AQUATIC VEGETATION IMPACTS ON SEDIMENT COMPOSITION, PHOSPHORUS POOLS, AND WATER QUALITY IN SOUTH FLORIDA FARM CANALS

By

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To my father Tom Sexton, my Mah, Cookie, Pete, Callie, and Puddy
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AQUATIC VEGETATION IMPACTS ON SEDIMENT COMPOSITION, PHOSPHORUS POOLS, AND WATER QUALITY IN SOUTH FLORIDA FARM CANALS

By

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The Everglades Agricultural Area (EAA) is an extremely productive farming region south of Lake Okeechobee in southern Florida, within the extensive Everglades system. It has been the subject of much debate due to the impacts of nutrient enrichment in the Everglades National Park, resulting in the Everglades Forever Act and the EAA Best Management Practices Regulatory Program for reduction of agricultural phosphorus (P) sources. The BMP Regulatory Program has continuously exceeded the 25% reduction of P requirement since its inception 20 years ago.

A significant portion of phosphorus (P) loads discharged from the EAA is in the form of particulates from biological sources during farm drainage events. This study was initiated on four treatment-control farm pairs over a five year period to investigate the role of suppressing floating aquatic vegetation (FAV), such as water lettuce (*Pistia stratiotes*), on the formation of more recalcitrant inorganic P forms in farm canal sediments. Treatment canals implemented FAV suppression, while control canals operated under normal management practices. Canal discharge water was more sensitive to changes in FAV cover than sediments, with lower total P and particulate P concentrations when suppressing FAV. Hydrology was the most influential factor
controlling P load, but FAV suppression did reduce P concentrations in discharge water. The fact that the P load for each canal was not affected by FAV suppression is a result of greater influences by flow and velocity on P load. Ultimately, this study found that suppressing FAV cover to less than 5% did reduce total P concentrations in water discharged from canals, and that percent FAV cover did significantly influence discharge water P concentration. This reduction and relationship may incentivize farmers to adopt the practice of year-round FAV suppression.
CHAPTER 1
REVIEW OF EVERGLADES AGRICULTURAL AREA ENVIRONMENT, BEST MANAGEMENT PRACTICES, AQUATIC VEGETATION, AND PHOSPHORUS POOLS IN CANAL SEDIMENTS

Introduction

The presence of floating aquatic vegetation (FAV) has been observed to negatively impact phosphorus (P) removal from farm canals in the Everglades Agricultural Area (EAA) of southern Florida (Stuck, 1996; Daroub et al., 2012). However, no direct comparative studies have been conducted to assess the effects of FAV suppression on P removal as a management tool or on the mechanisms controlling this process. Floating aquatic vegetation is able to take up and store high concentrations of P from the water column or canal sediments, depending on location of plant roots. After maximum P uptake is achieved early in the growing season, FAV becomes a source of P during death and decomposition (Menon & Holland, 2014). Suppression of FAV may allow greater removal of P from the water into recalcitrant P precipitates that will be deposited in canal sediments in different pools of bioavailability. This study quantified the effects of FAV suppression on P fractions in canal sediments, and will fill the knowledge gap in assessing this strategy as a means of reducing labile P export from EAA farm canals.

The EAA is a highly productive agricultural area south of Lake Okeechobee in southern Florida within the larger Everglades system. It is mostly situated within Palm Beach and Hendry Counties and is dominated by production of sugarcane, sweet corn, rice, sod, and winter vegetable farming due to its highly organic muck soils and subtropical climate (Daroub et al., 2009). Formerly sawgrass (Cladium jamaicense Crantz) marshes, the low topography, variable seasonal rainfall, and highly organic wetland soils required an intricate series of canals, levees, pumps, and control structures to optimize soil and water table conditions for agriculture (National Park Service, 2014a). Phosphorus entering the EAA from Lake Okeechobee, released
during soil oxidation, and applied as fertilizer is carried with agricultural drainage water and is considered one of the leading causes of nutrient enrichment in the downstream Water Conservation Areas (WCAs) and the Everglades National Park (ENP) (South Florida Water Management District, 2014a). The P-enriched drainage water has resulted in an ecological shift from oligotrophic, or nutrient poor, to eutrophic, or nutrient rich, ecosystems in the downstream Everglades National Park (Bottcher & Izuno, 1994). This change in nutrient regime has shifted vegetative communities from sawgrass marshes to predominately cattail (*Typha latifolia*) monocultures, and subsequently affected fauna composition and the associated food chain dynamics (Trexler & Goss, 2009).

Phosphorus is an essential nutrient and is a building block for DNA and energy and protein production. Phosphorus is present in many forms in an aquatic system either as organic or inorganic particulate or dissolved phosphates (PO$_4^{3-}$). Organic phosphates are those bound within plant or animal tissue and formed through biological processes. Inorganic phosphates are ortho- and polyphosphates and are not associated with plant or animal tissue. Orthophosphates are the most stable forms of phosphate and are considered reactive, or biologically available, because it is the form taken up by plants. Polyphosphates are not as stable in water and tend to convert to orthophosphates. Particulate P is P that is adsorbed to particles, precipitates of P, and living and dead biologically-bound P. Dissolved P is organically-bound or found as inorganic phosphates. Total P (TP) is the measure of all P in the system, including dissolved and particulates. Total dissolved P (TDP) is the total amount of P dissolved, and subtracting TDP from TP will give the amount of particulate P (PP). Soluble reactive P (SRP) is dissolved, inorganic orthophosphate and is considered the form directly taken up by plants. The presence of
calcium, iron, and aluminum can precipitate SRP out of the water column and render it biologically unavailable.

