Stormwater Pond Phosphorus Evaluation

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Contents

INTRODUCTION

Stormwater ponds have been designed and built to receive stormwater runoff that results from creating impervious surfaces in a watershed. These receiving ponds are constructed to both mitigate flooding and reduce pollutant loads to downstream surface waters. However, the outflow nutrient concentrations during pond discharge events and their potential impact on receiving waters are infrequently assessed. This work addressed whether stormwater ponds can serve as a source of phosphorus to surface waters with the development of numeric nutrient criteria (NNC) for Alachua County, Florida.

The objectives of this study were multi-fold with the overarching goal of examining the relationship of soil composition in stormwater ponds and the nutrient concentrations in surface waters. Recommendations for consideration during stormwater pond construction to reduce phosphorus export from ponds, which have high likelihood of being a phosphorus source, will be proposed in the conclusion of this study. Potential for exceeding NNC because of phosphorus export from stormwater ponds will also be examined.

BACKGROUND

Currently, regulations describe the volume of water storage that must be provided in a stormwater basin to provide 80% average annual load reduction of pollutants per the 1990 Florida Department of Environmental Protection (FDEP) Statewide Stormwater Treatment Rule (Chapter 62-40.432 FAC). This rule assumes compliance of water quality reductions if Best Management Practices (BMPs) are followed during construction. Once construction is completed, the responsibility of routine maintenance of these basins is often relinquished to the homeowners association and implementation of maintenance is often neglected. Routine maintenance includes excavating the accumulated sediments to maintain capacity for flood protection. Depending on the physiochemical properties of parent soil, these accumulated sediments could increase phosphorus sequestration by providing sorption sites, or could release bound phosphorus as oxidation/reduction conditions alternate, especially if concentration gradients exist between soil pore water and incoming stormwater.

Numeric nutrient criteria have been established for nitrogen (N) and phosphorus (P) in surface waters. Some consideration was given to soil physiographic variations when they were developed. The level to which natural phosphatic inputs from soils influence surface water quality is particularly important to investigate as an increased effort is devoted to projects that reduce phosphorus concentration in creeks and lakes. Within Alachua County there are areas where phosphatic soils occur near the soil surface, which increase the potential of stormwater ponds to contribute phosphorus to receiving waters. In general, the eastern portion of the county is underlain by the Hawthorn Group which consists of soils and deeper sediments with varying amounts of clay, quartz sand, carbonate, and phosphate grains which are diagnostic of this group (Scott, 1983 and 1988). The depth of these phosphatic materials varies throughout the county. In some cases, these materials have been transported and used as fill for construction, which can increase the difficulty of predicting soil composition. Transport of sediments in stormwater can also introduce these particles to new areas. No published studies have been conducted in Alachua County to examine the influence of stormwater pond soils on water quality of receiving water bodies during outfall events, specifically phosphorus concentration.

The differences in mechanisms of biotic and abiotic cycling of N and P are important to consider when trying to quantify the potential for stormwater pond soils to store or release nutrients. These ponds alternate between wet and dry conditions. Wet/dry cycles increase rates of denitrification (an important N removal mechanism) by facilitating necessary anoxic soil microsites for denitrifying bacteria (O'Reilly et al., 2012). Denitrification decreases N availability in both the soil pore waters and the overlying water column. Conversely, wetting and drying cycles are likely to increase P flux from soils. In the oxidized state, iron (Fe)-hydroxides strongly adsorb soluble phosphate ions, but the solubility of Fe-hydroxides in soils increases under the reducing conditions that often occur in flooded soils, remobilizing Fe-bound P. Calcium (Ca)-bound soil P is not affected by redox conditions, and can be a more stable mechanism for P retention in the stormwater pond environment.

In stormwater ponds, N and P can be lost from the dead algal material that accumulates on the bottom of the ponds when conditions are dry. Through examining soils both in terms of their inorganic chemical make-up and by conducting an incubation study, we are attempting to capture all possible methods of P loss to overlying surface water. Furthermore, basins that discharge to surface waters should be examined to determine if N or P loading is a greater threat to the receiving water, since the maximum reductions expected by stormwater ponds are very different for these two nutrients.

Previous studies conducted on stormwater basins in Florida observed nutrient concentrations with median values of total nitrogen (TN) of 1.80 mg/l (Taylor et al. 2005), NO_3 of 0.35-1.1 mg/L and total phosphorus (TP) of 0.09-0.29 mg/L (Clark and Pitt, 2007; Gobel et al., 2007). Depending on location in Alachua County, these values would not exceed the NNC. Two of the stormwater ponds in this study discharge to lakes, therefore it is important to consider the NNC of lakes in the region as well. The NNC for colored lakes, which was the type of lake that is connected to the stormwater ponds in this study, is that the annual geometric mean must not exceed 0.16 mg/L TP and 2.23 mg/L TN. NNC for streams state that annual geometric mean must not be exceeded more than once over a three year period. Regional nutrient criteria for streams state that TP concentrations may not exceed 0.30 and 0.12 mg/L and TN concentrations may not exceed 1.87 and 1.54 mg/L for north central and peninsular watershed regions, respectively (FDEP, 2016). The study area includes both regions, see Figure 1.

Identifying the source of these nutrients can be important for stormwater management. This is especially true when trying to identify internal nutrient loading vs. external input. Miguntanna et al. (2013) found N and P runoff from road surfaces to have different limiting factors, nitrogen was labeled as "source limiting" while phosphorus was labeled as "transport limiting" because phosphorus is frequently bound to sediments and velocity of stormwater flow determines the quantity of phosphorus that is transported as runoff. The phosphorus-laden soils in the Gainesville area can be responsible for elevated phosphorus concentrations in runoff and stormwater when they are transported as sediments. Furthermore, these soils are capable of increasing phosphorus concentrations by erosion of phosphatic soil particles and releasing sorbed phosphorus. Once phosphorus-laden sediments reach stormwater ponds, they settle out and undergo wetting and drying cycles that may increase phosphorus concentration in overlying surface water. The extent to which phosphorus concentrations will influence receiving waters will be determined by the phosphorus concentration of inflow, residence time, and mixing. Increasing the ability of a stormwater pond to function as a treatment wetland complete with emergent vegetation may increase phosphorus storage in soils since wetland soils and sediments are capable of storing appreciable concentrations of phosphorus, especially in comparison to their above and below ground biomass and overlying water column (Reddy et al., 2005). However, all soils have a finite capacity to sorb phosphorus, and additional loading could result in export of phosphorus from the soil.

Seasonal weather patterns in Florida and resulting changes in hydrologic inputs with alternating periods of flooding and drying conditions causes major shifts in oxidizing and reducing conditions which have an important role in transformation, availability, storage, and transport of phosphorus out of wetlands (Khalid et al., 1977; Richardson and Vaithiyanathan, 2009). Remobilization of phosphorus because of shifts in redox conditions complicate characterizing and measuring which forms of phosphorus are present in soils. Phosphorus retention in soils is most frequently associated with the abiotic sorption potential of soil Fe, aluminum (Al), Ca, and clay minerals (Richardson, 1985; Reddy et al., 1998a; Aldous et al., 2005 and 2007) and to some extent microbial activity (Reddy and DeLaune, 2008). Furthermore, mobility of phosphorus in soils is a function of phosphorus retention capacity or availability of sites for phosphorus sorption, which is determined by physio-chemical properties, and the current abundance of phosphorus in soil. Frequently, phosphorus that enters the water column is rapidly absorbed by algae, bacteria, periphyton, or floating aquatic plants or it is adsorbed onto particles of soil, sediment or particulates in the water column if sufficient Al, Fe, Ca, or magnesium (Mg) are present (Richardson and Reddy, 2012). In addition, phosphorus concentrations present in soil pore water may be reduced by phosphorus removal or biotic uptake, which will initially be replaced by the labile organic and mineral phosphorus as well as slow replacement from the refractory pools of organic and mineral phosphorus. Microbial activity of decomposition controls the release of phosphorus from organic matter while abiotic processes of adsorption and desorption of phosphorus help to mediate fluctuations in concentrations.

METHODS

Soil Core Analysis

In order to assess the objectives, nine stormwater ponds across Alachua County were selected and sampled for soil composition and surface water quality. Soil core samples were collected from the following stormwater ponds on August 11, 2011: SEEP, Forest Park, Huntington Neighborhood, and SW 43rd Street and on September 1, 2011: Duval, Owens-Illinois, Plum Creek, Lake Forest, and Northside Park (Figure 1, Table 1). Photographs are included in Appendix A. A second sampling was conducted during July and September 2013.

To quantify potential for phosphorus release over time, two sets of soil cores were collected with three replicate samples from each pond; one set was utilized for an incubation experiment and the other set for nutrient analysis. A predictive tool will be developed to quantify the potential of stormwater ponds as a phosphorus source. To achieve this objective, the repeated sampling of surface waters was coupled with estimation of phosphorus release rates from incubation studies and calculation of soil phosphorus storage capacity (SPSC). Hydrologic conditions vary greatly, depending on basin design and construction, which influences outflow frequency to neighboring surface waters. In the case of retention basins, outflow will not occur except during high water conditions. Several considerations were utilized when selecting basins to examine, such as type of basin (detention or retention) and the condition and function of the basin (Table 1). Describing specific behavior of each basin type is less important for the objectives of this study than describing potential soil influence of nutrients in surface water.

Soils cores were analyzed to determine if there were statistical differences between top and bottom layers for all nutrient extractions. See Appendix B for soil core analysis data. The analysis of variance (ANOVA) is capable of indicating if there is a difference between groups but does not provide information on which groups are different. When significant differences among groups are resultant from the ANOVA, a Tukey post-hoc test was conducted to identify the groups which are statistically different.

