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Phosphorus Retention and Storage by Isolated and Constructed Wetlands in the Okeechobee Drainage Basin

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1.0 INTRODUCTION

Wetlands are known to accrete nutrients and other contaminants and are sometimes managed to improve their overall performance, and to maintain expected water quality. The extent of management required depends upon the nutrient/contaminant retention capacity of wetlands, contaminant load to wetlands, and the desired effluent quality. Management scenarios can vary, depending on type of wetland and hydraulic loading rate. For example, small-scale wetlands can be managed efficiently by altering the hydraulic loading or integrating them with conventional treatment system while large-scale systems can be managed by controlling nutrient/contaminant loads (Reddy et al. 1999).

Phosphorus (P) retention by wetland soils includes surface adsorption on minerals, precipitation, microbial immobilization, and plant uptake, and these processes may be combined into two distinct P retention pathways: sorption and burial (Figure 1). Phosphorus sorption in soils is defined as the removal of phosphate from the soil solution to the solid phase, and includes both adsorption and precipitation reactions.

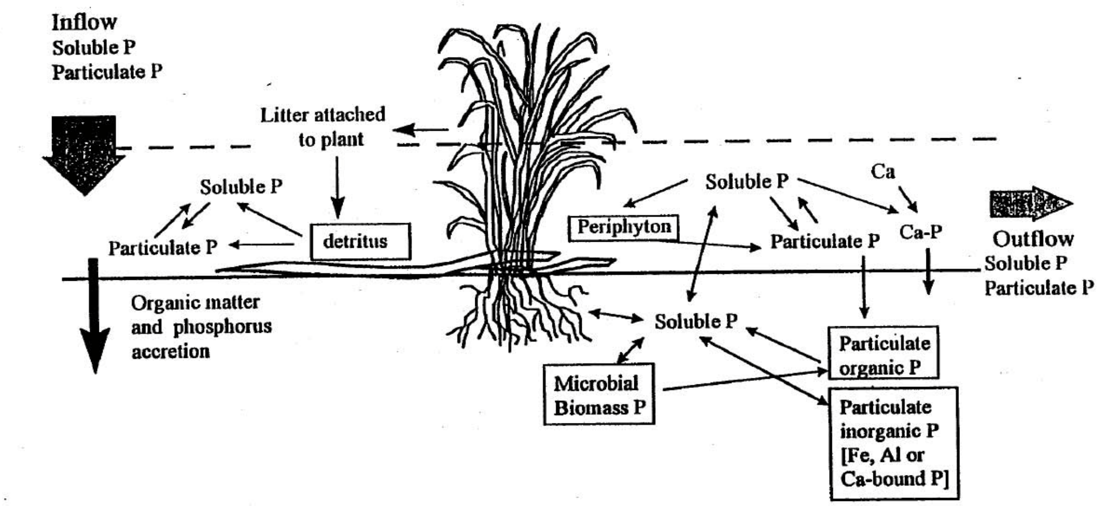


Figure 1.1. Schematic showing phosphorus cycling in isolated wetlands

Phosphorus immobilization through microbial and plant uptake are also significant pathways for P removal. However, when plants and microbes die off, the P contained in cellular tissue may either recycle within the wetland, or may be buried with refractory organic compounds.

Accretion of organic matter has been reported as a major mechanistic sink for phosphorus in wetlands. Wetland soils tend to accumulate organic matter due to the production of detrital material from biota and the suppressed rates of decomposition. Soil accretion rates for constructed wetlands are on the order of millimeters per year, although accretion rates in productive natural systems such as the Everglades have been reported as high as one centimeter or more per year. The genesis of this new soil is a relatively slow process, which may affect the P sorption characteristics of the wetland. With time, productive wetland systems will accumulate organic matter (which ultimately forms peat) that has different physical and biological characteristics than the underlying soil. Eventually, this new material settles and compacts to form new soil with perhaps different P sorption characteristics than the original soil. As the wetland ages, steady accumulation of organic matter can potentially decrease the efficiency of the wetland to assimilate additional P and alter the hydraulic flow paths, as organic accretion is seldom uniform throughout space. These conditions can result in elevated effluent P concentrations. However, management of newly accreted material by consolidation or removal can improve the overall P retention capacity of wetland.

Small historically isolated wetlands, which are a common feature throughout the Okeechobee Basin cover about 12,000 ha of the four priority sub-basins. These systems (about 50%) are presently ditched and drained. Hydrologic restoration of these wetlands may help to provide water storage and long-term phosphorus (P) retention within Okeechobee's four priority basins. There is interest in using these systems to store water and nutrients in the landscape, as the P load to Lake Okeechobee still needs to be reduced to achieve it's target TMDL of 140 metric tons of phosphorus by 2015.

During the time of the current project Larson Dixie and Beaty wetlands experienced extreme events (hurricanes in 2004), which delayed our monitoring program by about six months. Further, since April 2006 all sites have been dry (no surface water) due to the severe drought period. Due to this prolonged drought period, we have not been able to determine the effect of hydrological restoration on wetland P storage and retention of the current project. It was originally proposed that one of the wetlands at Larson Dixie and one of the wetlands at Beaty would be hydrological restored, while the other remaining wetland at each site would not. Thus, the effect of restoration would be determined by the difference between the restored and the unrestored wetland at each site.

This lack of knowledge precludes the ability to provide science to support best management practices to protect and conserve watershed water quality and the water quality in Lake Okeechobee. Further, very little information exists at the field-scale on the ability of hydrologically restored isolated wetlands to retain incoming nutrient loads.

Long-term monitoring is required to determine the effect of restoration. This may be more than 3 years and could be up to 10 years. Murkin et al. (2000) undertook similar work in isolated wetlands (prairie potholes) in northern portions of the US. They found that there was a time lag between the time of hydrological restoration, where wetland water levels were permanently increased, and when wetland components (vegetation) responded to these new water level regimes. Vegetation is the source material for plant litter, which in turn is the source material for soil organic matter, which in turn is considered critical for long-term phosphorus storage. From our soil data at Larson Dixie and Beaty, and from many of the other wetlands sampled in the four priority basins, we found that total P content in soils is related to soil organic matter.

Another concern at Larson and Beaty ranches that confounds the ability to determine the effect of hydrologic restoration is the impact of cattle on site. Cattle impacts in these isolated wetlands include direct grazing, manure deposition, and trampling of soils. There is little information on cattle impacts and from out experience to date at Larson and Beaty, cattle impact these systems so much that it hinders our ability to determine the effect of restoring hydrology to increase phosphorus storage.

1.1 Project Objectives:

The project objectives are to:

1. Quantify P storage in historically isolated wetland soils at the landscape-scale.
2. Determine soil characteristics and processes responsible for effective P storage in historically isolated wetland soils
3. Determine efficacy of hydrologic restored isolated wetlands and constructed wetlands to store and retain P from cow-calf and dairy operations, respectively
4. Measure P assimilation rates and equilibrium P concentrations of wetland soils.
5. Quantify the effect of fluctuations in hydrology on P flux.
6. Optimize on farm constructed wetlands to increase P removal performance using pilot scale studies.
7. Review current hydrologic and P models for adaptation to the Basin and use these models to simulate P retention capacity.
8. Communicate the findings and experiences gained during this project to dairy farmers and beef cattle ranchers through extension media.

Results of several experiments, which form components of the different tasks were presented in 2006-07 final report. This supplemental report represents final phase of this project.

2.0 PHOSPHORUS STORAGES AND DYNAMICS IN DITCH SOILS AND POTENTIAL IMPLICATIONS FOR WATER QUALITY

2.1 Introduction

Drainage ditches are constructed linear water bodies which are often designed to remove surface water and lower water tables below plant rooting zones in agricultural fields (Janse and Puijenbroek, 1998; Nguyen and Sukias, 2002; Smith et al., 2006). While conducting water from fields to receiving water bodies, ditches often transport nutrients such as phosphorus (P) and other contaminants. During transport, some of the particulate P may settle to the ditch bottom or be transported further down the ditch. There are also dynamics between soluble reactive P (SRP) in ditch soil porewater and the overlying water, which can govern whether ditch soils act as a source or a sink for P.

There is little information on P storage and dynamics in agricultural drainage ditches. Within the US, most of the research has focused in the mid-western (Smith et al., 2005, 2006) and eastern regions (Sallade and Sims 1997a,b). Agricultural drainage ditch soils collected from row crops and cow grazing pasture can contain variable amounts of P ranging between 30 and 2,880 mg P kg^{-1} (Sallade and Sims, 1997a,b; Nguyen and Sukias, 2002) with P content in soils often influenced by surrounding land uses (Stuck et al., 2001). For example, a study in South Florida suggested that total P concentrations in ditch soils were significantly greater in ditches draining improved cow-calf grazing pasture (322 mg kg^{-1}) relative to ditches draining semi-native cow-calf grazing pasture (149 mg kg^{-1}) (Prein, 2005).

Factors that influence whether ditch soils act as a source or a sink for P include the physicochemical characteristics of soils (Sallade and Sims (1997b; Axt and Walbridge, 1999; Haggard et al., 1999; Nguyen and Sukias, 2002), P concentration in soil relative to overlying water (Reddy et al., 1999), the duration and frequency of flooding (Yin and Shan, 2001), water velocity, oxidation-reduction potential and ditch size (Stuck et al., 2001).