To combat the increasing concentration of P in EAA discharge waters, a best management practice (BMP) program was established in 1994 by the Everglades Forever Act (Chapter 373, Florida Statutes, Section 373.4592, 1994) requiring a 25% reduction in P loads relative to a designated baseline. The Florida Department of Environmental Protection (FDEP) has charged the South Florida Water Management District (SFWMD) with the development, implementation, and monitoring of the EAA BMP program. Although it has been successful in meeting the 25% reduction requirement for 20 consecutive years (South Florida Water Management District, 2015a), there are still high P concentrations leaving some farms, overtaxing the Stormwater Treatment Areas (STAs) and WCAs, and affecting the ENP downstream.

Achieving further reductions in P transport from EAA farms can be done by focusing management on canal sediments and particulates to which P adsorbs. In the EAA, 40-60% of all discharged P is as PP, and 50% of the PP is generated by in-stream biological growth (Stuck, 1996; Daroub et al., 2005; Daroub et al., 2012). The biological growth most significant in particulate P export is recently deposited, easily transportable macrophyte detritus from FAV, filamentous algae, and plankton (Daroub et al., 2012). This study will provide missing data of the influence of FAV suppression on P loads from EAA farm canals. To generate a better understanding of FAV suppression as a management tool, this dissertation will strive to answer the following questions:

1. What are farmer and farm worker opinions on the EAA BMP program and BMP research?
2. Will the suppression of FAV in farm canals decrease the labile P pool in canal sediment as compared to farms not suppressing FAV?
3. Would implementation of FAV suppression within the entire EAA reduce discharge water P?

In order to answer these questions, this dissertation will focus on these objectives:

1. Assessment of farmer perception of the EAA BMP program and nutrient management strategies;
2. Analysis of EAA farm canal sediment composition, P retention capacity, P forms within the sediment, and P pools discharged downstream in relation to FAV suppression;
3. Utilization of a GIS-based model program to predict impacts of basin-wide FAV suppression.

The results of this study will include a better understanding of farmer perception of BMPs and nutrient load impacts downstream, feasibility of FAV suppression as a method to provide farmers another tool for their farm BMP management plans, and whether or not the basin-wide implementation of FAV suppression would have a significant effect on EAA P export.

This Chapter will provide an overview of the Everglades system, characterization of the EAA ecosystem, hydrology, and soils, as well as previous work conducted in the area. Chapter two will review the policies that have led to the current ecosystem dynamics and the state-farmer partnership BMP program, as well as explore farmers’ perceptions of the BMP program and its effectiveness. Chapter three analyzes FAV suppression as a means of reducing labile P pools within farm canal sediments. Chapter four explores the impacts of FAV suppression on discharge canal water and sediment. Chapter five uses the data collected from the experiment to create model parameters representing FAV suppression impacts on discharge water. Chapter six summarizes the various studies conducted and discusses implications and future works needed.

**Area of Study**

The Everglades is composed of a series of complex, intertwined ecosystems including cypress swamps, ridges and sloughs, sawgrass marshes, hardwood tree hammocks, pinewood
uplands, estuarine mangroves, and marine seagrass beds of Florida Bay. These systems are
dependent on and shaped by water and fire, experiencing frequent flooding in the wet season and
lightning fires in the dry season (National Park Service, 2014b).

Human habitation of the Everglades system dates back to as far as 15,000 years ago
(Bottcher & Izuno, 1994). Generally, people did not have a large impact in the area until the first
half of the twentieth century when drainage canals were constructed (Bottcher & Izuno, 1994).
The EAA is a subset watershed around 3,000 km$^2$ and was only officially defined by the state in
1949 (Izuno, 1989; Miedema, 2014). Today, the vegetation, hydrology, nutrients, and natural
hazards have been altered in the EAA and Everglades system due to human development and
drainage (Izuno, 1989). The population of the EAA is low, summing to around 45,000 people,
but extensive drainage structures and agricultural activities have altered the water and nutrient
regimes in the area (U.S. Census Bureau, 2010b).

**Geology and Soil**

The greater Everglades area is a large, karstic system and spans most of south Florida.
Geologically the entire system is young, between 5,000-15,000 years old (Bottcher & Izuno,
1994). The underlying geology of the EAA is primarily marine and freshwater sedimentary rock,
meaning the bedrock was accumulated over time and compacted, not metamorphosed or igneous,
making the bedrock more susceptible to erosion. The sedimentary rock was formed with the
changing sea level during the Pleistocene era (1.8 M – 10,000 years ago) (Bottcher & Izuno,
1994). Much of the EAA has Lake Flint marl, formed from freshwater shells that consolidated
into hard limestone or soft gray-white calcareous mud (Bottcher & Izuno, 1994). The
sedimentary limestone rock reaches a depth of up to 3,000 ft (915 m), and has low permeability.
Because of this, there is little percolation from the EAA into the underlying Floridan aquifer
(Cohen, 2014).
Overlying the limestone bedrock in the EAA are organic soils—Histosols. Due to the low drainage of the sedimentary rock and very low elevation above sea level, the area was submerged or wet during most of the year. The wetland plant sawgrass (*Cladium jamaicense*), which requires flooded conditions for most of the year, dominated the area (Florida Museum of Natural History, 2014). When the sawgrass died and fell into the oxygen-limited wetland, it was not completely decomposed to gaseous CO$_2$ and accumulated as a parent material for the organic soil. Accumulation of the organic matter began about 3,500 to 4,000 years ago at a rate of 3.3 inches (8.3 cm) each century (Izuno, 1989). Today in most areas of the EAA, depth from soil surface to the limestone bedrock ranges from 1 to 5 ft (0.3 to 1.5 m) thick (Gesch et al., 2007). Soil accumulation stopped, and oxidative subsidence loss began, when drainage programs started in the early 1900s.