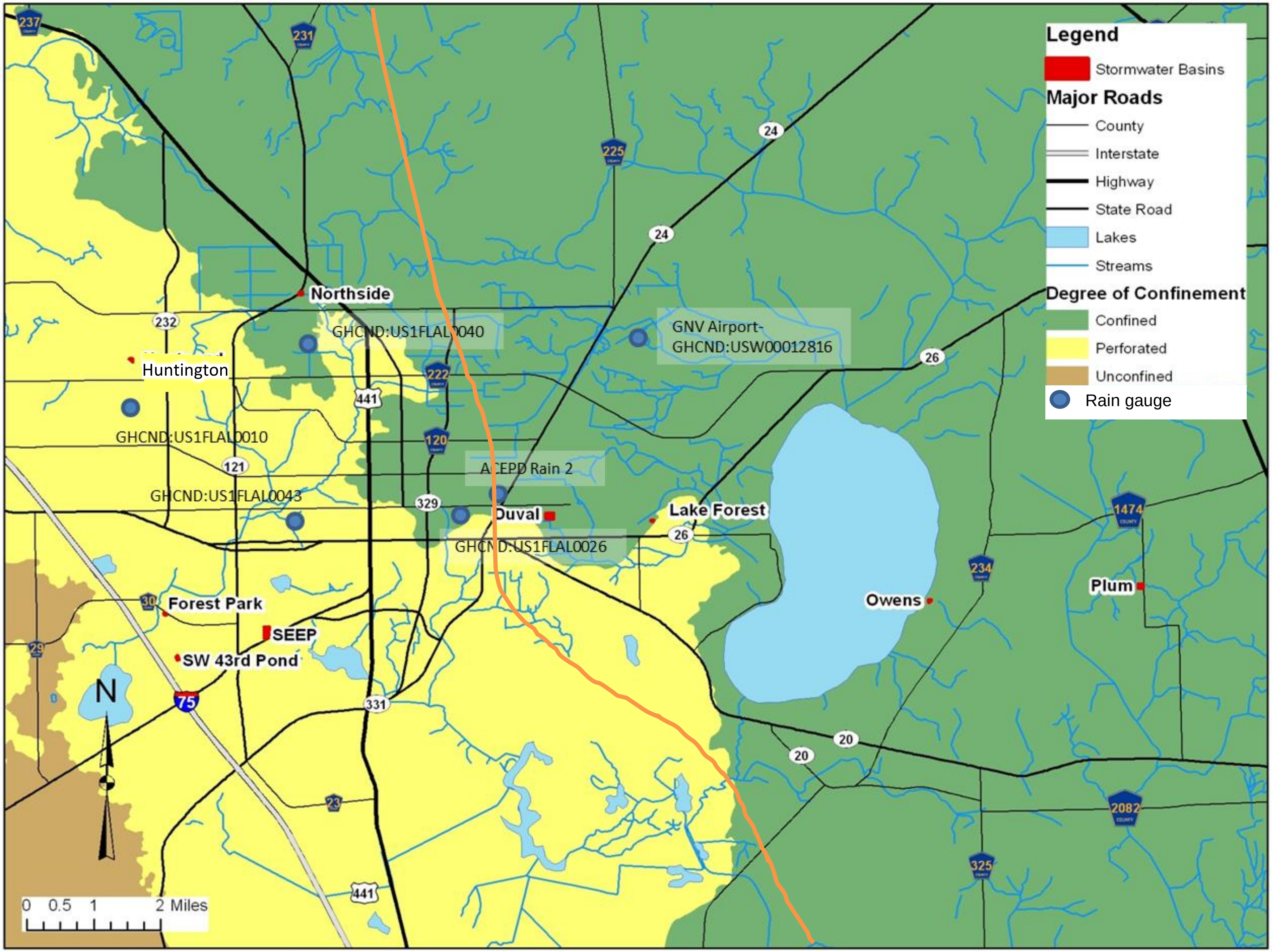

Figure 1. Stormwater Ponds and Rain Gauge Locations in Alachua County
Orange line shows approximate location of FDEP Numeric Nutrient Criteria regional boundary, with North Central on the west and Peninsula on the east.

Table 1. Description of Stormwater Ponds[1]

Stormwater Pond ID	Location	Contributing Area	Vegetation	Area (acre)	Max Depth	Pond Condition	Outfall to Natural Water	Watershed/ Receiving Waterbody	Watershed Nutrient Region[2]
Forest Park	North Side of Forest Park 4501 SW 20th Avenue	Parking lot at County sports park	Abundant algae	0.33	4 ft	Wet	Yes	Hogtown Creek	North Central
Huntington	Huntington Lakes Area NW 42nd Lane	Neighborhood Streets	Algae	0.97	4 ft	Wet	Yes	Possum Creek	North Central
Northside	Senior Center, South Entrance, at Northside Park 5701 NW 34th Road	Parking lot and building at City park	Emergent wetland plants (cattails, pickerel weed), submerged aquatic veg. and some algae	0.50	2.5 ft	Wet	No	Hogtown Creek	North Central
SEEP	University of Florida SEEP Project west of Natural Area/Surge Area Drive and east of SW 34th Street	Athletic fields and parking lots	Emergent wetland plants and algae	3.91	5 ft	Wet	No	Lake Alice	North Central
SW 43rd	West Side of SW 43rd Street, north of Archer Road and south of SW 20th Avenue	SW 43rd Street	Emergent wetland plants (cattails, pickerel weed), submerged aquatic veg. and abundant algae	1.20	3 ft	Wet	no	Hogtown Creek	North Central
Duval	Duval Stormwater Park 505 NE 21st Street	Neighborhood Streets	Emergent wetland plants (cattails, pickerel weed), submerged aquatic veg. and some algae	1.48	>5 ft	Wet	Yes	Lake Forest Creek Newnans Lake	Peninsula
Lake Forest	Lake Forest Farms NE 4th Road and NE 46th Terrace	Neighborhood Streets	Grass	0.22	2 ft	Dry	No	Lake Forest Creek Newnans Lake	Peninsula
Owens-Illinois	Owens-Illinois County Park 11309 NW 34th Boulevard Windsor	Parking lot for County park	Submerged aquatic veg.	0.75	2 ft	Wet	Yes	Newnans Lake	Peninsula
Plum Creek	West side of SE 163rd Street, south of east CR 1474 and north of SE 24th Avenue	Road Addition	Emergent wetland plants (cattails and rushes), submerged aquatic veg. and algae	2.92	3.5 ft	Wet	Yes	Lochloosa Creek	Peninsula

[1]See Appendix A for photographs of stormwater ponds.

[2]Stream Nutrient Region for NNC North Central Watershed Region (thresholds TN 1.87mg/L, TP 0.30 mg/L); Peninsular Nutrient Watershed Region (thresholds TN 1.65 mg/L, TP 0.12 mg/L).

Soil Sampling and Incubation Study

Stormwater pond soil samples were collected by pushing soil core tubes with a sharpened end into the ground to a depth between 20 and 30 cm, depending on soil hardness. Standing water was removed from core tubes by peristaltic pump before transporting them to the lab. Once cores were in the lab they were flooded with 750 mL of rainwater, which was the equivalent to 20 cm in the soil core tube. Aerobic conditions were maintained in the surface water by introducing air through a syringe and aquarium pump. In order to deter algal growth, tubes were incubated in the dark (Figure 2). Soil cores collected on August 11, 2011 were sampled for soluble reactive phosphorus (SRP) in the water column at 1, 4, 8, 14 days and soil cores collected on September 1, 2011 were sampled at 1, 3, 8, and 11 days. Incubation of soil cores was conducted in two batches because of space limitation in the lab. Sampling the water column consisted of removing 50 mL of surface water from each soil core tube and then adding 50 mL of rain water to maintain 20 cm of water depth. These 50 mL samples were filtered through single use 0.45µm filter and analyzed for SRP by Advanced Environmental Laboratories, Inc. The other set of soil core samples were divided into surface and subsurface soil categories for analysis at the University of Florida (UF) Analytical Soils Lab to determine Mehlich-1 P, Ca, Mg, Fe, Al, water soluble phosphorus (WSP), total extractable phosphorus, and loss on ignition (LOI) which indicates percent organic matter.

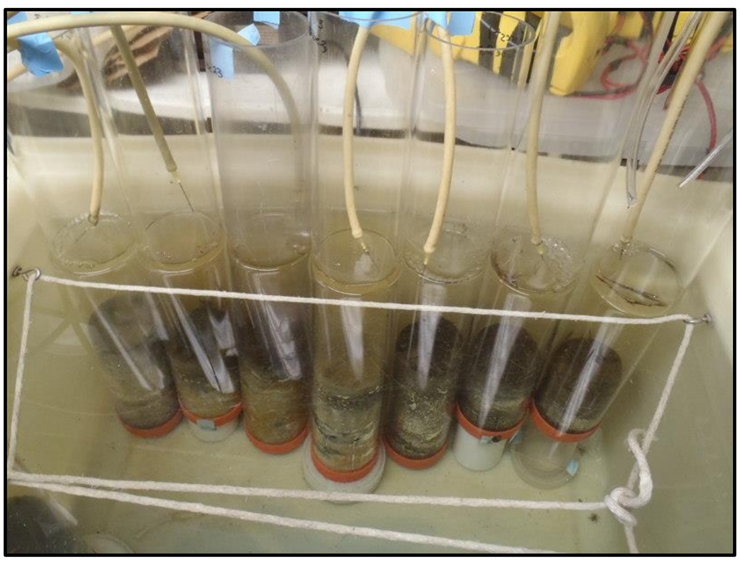

Figure 2. Soil Core Incubation

Incubation set up was covered with black plastic to reduce algal growth.
Aerobic conditions were maintained with aquarium pump and tubing with syringe.

Soils analysis of water soluble phosphorus, total extractable phosphorus, LOI, and Mehlich-1 extractions and analysis of P, Ca, Mg, Fe, and Al were conducted on cores from the incubation study according to the UF-ARL Handbook (Mylavarapu and Moon 2007). Mehlich-1 extraction is conducted colorimetrically after extraction with a double acid solution (0.05*M* HCl + 0.0125 *M* H_2SO_4) with a soil solution ratio of 1:4 (Mehlich, 1953). SPSC was determined by the equations described by Nair and Harris (2004) converting to molar mass ratios.

$$SPCS = (\text{Threshold } PSR_{\text{Mehlich-1}} - \text{Soil } PSR_{\text{Mehlich-1}})*\text{Mehlich-1}[(Fe/(56 \text{ mg Fe/mmol Fe}))+(Al/(27 \text{ mg Al/mmol Al}))]*31 \text{ mg P/mmol P}*X \text{ (mg/kg)}$$

where

$$PSR_{\text{Mehlich-1}} = (\text{Mehlich-1 P}/(31 \text{ mg P/mmol P}))/[(\text{Mehlich-1 Fe}/(56 \text{ mg Fe/mmol Fe}))+(\text{Mehlich-1 Al}/(27 \text{ mg Al/mmol Al}))]$$

X is the conversion factor of 0.1 used for the Mehlich-1 extraction technique (Nair et al. 2010).

These analyses were used to calculate the SPSC of each soil section and will be used to predict the potential of these stormwater ponds to retain or release phosphorus.

