11	0.3	0.02	0.01	0.02	0.01	0.01	0.00	0.00	0.00	2

Table D.8. Nutrient and sediment loads for the post-retrofit Museum pond outlet.

Storm No.	Date	Rainfall (in)	TKN (kg/ha)	NO_{2-3}-N (kg/ha)	TN (kg/ha)	TAN (kg/ha)	ON (kg/ha)	OP (kg/ha)	PBP (kg/ha)	TP (kg/ha)	TSS (kg/ha)
17	07/14/10	1.92	0.23	0.01	0.25	0.02	0.21	0.00	0.06	0.06	19
18	07/28/10	2.21	0.25	0.02	0.27	0.02	0.23	0.01	0.01	0.03	7
19	08/06/10	0.6	0.02	0.00	0.03	0.00	0.02	0.00	0.00	0.00	0
20	08/25/10	0.46	0.02	0.01	0.03	0.00	0.02	0.00	0.00	0.00	No Data
21	09/28/10	2.34	0.19	0.02	0.21	0.03	0.16	0.01	0.01	0.02	3
22	10/15/10	1.1	0.02	0.01	0.03	0.00	0.02	0.00	0.00	0.01	1
23	10/26/10	0.87	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0
24	02/07/11	1.38	0.04	0.01	0.05	0.01	0.03	0.00	0.00	0.00	1
25	03/01/11	0.85	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.00	2
26	03/07/11	0.45	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0
27	03/10/11	0.46	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0
28	03/28/11	0.59	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0

29	04/06/11	0.41	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.00	1
30	08/30/11	0.29	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0
31	09/07/11	3.78	0.42	0.03	0.45	0.02	0.40	0.03	0.01	0.04	8
32	09/22/11	0.49	0.02	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0
33	09/26/11	0.86	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0
34	09/28/11	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

Appendix E: Cumulative Probability Plots.

Cumulative probability plots are presented below in Figures E.1-E.6. They are created by ranking pollutant concentrations entering and leaving each SCM. Ranked concentrations are then regressed against the relative probability of that data point occurring. They are an excellent exploratory tool for water quality data, and provide an idea of the variation, range, and distribution of the data. At cumulative probabilities below 20%, there appeared to be little improvement in expected concentrations of TN, TP, and TSS due to potentially irreducible influent concentrations. As influent pollutant concentrations increased, there was a better chance of pollutant removal by the wet detention ponds. In general, about than 50% of the influent TN samples exceed the water quality benchmark of 0.99 mg/L. This percentage was improved to 40% at the Museum site and 30% at the DOT site. TP concentrations in both ponds exhibited little improvement until the influent concentration reached 0.20 mg/L. At the two sites, influent concentrations met the 25 mg/L TSS benchmark between 10-25% of the sampled events. This metric was met about 80% of the time by the effluent of the DOT pond and about 60% of the time for the Museum pond. For all pollutants, ranked effluent concentrations during the post-retrofit period were generally lower in magnitude than those from the pre-retrofit period, suggesting some improvement from the addition of floating wetland islands.

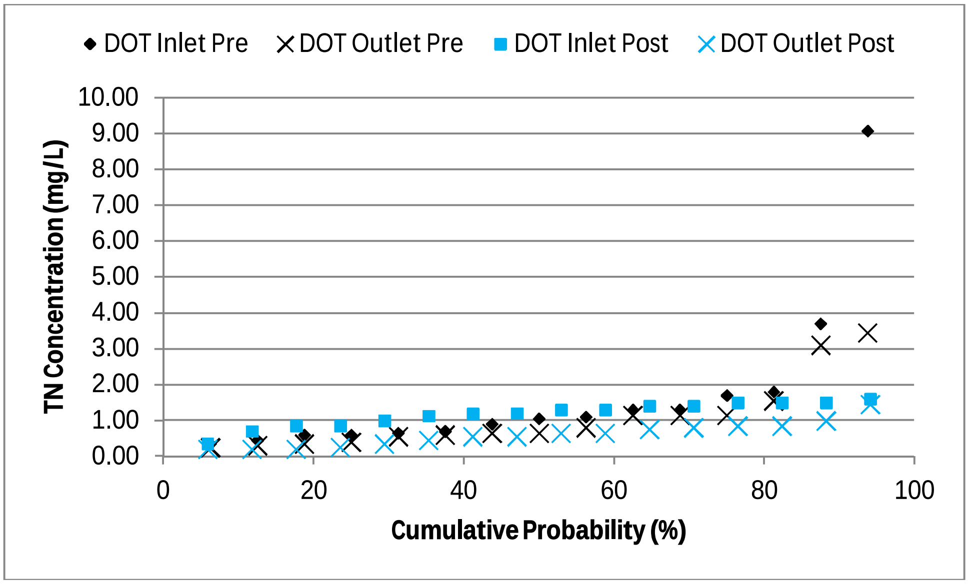


Figure E.1. Cumulative probability plot for TN at the DOT site.