There are seven types of soil, all muck soils, documented in the EAA (Bottcher & Izuno, 1994). Table 1-1 lists the characteristics of Torry muck, Terra Ceia muck, Pahokee muck, Lauderhill muck, Dania muck, Okeelanta muck, and Okeechobee muck found in the EAA. Muck soils generally belong to the Saprist suborder, which are more decomposed than Fibrist and Hemic Histosol suborders. The soils have low bulk densities and are classified as very poorly drained (Bottcher & Izuno, 1994). The Histosols can hold multiple times their weight in water at field capacity, so they can have over 100% moisture content when expressed on a weight basis. Water holding capacity increases with depth, while bulk density decreases. Muck soils have high cation exchange capacity (CEC) and strongly adsorb cations (Bottcher & Izuno, 1994).

**Slope, Climate, and Hydrology**

The Florida Everglades system is extremely flat. Spanning the 280 mile (450 km) long system from Lake Okeechobee to the Everglades National Park, the average slope is approximately 2 in/mile (3 cm/km), with a maximum elevation of about 17 ft (5.1 m) above sea
level (United States Geological Survey, 2013). Because of this low slope, water does not drain quickly off of the landscape. At a velocity of 0.2 in/s (0.5 cm/s), it takes water from Lake Okeechobee around 325 days to reach the Everglades National Park (Cohen, 2014). Saturated hydraulic conductivity is fairly high in EAA Histosols, ranging from 60.0-76.3 in/hr (15.2–193.7 cm/hr), but low slope prevents rapid water drainage (Bottcher & Izuno, 1994).

South Florida and the EAA have a subtropical climate consisting of two seasons: wet and dry. The wet season is from May to October, and is warm and humid, with temperatures averaging in the mid-90°F (30-35°C). The dry season is from November to April, and is cooler and drier, with temperatures ranging from 50-70°F (12-25°C) (National Park Service, 2014b). Over 75% of the EAA’s average annual 57 in/yr (145 cm/yr) rainfall occurs during the wet summer months (National Park Service, 2014b). Evapotranspiration (ET) rates vary by crop and water table levels. Average potential ET rates are approximately 55.4 in/yr (140.6 cm/yr) (Bottcher & Izuno, 1994). Because the rain and ET are not spatially or temporally equally distributed, farm canals are used to drain agricultural fields during the wet season and provide irrigation when needed.

Before development, water levels fluctuated over a wide range and wetlands were extensive. Today, the hydrology of the EAA is completely anthropogenically controlled by canals and pump stations. At the boundaries of the EAA are eight levees connected to Lake Okeechobee’s Herbert Hoover Dike. The canals, levees, gates, and pump stations are operated by the SFWMD to synchronize and monitor irrigation and drainage with the entire Everglades hydrologic system.

Inflows to the EAA are from precipitation and discharge from Lake Okeechobee, with outflows to the east coast, WCAs, or minimal back-pumping into the Lake. There are seven
major pump stations (S-2, S-3, S-4, S-5a, S-6, S-7, and S-8) in the EAA designed to move 0.75 in (1.91 cm) of rain per 24 hrs (Bottcher & Izuno, 1994). Each farm contains smaller pump stations and canals connected to the main district canals that pump from 3 to 24 in (8 to 61 cm) of rain in 24 hrs (Bottcher & Izuno, 1994). Farmer managers control the farm canal levels in accordance with crop need and SFWMD water supply requirements.

The SFWMD must consider quantity and timing of water supply to agricultural, urban, and environmental needs. Lake Okeechobee and the WCAs are designated storage areas for water in south Florida. Each area has a specific maximum allowable water level and discharge schedule. Highest levels are designated during the dry season and lowest during the wet season to allow additional storage and prevent downstream flooding. The compartmentalization of the EAA and the entire Everglades system has disrupted the historic, slow flowing hydrology. Historical hydroperiods – or distribution, duration, and timing of inundation – have been disrupted by human activities dropping from 270 to less than 1 day per year in the EAA (Stober et al., 2001). Hydroperiods affect plant and animal distributions, as well as water and soil quality and quantity. Current management by the SFWMD is being expanded to include flow stabilization areas within the EAA to slow the amount of water released into the WCAs in an attempt to restore the historic sheet flow and hydroperiod south of the EAA.

**Literature Review**

**Everglades Agricultural Area Best Management Practices (BMPs)**

There is a collection of past and on-going research on BMP implementation and effectiveness in south Florida specific to the highly organic muck soils of the EAA (Aillery, Shoemaker, & Caswell, 2001; Anderson & Rosendahl, 1998; Das et al., 2012; Letson & Milon, 2002; Daroub et al., 2009; Meals et al., 2010; Childers et al., 2003; Reddy & DeLaune, 2008). The SFWMD is required by the FDEP under the Everglades Forever Act to report annually on
the implementation, monitoring, and improvement of the basin’s P abatement progress. Past South Florida Environmental Reports extensively outline BMP options and their implementation methodology as a source control program (South Florida Water Management District 2014b; South Florida Water Management District 2015b).