Within a watershed context, many agricultural soils have elevated P levels that can contribute P to receiving water bodies (Sims et al., 1998). In the past several years, many management practices have been adopted in the USA to reduce P loss from agriculture (Bottcher et al., 1995). For example, within the Okeechobee Basin, Florida, agricultural best management practices (BMPs) are implemented for over 30 years. As a result, P imports that include fertilizer and cattle feed supplements to the basin decreased from 2,380 t P yr^{-1} (2,380 tonnes P yr^{-1}) in 1995 (Boggess et al., 1995) to 1,717 t P yr^{-1} (1,717 tonnes P yr^{-1}) (Mock Roos Associates, 2002). By land use, P imports to dairies decreased by about 61 percent between the years 1991 and 2002; to improved cow-calf grazing pasture, by 75 percent (~ 9 kg P $ha^{-1}yr^{-1}$) (~ 8.2 lb P $ac^{-1}yr^{-1}$); and to unimproved cow-calf grazing pasture by 80 % (0.05 kg P ha^{-1} yr^{-1}) (0.045 lb P ac^{-1} yr^{-1}) (Mock Roos Associates, 2002). Other BMPs used to reduce and mitigate P loss include buffer strips, improved nutrient and waste management systems, and the use of constructed and natural wetlands (Anderson and Flaig, 1995). As BMPs continue to be implemented, it is expected that P loss to receiving waters will continue to reduce with time, which could lead to a set of environmental conditions, whereby P could flux from ditch soil to relatively low-P waters flowing through and over them. Thus, to ensure continued improvement of water quality in the Lake Okeechobee watershed, biogeochemical characteristics of ditch soils needs incorporating into future BMPs.

The aim of our study was to better understand P storage and P dynamics in three agricultural land uses within the Lake Okeechobee watershed. Objectives of this study were to determine (i) P characteristics of agricultural ditch soils in the Lake Okeechobee Basin, FL; (ii) what controls soil P; (iii) relationships between different ditch soil P fractions; and (iv) compare ditch soil characteristics with upland and wetland soil characteristics. Further, we discuss: how ditch soil characteristics might impact water quality; soil characteristics that may be useful indicators of potential P loss, and; some management options that could be beneficial to mitigate potential P loss from ditch soils.

2.2 Methods and Materials

Site description. All sample sites were located in the four priority basins of the Lake Okeechobee Basin (Figure 2.1). These priority basins have contributed a disproportionate amount of P to Lake Okeechobee relative to their land area (Flaig and Reddy, 1995). Based on 2003 land-use data (SFWMD, 2003), 64 percent of the four priority basins were in agriculture (48 percent was in improved pasture, 7 percent in dairy, and six percent in unimproved pasture). All samples were collected from ditches that drained historically isolated wetlands in three different land uses (dairy, improved pasture, and unimproved pasture). Dairies were defined as any area pertaining to a commercial dairy. There was a range of land uses that pertained to dairies including ungrazed fields, fertilized hayfields, sprayfields, cow-calf grazing pastures, feeding pastures, and cowbarn areas. Improved pasture was defined as land which was cleared, tilled, reseeded with forage grasses, fertilized (FDOT, 1999) and used for beef, cow-calf grazing. Unimproved pastures were cleared land, often with some trees and brush or native grasses, and were not fertilized (FDOT, 1999) and used for beef cow-calf grazing.

Soils of the Lake Okeechobee Basin are mainly Alaquods formed in sandy marine sediments (Graetz and Nair, 1995) which have a naturally low native P content (Hodges et al., 1967). Immokalee (sandy, siliceous, hyperthermic Arenic Alaquod) and Myakka (sandy, siliceous, hyperthermic Aeric Alaquod) are the most common soil series occurring in upland areas. Soils in wetlands of the study area are dominated by Aquepts and Aquents and to a lesser extent, Aquolls and Aqualfs (USDA/NRCS, 1995; Lewis et al., 2001).

Drainage has been improved for producing grass, with extensive ditching of fields and wetlands to convey stormwater runoff towards Lake Okeechobee (Haan, 1995). Ditching densities in the landscape increase with land-use intensity from unimproved pastures to improved pastures to intensively managed pastures (dairies) to row crops (Heatwole, 1986). The National Wetland Inventory (NWI) suggests that 18 percent of the area consists of wetlands (McKee, 2005) with 59 percent being mostly small (typically less than 2 ha) (4.9 ac), depressional, nonriparian wetlands. It has been estimated that 45 percent of these wetlands in the four priority basins are ditched and drained (SFWMD et al., 2004).

During field sampling, ditches were classified into three classes; major, intermediate and minor. Major ditches were wide (more than 1m [39.4 in]) and deep (more than 40 cm). Minor ditches were unmaintained, shallow (less than 15 cm [5.9 in] deep), and narrow (less than 1m [39.4 in]), while intermediate ditches were somewhere in between major and minor ditches.

Soil sampling. All soils were collected between April and November 2003. Ditch soils were collected from ditches that drained small (~ 1 ha [2.47 ac]) historically isolated wetlands within pastures. Some wetlands were connected to more than one ditch. The outlet ditches from wetlands were identified by evidence of water flowing from the wetland or a topography change indicating outward flow. Three soil cores (0-10 cm [0-3.9 in]) were collected randomly from each ditch within 10 m (32.8 ft) of the wetland. Soil cores were collected by hammering a polycarbonate tube (10 cm [3.9 in] internal diameter x 0.3 cm [0.1 in] wall depth x 60 cm [23.6 in] in length), to a soil depth of 15 cm (5.9 in). The top 10 cm of soil cores were extruded, sectioned at 10 cm (3.9 in) and placed into a zip closure plastic bag. In the wetland, eight soil cores were collected at random, whereas in the upland, three soil cores were collected at random between 3 and 20 meters (9.8 and 65.6 ft) from the wetland. All wetland and upland soils were extruded and section as mentioned previous. All samples were stored on ice until return to laboratory, where samples were refrigerated at 4°C (39.2°F) until they were prepared for analyses.

Soil analyses. Composite soil samples were manually homogenized. Roots larger than 2 mm (0.08 in) in diameter, and live vegetation were removed. Soil pH was measured using a 1:2, soil to water, ratio (20 g of field-moist soil to 40 mL of distilled, deionized water). Water content was determined as the difference between wet and dry weights of an ovendried (70°C [158°F] for three days) sample. Bulk density was calculated on a dry-weight basis using the known volume of soil cores. A subsample of each homogenized soil was air-dried for three weeks. Air-dried samples were machine-ground and passed through a #100 mesh (0.15 mm [0.006 in] openings) sieve. Air-dried soil (5 g) was then extracted with 20 mL of Mehlich 1 solution (0.0125 M H_2SO_4 + 0.05 M HCl) for 5 minutes (Mehlich, 1953). Soil solutions were centrifuged and filtered through a Whatman # 41 filter paper. Extracts were stored at 4°C (39.2°F), and analyzed for P using the automated ascorbic acid method (Method 365.1; US EPA, 1993).

Total P was determined on an oven-dried, ground and sieved sample. Soils were ashed at 550ºC (1022°F) for 4 hours in a muffle furnace. Soil organic matter was measured using loss on ignition (LOI); quantified as the difference between the initial soil weight and ash weight. Ashed samples were then digested with 6 M HCl and filtered using Whatman #41 filter paper (Anderson, 1976). Digested solutions were analyzed colorimetrically for soluble reactive P (SRP) using the automated ascorbic acid method (Method 365.1; US EPA, 1993). A 0.5 g sample of soil was extracted with 25 mL of 1 M HCl to estimate inorganic soil P fractions (Reddy et al., 1998). Reddy et al. (1998) previously indicated that extracting soils with 1 M HCl was a good proxy for total inorganic P of organic wetland soils. The 1 M HCl soil solutions were filtered through 0.45 µm membrane filters after centrifuging (6000 rpm x 10 minutes). Extracts were stored at 4 °C (39.2 °F) and analyzed for SRP. Soil extracts were also analyzed on an inductively coupled plasma-atomic emission spectroscopy (ICP) to determine calcium (Ca), magnesium (Mg), iron (Fe), aluminum (Al) and P concentrations.

Ammonium oxalate-extractable Al (Al_{ox}) and Fe (Fe_{ox}), soils were extracted in the dark with 0.175 M ammonium oxalate and 0.1 M oxalic acid at a soil to solution ratio of 1:40 for 4 hours (Loeppert and Inskeep, 1996). Extracts were filtered to 0.45 µm and analyzed for P, Al, and Fe using ICP. Degree of P saturation (DPS) index was determined as outlined by Breeuwsma et al. (1995).

Statistical and data analyses. Data distributions were tested for normality. If data was not normally distributed it was log transformed to approximate normal distribution prior to statistical analyses. Statistical significant differences between land uses and soil P content were determined at the $p < 0.05$, $p < 0.01$, and $p < 0.001$ level. Comparison of means between land uses, soil physiochemical characteristics, and soil P fractions were by ANOVA using least square means, as we had unequal number of observations in the land use groupings. Multivariate linear correlations were determined using the Pearson product-moment correlation. In regression analyses between ditch soil P fractions and metal content, we used the standard least squares fit model. We also used stepwise regression to help explain total P storage in ditch soils. All statistical analyses were performed by ANOVA using the JMP software program (SAS Institute Inc., Cary, North Carolina).

To evaluate whether ditch soils had similar properties to other soils, we used soil physicochemical data collected from historically isolated wetlands and their surrounding uplands. Similar physicochemical parameters were measured on upland, ditch and wetland soils and all soils were sampled to the same soil sampling depth (10 cm) (3.9 in) We determined areal storage to normalize for the difference between soil bulk densities of the different landscape units (uplands, wetlands and ditches). We compared upland soils to wetland soils, upland soils to ditch soils, and wetland soils to ditch soils using ratios determined from areal storage data (g m^{-2}) (lb ac^{-1}). A ratio close to 1 for a particular parameter suggests the soil parameter was similar between landscape units, whereas values diverging from 1 suggest soil parameters were different between landscape units.

2.3 Results and Discussion

Soil physicochemical characteristics. Ditch soil pH values were acidic (5.25 ± 0.3; mean $\pm$ one standard error) and ditch soils in unimproved pasture had lower bulk densities and greater organic matter content than ditch soils collected from dairies and improved pasture (Table 2.1). This suggests that ditch soils in unimproved pasture were wetter for longer periods and/or had greater organic matter due to in-ditch vegetation, as they were often not maintained and grazed at a lower intensity.

