# Nutrient Reduction in Stormwater Pond Discharge Using a Chamber Upflow Filter and Skimmer (CUFS)

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**Abstract**: Stormwater runoff is a known pollutant source capable of causing surface water degradation, especially in highly populated areas such as Central Florida. Wet detention ponds manage this stormwater, but most of the ponds do not remove enough nutrients, specifically nitrogen and phosphorus, to meet TMDL regulations. This paper presents the use of a Chamber Upflow Filter and Skimmer (CUFS) filled with a specific green sorption medium as process modification of stormwater retention ponds, which can increase the removal of nitrogen and phosphorus in the stormwater runoff. Green sorption medium consists of recycled and natural materials that provide a favorable environment for pollutant removal. Water enters the system through the skimmer, which floats on the surface of the detention pond. It travels from the skimmer to the bottom of the chamber, where heavier particles settle out before entering the upflow filter. The upflow filter contains 61 cm (24 inches) of green sorption medium providing physicochemical and microbiological processes to remove nitrogen and phosphorus under anoxic/anaerobic conditions. After this treatment, water flows up through the filter and out of the system, and eventually travels to Lake Jesup, a eutrophic lake in Central Florida. A total of twenty-eight storm events and seven baseflows were sampled from the site in Seminole County, and ten storm events were sampled from a pilot study of CUFS for statistical analysis and performance evaluation. Significant reductions by the CUFS were confirmed in terms of turbidity, orthophosphorus, total phosphorus, and total suspended solids when the mean values were compared at a 95% confidence level. Reductions also occurred for total nitrogen, but could not be proved by the mean comparison in the field test, whereas the pilot scale application of the CUFS proved effective for reducing total nitrogen at a 95% confidence level. Hydraulic retention time should be increased so as to improve the design for total nitrogen removal in future applications.

**Keyword**: Stormwater management, Sorption media, Nutrient control, Best management practices, Green infrastructure, Sustainable development

## Introduction

Most of the environmental management in the past few decades has focused largely on point-source pollution of industrial and municipal effluents. Not much comparable effort has been made to restrict the input of nitrogen (N) and phosphorous (P) from dispersed or nonpoint sources such as agricultural and urban runoff. As a result, anthropogenic inputs of nonpoint pollutants, particularly N and P, have increased dramatically. Elevated nutrient levels in surface and ground water may cause human health problems, such as blue baby syndrome (Crittenden et. al, 2005), and may impair or destroy environmentally sensitive habitat through algal blooms and eutrophication (Allen and Kramer, 1972).

Many surface waters in Central Florida, such as Lake Jesup where nitrogen and phosphorus are considered the limiting nutrients for primary production (Allen and Kramer, 1972), currently experience eutrophication problems caused by high nutrient loading from stormwater detention ponds (i.e., wet ponds). Stormwater runoff is just one possible source of nitrogen; others include septic tanks and land-based applications of reclaimed wastewater or fertilizer, which can elevate nutrient concentrations. In a total maximum daily load (TMDL) report for water quality improvement proposed by the Florida Department of Environmental Protection (FDEP), the St. Johns River Water Management District (SJRWMD) examined several approaches to find a target nutrient concentration for Lake Jesup, which ranged from 0.04 to 0.08 mg/L for total phosphorus (TP) and 0.61 to 2.40 mg/L for total nitrogen (TN). The SJRWMD found concentrations of TN and TP that provide sufficient water clarity for growth of submerged aquatic vegetation (SAV) over 25% of Lake Jesup. SAV growth should enhance fisheries and provide wildlife habitat, as well as reduce the resuspension of flocculent organic sediments. The TMDL report for Lake Jesup also shows a current annual load entering the lake of 559,500 kg/year of TN and 36,000 kg/year of TP. Surface runoff accounts for 42% and 48% of the TN and TP loadings into the lake, respectively. To meet the TMDL standards, the loading into the lake should decrease 52% for total nitrogen and 37% for total phosphorus (Gao, 2005a). The TN and TP target concentrations that allow the 25% SAV criteria are 0.61 mg/L and 0.04 mg/L, respectively (Gao, 2005b). These concentrations were used as the standards for Lake Jesup in regards to this research project. No point sources currently discharge into the lake, so these goals must result from reduced nutrient concentrations in stormwater runoff.

Nitrogen- and phosphorous-containing compounds are found in urban stormwater runoff, primarily that from highways (USEPA, 1999). Nitrates normally result from vehicular exhaust on the roadway itself and are also contributed from fertilized landscaped areas and residential areas alongside the road (German, 1989; Vitousek et al., 1997). Considered one of the most efficient Best Management Practices (BMPs), a wet detention pond removes contaminants through physical, biological, and chemical processes (USEPA, 1999). This practice is used to treat stormwater runoff before it enters a surface water body. According to Chapter 62-40 of the Florida Administration Code, a stormwater pond shall achieve an 80% average annual load reduction of pollutants from the influent stormwater. The current law refers to the removal of solids only. However, the pond can only remove a certain percentage of a contaminant, and the discharged pollution, although significantly less than in stormwater runoff, may still damage fragile ecosystems in a receiving water body. The data compiled by Harper and Baker (2007a) from previous research studies suggest that detention ponds do not achieve this 80% goal for the nutrient pollutants of concern. The averages of the removal efficiencies from these studies show a 37% removal of TN, 79% for orthophosphorus, and 69% for TP (Harper and Baker, 2007a). There is an acute need to provide innovative methods, systems, apparatus and devices for nutrient control and management for sources of nitrogen and phosphorus including stormwater runoff.

The use of sorption media, such as compost, to capture pollutants from storm water runoff started from late 1990s (Richman, 1997; DeBusk et al., 1997). Stormwater infiltration systems were then widely used to address the quality issue of stormwater runoff through the use of either infiltration (Birch et al., 2005; Hatt et al., 2007) or exfiltration (Sansalone and Teng, 2004). Engineered soil mix that provides stormwater treatment through filtration has been deemed as a sustainable source-control option (Ellis, 2007; Chang et al., 2009), and various types of applications have been promoted recently in the context of green infrastructure systems (Kim et al., 2000; Hsieh and Davis, 2005; Seelsaen et al., 2006; Hossain et al., 2009). Sanz et al., (1996) discussed the simultaneous removal of nitrogen and solids in continuous upflow filters and a computer simulation of the nitrification process based on the Activated Sludge Model No. 1 developed by the International Association of Water Quality (IAWQ). Yet, the use of upflow filtration for stormwater treatment is a relatively new idea to remove pollutants from contaminated stormwater runoff. Upflow filters have the advantage of longer run times and less maintenance than traditional down-flow filters due to the design of the filter. Khambhammettu et al. (2006) used an upflow filter to treat runoff from highly contaminated critical source areas before it mixed with runoff from less contaminated areas. They studied a field application of the upflow filter inserted into a catch basin that achieved reductions of 70% for suspended solids, 65% for turbidity, and 18% for phosphorus (Khambhammettu et al., 2006). There are upflow filters commercialized for runoff treatment in stormwater inlets, and the successful integration of an upflow filter filled with the green sorption medium connected with surface skimmer could provide a new best management practice (BMP) to improve the quality of stormwater runoff. Green sorption medium consists of several recycled and natural media types that provide a favorable environment for pollutant removal to occur. Each type of media in the medium assists in the removal of specific nutrients. Phosphorus sorbs to one type of media, while another media is utilized as a carbon source for nitrate removal under anoxic conditions. Anoxic water has no free oxygen but does contain nitrate as electron acceptor for denitrification.