Some of the more common BMPs used in the EAA include ditch and canal berms, vegetated canal and ditch banks, and use of weed booms and trash racks (Diaz et al., 2006). Ditch and canal berms are mounds of soil and limestone rock piled parallel to the banks so as to minimize the transport of nutrients and soil from fields into the water body. By blocking the direct flow path of water from the agricultural field, the water must then percolate through the soil where soil particles will settle out (Diaz et al., 2006). These berms are able to reduce erosion by providing a physical barrier to water flow, which is increased with the addition of vegetation to stabilize canal banks. Above ground biomass serves to slow the flow of water and settle out heavy particulates, while roots stabilize the bank soil and absorb carried nutrients (Diaz et al., 2006). Weed booms and trash racks are a physical barrier to trash and aquatic vegetation present in canals and ditches. Booms and racks are installed to hold vegetation and trash upstream so as to allow settling of detrital matter before it reaches the discharge pumps and prevent obstruction by trash (Diaz et al., 2006). Because a significant portion of the TP exported from agricultural drainage canals originates from aquatic vegetation, these booms serve to reduce P discharge (Stuck, 1996; Daroub et al., 2005).

**Environmental Impacts of Floating Aquatic Vegetation Infestation**

Floating aquatic vegetation affect the quality of the water column and sediments by altering light penetration and oxygen diffusion, and depositing detrital matter to the floor of water bodies (Frodge et al., 1990; Graneli & Solander, 1988). The detrital matter and P may then be exported off farm during pumping events, depending on water velocity. There has been
research conducted on the effects of FAV mats on diurnal fluctuations of water temperature (Dale & Gillespie, 1976), light penetration (Scheffer et al., 2003), dissolved oxygen (DO) (Scheffer et al., 2003; Nahlik & Mitsch 2006; Frodge et al., 1990), pH (Frodge et al., 1990; Graneli & Solander, 1988), and redox potential (redox) (Graneli & Solander, 1988; Frodge et al., 1990; Boyd, 1971). Floating aquatic vegetation mats can increase temperatures; FAV mat temperatures were 4.0–11.0°C higher than surrounding open waters, and air temperatures were up to 12.2°C higher above FAV mats than open waters (Dale & Gillespie, 1976). In addition, temperatures 2 cm below the mats were higher than open waters, but temperatures 10–45 cm below mats were less than open water (Dale & Gillespie, 1976).

Mats of FAV can reduce DO concentrations by limiting O₂ diffusion, with the degree of reduction fluctuating with growth or shrinkage of canopy. This results in anoxic conditions in the lower water column (Frodge et al., 1990). Also, high FAV coverage reduces photosynthesis as a result of lack of light penetration and water circulation (Frodge et al., 1990), which in turn limits consumption of CO₂ and production of O₂ in the water. Higher concentrations of dissolved CO₂ will lead to lower water pH from formation of more carbonic acid, and lower O₂ concentrations will lead to lower redox (anaerobic) conditions.

Bioavailable P can be precipitated from the soluble phase with calcium and magnesium (Ca-Mg) under higher pH conditions, which can result from photosynthesis (Danen-Louwerse et al., 1995). With decreased light penetration into the water column by FAV mats, P binding to Ca-Mg may be reduced as photosynthesis on the canal bed ceases. As DO concentrations lower, redox potential is reduced, resulting in higher solubility of iron and manganese (Fe-Mn), releasing Fe-Mn bound P back into the water column (Boyd, 1971). Lower pH under high FAV
cover may also release P bound to aluminum (Al) minerals, which are more soluble under lower (4-6) pH (Brady & Weil, 2008; Ann et al., 1999; Nur & Bates, 1979).

Managing FAV once it is abundantly present has proven troublesome, with the potential for a sharp increase in dissolved reactive P when FAV mats are killed in-situ (Graneli & Solander 1988). Dissolved reactive P decreases as sediments absorb P, but desorption occurs as temperatures warm and decomposition increases (Graneli & Solander, 1988). Promisingly, long-term herbicidal FAV suppression resulted in decreased P concentrations in water and decreased soil redox have been observed in lentic systems (Boyle, 1979). An increase in soil redox potential could lower Fe-Mn-P desorption as the compounds become less soluble at higher redox potentials (Boyd, 1971; Boyle, 1979).

**Dominant Aquatic Vegetation Species in the EAA**

**Floating aquatic vegetation**

Floating aquatic vegetation are those that have leaves floating on the surface of the water. They can be free floating or be rooted in the sediment. Water lettuce (*Pistia stratiotes* L.), is a member of the family Araceae, and it is also known as tropical duckweed and Nile cabbage (Howard & Harley, 1997). It is the only species in its genus (Florida Fish and Wildlife Conservation Commission, 2016b), but a close relative has been identified as *Protarum sechellarum*, a species endemic to the Seychelles (Renner & Zhang, 2004). Water lettuce is native to South America, and prefers tropical to subtropical climates (Dray & Center, 1989). Water lettuce is a perennial floating obligate wetland species, meaning it requires the presence of water to survive (Florida Fish and Wildlife Conservation Commission, 2016b). The pale-green thick, soft leaves have no stems and grow in rosettes resembling lettuce heads. The roots are long (up to 1 m) and feathery (Hall & Okali, 1974). The plants are free floating, and the roots do not attach to a substrate. Water lettuce reproduces through seeds and stolons - or runner stems -
producing daughter clusters (Dewald & Lounibos, 1990). The flowers are inconspicuous and the seeds can remain dormant for months until favorable conditions occur (Dray & Center, 1989). Water lettuce is present in most tropical and subtropical regions in the world, and seeds germinate between 20-30°C (Dray & Center, 1989). The first recorded presence of water lettuce in Florida was in 1765 and is thought to be the result of commerce between Spanish Florida settlers and South America (Florida Fish and Wildlife Conservation Commission, 2016b). There has been an ongoing argument for the invasive status of water lettuce, with old and new research citing fossil records of the presence of the species in North America since at least the Eocene Epoch (56 to 33.9 MYA) (Stoddard, 1989; Evans, 2013). Water lettuce growth increases with increasing nutrient load, leading to infestations in eutrophic conditions (Howard & Haley, 1997). It is listed on the Florida State Noxious Weed list as a class 2 prohibited aquatic plant\(^1\). Water lettuce was the most common and abundant species of FAV found in experimental canals in this study. It is also one of the two most common FAV in EAA canals, the other species being water hyacinth.