Soil metal content values were much less than those reported for previous agricultural ditch soil studies (Table 2.2). For surface ditch soils (0-5 cm) (0-2 in) collected from row crop fields in Delaware, USA, Sallade and Sims (1997a) report mean values of 1,380 and 1,306 mg kg^{-1} (1,380 and 1,360 ppm) for total Al and Fe oxides, respectively. Nguyen and Sukias (2002) collected ditch soils (0-15 cm [0-5.9 in] in depth) from a pastoral catchment in New Zealand and also reported much higher mean values for Al and Fe ranging between 3,680-8,080 mg kg^{-1} (3,680-8,080 ppm) and 2030-1080 mg kg^{-1} (2030-1080 ppm), respectively. Thus, in comparison, ditch soils in our study area (Okeechobee Basin) have limited ability to retain P by sorbing P to Fe and Al oxides. Table 2.1 also shows that the ammonium oxalate solution extracted greater amounts of Fe relative to 1 *M* HCl solution; whereas the reverse was true for Al. We hypothesize that the ammonium oxalate solution is extracting organically bound Fe and the HCl solution is not, as ammonium oxalate can extract both inorganic and organic forms (Wang et al., 1986). As Al content was similar between ditch soils, irrespective of extracting procedure, it indicates that most Al is bound to inorganic P forms. Iron and Mg content of dairy ditch soils were slightly higher than improved and unimproved ditch soil (Table 2.2). Although this difference was not significant, it suggests that these soil components increase with degree of impact (Sims et al., 1998; Josan et al., 2005).

Variability in ditch soil metal content (Fe, Al, Mg, and Ca) was high in unimproved pasture ditch soils (sometimes as high as 85 percent of the mean) (Table 2.2), which may be due to the low number of samples collected. Comparing unimproved and dairy ditch soil metal content, Table 2.2 indicated that metal content variability somewhat decreased with increasing degree of land use impact. For wetland soils, it was found that with an increasing degree of impact, variability of soil parameters also decreased (Bruland and Richardson, 2005).

Ditch soil phosphorus. Land use was a significant factor regulating total P content of ditch soils ($p = 0.045$). Although ditch soils collected from dairies had slightly higher P concentrations in all P fractions measured (Table 2.1); this was not significant. Reddy et al. (1998a) found that surface soils (0-15 cm) (0-5.9 in) of a drainage ditch near a dairy in Okeechobee Basin had total P concentrations of about 221 mg kg^{-1} upstream and 1,590 mg kg^{-1} downstream of the dairy. Also within the Lake Okeechobee Basin, Prein (2005) report greater soil TP in ditches of improved pasture (322 mg kg^{-1}; whereas ditch soil TP in unimproved pasture were very similar to the TP observed in unimproved pasture of this study (Table 2.1).

Unimproved pasture ditch soils had significantly lower total P content, WEP, Mehlich 1 P and 1 *M* HCl P than ditch soils from both dairy and improved pasture ($p < 0.05$). The 1 *M* HCl (inorganic P) from dairy ditch soils was about twice the 1 *M* HCl P in improved pasture ditch soil, which had about twice the amount in unimproved pastures ditch soil (Table 2.1). Ditch soils in dairies had the greatest proportion (25 percent) and unimproved pasture ditch soils had the least amount of soil P stored as inorganic P (17 percent). Inorganic P, as a percentage of total P, is a useful quantitative indicator of how P-impacted a particular soil can be, as when soils are P impacted, inorganic P fractions typically increase (Reddy et al., 1998). Using such indices to rank a ditch soil's potential to impact water quality may be useful to water quality managers.

Soil WEP fraction decreased with decreasing land use intensity. Dairy ditch soils had 7 percent of soil total P stored as WEP compared to unimproved pasture ditch soils (4 percent as WEP). For soils to release P to overlying water, there must be a P concentration gradient from soil porewater to the overlying water (Reddy et al., 1999; Smith et al., 2005). We hypothesize that ditch soils in dairy and improved pasture have a greater potential to release P relative to unimproved pasture ditch soils. In a watershed where BMPs are implemented for over 30 years, we also hypothesize that P concentrations in water entering ditches will decrease in the future. Thus, during ditch flow events, the prevalent direction of P movement may be from ditch soil (historically loaded) to overlying water (low P waters due to present BMPs). A useful parameter to assess this (although not measured in this study) would be equilibrium P concentration (EPC). These could be determined using standard sequential P sorption isotherms (Richardson and Vaithiyanathan, 1995; Reddy et al., 1998a) and/or using soil-water core studies (Reddy et al., 1995). The benefit of determining EPC is that the concentration at which ditch soils release or retain P could be determined. Water SRP concentrations above the EPC would suggest ditch soils retain P, whereas if concentrations were below the EPC, ditch soils would potentially release P.

There was little evidence of land use impact on plant-available P (Mehlich 1 P), HCl P as measured using ICP, and ammonium oxalate P suggesting that these P fractions may not be useful indicators of P impacts. On average, 13 percent of soil total P was plant available. The HCl extracted P measured by ICP and P_{ox}, represented 42 and 43 percent of ditch soil total P. Both HCl P fractions and P_{ox} covaried best (r = 0.78, 0.75, and 0.72 for HCl P measured using AA, HCl P measured using ICP, and $P_{ox,}$ respectively) with soil total P content. The 1 *M* HCl P was greater in ditch soil solution extracts when extracts were measured for P using ICP, relative to extracts measured using colorimetry on an autoanalyzer. Determining P concentrations in solution using colorimetric methods are typically lower than those using ICP methods (Eliason et al., 2001; Sikora, 2005) as the ICP method measures inorganic and organic P forms.

The total amount of P stored in ditch soils was related to soil organic matter and soil metal content. Similarly, Sallade and Sims (1997b) indicated that ditch sediment organic matter was important to predict total P content of ditch soils. Rather than P bound directly to organic matter itself, it is probable that P is bound to metallic fractions, forming Al/Fe humic complexes (Axt and Walbridge, 1999). Organic matter and Ca extracted with 1 *M* HCl explained about 95% of the variability in dairy ditch soil total P content (TP = 1.472[OM] + 0.262[Ca_{HCl}] + 0.243; n = 7; p = 0.002). This implies that these soils were manure impacted (Nair et al., 1995; Josan et al., 2005). It also suggests that P storage in dairy ditch soils would be affected more by changes in soil pH, rather than changes in soil redox conditions. In improved pasture and unimproved pasture, organic matter and Al (TP = 0.706[OM] + 0.462[Al_{ox}] + 1.206; n = 48; p < 0.001), and organic matter and Fe (TP = 0.768[OM] + 0.407[Fe_{ox}] + 0.511; n = 5; p = 0.023; R^2 = 0.98) were important in determining total P content of soils. Thus, P stored in ditch soils of unimproved pasture would be less affected by changes in ditch soil redox conditions (for example ditch flooding and drawdown) relative to improved pasture ditch soil as Al is not affected by changes in soil redox conditions (D'Angelo, 2005).

Relationships between ammonium oxalate P, total P, Mehlich 1 P, HCl P, iron and aluminum. Phosphorus extracted with ammonium oxalate was closely related to ditch soil TP, Mehlich 1 P, and the best relationship was with 1 *M* HCl P (Figure 2.2) suggesting most of the ammonium oxalate extractable P was in an inorganic form; therefore potentially available to overlying water. Ammonium oxalate extracts for amorphous and poorly crystalline forms, in addition to active forms of Fe and Al oxides (water-soluble, exchangeable, and some organically bound Fe and Al) (Loeppert and Inskeep, 1996). Iron (Fe_{ox}) was a better predictor of P_{ox} than Al (Al_{ox}) (Figure 2.3).

Ditch soil Fe extracted with HCl was also related to WEP (r = 0.56) and Mehlich P (r = 0.70), whereas Fe_{ox} was not related to WEP and weakly associated with Mehlich P (r = 0.46). During ditch flooding, we hypothesize that P bound to ferric forms in soil will be released to overlying water columns, as ferric forms of Fe are transformed to ferrous forms, thereby releasing previously bound P.

Degree phosphorus saturation is typically used for upland agricultural soils (Breeuwsma at al., 1995; Maguire and Sims 2002); however, DPS was used for ditch soils in this study, as ditch soils had similar physicochemical characteristics to upland pasture soils (Table 2.3). Assuming that a DPS of 25 percent represents a risk of P loss (Breeuwsma at al., 1995), dairy and improved ditch soils represented risks for P loss, as DPS values were 36 and 31 percent, respectively. Degree of P saturation values of unimproved pasture ditch soils were less than the 25 percent threshold value (14 percent). To rank agricultural ditch soils for their potential to release and or retain P, it is important to incorporate an index like DPS with other site soil characteristics including adjacent land use, hydrological, physical, chemical and biological characteristics of ditches.

Biogeochemical relationships between different landscape units. Figure 2.4 suggests that the total P content in the surrounding upland soils were similar to, or slightly less than ditch soil P. Ditch soils possessed similar total P and ammonium oxalate P to upland soils. They also had similar bulk density and Fe content (1 *M* HCl) to wetland soils (Table 2.3). Stuck et al. (2001) found that P concentrations in ditch soils of the Everglades Agricultural Area, FL were similar to adjacent fields. At the landscape-scale, ditches could receive P directly from uplands during runoff events (Figure 2.5a). Also, a landscape continuum of P transport could exist between upland, wetland and ditch (Figure 2.5b). Comparing total P values between the different landscape units suggests that the greatest P storage gradient was between wetlands and ditches suggesting that wetland soils stored nearly twice the amount of P in ditch soils. This P storage gradient, also implies that during flow events from wetlands to ditches, it would be important to retain waters within wetlands (using controlled drainage) prior discharge to ditches. Therefore, active management of water levels would be important to mitigate P loss. Retaining waters within the wetland would allow time for wetland biogeochemical processes to transform P into less available forms (Braskerud, 2002).

Organic matter content of ditch soils was much less than that present in wetland soils; with ditch soil organic matter content being somewhat similar to upland soil organic matter. Although ditch soils had low amounts of organic matter, organic matter was still important in explaining P storage. The organic matter content of wetland soils was about twice the amount present in upland soils (Table 2.3). In general, it seemed that ditch soils were more similar to upland soils. This seems logical, as ditches would have been excavated out of upland pasture to drain upland pasture, in addition to draining wetlands. Table 2.3 also shows that upland and wetland soils tended to store more Fe, Al, Ca and Mg than ditch soils. Increased Ca content in uplands and wetland soils could indicate that these soils were manure impacted.