The combination of these elements provides a cost-effective treatment option to reduce nutrients traveling from wet detention ponds to surface waters. This paper presents the use of a Chamber Upflow Filter and Skimmer (CUFS) filled with a specific green sorption medium as process modification of stormwater retention ponds, which can increase the removal of nitrogen and phosphorus in the stormwater runoff. A similar study has proved the sorption medium effective for phosphorus removal from irrigation water in green roof chambers already (Hardin, 2006). Yet this study particularly evaluates the performance of a CUFS in terms of water quality, water quantity, and overall operation and maintenance. Specifically, the objectives of this study include: 1) estimate the head loss through an upflow filter with a chosen media mix; 2) test the applicability of a surface skimmer; and 3) assess nitrogen and phosphorus concentrations leaving a detention pond using a CUFS setup with a specific sorption media for pollution control.

## Materials and Methods

### Study Site

The wet detention pond used for this research is located in the Lake Jesup Watershed in Central Florida and discharges to Howell Creek that flows into Lake Jesup (Figure 1). The Lake Jesup Watershed extends into Seminole and Orange counties and covers more than 35,222 hectares (87,000 acres), and the lake itself has a surface area of 4316 hectares (10,660 acres) (Gao, 2005c). Lake Jesup has been identified as one of the most hypereutrophic lakes in Central Florida, as displayed by often fish kills and pea-green colored water (FDEP, 1997). Figure 1 shows the BMPs that have been applied to the Lake Jesup Watershed.

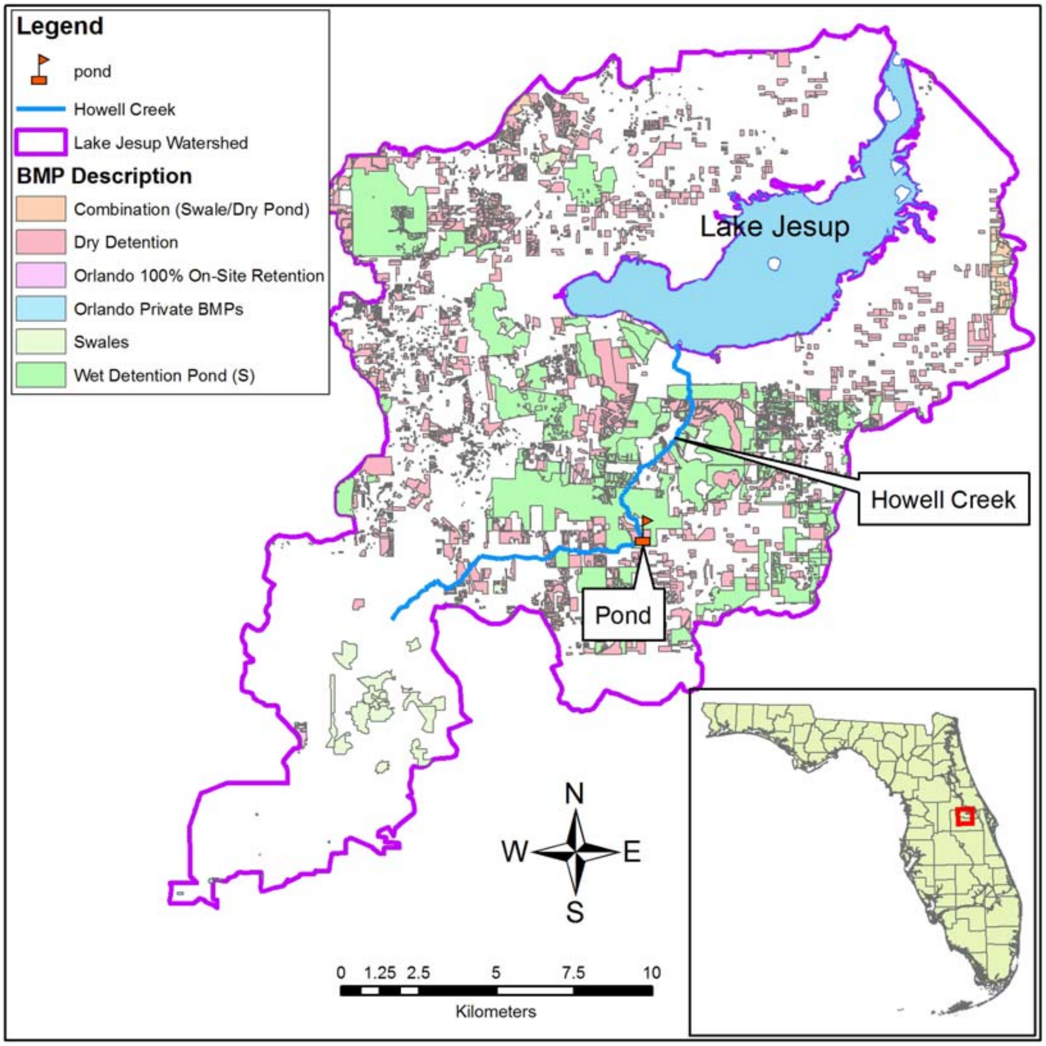


Figure 1: Lake Jesup Watershed and the study area

The CUFS receives water from Red Bug Stormwater Pond B in Seminole County which will be referred to as Red Bug Pond herein. This pond was constructed in 1990 as an improvement to stormwater control systems for the Lake Jesup Watershed in Seminole County. Red Bug Pond receives stormwater runoff from 3.65 hectares (9.02 acres) of impervious surfaces, 2.72 hectares (6.72 acres) of open spaced grassed areas, and 12.61 hectares (31.15 acres) of residential development (DCE, 1990).

## Experimental Setup

The setup of the CUFS consists of a floating pond skimmer connected by a pipe to the bottom of a precast concrete chamber. The chamber, a Department of Transportation (DOT) inlet, houses the filtering media which serves as the main nutrient removal mechanism in the setup. The floating pond skimmer is the inlet that directs water from the surface of the pond through the filter. The inlet at the water surface allows heavier particles to settle in the pond, and the water has fewer particles that will travel to the filter. The skimmer helps provide the power required to push the pond water through the filtering media and out to the pond effluent. This happens as a result of the difference in water elevations between the pond and upflow filter. The actual water surface elevation in the filter will be lower than that of the pond due to the head loss of the filtering media. At a time when no inflow to the pond is encountered (i.e., no stormwater runoff), the water level in the stormwater pond will equal the head difference of the upflow filter and pollution control media so that the filter media cannot treat any water. When water enters the pond (during and after a storm event), the pond water surface elevation rises, along with the floating skimmer. The rise in the skimmer provides a difference in water surface elevation between the pond and the surface of the upflow filter. The elevation head differential supplies the power required to push the pond water through the upflow filter and out, to the pond effluent pipe as shown in Figure 2.

Because water flows through the filtering media causing head loss, a bench study was performed over target surface loading rates to conclude the head loss of the chosen pollution control media, shown in Table 1. For flow conditions, ordinary filtration velocities are considered for the design of the filter (Cleasby and Logsdon, 1999). To confirm the head loss and functionality of the CUFS, a pilot scale design was built on a smaller detention pond than the target pond in Seminole County. As a pilot test, the Arboretum chamber structure on campus at the University of Central Florida (UCF) was installed adjacent to the rectangular weir outflow. The skimmer connects to the piping into the bottom of the chamber, and the filter effluent flows into the pond effluent downstream of the weir, as shown in Figure 3(a). This arrangement allows the CUFS to function in parallel with the pond effluent structure to directly compare the water quantity and quality data for storm events. The pilot study confirmed the head loss obtained at the lab-scale testing for the CUFS.