Water hyacinth [(Eichornia crassipes (Mart.) Solms)] is an invasive floating species to Florida, introduced in the 1880s from Brazil (Florida Fish and Wildlife Conservation Commission, 2016a). It is a floating plant with clustered leaves and spongy stalks. It also creates large-spanning mats that quickly infest water bodies (Wilson et al., 2005). The green leaves are large and glossy and form rosettes with bulbous, inflated bases. Roots are long and feathery, similar to water lettuce. Each plant forms a single flower spike with several light purple-blue flowers with yellow splotches. Optimal growth occurs in temperatures between 28-30°C, but it

\(^1\) A Class 2 Prohibited Aquatic Plant is one that the state considers to be highly invasive and noxious in areas of the State of Florida, but may be grown in a nursery and sold out of state. They cannot be collected from the wild or imported, and must be prevented from escaping nursery grounds (Florida Rule 5B-64.011).
can survive short-term freezes. It reproduces both by seed and vegetatively through fragmented pieces and stolons (Center & Spencer, 1981). It is listed on the Florida State Prohibited Aquatic Weed list as a class 1 prohibited aquatic plant\(^2\). While this species is prevalent in the EAA, it did not occur in experimental farm canals and was, therefore, not one of the represented FAV species.

Duckweed (\textit{Lemna minor}) is native to Florida and difficult to manage due to fast growth and senescence (USDA Natural Resources Conservation Service, 2016b). It is a small, light green floating vegetation with free-floating roots. It has 1-3 oval or tear-drop shaped leaves between 0.0625 in (0.16 cm) and 0.125 in (1.97 cm) in length, with one root protruding from each leaf (USDA Natural Resources Conservation Service, 2016b). It reproduces asexually as outgrowths from one end break off to form another plant, and rarely it will sexually reproduce by small (1 mm) unisexual flowers (JRank & Philosophy, 2017). The lifespan of a single plant is from five to six weeks (JRank & Philosophy, 2017). Rapid growth allows for high coverage mats to form and block water surface. It is usually associated with eutrophic stagnant waterbodies.

\textbf{Submerged aquatic vegetation}

Submerged aquatic vegetation (SAV) are those with the majority of their biomass under the water surface. They tend to be rooted to the water body substrate, but can have different behavior at different growth stages. Filamentous algae (\textit{Spirogyra} sp.), is a member of the family Zygnemataceae, and is known by the common names mermaid’s tresses, and water silk. There are over 300 species in the \textit{Spirogyra} genus in the world. It is related to genus \textit{Mougeotia} and genus \textit{Zygnema} (Caldwell, 1904). It is present worldwide and found in nearly every type of system from rain forests to deserts to tundra (Kim et al., 2005). It is an obligate wetland genus, \footnote{Class 1 Prohibited Aquatic Plants are ones that the state considers to be highly invasive and noxious in areas of the State of Florida and may not be grown in a nursery, collected, or sold (Florida Rule 5B-64.010).}

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and tends to grow in clean, eutrophic water bodies. Spirogyra is generally unattached algae that grows in long, thin, unbranched strands held together by a sheath of mucus (Kim et al., 2005). It grows near the water body bottom in a mat as an SAV, but becomes buoyant as gas becomes trapped by tangled strands and floats it to the water surface. Most grow in stagnant pools, but some species can grow in flowing water (Biology Discussion, 2013). Its lifecycle in Florida occurs year round. Reproduction usually takes place vegetatively as filaments break away, but they can also reproduce sexually and rarely asexually (Biology Discussion, 2013). Because Spirogyra is present all over the world, it does not seem to have many growth limitations. Spirogyra species are native to Florida and are present in periphyton assemblages in the Everglades (Vymazal & Richardson, 1995), but in many waterways it is considered a nuisance. When found in floating mats on the water surface, filamentous algae was considered FAV in our study canals. It was collected with FAV sampling and sprayed with herbicide when present.

Hydrilla (Hydrilla verticillata) is an SAV rooted in the canal sediments. It is also known as water thyme, Florida elodea, and waterweed (Wisconsin Department of Natural Resources, 2012). Hydrilla is an herbaceous perennial submerged obligate wetland species (Florida Fish and Wildlife Conservation Commission, 2016c). It has a long, slender branched stem up to 25 ft (7.5 m) long, with saw-toothed leaves that grow in spirals. It generally reproduces vegetatively through plant fragments, as well as through tubers that grow near the roots that are viable for more than four years (Florida Fish and Wildlife Conservation Commission, 2016c). A single tuber can produce more than 6,000 new tubers per m² (Sutton et al., 1992). It can also reproduce through axillary buds and can flower (small white flowers along stem), but does not produce seeds in southern states due to lack of male flowers. Hydrilla can grow in all freshwater bodies with salinities up to 7%, with depths varying between a few inches to 20 ft (6 m) (UF/IFAS
Center for Aquatic and Invasive Plants, 2015b). It can grow in low nutrient and high nutrient systems, low sunlight (1%), low CO\(_2\), and temperature ranges from 20-30°C (UF/IFAS Center for Aquatic and Invasive Plants, 2015b). Hydrilla was brought to the US in the 1950s as part of the aquarium trade in Tampa and Miami, FL (Florida Fish and Wildlife Conservation Commission, 2016c). It is listed on the Federal Noxious Weed list and the Florida State Noxious Weed list as a class 1 prohibited aquatic plant.