Surface Water Sampling

Prior to collecting soil cores, surface water samples were collected and field parameters measured if there was standing water in the stormwater pond. Field parameters of surface water included temperature, pH, specific conductance, and dissolved oxygen (measured using a YSI 556 multimeter) and turbidity (measured with a Hach 2001P portable turbidimeter). Water samples were collected using a standard grab collection method at mid-depth of the pond in three different locations upon initial sampling and at the outfall for subsequent sampling. Samples were transported on ice to Advanced Environmental Laboratory, where all water laboratory analyses were conducted. Analyses were conducted on unfiltered samples for ammonia, calcium, chloride, magnesium, nitrate+nitrite, potassium, sodium, Total Dissolved Solids (TDS), TP, Total Suspended Solids (TSS), sulfate, iron, Total Kjeldahl Nitrogen (TKN), and Total Organic Carbon (TOC). Samples for SRP were filtered with a 0.45 µm filter on site and transported on ice. Analyses were conducted using EPA recommended procedures as follows, ammonia: EPA 350.1; sodium, potassium, magnesium, iron, calcium: EPA 2007.6010 (ICP); chloride, sulfate: EPA 300.0; nitrate+nitrite: EPA 353.2/SM4500NO3F; TKN: EPA351.2; SRP: EPA 365.2/SM4500P-E; TP: EPA 365.3 (Spec); TOC: EPA 415.1/SM5310B; TDS: EPA 160.1; and TSS: EPA 160.2/SM2540D-100mL. Concentrations for TN were calculated as the sum of TKN and nitrate + nitrite values.

Subsequent surface water sampling occurred in 2013 on July 25 and 26th, September 19th, and September 26th. This sampling regime was determined to collect stormwater after various rainfall conditions. The seven day preceding rainfall for the July sampling was the highest rainfall observed during sampling (Table 2). Data for rainfall were collected from an online data set provided by National Oceanic and Atmospheric Administration (NOAA) and one rainfall gauge monitored by Alachua County. These six stations are located in the vicinity of stormwater ponds sampled during this study and are included in Figure 1. These stations demonstrate the spatial variably of summer rainfall events. Sampling on July 25th and 26th occurred after record setting daily rainfall and captured outfall conditions at sites where outfall was possible.

Table 2. Cumulative Rainfall (in.) for Seven Days Prior to Sampling Event

Rainfall Site	August 11 2011	September 1 2011	July 25 – 26 2013	September 19 2013	September 26 2013
GHCND:US1FLAL0040	No data	No data	3.86	0	2.4
GHCND:USW00012816 (GNV Airport)	0.8	0.1	5.1	0.2	2.3
GHCND:US1FLAL0010	1.2	0.2	6.1	0	2.8
GHCND:US1FLAL0043	No data	No data	No data	0	3.9
GHCND:US1FLAL0026	No data	0.8	5.5	0	2.9
ACEPD Rain 2	0.49	0.47	2.49	0.2	2.12

Data collected at five NOAA-NCDC rainfall gauge stations closest to the stormwater ponds and one rainfall gauge monitored by Alachua County.

Statistical analysis was conducted with JMP software by SAS. ANOVA was conducted to compare means among treatments and provide statistical analysis of differences among groups where present. If ANOVA results indicated significant differences among groups, a Tukey post- hoc test was conducted to determine which sites were statistically different from one another. Additional statistical analysis was conducted using Excel.

RESULTS

Soil Core Analysis

Significant differences between the layers occurred for Mg concentrations in Forest Park where the top layer was greater than the bottom layer. There were also statistical differences for several analytes from Huntington, where the top layer had significantly lower concentrations of Mehlich-1 P, P saturation ratio and P capacity, and significantly higher concentrations for Mehlich-1 Fe extraction, compared to the bottom layer. Subsequent comparison of core analytes were conducted on the cores as a whole, since the significant differences between the layers was not common.

Comparisons were conducted among soil core results to examine differences between sites. The SEEP stormwater pond had significantly greater concentration of Mehlich-1 Mg compared to Plum Creek, Huntington, Lake Forest, and Northside. There were several significant differences between Mehlich-1 Fe concentrations; SW 43rd had the greatest concentration which was significantly different from SEEP, Lake Forest, Owens-Illinois, Duval, and Northside soils, statistical differences are represented by different letters (Table 3). There were also several statistical differences among concentrations for Mehlich-1 Al (Table 4). Although there were no statistical differences among sites for Mehlich-1 Ca, there is a trend of lower Mehlich-1 Ca in the soils from Huntington (Figure 3). Soil nutrient concentrations are presented in mg/kg. Bulk density was not determined for these soils.

Table 3. Summary of Soil Core Results for Mehlich-1 Fe

Stormwater Pond	Mehlich-1 Fe (mg/kg)	
SW 43rd	118.97	a
Huntington	100.46	ab
Plum Creek	83.93	abc
Forest Park	59.12	abcd
SEEP	42.37	bcd
Lake Forest	35.88	bcd
Owens-Illinois	33.04	bcd
Duval	19.58	cd
Northside	14.27	d

Mean value calculated for each stormwater pond.
abcd = represent significant differences, determined by Tukey post-hoc test.

Table 4. Summary of Soil Core Results for Mehlich-1 Al

Stormwater Pond	Mehlich-1 Al (mg/kg)	
Duval	1105.35	a
Huntington	648.80	ab
Northside	408.57	bc
Plum Creek	257.65	bc
Lake Forest	230.65	bc
SW 43rd	229.43	bc
SEEP	212.74	bc
Forest Park	178.77	bc
Owen-Illinois	36.81	c

Mean value calculated for each stormwater pond.
abcd = represent significant differences, determined by Tukey post-hoc test.

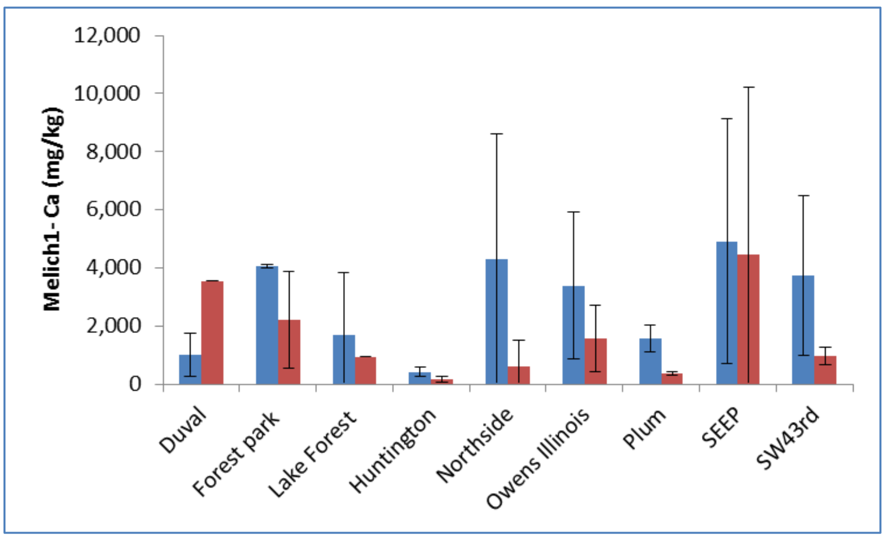

Figure 3. Summary of Soil Core Results for Mehlich-1 Ca
Blue bars represent upper portion of soil core; Red bars represent lower section.
Mean values with standard error bars displayed.

Of the three P extraction methods: Mehlich-1 P, TP, and WSP, each indicated similar trends among soil cores from all sites (Table 5). Forest Park had significantly higher Mehlich-1 P concentration in comparison to Northside and Plum Creek stormwater ponds. There were several significant differences for TP concentrations among sites. Soil cores from SEEP had significantly greater TP concentrations than Lake Forest, Owens-Illinois, SW 43rd, Huntington, Northside, Plum Creek, and Duval. TP concentrations in SEEP were not statistically different from Forest Park with mean concentrations of 2421.0 and 1427.1 mg/kg, respectively. There were similar trends for water soluble phosphorus concentrations with Forest Park, SEEP, and Lake Forest having the greatest potential to release P in the presence of deionized water. Statistical differences between WSP, TP and Mehlich-1 P are presented in Table 5.

Table 5. Summary of Soil Core Results for Phosphorus

Stormwater Pond	Mehlich-1 P (mg/kg)		Total P (mg/kg)		Water Soluble P (mg/kg)	
Forest Park	293.4	a	1427.1	ab	0.70	a
SEEP	60.8	ab	2421.0	a	0.47	ab
Lake Forest	47.8	ab	227.8	b	0.37	abc
Owens-Illinois	33.9	ab	187.8	b	0.31	bc
SW 43rd	45.9	ab	903.9	b	0.21	bc
Huntington	98.28	ab	536.4	b	0.20	bc
Northside	36.4	b	292.1	b	0.14	c
Duval	72.74	ab	245.5	b	0.09	c
Plum Creek	7.2	b	246.5	b	0.07	c

Mean value calculated for each stormwater pond.
abcd = represent significant differences, determined by Tukey post-hoc test.

In order to estimate potential loss of P from soils when they are flooded, soil phosphorus storage capacity was calculated (Figure 4). Calculations of SPSC incorporate sorption properties of Fe, Al, Ca, and Mg ions. The pH of a system will control which ions are most active in sequestering or releasing P. In acidic soils, inorganic P is adsorbed on Fe and Al, while in conditions where pH is greater than 8, Ca and Mg are dominant in binding P. For this study, SPSC was determined for Fe and Al based on surface water pH.

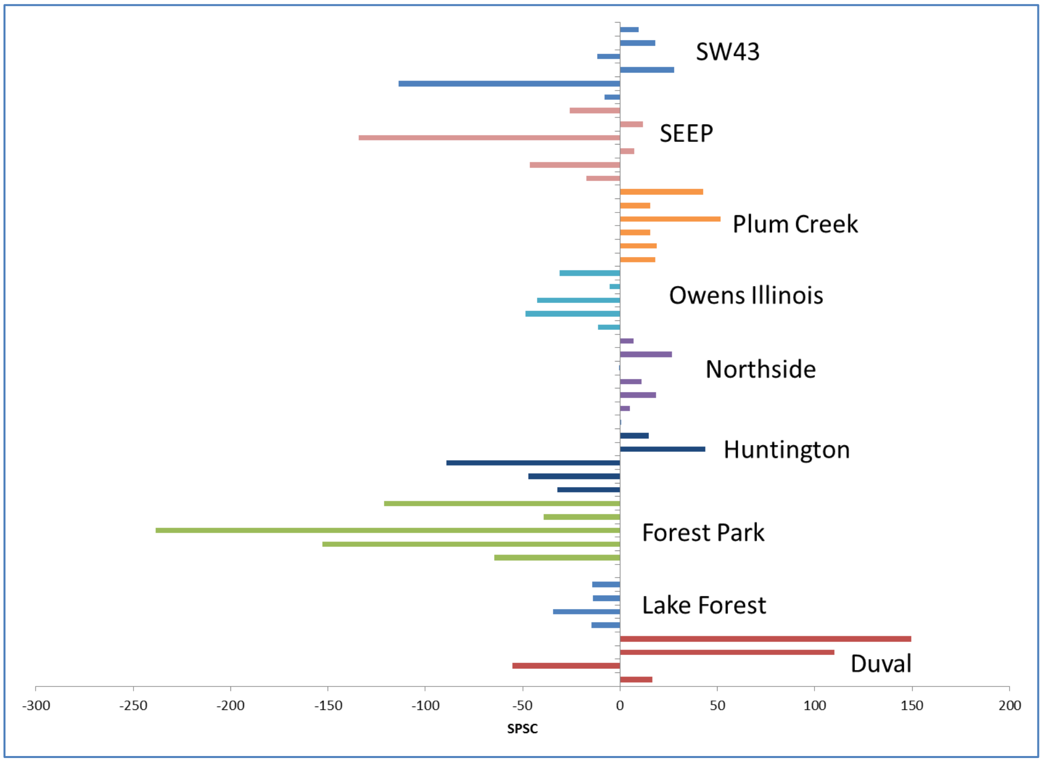

Figure 4. Soil Phosphorus Storage Capacity (SPSC)
Negative values indicate greater potential for phosphorus to be released by soil because of lack of available sorption sites.