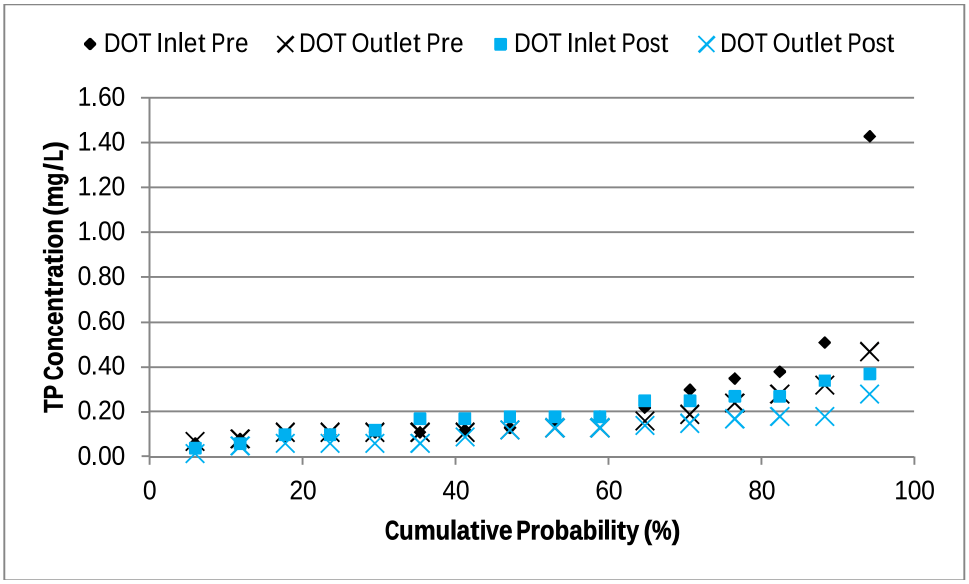


Figure E.2. Cumulative probability plots for TP at the DOT site.

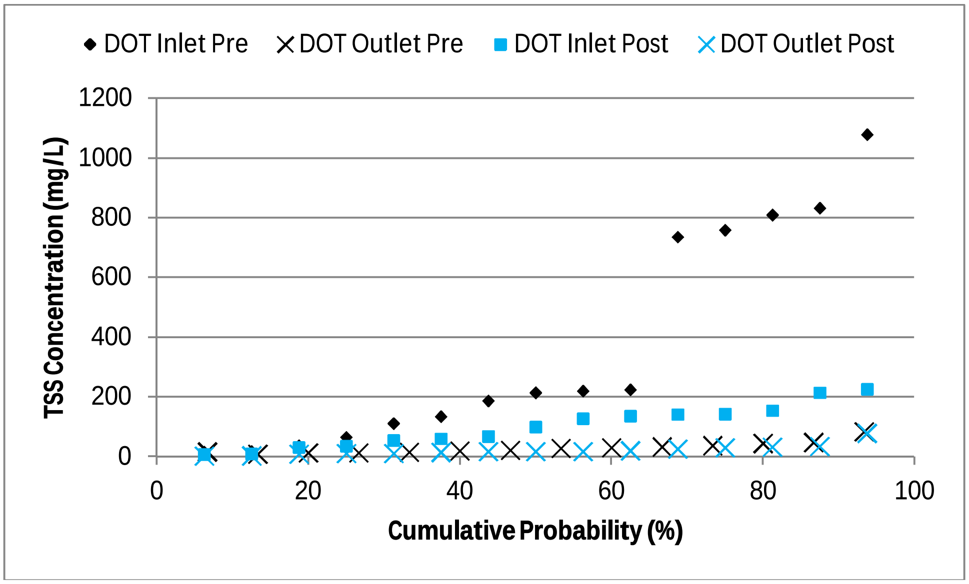


Figure E.3. Cumulative probability plot for TSS at the DOT site.