**Emergent aquatic vegetation**

Emergent aquatic vegetation are those with the majority of their biomass above the water surface while rooted to the bank or in shallow waters. Alligatorweed ([*Alternanthera philoxeroides* (Mart.) Griseb.]) is an invasive emergent weed originating from South America (Spencer & Coulson, 1976). It was first reported in Alabama in 1897, believed to have been transported in ballast water (Buckingham, 1996). It is an emergent plant that roots in the shallow banks of an aquatic system and then begins spreading across the water surface using floating stems. It is a perennial plant with hollow stems and roots at stem nodules. It reproduces both vegetatively when floating sections break off and by seed. The floating stems can reach up to 15 ft (4.5 m) long and create a interwoven mat stretching up to 50 ft (15 m) from the bank with the same negative effects of water lettuce and water hyacinth infestations (Zeiger, 1967). This species, although an emergent, was common in experimental canals floating across the water surface in mats. Due to the thickness of the floating mats, alligatorweed was collected with FAV during experimental sampling.

Torpedograss (*Panicum repens*) is an emergent species that can live in water up to 6 ft (2 m) deep and dry land (UF/IFAS Center for Aquatic and Invasive Plants, 2015). Torpedograss is in the family *Poaceae*, and it is native to Africa and Asia and was introduced to the United States before 1876. In the early 1900’s the United States Department of Agriculture readily distributed
torpedograss seed for planting in pastureland as a means of forage for cattle (UF/IFAS Center for Aquatic and Invasive Plants, 2015). It is called torpedograss because of its pointed, torpedo-like growing tips. It can grow up to 3 ft (1 m) tall, with hairy leaf sheaths and hair on the upper margins of the leaves. The leaves are stiff, with a waxy or whitish coating on the surface. It spreads over water surfaces in mats similar to alligatorweed, and can restrict water movement and navigation (Mossler & Langeland, 2006). It has extensive, starchy rhizomes reserves that allow it to grow back after damage or herbicidal treatment to above-ground biomass. Seeds do not germinate well under Florida conditions, so reproduction is primarily through rhizome expansion or vegetatively by fragmentation (UF/IFAS Center for Aquatic and Invasive Plants, 2015). This was another emergent species collected as FAV in this study due to the extensive mats.

**Aquatic Vegetation and Phosphorus Cycling**

Phosphorus can have many fates in an aquatic system, including uptake by plants, adsorption to sediments, microbial assimilation, and precipitation (Menon & Holland, 2014). Aquatic vegetation, and their associated rhizospheres, have been recognized for their ability to pull P out of water columns and sediments to aid in remediation projects and effluent treatment (Boyd, 1971; Nahlik & Mitsch, 2006; Polomski et al., 2009; Menon & Holland, 2014). Plant uptake is generally highest during the growing season, and storage rates vary based on type of vegetation, rate of senescence, and movement of P from roots to shoots biomass (Boyd, 1971; Menon & Holland, 2014). Phytoremediation of effluent and impacted wetland systems can be done using FAV, SAV, and emergent wetland vegetation. Each type of plant differs in P uptake and storage, leading to the need for alternative management strategies.

Floating aquatic vegetation that are not rooted into the sediment absorb P from the water column (Boyd, 1971). The benefit of FAV being not rooted to the substrate means there is no
remobilization of P stored in the sediment (Wen & Recknagel, 2002). Floating aquatic vegetation have high potential P-uptake capabilities, with P tissue concentrations in water lettuce and water hyacinth ranging from 1.75-1.88 mg/g (Polomski et al, 2009) at peak growth. Many FAV have high growth rates, for example water hyacinth can spread over many hectares in a single growing season (Boyd, 1971), with P assimilation rates ranging from 0.086- 0.2 g/m²/day (Nahlk & Mitsch, 2006; DeBusk et al., 1995). Growth rates have been shown to increase with the increasing nutrient concentration in the water column, and roots to shoots storage of P is generally evenly distributed with some increase of shoot storage as concentrations increase (Polomski et al., 2009). In water lettuce, the leaves decompose at a higher rate (50% of initial dry weight within the first week) than the roots (50% of initial dry weight after 20 days), quickly leaching 50% of P from the leaves and around 20% from the roots, within 24 hours after death (Sommaruga et al., 1993). All biomass-P originates from the water column, and is quickly returned upon decomposition of FAV.