Soil cores collected for the incubation study were divided to determine if there was a different potential P loss from surficial soils in comparison to the deeper soils. No statistical differences were present for the surface and lower soil layers so data for cores were compiled. The greater the negative value, the greater the potential for P to be desorbed during flooding; the greater the positive value, the greater concentration of P that will have sorption sites available. SPSC values suggest that there is the greatest potential for P loss from soils at Forest Park, Owens-Illinois, and Lake Forest soils in both soil layers. There is no consistent pattern to determine if top layer soils or lower layer soils have a greater potential to desorb P. Plum Creek and Northside stormwater ponds appear to have some ability to store P if it is introduced to the stormwater ponds. Other sites, such as SW 43rd, SEEP, Huntington, and Duval had some locations or soil cores that could act as a source and other soil cores that are capable of acting as a sink for P.

Soil Core Incubation Study

At the conclusion of the 11 and 14 day incubation studies, standing water in the cores had wide ranging concentrations of SRP (See Appendix C for incubation study results). At the end of the study the surface water from the Owens-Illinois cores had the greatest mean concentration, 0.23 mg/L, closely followed by the soil cores from Lake Forest neighborhood with a final SRP concentration of 0.21 mg/L (Figure 5). Both the Owens-Illinois and Forest Park sites were dry when soil cores were collected. The other incubated cores had final average SRP concentrations ranging from 0.005 to 0.07 mg/L for Huntington and Forest Park, respectively. Concentrations of SRP from this incubation study were in the range of those observed during direct sampling of stormwater ponds. These incubation studies are estimations of potential P release under controlled conditions as concentrations of P are approaching equilibrium between soil pore water and overlaying surface water.

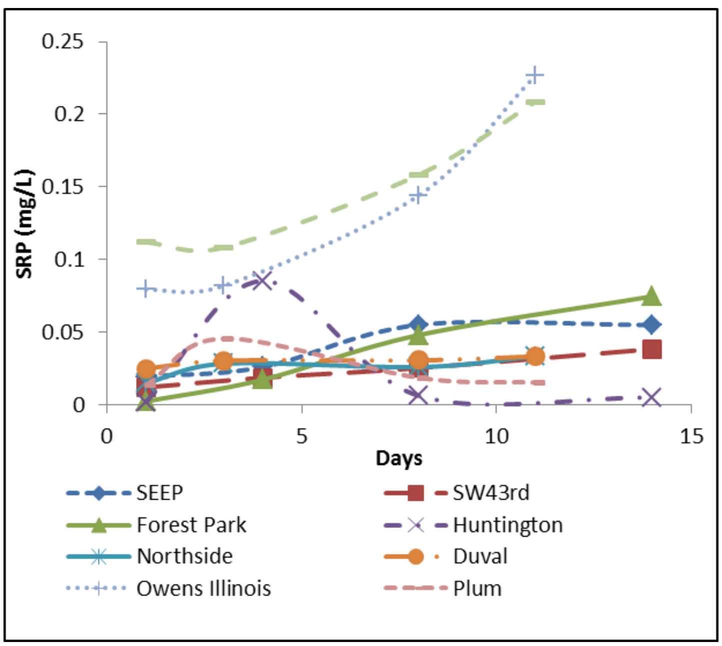

Figure 5. Estimated Phosphorus Release Curves for Incubation Study
Mean Values Calculated for Each Stormwater Pond.

Surface Water Quality Results

A statistical comparison of water quality results from all stormwater ponds was conducted for all dates and differences (field parameter measurements are provided in Appendix D). There were no differences among ponds for surface water temperature, which ranged from 21.5 to 30.7°C across all ponds and dates sampled. Measurements for pH at all sites had a wide range from 5.91 to 8.9 (Figure 6). The pH observed for the Northside stormwater pond was significantly more basic than the stormwater ponds at Duval, SW 43rd, Lake Forest, Owens-Illinois, Huntington, Forest Park, and SEEP. Plum Creek was also significantly more basic than SW 43rd, Lake Forest, Owens-Illinois, Huntington, Forest Park, and SEEP. Only Northside had a pH consistently greater than 8, which may be of importance for stormwater ponds and soil sorption availability.

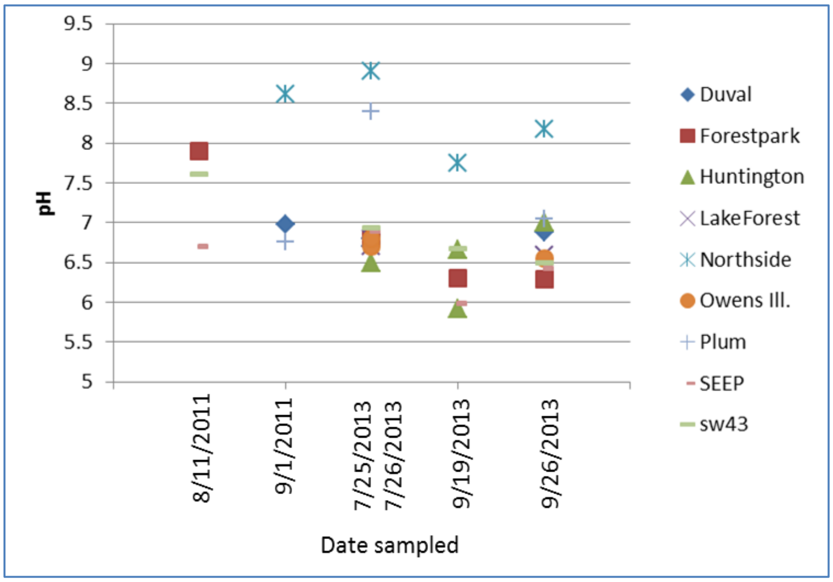

Figure 6. Field Sampled Surface Water pH Results for Each Sampling Event

Dissolved oxygen (DO) concentrations ranged from 0.15 to 9.47 mg/L. There were significant differences among ponds for DO; Northside had significantly higher DO concentrations than Huntington, Duval, Owens- Illinois, and Forest Park, while Plum Creek and SEEP concentrations were significantly higher than Duval, Owens- Illinois, and Forest Park. Elevated pH and DO concentrations in Plum Creek and Northside ponds may be related to the abundance of algae in the ponds. Conductivity ranged from 30 to 227 μmhos/cm. The Huntington stormwater pond had significantly higher specific conductivity than all other stormwater ponds except for Northside.

Statistical comparisons of the chemical composition of the surface water sampled in each stormwater pond resulted in several differences among ponds for sampling dates (See Appendix E for surface water quality data). For example, Northside had a greater calcium concentration compared to Huntington, Forest Park, SEEP, Lake Forest and SW 43rd. By contrast, no differences were observed for iron and aluminum concentrations among the stormwater ponds during these sampling events. Huntington had significantly greater Cl concentrations in comparison to all the other ponds with a mean value of 30 mg/L. Huntington also had significantly greater Mg concentrations than all other samples collected from the other ponds and SEEP had significantly greater Mg concentration compared to Lake Forest. For Na, Huntington was significantly higher in concentration than the other ponds. Sulfate concentrations during sampling events were significantly higher for Huntington than Northside, Forest Park, SW 43rd, or Plum Creek pond samples. At the time of sampling, indications of introduced water from a neighboring apartment complex's water fountain feature into the Huntington pond was evident by the blue colored water observed in the neighboring ditch. This location was brought to the attention of the SJRWMD and ACEPD as a possible illicit discharge.

The samples taken from the Plum Creek stormwater pond had significantly higher concentrations of K, as compared to all the other stormwater ponds in this study. Statistical differences were observed among ponds for TOC with Plum Creek having significantly greater mean concentration (14.8 mg/L) than SEEP, SW 43rd, Owens-Illinois, and Lake Forest stormwater ponds (6.7, 6.2, 4.9, and 4.4 mg/L, respectively). There were no significant differences in TDS or TSS.

Surface water samples were analyzed for TP, SRP, NO_3+NO_2, TKN, NH_3, and TN. Nitrogen species did not have statistical significant differences among ponds. Maximum TN concentrations of 2.7 mg/L and 2.35 mg/L were observed at Forest Park on September 19, 2013 and Plum Creek on September 1, 2013, respectively (Figure 7). Maximum TN value for Forest Park is attributable to TKN of 2.7 mg/L which was the greatest concentration of TKN observed as well. Most of the nitrogen is in the organic form since only 0.1 mg/L is ammonia. The highest Nitrate+Nitrite concentration observed was for Owens-Illinois at 0.045 mg/L.

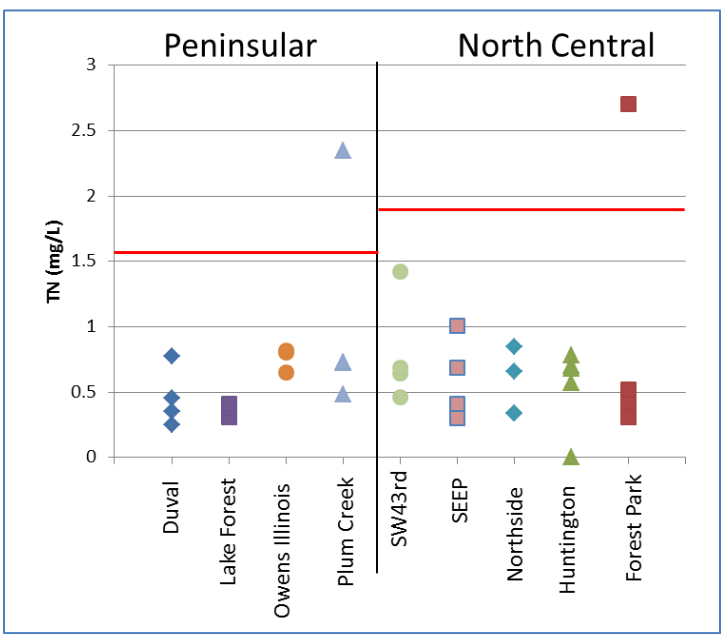

Figure 7. Surface Water TN Results

Numeric Nutrient Criteria region and corresponding maximum concentration indicated with red line.