In-ditch phosphorus management practices. To mitigate P loss from ditch soils, P binding soil amendments such as light expanded clay, crushed marble, calcium carbonate, vermiculite, bauxite (Drizo et al., 1999; Arias et al., 2003) calcite, aluminum/ferric sulfate, hematite (Elliot et al., 2002; Smith et al., 2005), and/or the dredging of surface P laden soils (Van der Does et al., 1992; Smith et al., 2006) could be used. However, Smith et al. (2006) suggested that dredging of ditch sediments may impair water quality, as the EPC was lower in pre-dredged ditch sediment relative to dredged ditch sediment. Implementing controlled drainage by using water control structures in ditches can provide water storage in fields for crop use and increase nutrient and contaminant retention by ditches.

2.4 Summary and Conclusions

Our findings suggest that ditch soil P content was affected by land uses such as dairy, improved pasture and unimproved pasture. Although ditch soils tended to have medium to low total P content (generally less than 600 mg kg^{-1} [ppm]), ditch soils collected from dairy and improved pasture had the potential to impact water quality (DPS > 25 percent). The inorganic P and WEP fractions of ditch soils were also good indicators of land use impacts, with dairy ditch soils having greater inorganic P and WEP fractions than improved pasture and unimproved pasture ditch soils. Soil characteristics that were important in determining total P storage in ditch soils were soil organic matter and soil metal content; however, the specific metal depended on land use with Ca being more important to predict total P in dairy ditch soils, whereas Al and Fe were more important in improved and unimproved ditch soils, respectively.

Understanding ditch soil P content relative to other landscape units is also important, as it provides information on P transport pathways at the landscape scale. From field observations and the data provided, we think P is being transported from uplands to depressional wetlands and then from wetlands to ditches during wetland flooding. Also, P may be entering ditches directly from surrounding uplands during runoff events.

Finally, in a watershed where BMPs are implemented for many years, P concentrations in waters entering ditches may decrease. This may result in environmental conditions favorable for P flux from ditch soil to overlying water during periods of ditch flooding. Various management practices such as the use of soil amendments and/or controlled drainage may be useful to mitigate potential P loss from ditch soils. We think it is important for future effective watershed BMPs to take into account other landscape units such as ditches and their soil characteristics to help protect and conserve watershed water quality.

Table 2.1. Soil organic matter and phosphorus characteristics of ditch, upland and wetland soils collected within the four priority basins of the Okeechobee Basin, FL. Soils were collected between April and November 2003. Values represent means ± one standard error. Per landscape unit (ditch, upland and wetland) soil characteristics were compared between land use. Values with similar letters, indicate that landuse was not a significant factor, whereas those with different letters indicate landuse was a significant factor at the $p < 0.05$ level.

Landuse	Landscape unit	*n*	Organic matter		Total P		Water extractable P		Mehlich I P		Ammonium oxalate P		HCl extractable P ICP		HCl extractable P AA	
			-----%-----		---mg kg^{-1}---											
Dairy	Ditch	7	17.6a	± 5	478a	± 192	18.7a	± 6.4	37.0a	± 9.6	153a	± 51	82a	± 26	145a	± 49
Improved		48	11.0a	± 1	253a	± 36	11.1ab	± 1.4	18.0a	± 2.4	72a	± 10	38ab	± 6	69a	± 9
Unimproved		5	21.8a	± 11	276a	± 147	7.6b	± 3.1	13.1a	± 5.1	114a	± 75	42b	± 22	98a	± 61
Dairy	Upland	21	13.8a	± 2	323a	± 76	13.8a	± 3.3	29.1a	± 6.5	116a	± 19	61a	± 11	105a	± 17
Improved		83	10.5a	± 1	181b	± 19	9.5a	± 0.8	20.1ab	± 3.7	66b	± 7	36b	± 5	60b	± 7
Unimproved		12	10.8a	± 2	110b	± 16	7.1a	± 1.6	9.7b	± 2.2	37b	± 8	17b	± 4	33c	± 7
Dairy	Wetland	42	25.6a	± 3	859a	± 141	26.6a	± 5.2	86.1a	± 29.5	381a	± 92	255a	± 92	370a	± 105
Improved		168	19.1ab	± 1	415b	± 29	16.4ab	± 1.3	22.2b	± 1.5	115b	± 10	56b	± 5	105b	± 9
Unimproved		24	25.7b	± 5	361b	± 57	14.3b	± 4.0	17.9b	± 4.6	222b	± 111	50b	± 13	101b	± 24

Table 2.2. Soil metal characteristics of ditch soils collected within the four priority basins of the Okeechobee Basin, FL. Soils were collected between April and November 2003. Values represent means ± one standard error. Values with similar letters, indicate that there was not a significant difference between the different concentrations of Fe and Al in 1 *M* HCl and ammonium oxalate extractions, whereas those with different letters indicate that extracting solution was a significant factor at the $p < 0.05$ level.

Landuse	*n*	Fe_{HCl}	Al_{HCl}	Ca_{HCl}	Mg_{HCl}	Fe_{ox}	Al_{ox}
		------------------mg kg^{-1}------------------					
Dairy	7	1920a ± 627	285a ± 65	502 ± 181	674 ± 270	674a ± 252	399a ± 114
Improved	48	989a ± 149	167a ± 26	446 ± 71	270 ± 52	382b ± 59	239b ± 35
Unimproved	5	671a ± 495	152a ± 114	754 ± 635	156 ± 96	233a ± 115	680a ± 573

Table 2.3. Relative landscape biogeochemical ratios between uplands, wetlands and ditches of the four priority basins of Okeechobee Basin, FL. Ratios between landscape units were determined for each parameter using site-specific surface soil (0-10 cm; 0-) data.

Parameter		**Upland: Wetland**	**Upland: Ditch**	**Wetland: Ditch**
Bulk Density	g cm^{-3}	1.36	1.31	0.96
Organic matter	%	0.51	0.88	1.73
Total P	g m^{-2}	0.72	1.07	1.50
Water extractable P	g m^{-2}	0.96	1.25	1.31
Fe_{HCl}	g m^{-2}	1.30	1.54	1.19
Al_{HCl}	g m^{-2}	0.68	1.39	2.03
Ca_{HCl}	g m^{-2}	1.11	2.55	2.29
Mg_{HCl}	g m^{-2}	0.69	1.35	1.94
P_{ox}	g m^{-2}	0.70	1.18	1.69
Al_{ox}	g m^{-2}	1.25	2.51	2.00
Fe_{ox}	g m^{-2}	0.87	1.45	1.66

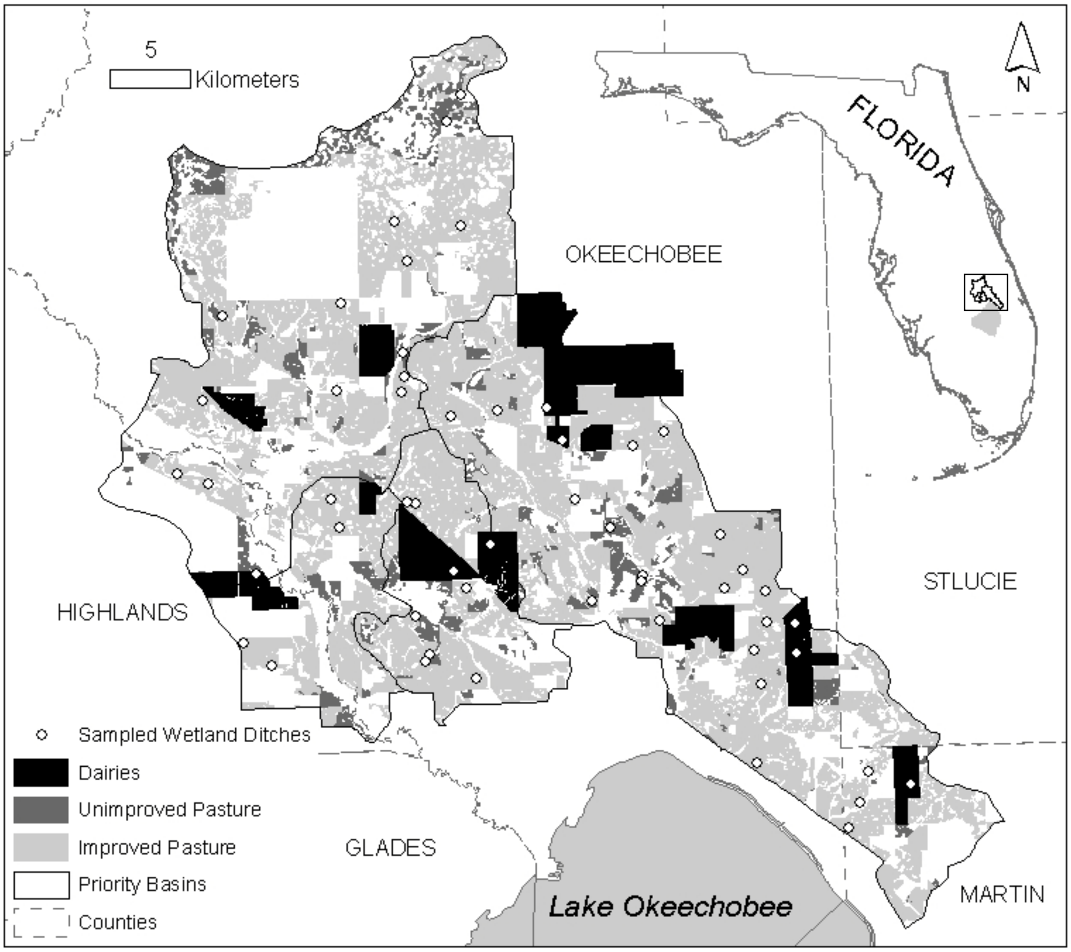


Figure 2.1. Map of ditch soil sampling locations with surrounding land use within the four priority basins of the Lake Okeechobee Basin, FL.