Submerged aquatic vegetation that are rooted to the substrate absorb P from the sediment (Boyd, 1971). The lack of structural cell walls leads to active uptake by the plant leaves, meaning SAV can also absorb P from the water column (Granéli & Solander, 1988). For rooted species, P uptake from the sediment accounts for over 70% of total P uptake by SAV (Carignan, 1982; Granéli & Solander, 1988). Species like filamentous algae, which do not root into the substrate and become floating at later life stages, behave as FAV and uptake nutrients completely from the water column. Phosphorus concentration in plant tissue varies with species, between 0.84-5.4 mg/g, and net P storage is between 0.41-1.63 g/m²/day (Dierberg et al., 2002). Plant tissue P concentration increases with the increase of P concentrations present in the system up to a limit (Granéli & Solander, 1988). Submerged aquatic vegetation tend to not contain much
cellulose and are therefore more easily and quickly decomposed, leading to a faster release of P as compared to emergent species and FAV (Boyd, 1971). Initial phosphorus release from SAV decomposition is rapid, losing between 20-80% in a few hours (Granéli & Solander, 1988). The high turnover rate of SAV biomass makes the total amount of P released greater than the peak highest concentration in its living tissue (Granéli & Solander, 1988). Furthermore, because SAV is utilizing P stored in the sediment, release of P from the plant is adding to the overall P in the water column, rather than cycling water column P.

Emergent wetland vegetation are rooted to and absorb P from the sediment (Boyd, 1971). Emergent species, like rooted SAV, are able to reach deeper pools of P within the sediment with their vascular roots, reactivating stored P previously unavailable to the system. Some also have adventitious roots that absorb P directly from the water column, like alligatorweed (Childers et al., 2003). The general P content of living tissue of emergent species is between 0.1-5 mg/g, and P uptake is between 0.37-0.43 g/m²/day, depending on the species (Granéli & Solander, 1988; Tanner, 1996). Plant tissue P concentration increases with the increase of P present in the system (Granéli & Solander, 1988). Phosphorus in the leaves is quickly translocated to the below-ground biomass once shoots begin to die, and after aboveground biomass falls into the water it releases P at a higher rate (Boyd, 1971; Granéli & Solander, 1988). The translocation of P between shoots and roots throughout the year is difficult to measure. After the initial plant establishment, an estimated 40% of the needed above-ground-P originated from pools stored in the roots from the previous year, with 23-50% returning to the roots after the growing season (Van der Linden, 1986; Granéli & Solander, 1988). Because emergent plants usually contain a large amount of cellulose, breakdown of the detrital matter tends to be slower than that of the
SAV. But if the belowground biomass begins to decompose, it releases P back directly into the soil.

Looking at the general characteristics of FAV, SAV, and emergent species, all had the tendency to increase growth as the nutrient content of the water column increased. For this study, two of the most important factors in choosing which type of aquatic plant to manage were origin of plant source P (water column or sediment) and ability to form mats, with the goal to cycle P from the water column. Phosphorus origin was generalized as: 100% water column for FAV; 73% sediments, 23% water column for SAV; and 60% sediment, 40% internally stored after initial establishment for emergent. All species from this experiment existed in floating mats covering surface water, and were therefore considered FAV for the purpose of this experiment.

**Floating Aquatic Vegetation Removal in the EAA**

Floating aquatic vegetation quickly spreads out of control to the point of causing biological and infrastructure damage to infested waterways (Howard & Harley, 1997; Sommaruga, 1993). Florida has a noxious weed list that includes water hyacinth and water lettuce, two of the most common FAV species in Florida’s waterways (USDA Natural Resource Conservation Service, 2016a). The state spent approximately $17.9 million to remove aquatic plants in public waters in 2015-2016, with about 24% ($4.3 million) dedicated to FAV (Phillips, 2016). However, many FAV are able to accumulate nutrients and heavy metals, suggesting that use for remediation is possible if effectively managed and physically removed (along with contaminants) from the system. Growth can also be suppressed to open the water surface and negate impacts of FAV mats. There are two means of FAV removal that are generally considered: herbicidal or mechanical harvesting. Both have positive and negative aspects and successfully reduce the amount of FAV covering a water body.
Herbicidal application is one of the most common methods of FAV removal due to its relative ease of use and low costs (Phillips, 2016; Boyd, 1971). There are two types of chemical herbicides, those that work on contact (contact) and those that must be absorbed by the plant before disrupting biochemical pathways (systemic) (Gettys et al., 2009). Herbicides can be applied using floating devices, hand sprayers, dispersal of granules, hoses mounted on trucks, and even helicopters equipped with boom sprayers (Langeland, 1994). There are three main herbicides used on public waterways to suppress FAV growth, 2,4-Dichlorophenoxyacetic acid (2,4-D), glyphosate (as Rodeo), and diquat dibromide (Diquat). 2,4-D is a systemic herbicide mainly used to kill water hyacinth and is not recommended for water lettuce (Mossler & Langeland, 2006; Gettys et al., 2009). Rodeo and diquat are non-selective contact herbicides and preferred for water lettuce. During 2004-2005, $2,812,231 were spent chemically treating 28,549 acres of FAV, equaling a cost of approximately $98.50 per acre (Mossler & Langeland, 2006). Another estimate, based on five years of cost data, proposed around $107 per acre to suppress water lettuce and water hyacinth (Adams & Lee, 2007). In south Florida, $2,824,215 were spent in 2015 treating 21,326 acres of FAV, equaling approximately $132/acre (Phillips, 2016).

Mechanical removal is another option for managing FAV. If the plants are allowed to grow to high density coverage during the early growing season before peak biomass is reached, they will accumulate the highest amount of P and contaminants. If the plants can then be physically removed from the system, the P they contain would be removed as well. Because the plants contain over 90% water (Howard & Harley, 1998), large vehicles would be needed to transport the heavy plant material away from the water body. Optimally, mechanical harvesters can process around 5 acres per day (Mossler & Langeland, 2006; State of Washington, 2016). Private contractors charge approximately from $800 to over $2000 per acre, and harvesters range
from $35,000 to over $110,000 to own, not including maintenance costs (State of Washington, 2016).