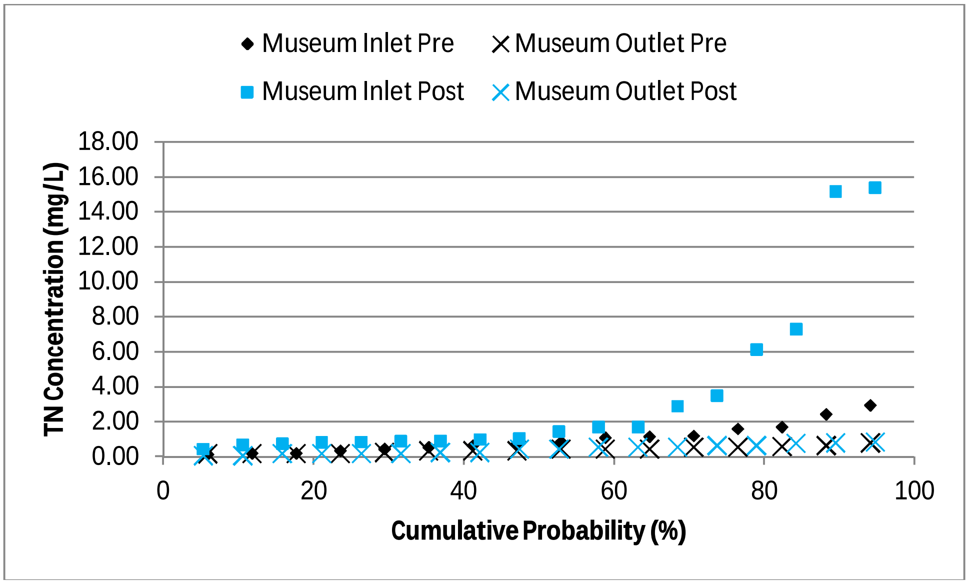


Figure E.4. Cumulative probability plot for TN at the Museum site.

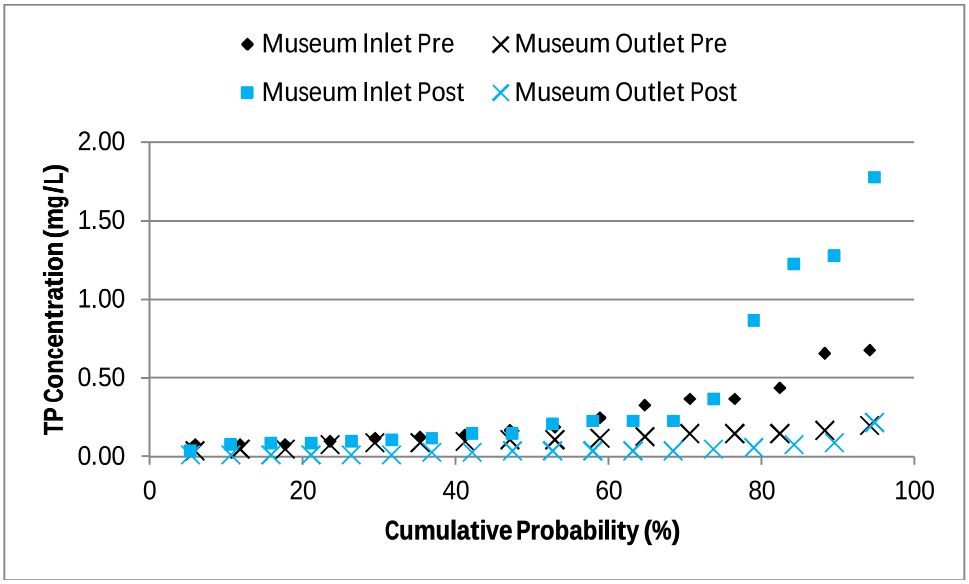


Figure E.5. Cumulative probability plot for TP at the Museum site.