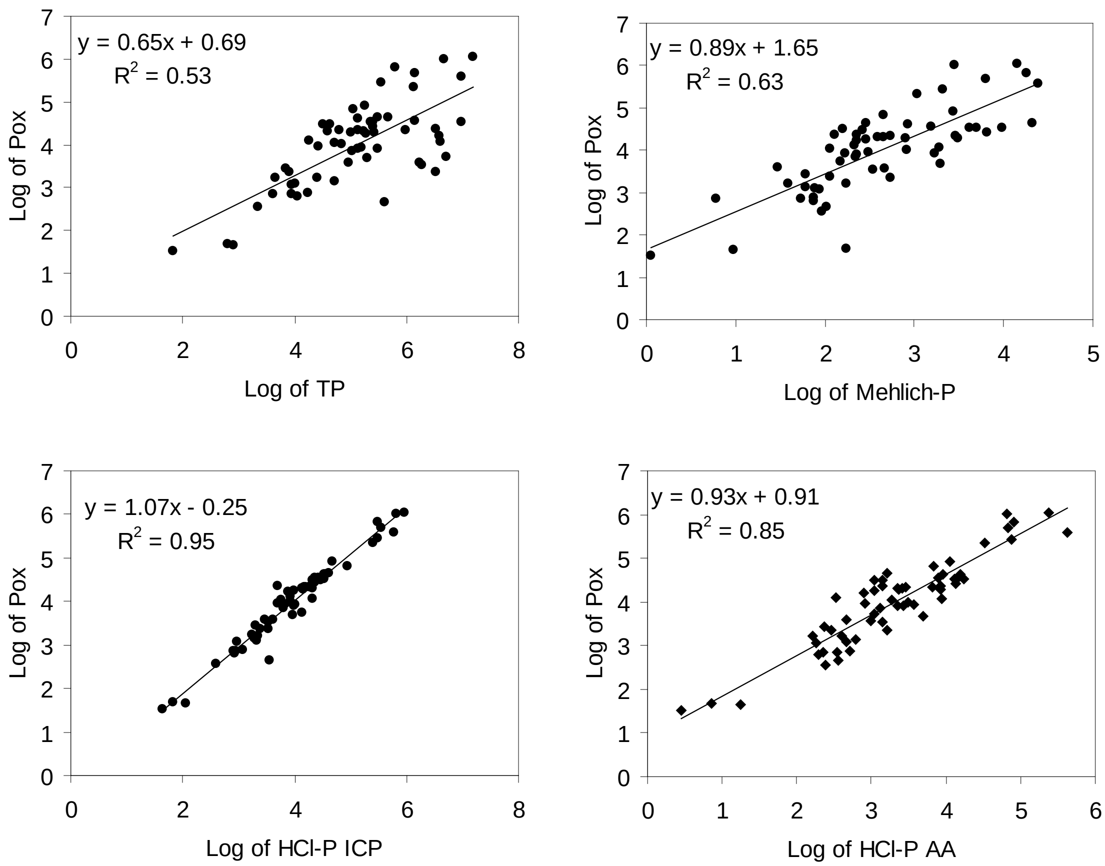


Figure 2.2. Relationships between available P (P_{ox}) and total P (a), Mehlich P (b), HCl extractable P measured using an autoanalyzer (c), and HCl extractable P measured using ICP (d) of ditch soils (n = 60). Values are log transformed concentrations (mg kg^{-1}).

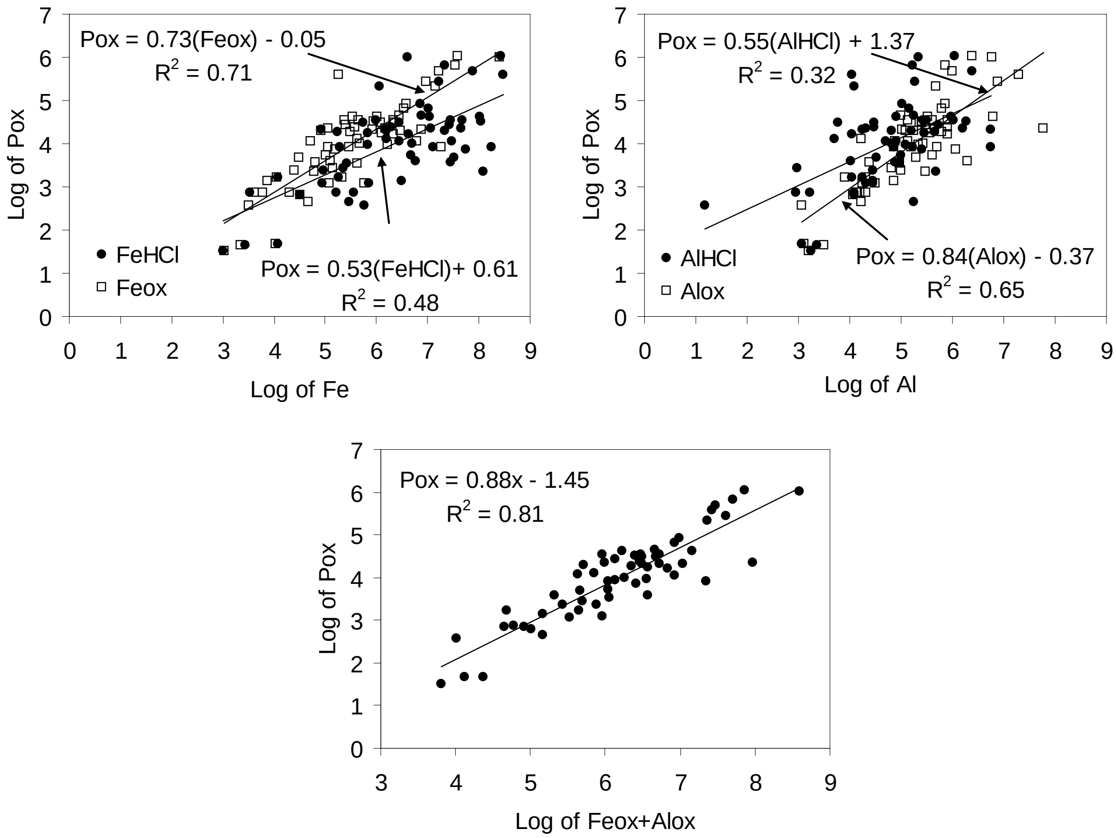


Figure 2.3. Relationships between ammonium oxalate extractable phosphorus (P_{ox}) concentrations in ditch soils and iron (Fe), and Al (aluminum), extracted with 1 *M* HCl and 0.2 *M* ammonium oxalate. Values are log transformed concentrations (mg kg^{-1}).

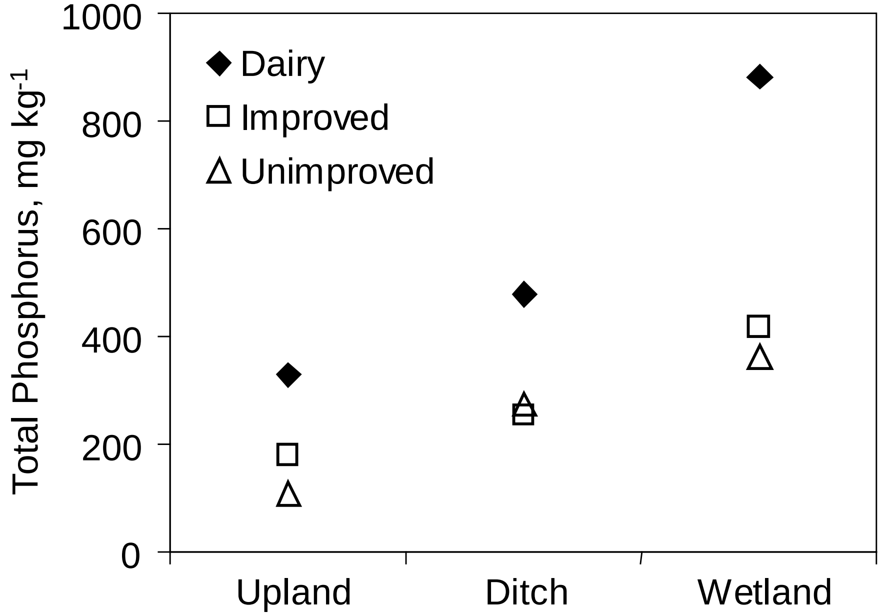
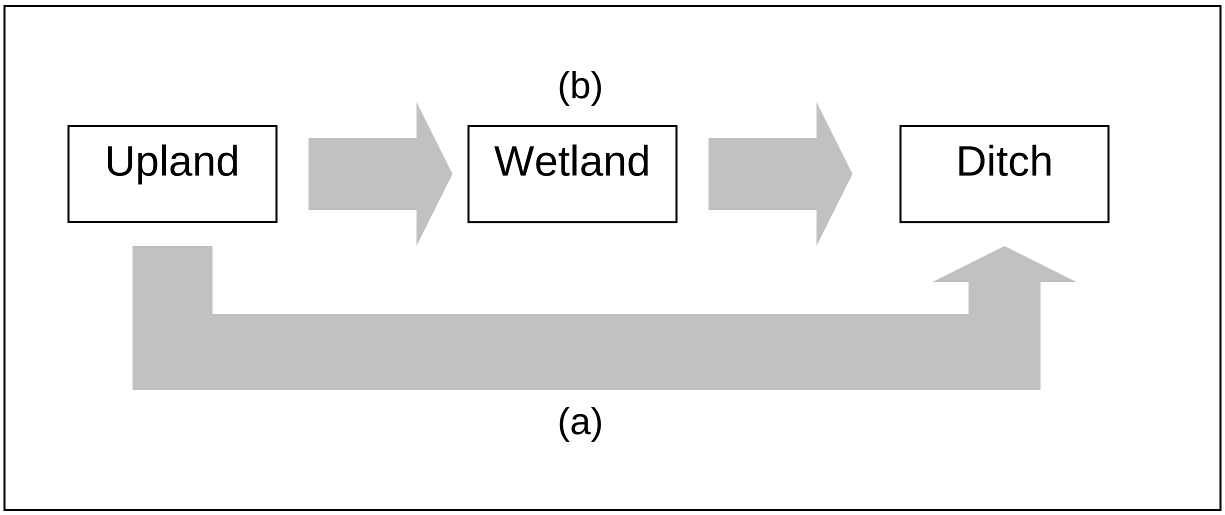


Figure 2.4. Soil total phosphorus concentrations in uplands, ditches and wetlands sampled in four priority basins of the Lake Okeechobee Basin, FL.