The highest observed surface water concentration of TP was 0.304 mg/L in the SEEP and 0.278 mg/L in Owens-Illinois (Figures 8 and 9). Rainfall quantity was not a predictor of TP concentrations in surface waters of the stormwater ponds (Figure 8) and trends were not evident with respect to timing of sampling after rainfall. For temporal trends, SEEP did not consistently have elevated TP concentrations as Owens-Illinois did. There were significantly higher concentrations of TP observed during this study for Owens-Illinois as compared to the storm water ponds at Northside, Plum Creek, Huntington, and Duval.

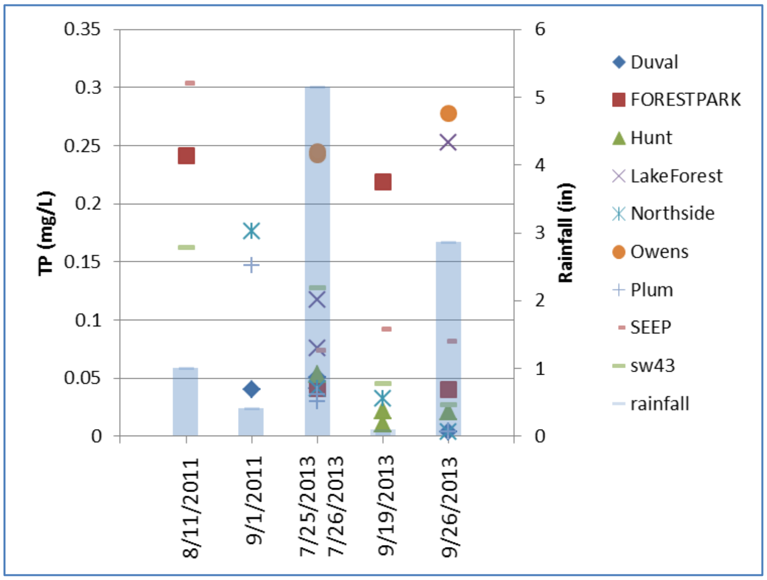

Figure 8. Surface Water TP Results
Blue bar represents total rainfall seven days prior to sample event.

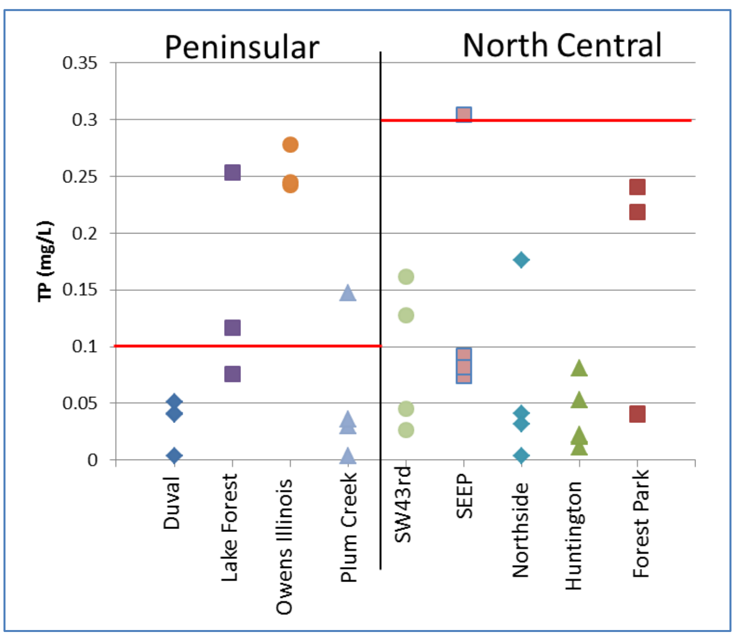

Figure 9. Surface Water TP Results
Numeric Nutrient Criteria region and corresponding maximum concentration indicated with red line.

When ponds were grouped by confinement zone, there was not a statistical difference between the zones for field sampled surface water TP or SRP. The mean TP and SRP for the confined are 0.11 and 0.09 mg/L and mean TP and SRP for the perforated are 0.02 and 0.06 mg/L, respectively for field sampled surface water. Similarly, final SRP concentrations in the incubation study did not have a statistical difference between the two confinement zones examined in this study. Mean SRP for the final sampling of the incubation study was 0.08 and 0.10 mg/L in the perforated and confined zones, respectively. There were statistical differences between confinement zones for WSP with the confined and the perforated zones having a mean WSP of 0.23 and 0.35 mg/L, respectively.

The maximum values of SRP observed in surface water for this study were 0.232 and 0.230 mg/L at Lake Forest and Owens-Illinois, respectively (Figure 10). Owens-Illinois also had significantly greater concentrations of SRP than the other ponds, with the exception of Lake Forest. There was a statistically significant positive relationship between WSP in soil and the TP in surface water (Figure 11). This was the strongest relationship for each combination of soil P extraction method to surface water P concentration. All relationships between soil P and water P were positively correlated except for total extractable P from soil and SRP from water, which had a slight negative relationship.

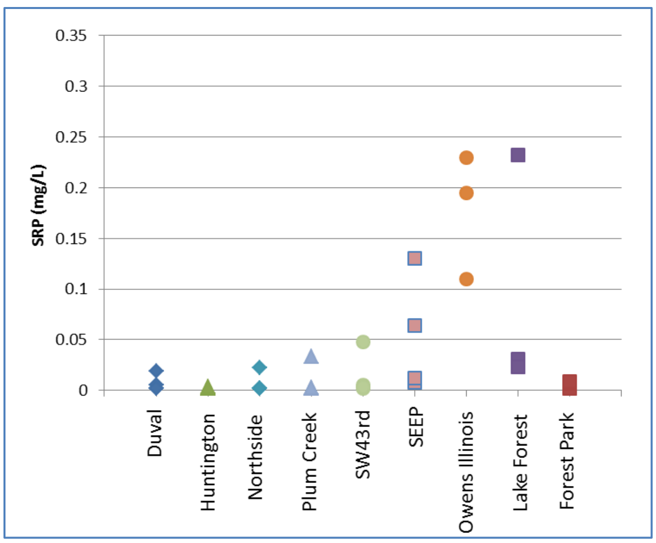

Figure 10. Soluble Reactive Phosphorus (SRP) Results

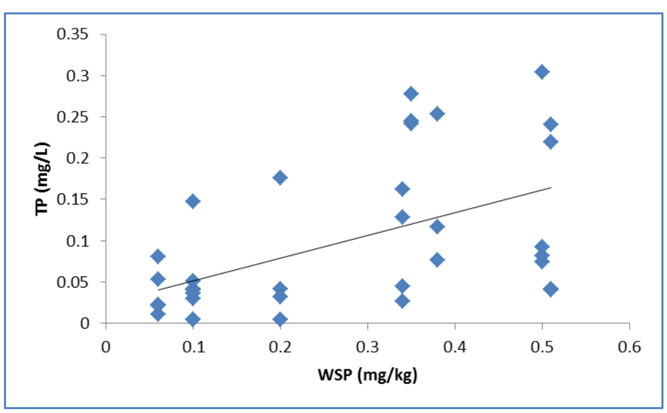

Figure 11. Surface Water TP and Soil Core WSP Results

Linear regression results in a R^2=0.266.

DISCUSSION

This study helps to predict the potential for stormwater ponds to influence phosphorus concentrations of neighboring surface waters while examining a variety of considerations. The ponds selected were across both the confined and perforated zones of the Floridan aquifer in Alachua County, with different ages and designs. The perforated zone in Alachua County is generally the area of the Cody Escarpment where the Hawthorn Group has been exposed by erosion and the phosphatic units in the Hawthorn are likely closer to land surface. For the purpose of this study, it was expected that there would be a greater soil P release in the perforated zone. Although the confinement zones were established to delineate areas of high aquifer recharge and pollution potential of the Floridan aquifer, they identify three distinct zones which allow for a comparison among zones for this study. Confinement zones, as defined by Macesich (1988), did not serve as a predictor for field sampled surface water TP or SRP concentration. There were two ponds that consistently had field surface water TP greater than 0.2 mg/L and those were Owens-Illinois and Lake Forest which both began this study dry and are frequently dry. The wetting and drying of stormwater basins will cause an initial pulse of P to be released from the soils. This initial pulse of P is of interest for the overall function of the stormwater ponds and their influence on the receiving water bodies.

This study focused on TP because the numeric nutrient criteria (NNC) is defined for TP and TN. Numeric nutrient criteria are defined for several regions around the state, with two regions occurring within Alachua County. The North Central region contains the watersheds of the Santa Fe River, Hogtown Creek, and Paynes Prairie and has criteria of 0.30 mg/L TP and 1.87 mg/L TN (Figures 7 and 9). The Peninsular region is located on the eastern portion of the county, encompassing the Orange Creek watershed. This watershed is underlain by the Hawthorn Group, yet maximum allowable nutrient concentrations are 0.12 mg/L TP and 1.54 mg/L TN (Figures 7 and 9), which will be difficult to attain with these high-P soils. The NNC for colored lakes (which would be the type of lake that is connected to the stormwater ponds in this study) is 0.16 mg/L TP and 2.23 mg/L TN. In order to put these consistently-high TP surface water concentrations into context, it is important to consider where these stormwater ponds drain. While the Owens-Illinois pond has a direct connection to Newnans Lake, the stormwater pond at Lake Forest does not have an outfall structure and will not directly influence neighboring surface water. Field-sampled surface water TN concentrations observed in this study were 0.25- 2.7 mg/L, with a median value of 0.64 mg/L, and TP concentrations were between 0.004-0.304 mg/L, with a median value of 0.053 mg/L. These values are within the range of other studies conducted in Florida, where median values of TN were 1.80 mg/L (Taylor et al., 2005), NO_3 ranging from 0.35 to 1.1 mg/L and TP ranging from 0.09 to 0.29 mg/L (Clark and Pitt, 2007; Gobel et al., 2007).

Soils in stormwater ponds across Alachua County were not a large enough source of P to exceed surface water criteria for the North Central region by the end of the incubation, but some exceeded the Peninsular criteria. Low SPSC values suggest that pond sediments may not be P sinks through sorption alone. As a result, P from stormwater may not be reduced in these ponds. In comparison to other storm water sampling in Alachua County, the concentrations of P leaving these ponds is small. However, the long time frame for potential release and total contribution of P is of concern, especially in watersheds which frequently exceed NNC concentrations.