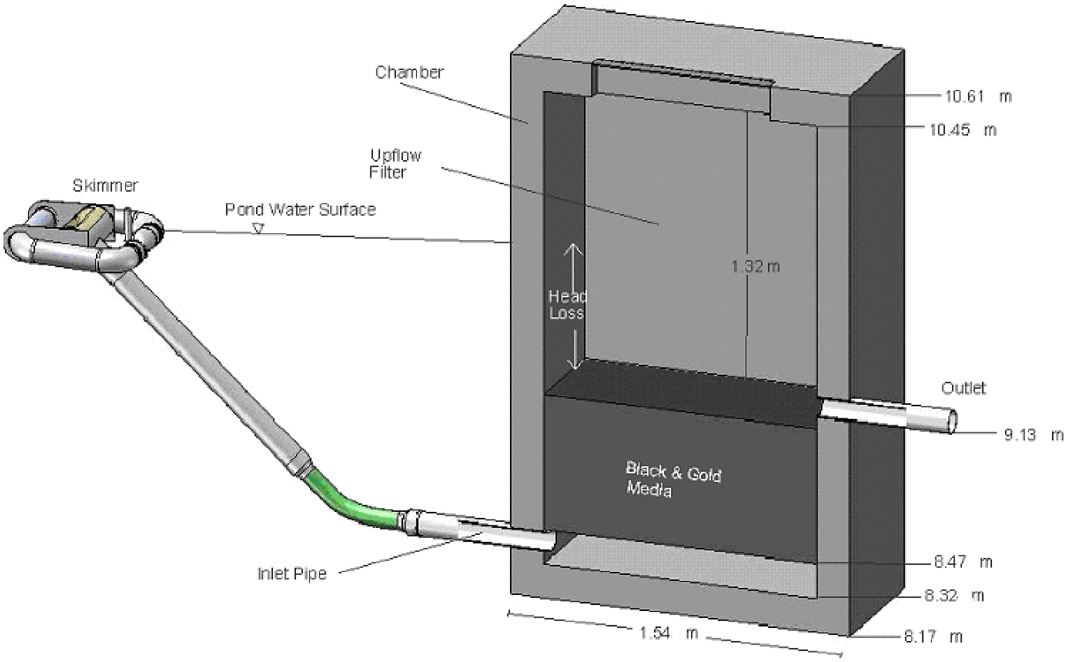


**Figure 2: Red Bug Pond CUFS with example elevations (cleanout pipe not pictured)**

The full-scale CUFS is installed in parallel with the detention pond outlet in Seminole County, as shown in Figure 3(b). Stormwater from the detention pond flows down the inlet pipe, up through the filtering media, and out the filter outlet pipe. The outlet from the filter connects to the concrete outlet pipe of the pond, and the filtered water and effluent pond water mix and travel to Howell Creek. The first field application of the CUFS occurred on site at Red Bug Stormwater Pond B. At the maximum possible flow from the skimmer (J. W. Faircloth & Son, 2005), the pollution control media treats the stormwater at a surface loading rate within the target range. The outflow pipe in the upflow filter must also be large enough to handle the inflow. The filter outflow pipe is sized using the orifice equation (Finnemore and Franzini, 2002):

$$Q = C_d A \sqrt{2gH} \tag{1}$$

where Q = flow ($m^3/s$), $C_d$ = coefficient of discharge, A = area of orifice ($m^2$), g = acceleration from gravity (9.81 $m/s^2$), and H = head acting on the top of the CUFS (m). The result of this equation yields the minimum size outflow pipe required to achieve the target flow.

**Table 1: Sizing specifics of the CUFS**

| Design Criteria | |
|---|---|
| Bold and Gold$^{TM}$ media | 61.08 cm (2 ft.) |
| Head Loss | 22.86 cm (9 in.) |
| Target Velocity Range | 140.23-353.21 $m^3$/day/$m^2$ (2-5 gpm/$ft^2$) |
| **UCF Arboretum CUFS** | |
| DOT Type C Inlet | 0.61m X 0.91m (2' X 3') Surface Area |
| Skimmer Diameter | 5.08 cm (2 in.) |
| Max. Inflow from Skimmer | 92.96 $m^3$/d (3,283 $ft^3$/d) |
| Outflow Pipe Diameter | 5.08 cm (2 in.) |
| **Full Scale CUFS** | |
| DOT Type D Inlet | 1.22m X 0.91m (4' X 3') Surface Area |
| Skimmer Diameter | 10.16 cm (4 in.) |
| Max. Inflow from Skimmer | 515.73 $m^3$/d (18,267 $ft^3$/d) |
| Outflow Pipe Diameter | 10.16 cm (4 in.) |

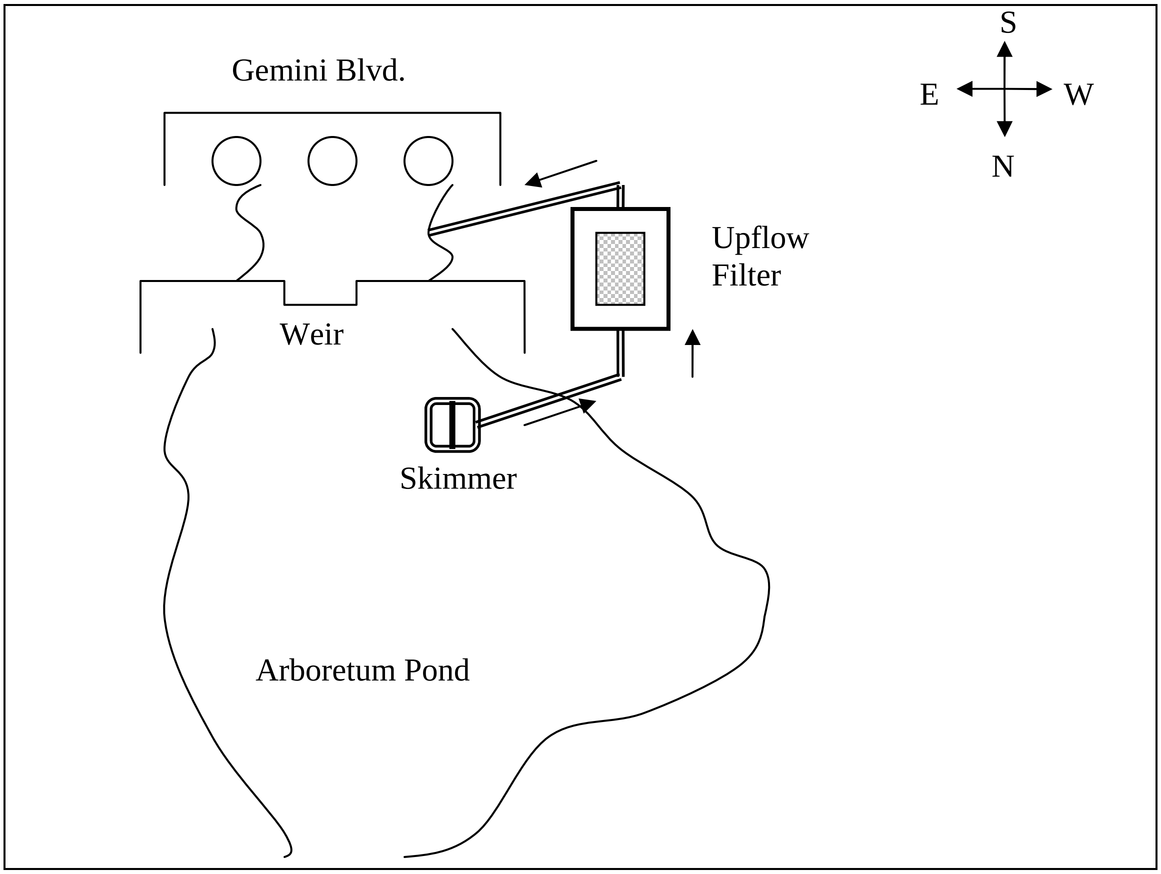


Figure 3(a): Plan view of the Arboretum pond at UCF (N.T.S.)