Figure 2.5. Schematic of phosphorus transport between uplands, ditches and wetlands. Arrows indicate P transport between (a) uplands, wetland and ditches and (b) uplands and ditches.



3.0 PHOSPHORUS STORAGES IN ISOLATED WETLAND ECOSYSTEMS

The specific objective of the this task was to continue to quantify P storages in isolated wetland ecosystems

3.1 Materials and methods

Two wetlands were located at the Larson Dixie Ranch, while the other two were located at the Beaty Ranch. See site details in previous annual report 2006-’07.

Wetland surface water depth was monitored for four years at the four study wetlands. See details of site hydrology monitoring in previous annual report 2006-’07.

Wetlands were sampled twice (June 2006 and March 2007) using a stratified random sampling design. The deep marsh, shallow marsh/wet grassland, and surrounding pasture upland zones were identified using hydrological indicators and vegetation type.

Above-ground biomass, litter, below-ground biomass and soil samples were collected from a 1 x 1 m quadrat at each location within each sampling zone. Above-ground plant biomass was sorted by species and then into live and dead fractions. All above-ground plant biomass, below ground biomass and litter samples were oven dried. Samples were then weighed, ground and sieved. Ground and sieved samples were stored for analyses.

Soils characteristics determined included soil water content, bulk density and pH. All plant biomass, litter and soil samples were analyzed for total phosphorus (TP). Above-ground biomass, litter and below ground biomass was analyzed for total carbon (TC), and total nitrogen (TN).

3.2 Results and Discussion

Wetland hydroperiods at Beaty ranch were much greater (about twice) than the hydroperiod calculated for Larson Dixie (Table 3.1). The surrounding upland pasture at both sites had a hydroperiod of less than 11 days.

Isolated wetland soils (deep marsh and shallow marsh soils sampled to a depth of 10 cm) had greater water content, less bulk density and similar pH to surrounding upland soils (Table 3.1). Organic matter was also greater in wetland soils, with Beaty wetland soils having greater organic matter content relative to Larson Dixie soils. Similar to previous findings that we reported in the annual report 2006-2007, wetland soils had greater concentrations and stored phosphorus relative to their surrounding upland pasture soils (Table 3.1). Phosphorus storages were somewhat greater in Larson Dixie soils relative to Beaty. Relative to the other ecosystem components (above-ground biomass, litter and below-ground biomass) soils stored greatest amounts of phosphorus (Tables 3.1 and 3.2)

Similar to soils, phosphorus concentrations in wetland litter and below-ground biomass were greater than the phosphorus concentrations in upland litter and below-ground biomass (Table 3.3). Total nitrogen and total carbon were also greater. In terms of site differences, Larson Dixie also had greater concentrations relative to Beaty, possibly indicating the historical nutrient loading at this site relative to Beaty. Table 3 reorts that the phosphorus stored in above-ground biomass was similar between zones and sites; however, the dry weight of above-ground biomass was greater at Beaty relative to Larson Dixie. The dry weight of litter material collected from wetland zones and phosphorus storage in wetland littler was typically greater then the phosphorus storage in litter collected from upland zones. Below-ground biomass had much greater material and phosphorus storage relative to above-ground biomass and litter. In contrast to the greatest phosphorus storages being in wetland above-ground biomass, litter and soil, the reverse was true for below ground biomass. Phosphorus stored in below-ground biomass in uplands was greater than the phosphorus stored in wetland below-ground biomass.

A phosphorus storage gradient existed between deep marsh, shallow marsh and upland pasture. Overall storage (sum of above-ground biomass, litter, soil and below-ground biomass) was greater in Larson Dixie relative to Beaty. Storage in wetland zones varied between 12 and 30 g TP m^{-2} depending on site, whereas overall storage in upland zones ranged between 12 and 16 g TP m^{-2}.

Table 3.1. Soil characteristics of Beaty and Larson Dixie wetland and upland soils (soil sampling depth = 0-10 cm). Soils were sampled in June 2006 and March 2007. Values are means ± one standard deviations. (n = 6).

Site	Zone	Hydroperiod		Water Content		Bulk Density		pH		Organic Matter		Total Phosphorus			
				------%-----		------g cm^{-3}---				------%------		mg kg^{-1}		-----g m^{-2}-----	
BN*	Deep marsh	300	11	46.7	3	0.399	0.15	4.07	0.2	32.5	12	449	162	16.89	5.1
BN	Shallow marsh	142	20	21.5	16	0.740	0.33	4.31	0.3	15.0	7	321	196	18.85	5.8
BN	Upland	0	0	8.4	2	0.851	0.09	4.66	0.3	10.4	2	125	19	10.64	2.4
BS	Deep marsh	238	9	26.5	5	0.457	0.06	4.39	0.4	26.4	3	345	65	15.92	4.3
BS	Shallow marsh	129	58	14.3	15	0.734	0.20	5.03	0.2	14.2	9	190	130	11.88	3.8
BS	Upland	10	22	6.7	4	0.902	0.10	4.92	0.6	10.3	7	111	20	10.10	2.8
LE	Deep marsh	172	26	11.9	3	0.804	0.09	4.55	0.2	15.0	4	279	82	22.21	6.1
LE	Shallow marsh	51	32	9.4	11	0.985	0.11	4.74	0.1	11.4	6	180	96	17.27	8.0
LE	Upland	10	19	3.7	2	1.015	0.07	4.82	0.6	6.1	2	100	31	10.14	3.1
LW	Deep marsh	175	57	11.5	3	0.836	0.08	4.55	0.3	16.5	3	349	48	28.92	2.2
LW	Shallow marsh	56	41	5.4	3	0.937	0.08	4.72	0.2	10.9	4	247	173	22.56	15.2
LW	Upland	4	8	4.3	1	1.441	1.17	4.03	1.6	8.4	1	177	88	16.47	7.9

* BN = Beaty North, BS = Beaty South, LE = Larson East, LW = Larson West.

Table 3.2. Litter and below ground biomass collected from Beaty and Larson Dixie wetlands and uplands. Litter and below ground biomass samples were sampled in June 2006 and March 2007. Values are means ± one standard deviations. (n = 6).

Site	Zone	TP		TN		TC	
		--------------------------------%----------------------------					
---Litter--							
BN	Deep marsh	0.077	0.04	1.457	0.26	40.71	0.5
BN	Shallow marsh	0.042	0.03	1.226	0.23	34.67	7.4
BN	Upland	0.038	0.03	0.963	0.09	40.50	0.7
BS	Deep marsh	0.099	0.04	2.020	0.17	39.78	3.6
BS	Shallow marsh	0.112	0.06	1.467	0.42	39.12	1.1
BS	Upland	0.055	0.03	1.182	0.11	41.37	0.5
LE	Deep marsh	0.107	0.05	1.767	0.17	33.98	4.4
LE	Shallow marsh	0.071	0.09	2.133	0.33	36.46	0.3
LE	Upland	0.062	0.05	1.288	0.18	41.71	0.8
LW	Deep marsh	0.116	0.10	1.854	0.11	38.70	0.6
LW	Shallow marsh	0.103	0.11	1.609	0.50	39.18	2.9
LW	Upland	0.060	0.05	1.273	0.22	40.87	1.5
---------------------------------Below ground biomass-----------------------------------							
BN	Deep marsh	0.085	0.02	1.410	0.23	39.60	2.7
BN	Shallow marsh	0.092	0.03	1.004	0.03	26.59	4.1
BN	Upland	0.077	0.03	0.996	0.18	31.13	7.7
BS	Deep marsh	0.110	0.02	2.003	0.28	36.34	1.6
BS	Shallow marsh	0.084	0.02	1.455	0.26	34.18	3.1
BS	Upland	0.083	0.02	1.253	0.10	31.83	4.1
LE	Deep marsh	0.094	0.05	1.477	0.13	33.62	1.2
LE	Shallow marsh	0.074	0.04	1.852	0.24	29.08	4.3
LE	Upland	0.057	0.05	1.344	0.42	36.79	1.9
LW	Deep marsh	0.065	0.06	1.416	0.04	31.51	7.0
LW	Shallow marsh	0.041	0.06	1.803	0.23	36.36	3.0
LW	Upland	0.039	0.05	1.135	0.04	34.19	8.7

Table 3.3. Dry weight of vegetation and phosphorus storage in above-ground biomass, litter, and below-ground biomass.