Concentration of Mg and Ca are not included in soil phosphorus storage capacity (SPSC) of these systems because surface water pH was less than 8 where Al and Fe dominate P sorption and desorption, but Ca and Mg may help to reduce P flux in the incubation study in a non-dominant way. The pH of a system will control which ion is most actively sequestering or releasing P. In acidic soils, inorganic P is adsorbed on hydrous oxides of Fe and Al, and may precipitate as insoluble iron phosphate under aerobic conditions and as aluminum phosphate (Al-P) under alternating wet/dry conditions. Under conditions where pH is greater than 8, precipitation of insoluble Ca-P or Mg-P is the dominant transformation which occurs, but is not likely to be a dominant P removal process here. Considerations of suspended ions may rapidly sorb P as it enters these systems (Richardson and Reddy, 2012). However, it must be noted that sorption is only one of the numerous processes that are at work in stormwater pond P cycling.

Results of this study indicate that soils with a WSP value greater than 0.2 mg/kg have an increased likelihood of releasing P to overlying surface water to a level that may cause a violation of the NNC (Figure 11). This information could be utilized by testing soils as stormwater ponds are constructed to examine if native soils pose a risk to releasing sorbed P. In ponds where WSP exceeds 0.2 mg/kg, amendments or alternative soils may be utilized to act as a buffer between surface water and high-P soils, thereby reducing P release. As predicted, the ponds which had the greatest concentration for WSP similarly had at least one observation of higher than 0.2 mg/L TP. These ponds are SEEP, Forest Park, Lake Forest, and Owens-Illinois.

In conclusion, stormwater ponds could be designed so that soils where WSP concentrations are greater than 0.2 mg/kg are avoided or soils are amended to reflect such soil conditions to decrease P export. While there are great variations across soil conditions in individual stormwater ponds as seen in this study, this provides information on the importance of soil sampling during pond construction. Stormwater P export is not likely to be problematic in these stormwater ponds, since they have been designed as either dry or wet retention ponds and, therefore, only release stormwater to neighboring surface waters during high-water events.

CONCLUSIONS

1. Only one surface water sample exceeded the TP criteria for the North Central Region (0.3 mg/L), while many ponds exceeded Peninsular TP Criteria (0.12 mg/L).

2. Soils in stormwater ponds across Alachua County were not a large enough source of P to exceed surface water criteria for the North Central region by the end of the incubation, but some exceeded the Peninsular criteria.

3. Soil TP was a poor indicator of P release potential, while dryout appeared to be the key factor affecting P release.

4. It was unclear from grab sampling whether pond surface water nutrient levels were lower than inflow levels. Removal of P by particulate settling is likely the primary P removal mechanism in many stormwater basins, yet the current study only addressed sorption mechanisms. Future stormwater pond water quality characterization efforts should include upstream and downstream water sampling.

5. Stormwater ponds could be designed so that soils where WSP concentrations are greater than 0.2 mg/kg are avoided or soils are amended to reflect such soil conditions to decrease P export

6. Future efforts should focus on the part of the county with lower criteria (Peninsular Region), and on ponds that discharge to nutrient-impaired surface waters.

IDEAS FOR FUTURE STUDY

This study provided some important background information on soil relationships to surface water TP concentration. However, further work would allow ACEPD to examine the relationship between stormwater pond surface water and neighboring streams and lakes. Future studies should focus on stormwater ponds that have outfall devices, in order to quantify the impact they may have on neighboring surface water. Furthermore, identification of some detention ponds would provide information on ponds that continually release water. Of greatest importance is proximity and connection to neighboring surface waters through overflow device or channel. A future study which samples both effluent from the storm water basin and neighboring water body would allow ACEPD to determine if the stormwater ponds increase P concentration for downstream locations during discharge events. Samples collected on July 25th and 26th in 2013 captured outflow conditions during high water conditions. Rain events can cause particles to become suspended in stormwater and increase P sorption in the water column and then settle out or are transported downstream. Overflow conditions typically occur only after a large rain, during which rainfall has diluted P concentration in surface water of the pond. Future studies should focus on selecting ponds which have a connection to neighboring creeks or lakes, in order to assess load contribution to receiving water bodies. A comprehensive sampling of receiving water body upstream, downstream, and at the stormwater outfall should be considered for future studies.

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Appendix A. Photographs of Stormwater Ponds

Duval Stormwater Pond (July 26, 2013)

Forest Park Stormwater Pond (August 11, 2011)

Forest Park Stormwater Pond (July 26, 2013)

Huntington Stormwater Pond (July 26, 2013)

Lake Forest Stormwater Pond (July 26, 2013)

Northside Park Stormwater Pond (July 26, 2013)

Owens-Illinois Stormwater Pond (July 26, 2013)

Plum Creek Stormwater Pond (July 19, 2011)

Plum Creek Stormwater Pond (July 26, 2013)

University of Florida SEEP (July 26, 2013)

SW 43rd Street Stormwater Pond (August 11, 2011)

SW 43rd Street Stormwater Pond (July 26, 2013)

Appendix B. Soil Core Analysis Data

Tube	Sample ID	Depth (cm)	Top/ bottom	Mehlich-1 P (mg/kg)	Mehlich-1 Ca (mg/kg)	Mehlich-1 Mg (mg/kg)	Mehlich-1 Fe (mg/kg)	Mehlich-1 Al (mg/kg)	Organic Matter (%)	WSP (mg/kg)	TP (mg/kg)	PSR	SPSC (mg/kg)
26	Duval 1	10-20	b	44.56	3560	91.56	39.28	512.8	3.67	0.065	182.9	0.073	-14.034
42	Lake Forest 2	10-16	b	55.12	937.2	8.40	37.88	333.2	2.61	0.340	176.7	0.137	-34.943
12	Forest Park 3	10-20	b	1028	3688	165.3	56.24	202.0	2.33	0.974	2627	3.906	-1014.447
8	Forest Park 1	10-10.5	b	81.72	594.0	16.44	77.48	111.4	0.53	0.782	426.2	0.478	-73.178
10	Forest Park 2	14.5-22.5	b	174.2	3628	55.96	75.60	149.2	1.11	0.884	603.2	0.817	-163.500
14	Huntington 1	6.5-16.5	b	113.9	44.52	19.59	83.52	670.8	0.80	0.094	630.5	0.140	-73.099
16	Huntington 2	6-16	b	126.7	237.6	20.12	63.00	662.4	0.55	0.498	484.3	0.159	-86.910
18	Huntington 3	6-16	b	186.7	236.8	29.72	36.72	832.0	2.83	0.449	570.0	0.191	-137.901
35	Northside 1	7-14	b	21.48	1649	13.53	20.36	220.8	0.74	0.188	126.1	0.081	-8.241
37	Northside 2	6-16	b	89.32	72.64	3.01	1.59	937.2	0.99	0.008	496.8	0.083	-35.474
39	Northside 3	7.5-17	b	26.56	76.20	12.76	8.70	322.0	0.83	0.029	177.5	0.071	-7.834
31	Owens 2	10-20	b	17.01	2400	234.8	42.24	29.44	1.27	0.138	187.4	0.297	-14.149
33	Owens 3	10-20	b	54.08	769.6	200.4	48.80	23.80	1.25	0.385	195.8	0.995	-51.363
45	Plum 1	6.5-16.5	b	1.47	306.4	15.15	76.64	134.1	0.67	0.101	83.94	0.007	8.352
47	Plum 2	3-13	b	0.19	366.4	24.52	50.20	140.8	2.02	0.023	94.18	0.001	9.289
49	Plum 3	3.5-13.5	b	0.07	423.6	46.84	45.24	114.6	3.06	0.000	102.4	0.000	7.754
2	SEEP 1	10-20	b	17.78	11070	698.4	0.00	4.96	24.89	0.743	4798	3.121	-17.495
3	SEEP 1	25-35	b	80.76	1797	162.7	68.72	266.8	2.84	0.461	1340	0.235	-63.542

Tube	Sample ID	Depth (cm)	Top/ bottom	Mehlich-1 P (mg/kg)	Mehlich-1 Ca (mg/kg)	Mehlich-1 Mg (mg/kg)	Mehlich-1 Fe (mg/kg)	Mehlich-1 Al (mg/kg)	Organic Matter (%)	WSP (mg/kg)	TP (mg/kg)	PSR	SPSC (mg/kg)
25	Duval 1	0-10	t	105.7	1770	61.16	27.12	427.6	1.45	0.097	125.9	0.209	-80.422
27	Duval 2	0-10	t	45.52	309.2	29.68	5.89	1353	2.73	0.041	117.0	0.029	32.304
28	Duval 3	0-10	t	95.16	972.4	42.08	6.04	2128	3.43	0.163	556.4	0.039	27.170
11	Forest Park 3	0-10	t	275.4	4032	298.0	80.88	283.2	19.10	0.304	2820	0.744	-256.904
7	Forest Park 1	0-10	t	49.68	50104	334.8	17.14	83.60	1.97	0.473	332.1	0.471	-44.406
9	Forest Park 2	0-14.5	t	151.9	4096	336.0	47.40	243.2	9.08	0.753	1754	0.497	-136.607
13	Huntington 1	0-6.5/ 0-6.5	t	40.28	262.4	31.52	172.4	649.2	4.24	0.016	438.5	0.048	1.760
15	Huntington 2	0.6/ 0-5	t	51.80	553.2	47.60	137.2	513.2	2.27	0.058	482.0	0.078	-18.542
17	Huntington 3	0-6/ 0-6	t	70.32	477.6	61.48	109.9	565.2	2.06	0.097	613.0	0.099	-34.832
40	Lake Forest 1	0-16	t	55.44	4188	77.76	18.48	175.4	1.68	0.449	297.0	0.262	-44.859
41	Lake Forest 2	0-10	t	36.36	635.6	23.88	48.16	171.6	1.52	0.365	242.7	0.163	-25.174
43	Lake Forest 3	0-10	t	44.40	251.6	10.74	39.00	242.4	0.95	0.327	194.8	0.148	-29.405
34	Northside 1	0-7	t	0.51	5923	42.68	0.00	2.63	2.17	0.174	289.5	0.170	-0.363
36	Northside 2	0-6	t	56.24	2840	23.40	25.92	710.4	2.16	0.272	469.9	0.068	-14.740
38	Northside 3	0-7.5	t	24.48	4180	38.68	29.04	258.4	10.20	0.162	192.8	0.078	-8.842
30	Owens 2	0-10	t	50.16	4614	182.6	22.48	53.24	2.79	0.478	211.1	0.682	-46.481
32	Owens 3	0-10	t	10.60	505.6	54.52	37.44	28.16	0.94	0.133	77.25	0.200	-7.947
29	Owens 1	0-10	t	37.68	5078	306.0	14.24	49.40	2.77	0.433	267.7	0.583	-34.450
44	Plum1	0-6.5/ 0-3	t	18.76	2108	111.0	77.72	575.6	10.69	0.068	602.9	0.027	16.435
46	Plum2	0-3/ 0-3	t	18.70	1185	58.56	109.3	244.4	7.84	0.166	256.2	0.055	-1.641
48	Plum 3	0-3/ 0-3.5	t	3.90	1429	65.84	144.5	336.4	9.80	0.080	339.4	0.008	19.416