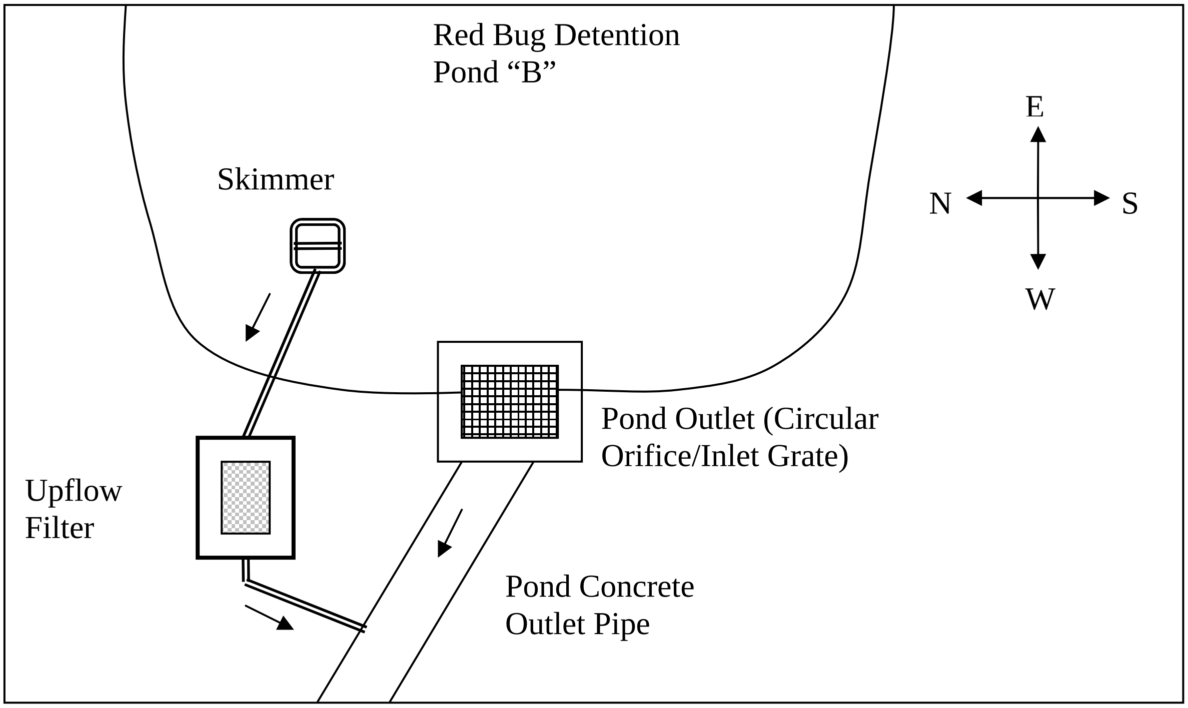


**Figure 3(b): Plan View of Red Bug Pond B in Seminole County (N.T.S.)**

## Material Characterization

The upflow filter uses several types of green sorption media to improve water quality in stormwater runoff. This mix consists of 45% expanded clay, 45% recycled tire crumb, and 10% saw dust. The mix is poorly graded, with an uneven curve over the range of consideration. More details of the mix are shown in Table 2 and Figure 4 (Penn State AASL, 2006). The water permeability is good for operation though.

**Table 2: Media characteristics**

| Characteristic | Value |
|---|---|
| Bulk density (dry wt. basis) | 0.56 g/cm$^3$ (34.87 lb/ft$^3$) |
| Bulk density (max. water cap.) | 0.98 g/cm$^3$ (61.35 lb/ft$^3$) |
| Water permeability | 9.65 cm/min (3.80 in/min) |
| Total pore volume | 62.40% |
| Uniformity coefficient | 4.13 |

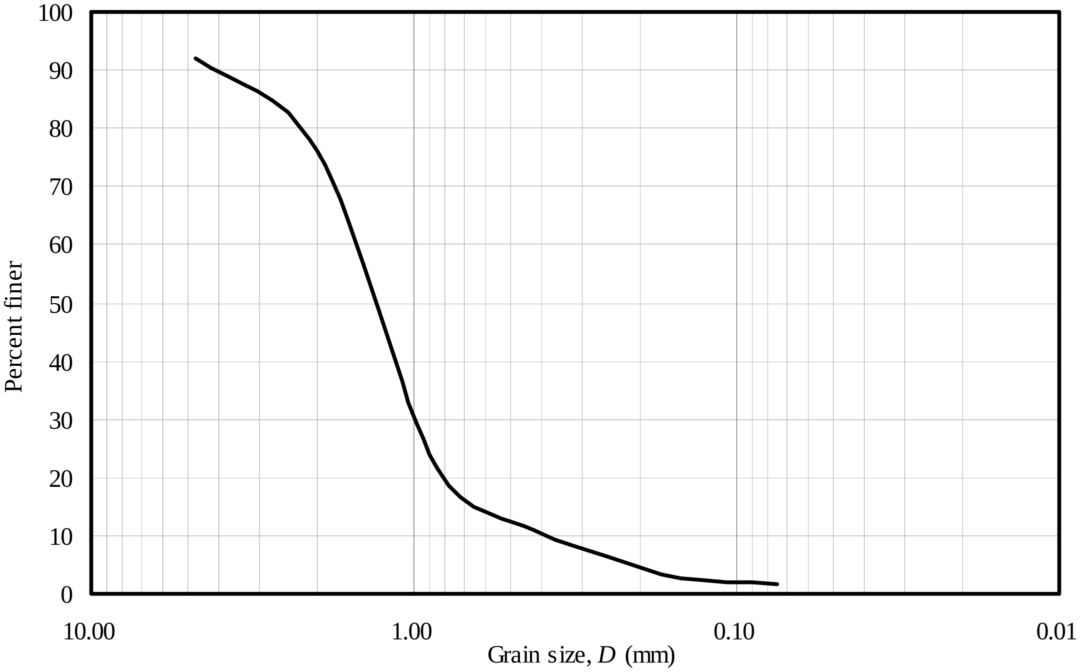


**Figure 4: Graduation curve for particle size distribution**

**Reaction Mechanism**

The adsorption, absorption, ion exchange, and precipitation processes are intertwined with the overall physicochemical process. Some nutrients such as phosphorus, removed by inorganic media, are likely a sorption/precipitation complex. The distinction between adsorption and precipitation is the nature of the chemical bond that might form between the pollutant and sorption media (Cucarella and Renman, 2008). The attraction of a sorption surface between the pollutant and the sorption media causes the pollutants to leave the aqueous solution and simply adhere to the sorption media. Ammonia, nitrite, nitrate, and phosphorus may be sorbed in the CUFS between sequential storm events.

Within the microbiological process, if organic sources are present in the stormwater runoff, hydrolysis converts particulate organic nitrogen (N) to soluble organic N, and ammonification releases ammonia into the water (Metcalf and Eddy, 2003). Nitrification in the detention pond occurs in the presence of oxygen, in which ammonium is converted to nitrite ($NO_2^-$) and nitrite is converted to nitrate ($NO_3^-$) continuously (Metcalf and Eddy, 2003). Because the filter media contain water on the top and bottom and is enclosed within a chamber, the media is not exposed to air, developing anoxic conditions. Denitrification occurs in the absence of free oxygen (under anoxic conditions) using nitrate as a final electron acceptor resulting in the stepwise reduction of $NO_3^-$ to $NO_2^-$, nitric oxide (NO), nitrous oxide ($N_2O$), and nitrogen gas ($N_2$) (Clark et al, 2001; Metcalf and Eddy, 2003). Denitrification also requires the presence of an electron donor, which is provided in the green sorption medium by sawdust and part of the expanded clay with bioavailable organic content. Ultimately the amount of denitrification may be limited by the frequency and duration of the oxic/anoxic fluctuations within the filter with respect to the reaction rates during the intermittent storm events.