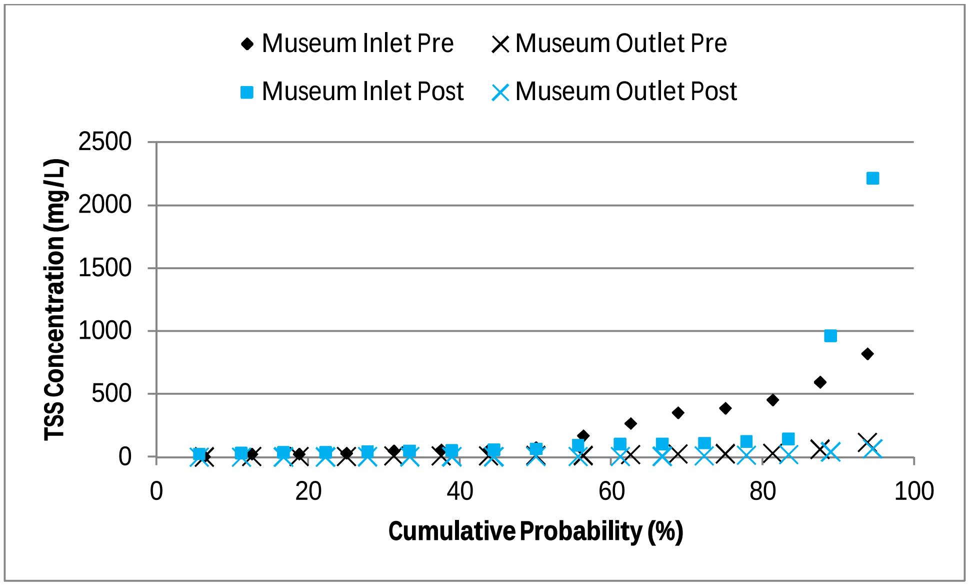


Figure E.6. Cumulative probability plot for TSS at the Museum site.

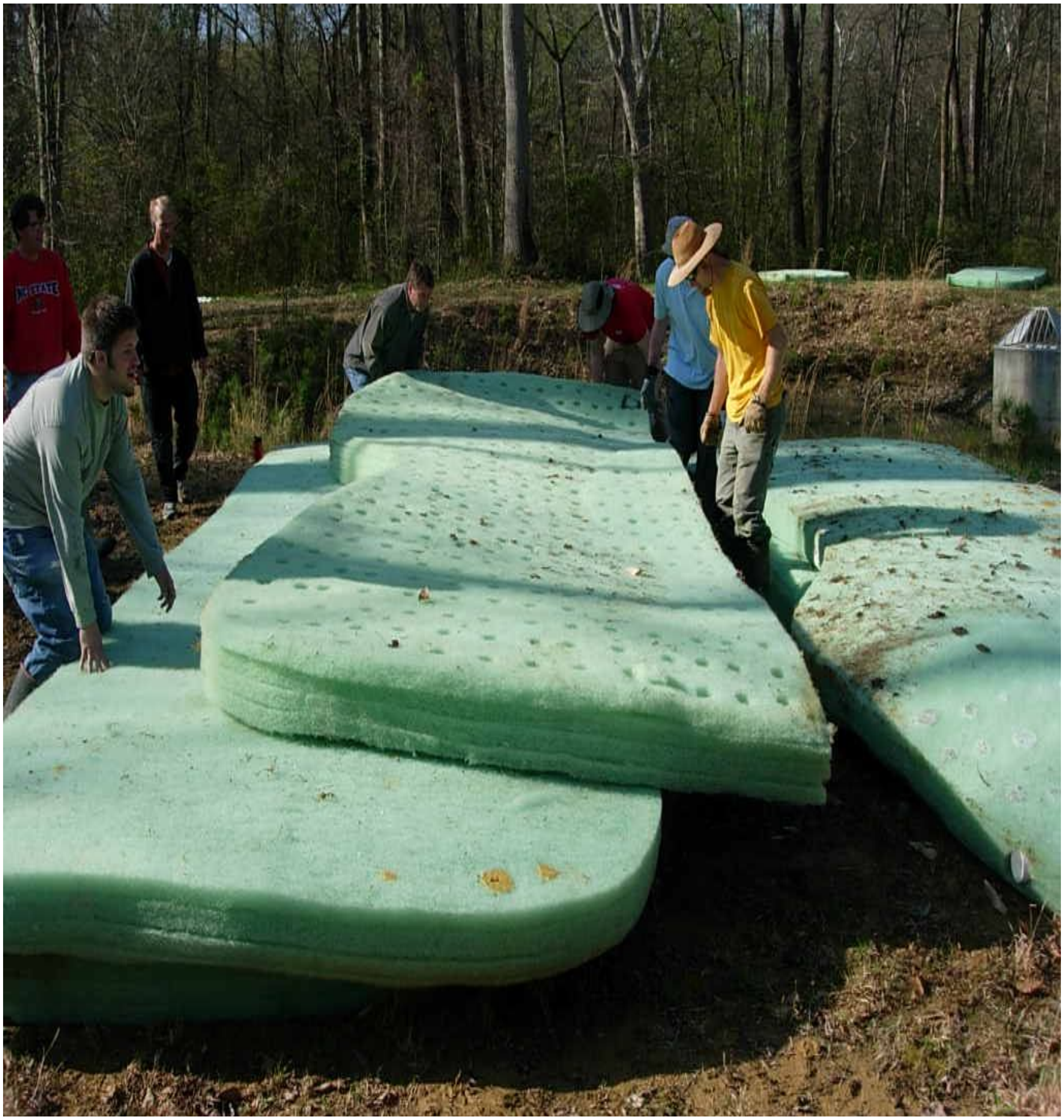
Appendix F: Wetland Island Plant Data.