Site	Zone	Dry weight		TP	
		--------g m^{-2}---		---mg m^{-2}----	
Total above ground biomass					
BN	Deep marsh	353	131	.	.
BN	Shallow marsh	258	176	84.5	80.9
BN	Upland	220	117	301	237
BS	Deep marsh	274	163	149	.
BS	Shallow marsh	86.8	52.6	26.1	13.9
BS	Upland	386	438	102	24.5
LE	Deep marsh	56	105	26.5	7.78
LE	Shallow marsh	60.5	43	162	.
LE	Upland	87.7	71.4	91.7	79.2
LW	Deep marsh	299	287	18.7	12.7
LW	Shallow marsh	55.5	41.8	.	.
LW	Upland	113	59.9	71.6	23.7
Litter					
BN	Deep marsh	625	414	580	186
BN	Shallow marsh	146	105	89	90.9
BN	Upland	144	50	111	20.4
BS	Deep marsh	550	302	459	45.4
BS	Shallow marsh	469	572	244	334
BS	Upland	211	52.8	173	56.7
LE	Deep marsh	380	408	86.4	47.7
LE	Shallow marsh	57.9	41.4	80.5	50.8
LE	Upland	108	66.8	65.8	23.1
LW	Deep marsh	126	147	54.3	16.4
LW	Shallow marsh	84.6	53.2	129	70.6
LW	Upland	175	90.5	234	115
Below ground biomass					
BN	Deep marsh	1252	741	1021	567
BN	Shallow marsh	1423	728	1192	418
BN	Upland	1576	947	1204	776
BS	Deep marsh	1390	781	1578	1192
BS	Shallow marsh	1630	961	1313	696
BS	Upland	2637	171	2178	640

LE	Deep marsh	561	245	496	347
LE	Shallow marsh	1980	962	1224	760
LE	Upland	1528	572	818	787
LW	Deep marsh	448	370	171	244
LW	Shallow marsh	1274	665	883	1249
LW	Upland	2374	2078	783	1108

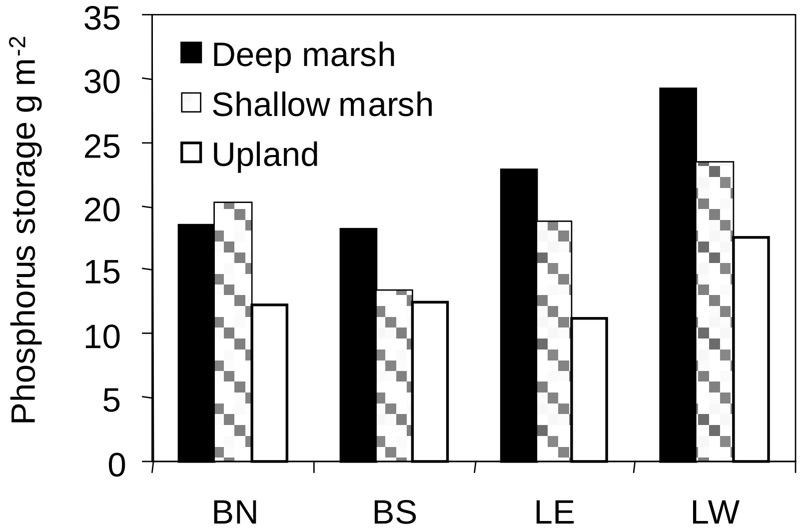


Figure 3.1. Phosphorus storage in wetlands and uplands in Beaty and Larson Dixie ranches. Phosphorus storage includes the sum of phosphorus stored in above-ground biomass, litter, soil and below-ground biomass.

4.0 VALIDATE HYDROLOGIC AND P MODELS FOR ADAPTATION TO ISOLATED WETLANDS IN THE BASIN AND USE THESE MODELS TO SIMULATE P RETENTION CAPACITY

A hydrologic model of the isolated wetlands was calibrated using our multi-year monitoring data. Our experiments and observations have provided understanding of how the wetlands interact with the landscape and we have built this understanding into a mathematical model. The model was used to examine how raising the ditch outlet elevation would affect the hydrology of these isolated wetlands. Also examined was how raising the ditch elevation would affect the inundation duration (hydroperiod) and frequency for different portions of the wetland (varies with elevation). Finally effects on water (and P) budgets were evaluated.

Model formulation

A schematic of the simplified hydrologic model is illustrated in Figure 4.1. Critical hydrologic considerations included inflow to the wetland from the landscape (overland flow) and outflow from the wetland (groundwater vs ditch). Rainfall and ET were the primary drivers and two state variables were monitored: wetland stage and upland groundwater level. These were controlled by five model parameters: specific yield in the upland and wetland, runoff coefficient, weir coefficient, and wetland hydraulic resistivity.

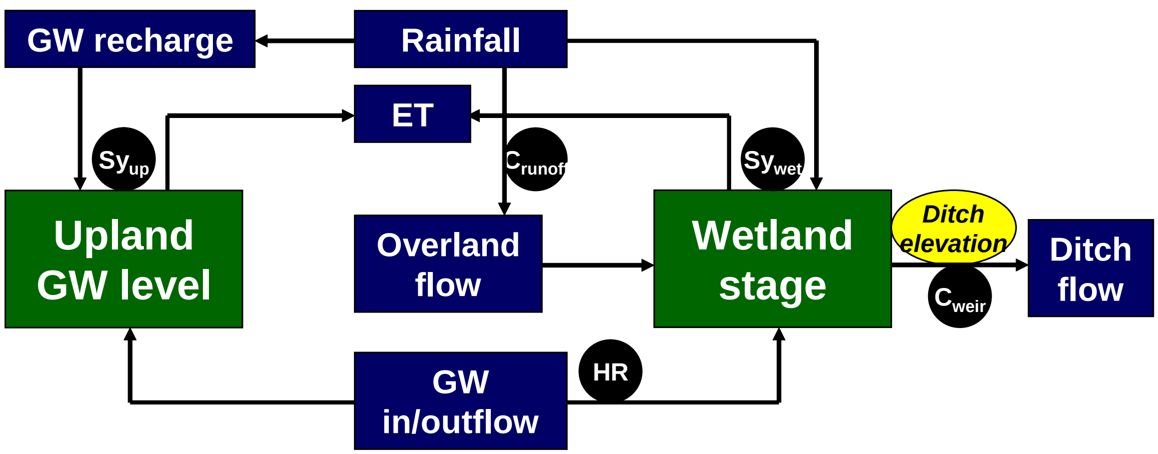


Figure 4.1. Schematic of simplified hydrologic model for isolated wetlands.

It is emphasized that in this treatment the following hydrologic processes were simplified: a lumped specific yield does not represent upland and wetland soil heterogeneity, a linear relationship between rainfall and overland flow was assumed, ditch flow was estimated from a simple weir equation, and surface water-groundwater interaction was controlled by Darcy's law.

Model calibration and validation

The model was calibrated to the wetland stage and upland groundwater level of BW1 for 297 days (Figure 4.2). The simulation mimicked the up and down of wetland stage and upland groundwater level well. Also, the gently decreasing wetland stage and more sharply decreasing groundwater level were both well simulated.

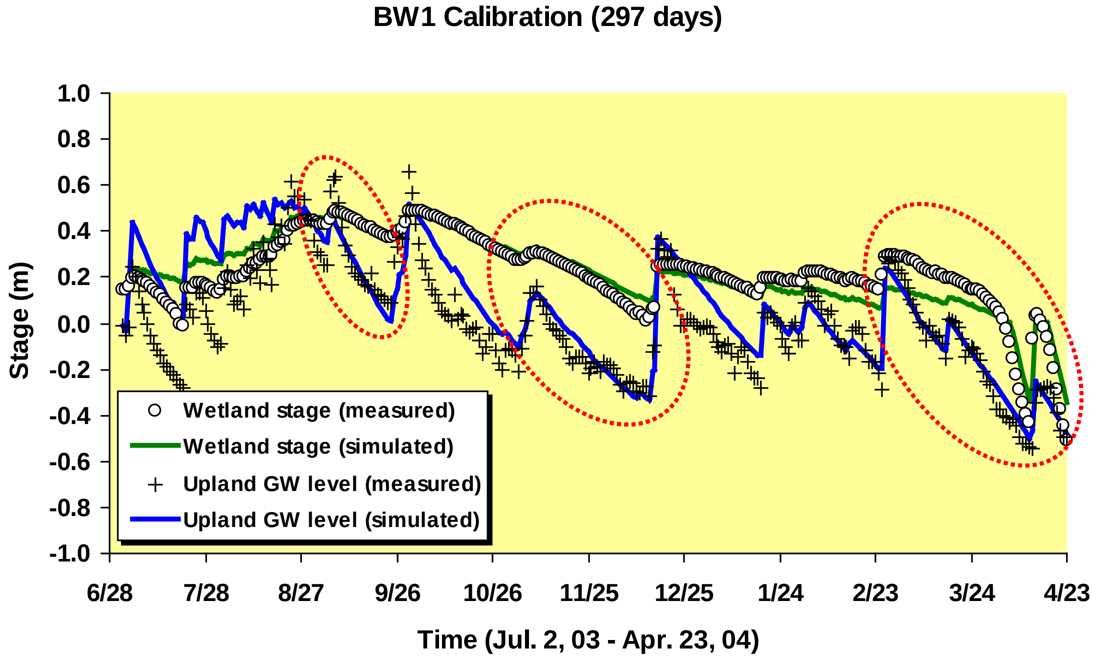


Figure 4.2. The model was calibrated to the wetland stage and upland groundwater level of BW1 for 297 days Open circles represent measured wetland stage and crosses indicate measured upland groundwater level. The green line represents simulated wetland stage and the blue line is simulated upland groundwater level.

The model calibration and validation results are shown in Figure 4.3. Of the four study areas, this modeling study was carried out only in BW1 and LW1 wetland because these two wetlands exhibited the most extreme values of relative ditch elevation. For BW1, the wetland stage was below the ditch elevation for the majority of the model period. On the other hand, for LW1, several big storm events made the stage higher than the ditch elevation. The model calibration followed the fluctuating pattern of wetland stage and upland groundwater level well. The Root Mean Square Error value of wetland stage is 7 to 13 cm which corresponds to just 7 to 9% of maximum fluctuation and for groundwater level, RMSE value is 15 to 17 cm. The model validation results were a bit worse than calibration results but the model validation in both wetlands also matched the fluctuation pattern.