## Sampling and Analysis

The experiment was performed in a 9-month period with water quality samples taken after storm events that contribute at least 0.51 cm (0.2 inches) of rainfall. During times of no rainfall, baseflows from the detention pond were sampled. A sample was considered baseflow if no stormwater entered the pond within the past six days. In order to collect a range of samples for comparison, the sampling times following a rainfall event varied in the study, with no more than one sample taken per day. All storm samples were collected within 24 hours of a rainfall event. Rainfall is documented using an on-site rain gauge and a backup U.S. Geological Survey tipping bucket rain gage located nearby.

For sampling, this experiment compares the detention pond outflow to the CUFS outflow. Since the CUFS is installed in parallel with the detention pond, the two concentrations are directly compared. One liter of sample is taken after the water travels through the CUFS and from the surface of the detention pond near the outlet structure, in line with the skimmer. The sampling bottles are cleaned between sampling events with distilled water. A list of methods used to determine the concentrations of these chemicals is shown in Table 3

Quality assurance and quality control was conducted for each constitute in a sample set. To measure precision, duplicate samples are analyzed to produce a relative percent difference (RPD) between the two measurements. The accuracy of the measurements is determined by spiking a sample with a known concentration of the parameter and calculating the percent recovery. Two-tailed t-tests were used to find the difference between the mean values of the Red Bug Pond (referred to as “RBP” herein) and Red Bug CUFS (referred to as “RBF” herein) samples. The two random samples were collected independently of each other and have normal distributions for all parameters except pH. The normal distributions were verified via a normal probability plot and interquartile range test, where the ratio of interquartile range to standard deviation equals approximately 1.3 (Mendenhall and Sincich, 1995). Extreme values were not considered outliers due to the varying nature of rainfall events and pollution carried by stormwater runoff. An unusually high value may just be a characteristic of a large storm event, or a recent fertilizer application in a nearby neighborhood.

**Table 3: Methods and detection limits for each chemical species**

| Chemical Species | Title of Method | Detection Range (mg/L as element) | Method No. |
|---|---|---|---|
| Turbidity | Standard Method | 0.02 - 10 NTU | 2130B |
| Nitrate as Nitrogen | Cadmium reduction | 0.01 - 0.5 | 8192, 8171 |
| Total nitrogen | Persulfate digestion | 0.5 - 25.0 | 10071 |
| Total phosphorus | Acid persulfate digestion | 0.02 - 1.10 | 8190 |
| Orthophosphate | PhosVer 3 (Ascorbic acid) | 0.01 - 0.8 | 8048 |

## Results and Discussion

### Water Quality Samples

We compare the RBP outflow water quality to the RBF effluent water quality within a total of thirty-five sampling dates. These samples come from twenty-eight storm events and seven baseflows collected over a period of nine months from 2007 to 2008. The storm samples were taken at different time intervals following the event, with time ranges shown in Figure 5. Ten stormwater samples collected at the pilot study location can be used to compare the pond effluent (referred to as "AP" herein) to the pilot scale CUFS outflow (referred to as "AF" herein). Such a sampling strategy may capture more broaden scenarios of nitrification versus denitrification in such a simultaneous system.

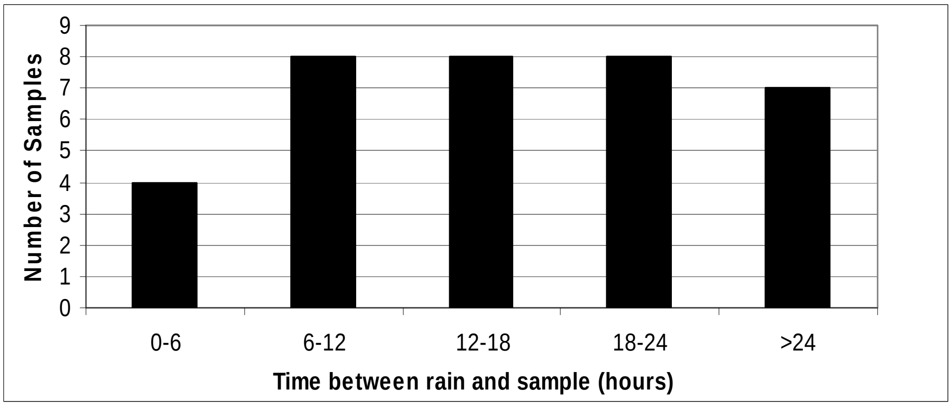


**Figure 5: Number of samples taken at different time intervals**

## pH and Alkalinity

Note that background concentration of the pollutant, dissolved oxygen concentration, pH values, and alkalinity may cause changes in thermodynamic equilibrium between the sorption media and aqueous solution. Table 4 shows the pH and alkalinity averages for thirty-two samples at the Red Bug site and ten samples at the pilot scale site. The pollution control media in the CUFS at both locations did not alter the pH. The alkalinity increased slightly in the CUFS at the Red Bug Pond site and more substantially at the pilot study site. However, the increases at both locations were not enough to conclude that the mean values are not equal based on the statistical analysis using a 95% confidence level. This is acceptable because denitrification recycles the alkalinity needed for nitrification.

**Table 4: pH and alkalinity data summary**

| | pH | | | | Alkalinity(mg/L $CaCO_3$) | | | |
|---|---|---|---|---|---|---|---|---|
| | RBP | RBF | AP | AF | RBP | RBF | AP | AF |
| Avg. | 6.94 | 6.87 | 6.49 | 6.71 | 44.00 | 47.00 | 75.00 | 91.00 |
| St. Dev. | 0.33 | 0.33 | 0.50 | 0.40 | 18.00 | 32.00 | 49.00 | 48.00 |
| n | 32 | 32 | 10 | 10 | 32 | 32 | 10 | 10 |
| p-value | | | | | 0.4777 | | 0.459 | |

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = Pilot Study Pond, AF = Pilot Study CUFS

## Turbidity

The turbidity ranges from 8.19 NTU to 1.94 NTU for the Red Bug Pond and 4.54 NTU to 1.38 NTU for the CUFS based over thirty-two observations. Table 5 shows the sampling statistics. The average turbidity for the CUFS is lower than that of the pond outflow at both the Red Bug and pilot locations. For the turbidity measured at the Red Bug site, there is enough statistical evidence to conclude that the mean values are not equal at a 5% significance level. The 95% confidence interval (C.I.) for the Red Bug Pond samples shows that the CUFS reduces the mean detention pond turbidity value between 0.8 and 1.7 NTU.

**Table 5: Turbidity data summary**

| | Turbidity | | | |
|---|---|---|---|---|
| | RBP | RBF | AP | AF |
| Avg. | 3.55 | 2.29 | 6.83 | 3.08 |
| St. Dev. | 1.39 | 0.66 | 3.23 | 1.72 |
| n | 32 | 32 | 9 | 9 |
| p-value | 0.001 | | 0.152 | |
| C.I. | 1.26 ± 0.45 | | 1.75 ± 2.03 | |

*RBP = Red Bug Pond, RBF = Red Bug CUFS,
AP = Pilot Study Pond, AF = Pilot Study CUFS

### Solids

Thirty-one observations are used to compare the total suspended solids (TSS) and total dissolved solids (TDS) concentrations for the Red Bug site. As shown in Table 6, the CUFS at the Red Bug Pond reduced the TSS concentration almost in half. The mean values of the Red Bug Pond and CUFS are not equal at a 5% significance level, and the CUFS reduced the mean pond TSS concentration between 1.9 and 6.8 mg/L. Even though the total dissolved solids concentrations decreased in the CUFS for both sites, there was not enough evidence to reject the equality of the two means.