Species	Location	Sample #	Roots or Shoots?	Dry Wt Biomass Before Grinding (g)	Total Sample Wt (g) *Used by lab	Sand Wt (g) *Found by lab	Biomass Wt (g) *Used for analysis	C	N	P	K
Juncus	DOT	1	Roots	43.0	2.5	0.382	2.118	31.21%	1.71%	0.21%	1.15%
Juncus	DOT	1	Shoots	60.4	2.5		2.500	45.34%	1.39%	0.14%	1.49%
Juncus	DOT	2	Roots	13.5	2.5	0.316	2.184	34.54%	1.81%	0.20%	1.06%
Juncus	DOT	2	Shoots	173.0	2.5		2.500	44.97%	1.22%	0.08%	0.76%
Juncus	DOT	3	Roots	78.5	2.5	0.544	1.956	30.50%	1.82%	0.22%	0.81%
Juncus	DOT	3	Shoots	85.5	2.5		2.500	45.77%	1.27%	0.14%	1.50%
Juncus	Museum	1	Roots	29.5	2.5	0.206	2.294	39.54%	1.91%	0.18%	0.52%
Juncus	Museum	1	Shoots	57.0	2.5		2.500	46.03%	1.01%	0.05%	0.71%
Juncus	Museum	2	Roots	39.5	2.5	0.238	2.262	36.49%	1.57%	0.14%	1.04%
Juncus	Museum	2	Shoots	94.5	2.5		2.500	46.06%	1.12%	0.06%	0.94%
Juncus	Museum	3	Roots	56.0	2.5	0.203	2.297	37.49%	1.68%	0.14%	0.98%
Juncus	Museum	3	Shoots	47.0	2.5		2.500	46.25%	0.98%	0.05%	0.90%
Sedge	DOT	1	Roots	170.0	2.5	0.131	2.369	40.74%	0.97%	0.13%	0.87%
Sedge	DOT	1	Shoots	156.0	2.5		2.500	45.29%	0.90%	0.07%	0.80%
Sedge	DOT	2	Roots	271.0	2.5	0.582	1.918	27.83%	0.86%	0.12%	0.66%
Sedge	DOT	2	Shoots	288.5	2.5		2.500	45.33%	1.13%	0.09%	1.01%
Sedge	DOT	3	Roots	220.5	2.5	0.204	2.296	38.53%	0.93%	0.14%	0.98%
Sedge	DOT	3	Shoots	128.5	2.5		2.500	45.94%	0.86%	0.10%	1.13%
Sedge	Museum	1	Roots	225.5	2.5	0.036	2.464	43.82%	1.14%	0.09%	0.81%
Sedge	Museum	1	Shoots	75.5	2.5		2.500	44.91%	1.30%	0.07%	0.80%
Sedge	Museum	2	Roots	227.0	2.5	0.044	2.456	42.99%	1.06%	0.09%	0.94%
Sedge	Museum	2	Shoots	65.5	2.5		2.500	45.47%	1.31%	0.07%	0.79%
Sedge	Museum	3	Roots	131.5	2.5	0.049	2.451	44.35%	1.07%	0.09%	0.56%