Tube	Sample ID	Depth (cm)	Top/ bottom	Mehlich-1 P (mg/kg)	Mehlich-1 Ca (mg/kg)	Mehlich-1 Mg (mg/kg)	Mehlich-1 Fe (mg/kg)	Mehlich-1 Al (mg/kg)	Organic Matter (%)	WSP (mg/kg)	TP (mg/kg)	PSR	SPSC (mg/kg)
1	SEEP 1	0-10	t	161.8	9512	1846	0.00	239.3	30.81	0.579	3208	0.589	-148.064
4	SEEP 3	0-3/ 0-5	t	21.52	3996	389.6	19.15	281.6	22.01	0.635	2248	0.064	-4.824
6	SEEP 4	0-10	t	45.48	1246	234.0	26.72	159.4	2.98	0.259	2008	0.230	-35.590
5	SEEP 3	3-13	b	37.52	564.4	99.16	139.6	324.4	2.35	0.164	924.6	0.083	-15.034
20	SW43rd 1	10-20	b	27.68	1314	119.8	77.12	134.0	2.50	0.179	850.3	0.141	-17.855
22	SW43rd 2	3.5-13.5	b	4.45	726.0	54.96	208.4	180.0	2.55	0.039	412.3	0.014	11.650
24	SW43rd 3	6-16	b	7.53	859.2	51.08	139.3	156.0	2.53	0.043	372.3	0.029	5.284
19	SW43rd 1	0-10	t	165.2	6288	422.0	77.56	411.2	24.27	0.404	1993	0.321	-139.447
21	SW43rd 2	0-3.5/ 0-4	t	59.36	4128	399.0	121.0	358.0	4.61	0.566	1336	0.124	-35.459
23	SW43rd 3	0-6/ 0-6	t	11.28	840.0	63.12	90.44	137.4	3.39	0.053	459.0	0.054	-0.895

Soil Core analyses were conducted by the University of Florida Analytical Research Laboratory (ARL)

Appendix C. Soil Core Incubation Study Data

Results from First Study SRP (mg/L)				
Sample ID	**Day 1**	**Day 4**	**Day 8**	**Day 14**
SEEP 1	0.030	0.045	0.081	0.087
SEEP 2	0.007 I	0.013	0.030	0.025
SEEP 4	0.021	0.020	0.054	0.053
SW43rd 1	0.032	0.048	0.063	0.097
SW43rd 2	0.002 U	0.004 I	0.005 I	0.004 I
SW43rd 3	0.002 U	0.004 I	0.008 I	0.014
Forestpark1	0.002 U	0.013	0.034	0.033
Forestpark2	0.002 U	0.012	0.028	0.059
Forestpark3	0.003	0.027	0.082	0.132
Huntpond1	0.002 U	0.004 I	0.005 I	0.008 I
Huntpond2	0.002 U	0.004 I	0.007 I	0.003 I
Huntpond3	0.002 U	0.248	0.007 I	0.004 I
Rain-1	0.002 U	0.004 I	0.008 I	0.003 I
Blank	NC	NC	0.005 I	NC

Soil Core Samples Collected August 11, 2011

NC = Not Collected

Results from Second Study SRP (mg/L)				
Sample ID	**Day 1**	**Day 3**	**Day 8**	**Day 11**
Northside 1	0.007 I	0.020	0.014	0.020
Northside 2	0.024	0.039	0.032	0.039
Northside 3	0.014	0.026	0.032	0.041
Duval 1	0.024	0.032	0.027	0.018
Duval 2	0.016	0.017	0.015	0.028
Duval 3	0.035	0.042	0.050	0.054
Owens 1	0.064	0.075	0.124	0.209
Owens 2	0.131	0.111	0.197	0.304
Owens 3	0.043	0.060	0.111	0.167
Plum 1	0.037	0.048	0.052	0.042
Plum 2	0.002 U	0.005 I	0.002 U	0.002 I
Plum 3	0.002 U	0.084	0.002 U	0.002 U
Forestneighborhood1	0.058	0.151	0.129	0.176
Forestneighborhood2	0.135	0.133	0.189	0.264
Forestneighborhood3	0.143	0.041	0.157	0.186
Rain-1	0.030	0.010	0.039	0.042

Soil Core Samples Collected September 1, 2011

I = The reported value is between the lab minimum detection limit and the lab practical quantitation limit.
U = The compound was analyzed for but not detected.
Forest neighborhood sample ID = Lake Forest
Water quality samples analyzed by Advanced Environmental Laboratories, Inc. (AEL)

Appendix D. Surface Water Field Data

Sample ID	Date	Time	Location	Temp. (°C)	Sp. Cond. (µS/cm)	DO (%)	DO (mg/l)	pH	Turbidity (NTU)
Duval	9/1/2011	11:35	Unspecified	30.01	102	10.3	1.08	6.97	NA
Duval	7/26/2013	9:00	Outfall	26.4	80	24.1	1.94	6.7	0.72
Duval In	7/26/2013	9:20	Inflow	26.7	90	35.5	2.81	6.8	0.91
Duval	9/26/2013	12:00	Outfall	25.09	194	2.5	0.21	6.88	4.11
Forest Park	8/11/2011	12:50	Unspecified	31.1	76	110.5	8.16	7.9	1.44
Forest Park	7/25/2013	13:00	Outfall	26.2	55	28.4	2.33	6.81	1.59
Forest Park	9/19/2013	9:45	Outfall	25.74	99	1.8	0.15	6.3	5.35
Forest Park	9/26/2013	15:00	Outfall	26.05	57	5.6	0.45	6.29	4.34
Hunt Pond	7/25/2013	14:00	Outfall	27.7	164	26.6	2.1	6.5	1.59
Hunt Pond	9/19/2013	10:30	Outfall	26.04	206	35.1	2.88	5.91	0.61
Hunt Pond	9/19/2013	10:35	Center	26.55	227	21.5	1.71	6.66	4.8
Hunt Pond	9/26/2013	14:00	Outfall	21.52	209	NA	4.68	7	3.21
Hunt Pond	8/11/2011	15:15	Unspecified	32.7	147	87.5	6.25	7.17	1.83
Lake Forest	7/26/2013	10:15	Pond	28.3	30	33.4	2.6	6.7	0.74
Lake Forest 2	7/26/2013	10:30	Outfall	28.8	38	40.8	3.15	6.8	1.48
Lake Forest	9/26/2013	11:40	Center	26.54	61	55.2	4.42	6.59	1.23
Northside	9/1/2011	9:45	Unspecified	29.68	212	88.1	6.69	8.61	33.2
Northside	7/25/2013	14:40	Outfall	27.8	93	113	8.88	8.9	1.57
Northside	9/19/2013	11:40	Outfall	27.18	120	79	6.27	7.74	1.83
Northside	9/26/2013	13:20	Outfall	27.57	110	99.5	7.83	8.18	1.7
Owens	7/26/2013	11:15	Outfall	25.5	75	18.9	1.55	6.7	1.72
Owens In	7/26/2013	11:40	Pond	25.8	86	33	2.68	6.8	2.87
Owens Illinois	9/26/2013	11:15	Center	24.59	111	7.9	0.66	6.55	16.3
Plum	9/1/2011	14:05	Unspecified	32.22	74	26	2.08	6.75	23.8
Plum	7/26/2013	12:30	Pond	29.1	102	93.7	7.21	8.4	1.13
Plum Out	7/26/2013	13:00	Outfall	29	105	123.1	9.47	8.4	0.98
Plum	9/26/2013	10:20	Outfall	25.42	97	42.7	3.46	7.04	0.63
SEEP	8/11/2011	10:20	Unspecified	27.72	109	20.8	1.65	6.7	5.77
SEEP	7/25/2013	16:00	Pond	27.1	61	88.4	7.03	6.9	4.86
SEEP	9/19/2013	14:00	Pond	26.3	43	30.01	5.99	5.99	3.01
SEEP	9/26/2013	14:30	Pond	27.39	65	75.6	5.97	6.43	1.9
SW 43 Pond	8/11/2011	11:40	Unspecified	31.27	40	109.2	8.23	7.61	NA
SW 43 Pond	7/25/2013	12:15	Inflow	28.88	42	72.5	5.58	6.93	10.3
SW 43 Pond	9/19/2013	9:15	Center	24.93	54	28.9	2.39	6.67	1.89
SW 43 Pond	9/26/2013	15:20	Center	30.7	43	99.7	7.46	6.5	6.16

Field parameters measured with YSI 556; NA = not analyzed.