**Table 6: Total solids data summary**

| | TSS (mg/L) | | | | TDS (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|
| | RBP | RBF | AP | AF | RBP | RBF | AP | AF |
| Avg. | 9.00 | 5.00 | 7.00 | 9.00 | 109.00 | 102.00 | 183.00 | 171.00 |
| St. Dev. | 6.80 | 4.70 | 4.50 | 4.50 | 40.70 | 38.20 | 81.40 | 87.10 |
| n | 31 | 31 | 9 | 9 | 30 | 30 | 9 | 9 |
| p-value | 0.0033 | | 0.3887 | | 0.474 | | 0.7733 | |
| C.I. | 4.36 ± 2.48 | | -2.15 ± 4.16 | | 7.30 ± 17.0 | | 11.4 ± 66.3 | |

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = Pilot Study Pond, AF = Pilot Study CUFS

## Phosphorus

The orthophosphorus (OP) and total phosphorus (TP) concentrations are measured using thirty-seven observations at the Red Bug site. For the majority of the sampling dates, total phosphorus consists of mostly orthophosphorus and very little organic phosphorus. The OP values at the Red Bug Pond outflow are very low, but the CUFS reduces the values almost in half (Table 7). Mean hypothesis testing at a 95% confidence level confirms the reductions of both OP and TP from the Red Bug CUFS.

**Table 7: Phosphorus Data Summary**

| | Ortho-P (mg/L P) | | | | TP (mg/L P) | | | |
|---|---|---|---|---|---|---|---|---|
| | RBP | RBF | AP | AF | RBP | RBF | AP | AF |
| Avg. | 0.03 | 0.02 | 0.05 | 0.04 | 0.06 | 0.04 | 0.07 | 0.05 |
| St. Dev. | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.04 | 0.02 |
| n | 37 | 37 | 11 | 11 | 34 | 35 | 11 | 11 |
| p-value | 0.0047 | | 0.1909 | | 0.0057 | | 0.1426 | |
| C.I. | 0.012 ± 0.007 | | 0.011 ± 0.014 | | 0.013 ± 0.008 | | 0.019 ± 0.022 | |

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = Pilot Study Pond, AF = Pilot Study CUFS

## Nitrogen

The nitrogen forms compared in the CUFS experiment include nitrate + nitrite (NOx) and total nitrogen (TN). To ensure that denitrification could occur, dissolved oxygen measurements were taken periodically throughout the experiment. These measurements were taken below the filter in the CUFS, above the filter in the CUFS, and in Red Bug Pond itself. The low dissolved oxygen measurements show that anoxic conditions occur within the filtering media of the CUFS, allowing denitrifying bacteria to utilize nitrate and remove it from the water. As with orthophosphorus, the Red Bug Pond discharges very low concentrations of nitrite + nitrate (Table 8). The average TN concentration of the Red Bug CUFS is relatively lower than the pond outlet, but at a 95% confidence level there is not enough data to conclude that the two mean values are not equal. There is enough data to conclude that the pilot study CUFS reduced the mean TN concentration from the pond when compared at a 5% significance level.

**Table 8: Nitrogen data summary**

| | $NO_x$ (mg/L N) | | | | TN (mg/L N) | | | |
|---|---|---|---|---|---|---|---|---|
| | RBP | RBF | AP | AF | RBP | RBF | AP | AF |
| Avg. | 0.03 | 0.03 | 1.04 | 0.68 | 1.11 | 0.92 | 2.93 | 1.54 |
| St. Dev. | 0.02 | 0.02 | 1.36 | 0.93 | 0.86 | 0.66 | 0.81 | 0.86 |
| n | 34 | 33 | 7 | 6 | 24 | 24 | 6 | 6 |
| p-value | 0.5209 | | 0.5803 | | 0.3931 | | 0.004 | |
| C.I. | 0.0 ± 0.01 | | 0.36 ± 1.06 | | 0.19 ± 0.37 | | 1.30 ± 0.80 | |

*RBP = Red Bug Pond, RBF = Red Bug CUFS, AP = Pilot Study Pond, AF = Pilot Study CUFS, $NO_x$ = Nitrite + Nitrate

## Comparative Analysis of Water Quality in Storm Events and Baseflows

The data analyzed in Tables 4-8 resulted from twenty-eight storm events and seven baseflows in the Red Bug detention pond. Separating the concentrations between storm events and baseflows results in the values shown below in Table 9. It shows the turbidity level in storm events is higher than that in baseflows. Analysis of TN and TP has similar results, but this is not the case with TSS.

**Table 9: Storm Events and Baseflows Separated**

| | Sample | pH | Alk (mg/L $CaCO_3$) | Turbidity (NTU) | OP (mg/L P) | TP (mg/L P) | NOx (mg/L N) | TN (mg/L N) | TSS (mg/L) | TDS (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| Storm Events | RBP | 6.91 | 42.00 | 3.59 | 0.03 | 0.06 | 0.02 | 1.33 | 9.00 | 111.00 |
| | RBF | 6.89 | 45.00 | 2.36 | 0.01 | 0.04 | 0.03 | 1.11 | 4.00 | 103.00 |
| Base Flow | RBP | 7.09 | 52.00 | 3.40 | 0.03 | 0.04 | 0.04 | 0.54 | 14.00 | 102.00 |
| | RBF | 6.80 | 57.00 | 1.92 | 0.02 | 0.04 | 0.04 | 0.43 | 10.00 | 99.00 |

*RBP = Red Bug Pond, RBF = Red Bug CUFS, NOx = Nitrite + Nitrate

A graph comparing the combined storm events and baseflows to storm events only and baseflows only is shown below for TP and TN (Figures 6 and 7). The standards chosen for Lake Jesup (0.04 mg/L TP and 0.61 mg/L TN) are shown on the graphs, as well as error bars representing 95% confidence intervals. As shown in Figure 6, the CUFS reduces TP below the standard concentration for all the samples (Storm + Base) and the storm events. The baseflow TP concentration from the Red Bug Pond does not exceed the standard concentration. The high contribution of TN from the storm events is shown in the Total Nitrogen graph in Figure 7. The “baseflow only” concentration at Red Bug Pond does not exceed the standard, but the storm event concentration greatly exceeds the standard. The CUFS reduces the TN concentration, but not below the standard of 0.61 mg/L N.