Sedge	Museum	3	Shoots	74.0	2.5		2.500	46.00%	1.10%	0.06%	0.86%
Grass	DOT	1	Roots	138.0	2.5	0.169	2.331	39.65%	1.14%	0.18%	0.80%
Grass	DOT	1	Shoots	63.0	2.5		2.500	44.62%	0.71%	0.06%	0.86%
Grass	DOT	2	Roots	38.5	2.5	0.139	2.361	41.05%	1.67%	0.15%	0.77%
Grass	DOT	2	Shoots	96.5	2.5		2.500	46.15%	0.82%	0.07%	0.49%
Grass	DOT	3	Roots	20.0	2.5	0.240	2.260	38.60%	1.82%	0.19%	0.74%
Grass	DOT	3	Shoots	318.5	2.5		2.500	44.38%	0.79%	0.07%	1.01%
Grass	Museum	1	Roots	46.5	2.5	0.159	2.341	38.48%	1.69%	0.15%	0.71%
Grass	Museum	1	Shoots	90.5	2.5		2.500	45.94%	0.36%	0.03%	0.61%
Grass	Museum	2	Roots	11.5	2.5	0.045	2.455	43.04%	1.53%	0.13%	0.71%
Grass	Museum	2	Shoots	123.0	2.5		2.500	46.22%	0.25%	0.01%	0.74%
Grass	Museum	3	Roots	34.0	2.5	0.165	2.335	40.45%	1.79%	0.16%	0.89%
Grass	Museum	3	Shoots	38.5	2.5		2.500	45.91%	0.71%	0.05%	0.68%
Hibiscus	DOT	1	Roots	116.0	2.5	0.059	2.441	41.41%	1.76%	0.26%	0.99%
Hibiscus	DOT	1	Shoots	604.5	2.5		2.500	44.48%	0.35%	0.06%	0.53%
Hibiscus	DOT	2	Roots	51.5	2.5	0.073	2.427	42.01%	1.67%	0.21%	0.82%
Hibiscus	DOT	2	Shoots	512.0	2.5		2.500	46.46%	0.24%	0.02%	0.16%
Hibiscus	DOT	3	Roots	54.5	2.5	0.150	2.350	39.08%	1.78%	0.22%	0.69%
Hibiscus	DOT	3	Shoots	272.0	2.5		2.500	45.13%	0.34%	0.04%	0.46%
Hibiscus	Museum	1	Roots	40.5	2.5	0.029	2.471	42.51%	2.18%	0.23%	1.53%
Hibiscus	Museum	1	Shoots	80.5	2.5		2.500	44.15%	0.36%	0.02%	1.09%
Hibiscus	Museum	2	Roots	17.0	2.5	0.037	2.463	43.80%	2.29%	0.23%	1.22%
Hibiscus	Museum	2	Shoots	17.0	2.5		2.500	43.33%	0.40%	0.03%	1.13%
Hibiscus	Museum	3	Roots	74.0	2.5	0.025	2.475	43.55%	2.11%	0.25%	1.33%
Hibiscus	Museum	3	Shoots	125.5	2.5		2.500	44.71%	0.29%	0.02%	0.85%
P-weed	DOT	1	Roots	113.0	2.5	0.131	2.369	40.24%	1.56%	0.18%	0.97%
P-weed	DOT	1	Shoots	149.0	2.5		2.500	41.05%	0.95%	0.13%	4.51%

P-weed	DOT	2	Roots	51.5	2.5	0.134	2.366	40.64%	1.59%	0.20%	0.87%
P-weed	DOT	2	Shoots	52.5	2.5		2.500	40.02%	1.01%	0.14%	5.78%
P-weed	DOT	3	Roots	8.5	2.5	0.099	2.401	39.74%	1.65%	0.20%	1.74%
P-weed	DOT	3	Shoots	14.0	2.5		2.500	40.91%	1.15%	0.18%	4.23%

Appendix G: Pictorial Description of Floating Wetland Island Installation.



Large islands with pre-drilled holes move moveable by groups of 4 to 5 people.

An example of one off the pre-set holes.


The holes were filled with peat moss to “jump start” plant growth.

Vegetation was able to easily slide into the available “slots.”

Floating the islands was relatively simple. They were anchored" using cinderblocks tethered to each corner of the island.

At the DOT pond, it was imperative to install goose fencing to deter goose predation. It did appear to thwart geese.

Even by May, a substantial amount of growth was evident on some islands.

How the islands looked in July 2010, when monitoring began.

Islands 1 year after planting (April 2011).