Appendix E. Surface Water Quality Data

Location/ Sample ID	Date	Time	Location	TP	SRP	NH3	NOx	TKN	TN
Duval	9/1/2011	11:35	Unspecified	0.040	0.019	0.039	0.014	0.76	0.774
Duval	7/26/2013	9:00	Outfall	0.041	0.002 U	NA	0.016	0.33	0.35
Duval In	7/26/2013	9:20	Inflow	0.051	0.005 I	NA	0.020	0.23	0.25
Duval	9/26/2013	12:00	Outfall	0.004 U	0.002 U	0.07	0.008	0.44	0.45
Forest Park	8/11/2011	12:50	Unspecified	0.241	0.004	0.009 U	0.005	0.42	0.425
Forest Park	7/25/2013	13:00	Outfall	0.041	0.002 U	NA	0.012	0.30	0.31
Forest Park	9/19/2013	9:45	Outfall	0.219	0.007	0.10	0.004	2.7	2.7
Forest Park	9/26/2013	15:00	Outfall	0.040	0.009	0.12	0.023	0.50	0.52
Hunt Pond	7/25/2013	14:00	Outfall	0.053	0.002 U	NA	0.017	0.68	0.70
Hunt Pond	9/19/2013	10:30	Outfall	0.011	0.002 U	0.05	0.004 U	0.68	0.68
Hunt Pond	9/19/2013	10:35	Center	0.022	0.002 U	0.05	0.004 U	0.071 U	0.071 U0.004 U
Hunt Pond	9/26/2013	14:00	Outfall	0.021	0.004 I	0.19	0.004	0.57	0.57
Hunt Pond	8/11/2011	15:15	Unspecified	0.081	0.002 U	0.011	0.010	0.77	0.78
Lake Forest	7/26/2013	10:15	Pond	0.076	0.031	NA	0.019	0.29	0.31
Lake Forest 2	7/26/2013	10:30	Outfall	0.117	0.023	NA	0.012	0.37	0.38
Lake Forest	9/26/2013	11:40	Center	0.253	0.232	0.15	0.006	0.40	0.41
Northside	9/1/2011	9:45	Unspecified	0.176	0.022	0.066	0.009	0.84	0.849
Northside	7/25/2013	14:40	Outfall	0.041	0.002 U	NA	0.008	0.33	0.34
Northside	9/19/2013	11:40	Outfall	0.032	0.002 U	0.04	0.004 U	0.66	0.700.66
Northside	9/26/2013	13:20	Outfall	0.004 U	0.002 U	0.19	0.005	0.34	0.34
Owens	7/26/2013	11:15	Outfall	0.242	0.195	NA	0.045	0.76	0.80
Owens In	7/26/2013	11:40	Pond	0.245	0.110	NA	0.028	0.62	0.65
Owens Illinois	9/26/2013	11:15	Center	0.278	0.230	0.17	0.009	0.81	0.82
Plum	9/1/2011	14:05	Unspecified	0.147	0.033	1.350.135	0.022	2.33	2.35
Plum	7/26/2013	12:30	Pond	0.03	0.002	NA	0.016	0.70	0.72
Plum Out	7/26/2013	13:00	Outfall	0.036	0.002 U	NA	0.016	0.71	0.73
Plum	9/26/2013	10:20	Outfall	0.004 U	0.003 I	0.20	0.033	0.45	0.48
SEEP	8/11/2011	10:20	Unspecified	0.304	0.130	0.016	0.010	1.00	1.01
SEEP	7/25/2013	16:00	Pond	0.074	0.008	NA	0.030	0.38	0.41
SEEP	9/19/2013	14:00	Pond	0.092	0.012	0.09	0.004 U	0.69	0.69
SEEP	9/26/2013	14:30	Pond	0.082	0.064	0.13	0.023	0.28	0.30
SW 43 Pond	8/11/2011	11:40	Unspecified	0.162	0.048	0.031	0.009	1.41	1.42
SW 43 Pond	7/25/2013	12:15	Inflow	0.128	0.005 I	NA	0.015	0.62	0.64
SW 43 Pond	9/19/2013	9:15	Center	0.045	0.002 U	0.03	0.004 U	0.69	0.69
SW 43 Pond	9/26/2013	15:20	Center	0.027	0.004 I	0.32	0.004 U	0.46	0.46
Rain	8/11/2011	14:20	Unspecified	0.026	0.002	0.098	0.036	0.41	0.446

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U = The compound was analyzed for but not detected.
NA = Not analyzed.
Water quality samples analyzed by Advanced Environmental Laboratories, Inc. (AEL)

Sample ID	Date	Time	Location	TOC	TSS	TDS	SO4	Cl
Duval	9/1/2011	11:35	Unspecified	7.5	8 I	86	NA	2.1
Duval	7/26/2013	9:00	Outfall	NA	2 U	NA	NA	NA
Duval In	7/26/2013	9:05	Inflow	NA	2.0 U	NA	NA	NA
Duval	9/26/2013	12:00	Outfall	7.8	2.0 U	120	7.0	9.0
Forest Park	8/11/2011	12:50	Unspecified	12.5	2	73	2.2	1.6
Forest Park	7/25/2013	13:00	Outfall	NA	4 U	NA	NA	NA
Forest Park	9/19/2013	9:45	Outfall	7.3	17	50	0.28 I	0.85
Forest Park	9/26/2013	15:00	Outfall	10	8.8	45	0.46	0.47
Hunt Pond	7/25/2013	14:00	Outfall	NA	6.8	NA	NA	NA
Hunt Pond	9/19/2013	10:30	Outfall	11	2.0 U	130	9.1	37
Hunt Pond	9/19/2013	10:35	Center	11	2.8	120	9.0	37
Hunt Pond	9/26/2013	14:00	Outfall	10	8.2	140	7.3	30
Hunt Pond	8/11/2011	15:15	Unspecified	10.3	4	128	4.7	19.2
Lake Forest	7/26/2013	10:15	Pond	NA	2.0 U	NA	NA	NA
Lake Forest 2	7/26/2013	10:30	Outfall	NA	3.0	NA	NA	NA
Lake Forest	9/26/2013	11:40	Center	4.4	2.4	50	0.49 I	0.48 I
Northside	9/1/2011	9:45	Unspecified	12.6	36	182	NA	6.7
Northside	7/25/2013	14:40	Outfall	NA	2.6	NA	NA	NA
Northside	9/19/2013	11:40	Outfall	6.7	2.4	61	1.8	0.61
Northside	9/26/2013	13:20	Outfall	5.9	2.8	79	1.5	0.63
Owens	7/26/2013	11:15	Outfall	NA	2.0 U	NA	NA	NA
Owens In	7/26/2013	11:40	Pond	NA	3.2	NA	NA	NA
Owens Illinois	9/26/2013	11:15	Center	4.9	9.2	110	0.11 I	3.7
Plum	9/1/2011	14:05	Unspecified	15.6	36	110	NA	4.5
Plum	7/26/2013	12:30	Pond	NA	2.8	NA	NA	NA
Plum Out	7/26/2013	13:00	Outfall	NA	2.0 U	NA	NA	NA
Plum	9/26/2013	10:20	Outfall	14	2.0 U	86	0.07 U	2.6
SEEP	8/11/2011	10:20	Unspecified	8.4	35	107	3.4	3.0
SEEP	7/25/2013	16:00	Pond	NA	3.0	NA	NA	NA
SEEP	9/19/2013	14:00	Pond	6.4	8.8	27	4.6	3.3
SEEP	9/26/2013	14:30	Pond	5.4	2.6	58	8.3	2.6
SW 43 Pond	8/11/2011	11:40	Unspecified	6.0	10	77	1.7	1.7
SW 43 Pond	7/25/2013	12:15	Inflow	NA	8.0	NA	NA	NA
SW 43 Pond	9/19/2013	9:15	center	8.0	4.0	38	0.077 I	0.13 I
SW 43 Pond	9/26/2013	15:20	center	4.7	6.6	38	0.19 I	0.077 U
Rain	8/11/2011	14:20	Unspecified	10.3	NA	NA	NA	NA

I = The reported value is between the lab minimum detection limit and the lab practical quantitation limit.
U = The compound was analyzed for but not detected.
NA = Not analyzed.
Water quality samples analyzed by Advanced Environmental Laboratories, Inc. (AEL)

Sample ID	Date	Time	Location	Ca	Mg	Fe	Al	K	Na
Duval	9/1/2011	11:35	Unspecified	14	1.2	NA	NA	0.84	0.71 U
Duval	7/26/2013	9:00	Outfall	13	0.82	0.071 I	0.027 I	0.41	1.42
Duval In	7/26/2013	9:20	Inflow	14	1.1	0.078 I	0.061 I	0.46	1.95
Duval	9/26/2013	12:00	Outfall	27	2.6	0.21 V	0.035 I	1.71	8.4
Forest Park	8/11/2011	12:50	Unspecified	11.2	1.33	0.1	NA	0.03	0.29
Forest Park	7/25/2013	13:00	Outfall	9.2	0.93	0.058 I	0.023 I	0.46	0.36
Forest Park	9/19/2013	9:45	Outfall	15	1.6	0.28	0.061 U	1.2	0.74
Forest Park	9/26/2013	15:00	Outfall	9.8	1.0	0.12 I,V	0.044 I	0.66	0.41
Hunt Pond	7/25/2013	14:00	Outfall	15	3.7	1.6	0.150 I	1.58	11.01
Hunt Pond	9/19/2013	10:30	Outfall	14	4.1	0.074 I	0.061 U	2.2	14
Hunt Pond	9/19/2013	10:35	Center	13	3.8	0.43	0.24	2.1	14
Hunt Pond	9/26/2013	14:00	Outfall	14	3.8	0.12 I,V	0.22	2.17	14
Hunt Pond	8/11/2011	15:15	Unspecified	10.1	3.23	0.54	NA	2.07	7.46
Lake Forest	7/26/2013	10:15	Pond	5.2	0.39	0.014 I	0.033 I	0.30	0.12
Lake Forest	7/26/2013	10:30	Outfall	6.1	0.46	0.017 I	0.034 I	0.19	0.15
Lake Forest	9/26/2013	11:40	Center	11	0.83	0.062 I,V	0.049 I	1.26	0.38
Northside	9/1/2011	9:45	Unspecified	33	3	NA	NA	1.7	3
Northside	7/25/2013	14:40	Outfall	18	0.76	0.051 I	0.084 I	0.19	0.57
Northside	9/19/2013	11:40	Outfall	21	0.96	0.047 I	0.061 U	0.099 I	0.51
Northside	9/26/2013	13:20	Outfall	21	0.90	0.05 I, V	0.045 I	0.22	0.53
Owens	7/26/2013	11:15	Outfall	13	1.5	0.21	0.16 I	0.45	1.12
Owens In	7/26/2013	11:40	Pond	17	1.5	0.18 I	0.32	0.57	0.85
Owens Illinois	9/26/2013	11:15	Center	22	2.6	0.4 V	0.24	2.73	1.9
Plum	9/1/2011	14:05	Unspecified	9.3	1	NA	NA	4.1	1.7
Plum	7/26/2013	12:30	Pond	18	1.3	0.26	0.094	0.35	1.56
Plum Out	7/26/2013	13:00	Outfall	18	1.3	0.22	0.041	0.40	1.42
Plum	9/26/2013	10:20	Outfall	17	1.2	0.12 I, V	0.024 I, V	0.87	1.8
SEEP	8/11/2011	10:20	Unspecified	14.5	2.8	0.684	NA	0.50	1.58
SEEP	7/25/2013	16:00	Pond	7.5	2.0	0.20	0.74	0.43	2.29
SEEP	9/19/2013	14:00	Pond	4.8	1.5	0.11 I	0.24	0.57	1.9
SEEP	9/26/2013	14:30	Pond	6.6	1.9	0.095 I, V	0.094 I	1.31	1.9
SW 43rd Pond	7/25/2013	12:15	Inflow	6.9	0.78	0.43	0.95	0.11	0.19
SW 43rd Pond	9/19/2013	9:15	center	7.8	1.1	0.32	0.061 U	0.33	0.43
SW 43rd Pond	9/26/2013	15:20	center	5.8	0.78	0.27 V	0.41	0.29	0.29
SW 43rd Pond	8/11/2011	11:40	Unspecified	6.95	1.17	0.816	NA	0.22	0.20 U
Rain	8/11/2011	14:20	Unspecified	NA	NA	NA	NA	NA	NA

I = The reported value is between the lab minimum detection limit and the lab practical quantitation limit.
U = The compound was analyzed for but not detected.
V = Method blank contamination.
NA = Not analyzed.
Water quality samples analyzed by Advanced Environmental Laboratories, Inc. (AEL)