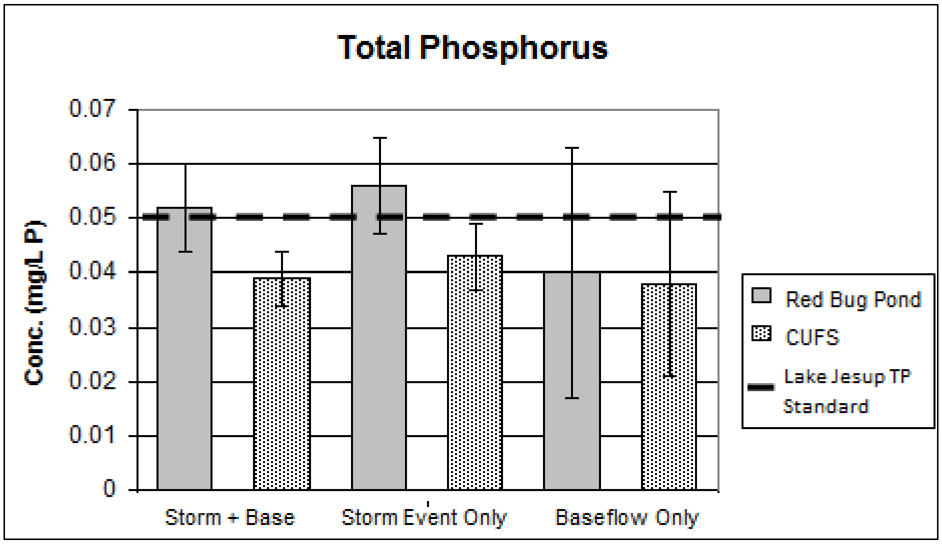


**Figure 6: Storm event and baseflow comparison for TP**

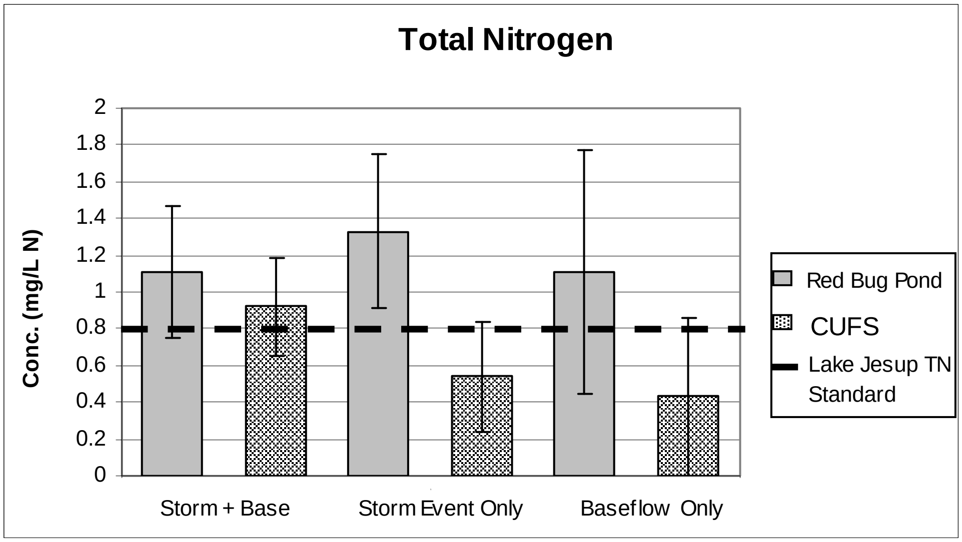
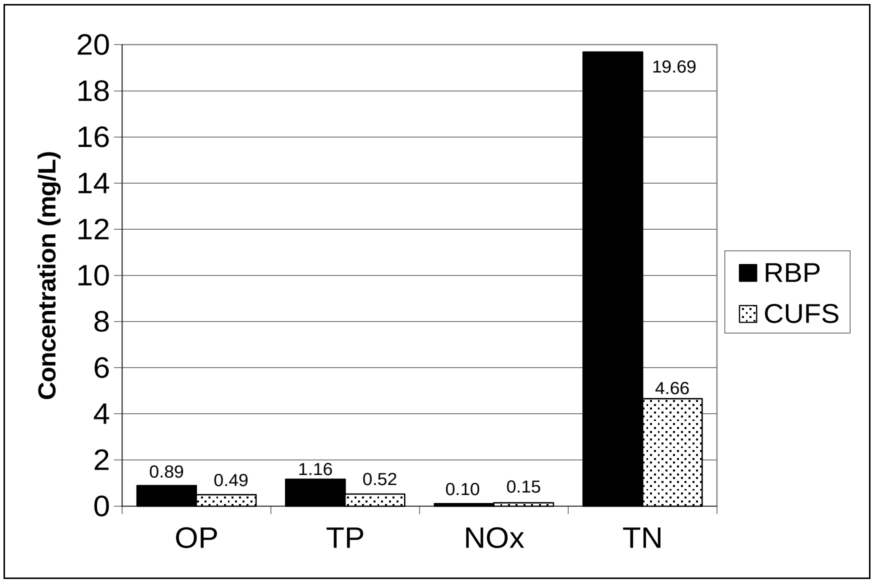


**Figure 7: Storm event and baseflow comparison for TN**

### System Reliability Test

The nutrient concentrations leaving the detention pond are relatively low compared to those in typical stormwater detention ponds. To see how the CUFS performed under higher nitrogen and phosphorus loading conditions, two experiments were conducted to increase the nutrient concentrations in the pond and inflow to the CUFS. Fertilizer was scattered into the detention pond near the skimmer, and samples were taken at periodical times after the introduction of fertilizer. Flow measurements were taken from the CUFS to see how long it would take the water to cycle through the filtering system, so representative samples from the pond and CUFS could be directly compared. Figure 8 displays the average concentrations from the two experiments for phosphorus and nitrogen.

The addition of fertilizer increased the phosphorus concentration in the pond with mainly OP as expected, because fertilizer supplies phosphorus in a form readily available for plant uptake. The CUFS reduced the two phosphorus species approximately in half and increased the OP/TP ratio compared to the pond. In the analysis of nitrogen, the CUFS increased the $NO_x$ (nitrite + nitrate) concentration compared to the pond. This could be caused by nitrification of the ammonia in the fertilizer (the TN of the selected fertilizer consisted of urea/ammonia mix). The water in the CUFS begins in the skimmer and inlet pipe, which is still under aerobic conditions until it reaches the filtering media. Therefore, the water in the CUFS is exposed to aerobic conditions for a longer time before sampling than the pond, which will allow nitrifying bacteria more time to convert ammonia to nitrate. Because this experiment was performed during a period of no rainfall, the flow measurements indicate that it would take the water approximately two hours to cycle through the CUFS. Theoretically the $NO_x$ (nitrite + nitrate) should be removed by denitrification in the anoxic filter, but the removal rate might be lower than the formation rate due to the excessive ammonia concentrations, and the $NO_x$ concentrations may increase.



*NOx = Nitrite + Nitrate

**Figure 8: Simulated Event for Reliability Testing**

Evidence of denitrification in the filter is shown in the comparison of TN values. It is known that the $NO_x$ (nitrite + nitrate) concentrations are relatively low, but the TN concentration in the pond is close to 20 mg/L N. Since the selected fertilizer contains TN in the form of urea and ammonia, the TN concentration is composed of mainly ammonia or ammonium ion. The reduction in TN is presumably due to denitrification in the media after the ammonia is converted to nitrate before entering the filtering media. This does not remove all the TN because 4.7 mg/L N remains in the CUFS samples, which is assumed to be ammonia or organic since the $NO_x$ concentration is low. The low dissolved oxygen concentrations above and below the filter show that chamber is anoxic, allowing denitrification to occur.

## Flow Measurements and Hydraulic Loading

The flow measurement is performed by using the “bucket and stopwatch” method. This method achieves a direct measurement for the flow rate with no estimation involved. The flow is taken directly from the outlet pipe of the filter, which discharges into the stormwater effluent pipe from the pond. Since the flow through the filter increases with head (pond water elevation), a water surface measurement was taken from the outlet weir structure. The head on the filter outlet pipe was also measured.

Calculation of a surface loading rate requires the surface area of the filter that allows water to flow through it. The Red Bug chamber measures 1.22 m X 0.91 m (4’ X 3’), equating to an inside area of 1.11 $m^2$ (12 $ft^2$). However, part of this area is occupied by the 15.24 cm (6”) cleanout pipe, which reduces the surface area to 1.09 $m^2$ (11.80 $ft^2$). With this surface area, the surface loading rates of the CUFS for the two observations measured are 22.90 and 31.74 $m^3$/day/$m^2$ (0.39 and 0.54 gpm/$ft^2$), respectively. These surface loading rates correspond to a pond water elevation that is 40.64 cm (16 inches) and 31.75 cm (12.5 inches) below the top of the concrete overflow structure of Red Bug Pond. Although the peak flow rate through the CUFS during this experiment would be important data, obtaining a flow measurement when the water flows over the concrete structure would be too dangerous due to the large flow of water coming from the pond. The largest surface loading rate measured, 31.74 $m^3$/day/$m^2$ (0.54 gpm/$ft^2$), is much smaller than the range of loading rates considered in the laboratory 140.23 to 353.21 $m^3$/day/$m^2$ (2 to 5 gpm/$ft^2$). However, in this measurement, the water level in the outlet pipe of the CUFS only occupied 70% of the outlet pipe cross-sectional area. The bench scale study was also performed with clean tap water and new media, with fewer solids to restrict the flow through the media.