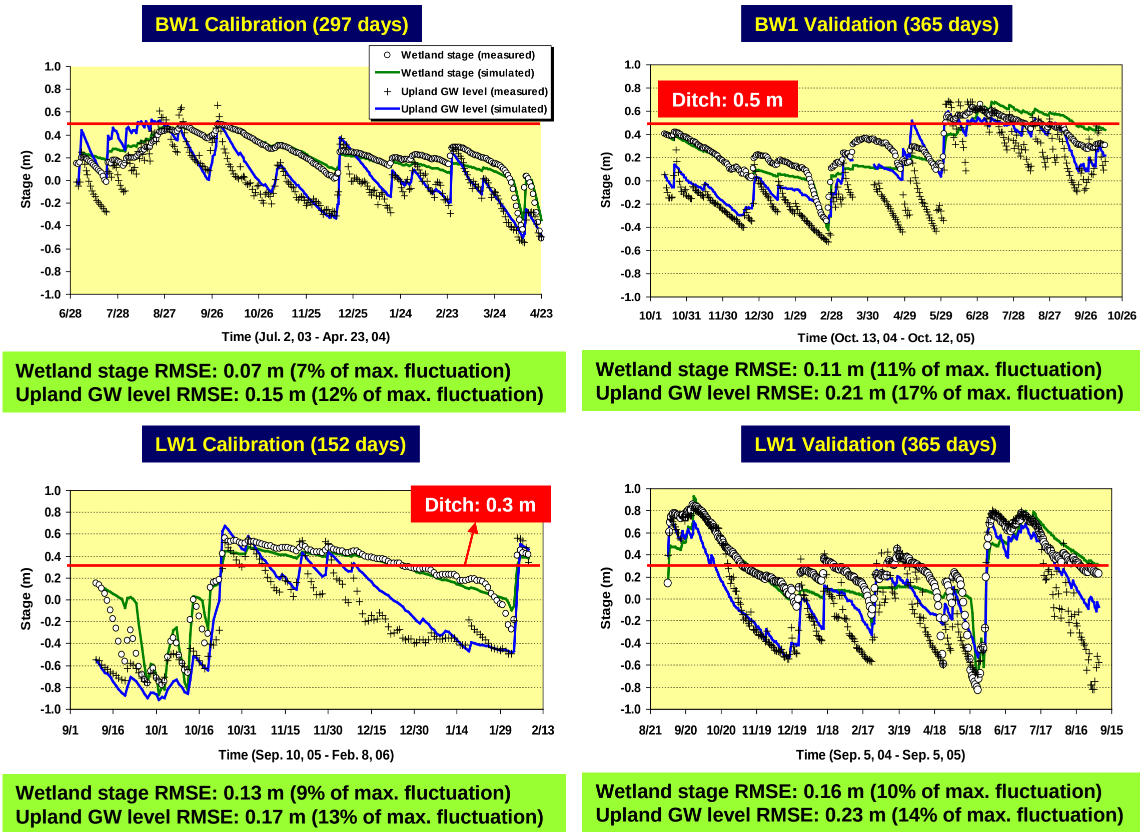


Figure 4.3. Model calibration and validation results.

Raised ditch elevation effect on hydroperiod

The ditch outlet elevation was increased by 0.1 m, 0.3 m, and 0.5 m. The effect on hydroperiod is shown in Figure 4.4. This diagram shows the model prediction results on the change of annual hydroperiod percent as a function of elevation. Hydroperiod of 100% corresponds to inundation throughout the year. As the ditch bottom elevation increases, the hydroperiod increases at a certain stage. For example, the wetland at elevation of 0.5 m has a hydroperiod of about 25% under baseline conditions. However, for scenario 3, the wet period is over 40%. Scenario 1 is not very different from the baseline case, however, when the ditch elevation is increased by 0.3 m, a significant change was observed in lower wetland stages. These results will be useful in estimating the impacts of vegetation or biogeochemical cycle with respect to hydrologic restoration.

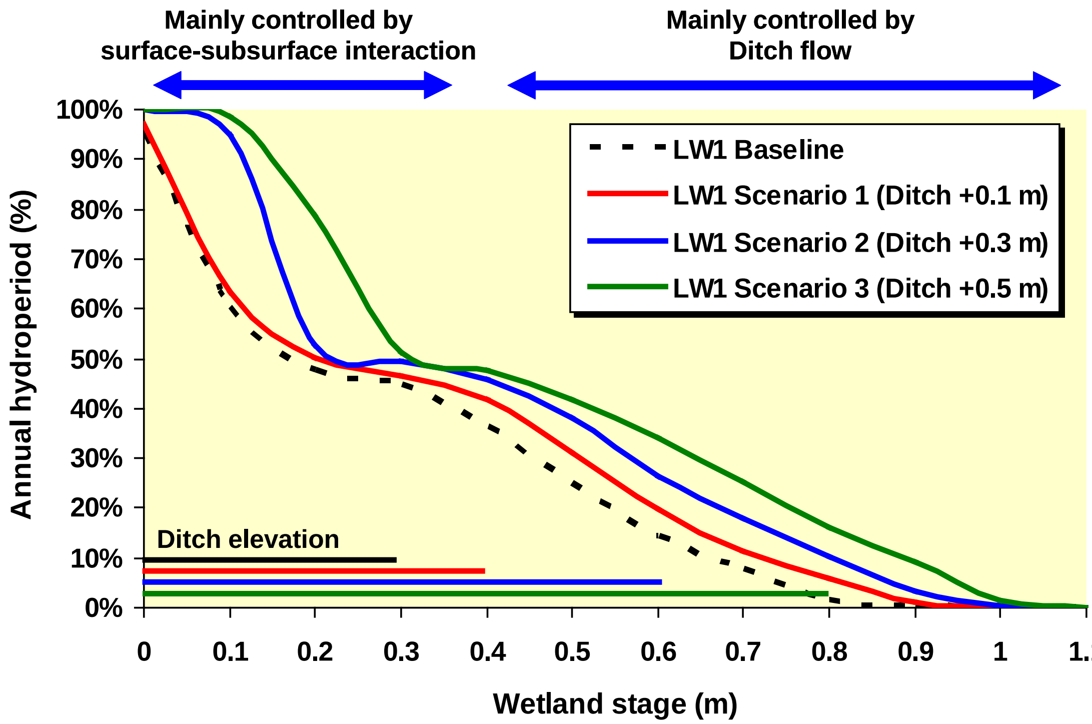


Figure 4.4. Effect on hydroperiod of increasing ditch outlet elevation by 0.1 m, 0.3 m, and 0.5 m.

Raised ditch elevation effect on water and P budgets

A volume base water budget was estimated using daily-based stage-area relationship. The simulations indicate that increasing the ditch elevation in LW1 would cause a significant change in outflow fractions (Figure 4.5). For the baseline case, 54% of total outflow was ditch flow, 27% was groundwater outflow and ET was 19%. Increasing the ditch elevation caused ditch flow to decreased from 54% to 8%, while groundwater outflow was increased from 27% to 66%. This result show that raising the ditch outlet elevation is favorable to reduce the surface outflow and to stimulate more groundwater outflow.

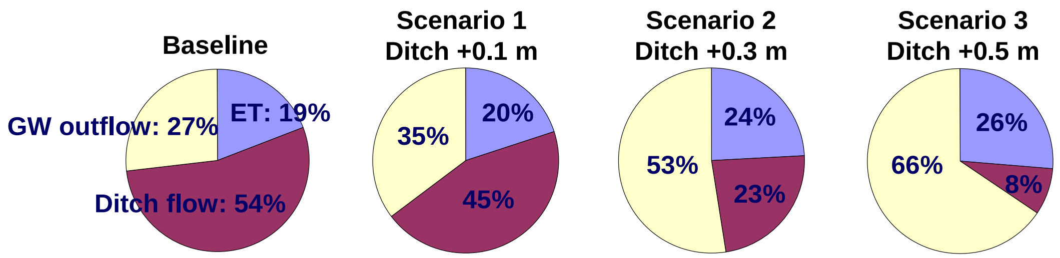


Figure 4.5. Effect on water budget of increasing ditch outlet elevation by 0.1, 0.3, and 0.5 m.

The measured mean TP concentration in LW1 water column was assumed to be annually constant at 1.2 mg/L. For a simple calculation, this concentration was multiplied by the reduced amount of water in ditch flow to estimate TP retention. In the Okeechobee basin, if we can assume there are 800 similar isolated wetlands, we can calculate annual total TP removal. If the ditch elevation is increased by 0.3 m, 32.6 metric ton of TP will be blocked from the ditch discharge at the entire basin level. If increased by 0.5 m, about 51 ton of TP will be retained in the wetland.

Isolated wetland restoration questions for future work

The simple model presented here did not account for effects of enhanced subsurface flow around control structures. It is possible the steep hydraulic gradient at the wetland/weir interface will lead to enhanced groundwater flow in this vicinity. A further question to be examined is the optimal location for weir control structures: at the wetland/ditch interface, or farther downstream? Also, further study is required to understand the fate of P exported via subsurface flow from the wetland.

Longer-term modeling of hydroperiod and water budget are needed to compare project period observations to model predictions from long-term climatic data. The scenario tests here were based on LW1 validation period which was a historically wet season (Fall 2004 to Fall 2005). Therefore, the scenario test results on annual water budget and phosphorus retention may not represent the long term annual average. Therefore, long-term hydrologic modeling is required.

Finally, a comprehensive modeling approach of hydrology, biogeochemistry, vegetation, and management is required. Example questions that could then be answered include effects of cattle interactions (grazing, sediment resuspension) on wetland performance.

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6.0 PHOSHORUS MANAGEMENT IN THE OBKEECHOBEE BASIN

We have conducted a workshop on June 4, 2008 in Okeechobee, Florida, to discuss key research findings of various projects funded by the Florida Department of Agriculture and Consumer Services, Florida Department of Environmental Protection, and South Florida Water Management District. Topics presented at the workshop are listed below.

June 4, 2008	
9:20 am	Introduction – Overview – K. Ramesh Reddy
9:30 am	Determining Minimum P Fertilizer Requirements for Sustainable Bahiagrass Production and Use of Forage Grasses for P Remediation of Impacted Sites - Lynn Sollenberger
10:00	Phosphorus storage and release characteristics pertinent to water table management and BMP implementations for Okeechobee Basin soils Vimala Nair
10:30	Water Treatment Residuals to Remediate Off-site P Losses George O'Connor
11:00 am	Effectiveness of Water Retention and Structural BMPs at Pelaez Ranch: Lessons Learnt and Questions Remaining Sanjay Shukla Wendy Graham
12:00 noon	Lunch
1:00 pm	Phosphorus retention and storage in isolated and constructed wetlands in the Okeechobee Basin - Mark Clark - James Jawitz and - Ramesh Reddy
2:00 pm	Provenance and turbidity effects of suspended magnesium-rich minerals in Lake Okeechobee" Willie Harris
2:30 pm	Discussion – Future research needs (all projects) - Ramesh Reddy

In addition to workshop, we have developed a synthesis document summarizing key findings and research needs on phosphorus management in the Okeechobee Basin. This report was submitted to Florida Department of Agriculture and Consumer Services.