### Nutrient Loading Reduction

The nutrient removals from the CUFS can be expressed in the form of nutrient loading reductions by multiplying the flow and concentration. These calculations show the amount of mass per time that can be removed by the CUFS during storm events. The two flow rates measured 24.50 and 32.70 $m^3$/day (4.5 and 6.0 gpm), the inflow to the CUFS (0.05 mg/L TP and 1.11 mg/L TN), and the outflow from the CUFS (0.04 mg/L TP and 0.92 mg/L TN) create a loading reduction range of 0.12 to 0.16 kg/year of TP and 1.70 to 2.27 kg/year of TN. For the simulated event using the same two measured flow rates, the loading reduction ranges become 5.73 to 7.64 kg/year of TP and 134 to 179 kg/year of TN. These numbers may seem quite small when compared to the target loading reductions from Florida Department of Environmental Protection (FDEP) of 252,600 kg for TN and 21,400 kg for TP (Gao, 2005c). However, these reductions occur at only one detention pond in a watershed that includes hundreds of stormwater ponds. Also, these loading reductions do not represent the maximum loading reduction possible because the maximum flow from the CUFS was not measured.

### Removal Efficiency in Detention Pond

The phosphorus concentrations leaving the Red Bug Pond are lower than average for wet detention facilities in Florida. Values compiled by Harper and Baker (2007b) from previous studies show that stormwater from single family residential developments contains average concentrations of 0.38 mg/L of TP and 2.07 mg/L of TN. According to Seminole County Engineering (2007), stormwater in the Howell Creek subbasin contains a net concentration of 0.31 mg/L of TP and 1.72 mg/L of TN. These numbers are similar to those found by Harper and Baker (2007b). Harper and Baker (2007a) compiled several treatment efficiencies for wet detention ponds and found an average removal of 69% for TP and 37% for TN. Using these removal efficiencies for a wet detention pond and the typical stormwater concentrations for the Howell Creek subbasin from Seminole County Engineering (2007), the expected effluent concentrations from the Red Bug Pond should be approximately 0.10 mg/L of TP and 1.09 mg/L of TN. The TN value matches the measured concentration from the Red Bug Pond of 1.11 mg/L (Table 8). This results in a TN removal efficiency of 35% in the Red Bug Pond. However, more phosphorus removal occurs in the Red Bug Pond than in an average wet detention pond. The measured TP value is 0.05 mg/L for the Red Bug Pond (Table 7), compared to the expected value of 0.10 mg/L. This shows a TP removal of 83% assuming the influent concentration is 0.31 mg/L.

The high phosphorus removal may be due to the sediment and solids removed by sedimentation in the pond. The basin that includes Red Bug Pond consists of Tavares-Millhopper, Myakka, and Eaugallie fine sands (DCE, 1990). To conclude if dissolved phosphorus was sorbing to the sediment, an extra sample was taken on August 7, 2007 in which the pond water was stirred by walking around the outlet area in the pond. This should physically break the bond between the sorbed phosphate and sediment, resulting in an increase in the OP and TP concentrations. The OP concentration increased from 0.04 mg/L P to 0.14 mg/L P after agitation. This indicates good removal of dissolved phosphorus by the sediment in the bottom of the pond. The pond also contains a littoral zone, in which different types of aquatic grasses and plants inhabit. These plants utilize the dissolved phosphorus, removing it from the water.

Under the normal storm events sampled, the CUFS reduced the OP concentration by 46%, TP by 25%, and TN by 17% when compared to the pond effluents. Based on the typical values for stormwater in the Howell Creek sub basin, the Red Bug detention pond and CUFS together reduced TP by 87% and TN by 47%. The percent removals are shown below in Table 10. The lower removals with nitrogen could be due to the low values of NOx (nitrite + nitrate) in the pond, limiting denitrification in the filter. Harper and Baker (2007c) show an average TSS concentration from stormwater in single-family residential subdivisions with curb and gutter of 48.40 mg/L. Using this value as the influent TSS concentration to the detention pond, it removes 81% of the TSS. With at least 50% particulate influent concentrations of TN, TP, removal would be at least 67% for TN and at least 85% for TP.

**Table 10: Percent Removals in System Assessment**

| | TN | | | TP | | | TSS | | |
|---|---|---|---|---|---|---|---|---|---|
| | IN | OUT | Removal (%) | IN | OUT | Removal (%) | IN | OUT | Removal (%) |
| Pond only | 1.72 | 1.11 | 35 | 0.31 | 0.05 | 83 | 48.40 | 9.00 | 81 |
| CUFS only | 1.11 | 0.92 | 17 | 0.05 | 0.04 | 25 | 9.00 | 5.00 | 44 |
| Pond+CUFS | 1.72 | 0.92 | 47 | 0.31 | 0.04 | 87 | 48.40 | 5.00 | 90 |

* All concentrations are in mg/L as element

### Operation of the CUFS

Overall, the CUFS performed with minimal maintenance throughout the life of the experiment. Early in the experiment, problems with the upflow filter lifting up due to a high flow of water occurred, but they were resolved with the installation of unitsrut pieces to supply more force to keep it down. The pilot study pond is proliferated with algae, which caused a clogging problem in the skimmer and upflow filter. Once unclogged, the intake on the skimmer at both locations was wrapped with back fabric mat to prevent the algae, small plants, or fish from entering the system. This solved the problem and both the pilot and full scale CUFS remained unclogged throughout the experiment.

The Red Bug CUFS was cleaned twice to see how the system responded. Cleaning consists of pumping out the bottom of the chamber by inserting the intake hose of a small pump down the 15.24 cm (6 inches) cleanout pipe. All the water is pumped out of the filter three times to ensure removal of the sediment. The CUFS performed with no problems following the cleanout in both cases.

## Conclusions

This study provides unique contributions to the research endeavor of using the CUFS for nutrient removal. It is intended to facilitate greater Best Management Practices (BMPs) and promote sustainable development. It is known that the concentrations of TN and TP leaving the Red Bug Pond B (wet detention pond) exceed the concentrations causing impairment to the receiving water body, Lake Jesup. To remediate this pollution impact, this paper presents laboratory, pilot and full-scale testing of the CUFS that has not been tested elsewhere. Findings indicate that the desired surface loading rates for the CUFS experiment were between 140.23 to 353.21 $m^3/day/m^2$ (from 2 to 5 $gpm/ft^2$). The head loss determined for this range of loading rates for 61.08 cm (24 inches) of the chosen pollution control media is 22.86 cm (9 inches). This value was originally determined in the laboratory with the bench scale study and then confirmed in both the pilot and full-scale field applications. With the filter outlet pipe set at an elevation 22.86 cm (9 inches) lower than the pond effluent pipe elevation, the CUFS will discharge water when the pond discharges water, making the CUFS hydraulically operational. During operation, a surface skimmer supplies a design flow of water through the upflow filter in the CUFS while improving water quality in the pond effluent. In ponds with high levels of algae, small plants, or other small debris, a layer of black fabric mat must be placed over the intake of the skimmer to prevent the debris from clogging the upflow filter after short periods of time without affecting the hydraulic performance of the CUFS. The Red Bug CUFS significantly reduced the concentrations of turbidity, OP, TP, and TSS compared to the pond effluent. The CUFS is also capable of nutrient removals in highly polluted water, as shown in the reliability analysis. The results of this research are limited to the Central Florida climate, one media mix, and a well functioning detention pond design based on the current standards.

Future research should be conducted on adding more skimmers to possibly increase the flow of filtered water from the CUFS, but it cannot flow too fast as to inhibit adsorption of phosphorus to the media or prevent anoxic conditions in the chamber. Different sorption media mixes may be tested to improve the removal efficiencies. The addition of a fountain in the detention pond should also be investigated to aid in the reduction of nitrogen in the CUFS. The fountain may encourage more aerobic conditions to convert ammonia to nitrate, which should increase denitrification in the CUFS. To further investigate denitrification in the CUFS, samples should be analyzed to see what types of bacteria are present for denitrification. Also, the limiting variable that governs the CUFS design should be identified. The most likely options for the limiting variable are flow and oxygen content in the CUFS.

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