Advantages of herbicidal use include the ability to apply the chemical directly to the desired plants, allowing complete or partial removal of FAV. Additionally, application is easily done in a variety of ways, and allows for maintenance by spot spraying once the plants are fully suppressed. Drawbacks of herbicide use include release of stored nutrients once the plants dies, re-infestation by another plant species (Boyd, 1971), and additions of chemicals to the water body – which may limit its use for designated periods after application.

Benefits of mechanical harvesting include the lack of chemicals added to a natural system, physical removal of contaminants with the plants, and potential reuse of plant biomass - either through composting, biofuel, or as soil amendments (Gettys et al., 2009). Drawbacks of mechanical harvesting include the high cost, potential physical alterations of banks which can increase erosion, sedimentation, and turbidity of the water, the limited areas that harvesters can access due to their large size, and the inability to selective target undesired species.

Due to the ability of many FAV to reproduce vegetatively, new growth can sprout from FAV fragments following mechanical removal and there is risk of introducing a new invasive species to subsequent harvest locations. Floating aquatic vegetation can have up to 90% water content, so the weight of harvesting and the time to transport loads to the shore hinder the efficiency of mechanical harvesting. Once collected, the plant material must be either transported elsewhere, another cost, or left to decompose and leach nutrients back into the system (Nahlik & Mitsch, 2006). This experiment tests herbicidal FAV suppression as a means of reducing P loads from farm canals.
**Phosphorus Fractionation Method**

To understand the dynamics of P in the canal sediments relative to changes in canal FAV management, it is important to know the different degree of P bioavailability. Studies have been conducted demonstrating the success of P fractionation procedures in explaining P movement and transformation in organic soils, calcareous lake sediments, and upland soils (Das et al., 2012; Negassa & Leinweber, 2009; Cross & Schlesinger, 1995; Condron & Newman, 2011). Phosphorus fractionation has been used extensively to separate pools of P in soils and sediments using a series of reagents that selectively free bound P (Condron & Newman, 2011). Previous studies have also described the benefits of suppressing FAV biomass in reducing P lability in aquatic sediments (Murphy et al., 1983; Reddy et al., 1987; Granéli & Solander, 1988; Danen-Louwerse et al., 1995; Daroub et al., 2005; Daroub et al., 2012). The P fractionation method used in this study is a sequential fractionation (KCl-NaOH-HCl) scheme (Hieltjes & Lijklema, 1980; Koch & Reddy, 1992; Reddy et al., 1998b) modified from the Hedley fractionation method (Hedley & Stewart, 1982; Hedley et al., 1982). Extensive literature reviews on P fractionation efficiency and the Hedley method have been previously assembled by Cross and Schlesinger (1994), Condron and Newman (2011), and Negassa and Leinweber (2009). Phosphorus fractionation is limited by deviations in researcher performance and sediment sample variability, but the Hedley fractionation method has the advantage of performing the extractions on the same sediment sample so fraction values can be compared to total P to estimate procedure efficiency (Cross & Schlesinger, 1994).

An important factor to note when using P fractionation is the operational definition of P pools. In the sequence used during this study, 1.0 M KCl is used to extract what is defined as the labile, inorganic P \( (P_i) \) pool. The labile \( P_i \) pool is an important factor for plant growth and water column P, and it is considered the most mobile, bioavailable form (Reddy et al., 1995). The 0.1
M NaOH extract is analyzed so as to represent both the Fe-Al oxides bound Pi pool and the organic humic-fulvic bound Po pool. Using 0.5 M HCl, the Ca-Mg bound Pi pool is extracted, which is considered biologically unavailable, or recalcitrant under most natural conditions (Reddy et al., 1995). The last fraction, the residual P, is considered highly recalcitrant and can be calculated in two ways. Residual is calculated either indirectly, by summing the four quantified P fractions (KCl-Pi, NaOH-Pi, NaOH-Po, HCl-Pi) and subtracting the total value from the separately determined total P (Koch & Reddy, 1992; Reddy et al., 1995; Condron & Newman, 2011), or directly through extraction using a strong acid (6.0 M HCl) and conducting TP analysis of the residual fraction extract (Condron & Newman, 2011; Reddy et al., 1998b). In this study, residue was directly analyzed allowing for the calculation of procedure efficiency.

Because these fractions are defined by their solubility in increasingly strong extractants, they do not provide information on P speciation or biogeochemical behavior (Negassa & Leinweber, 2009). There are new methods that have been developed to further advance P fractionation into P species, such as 31P nuclear-magnetic resonance (NMR) spectroscopy and X-ray absorption near-edge structure (XANES); however, the goal of this research was to determine whether or not FAV have an effect on labile P, not to determine the species of P within the pools.

**Conclusions**

This study strived to provide a holistic understanding of current and future BMP use. Interviewing farmers that are designing and executing farm BMP plans will give a realistic view on current benefits and problems associated with farming practices and water quality standards. Field experiments will assess the effectiveness of FAV suppression as a potential new BMP, as well as reveal any possible feasibility issues for farmers. Creation of parameter equations representing FAV suppression effects will provide a new tool for the modeling community to
incorporate into large-scale hydrologic models. Having an estimate of overall contribution to percent P reduction in relation to cost of implementation will let farmers make more informed decisions as to whether or not to implement the practice.

Currently, there are no studies measuring the effects of suppressing FAV growth on sediment properties and P loads from farm canals. This study will provide missing evidence of the influence of FAV suppression on P loads from EAA farm canals. Future works would be needed to further develop and refine the model to include specific crops, and to test the actual fate of P in the canals with FAV removal in relation to formation of Fe-Al-Mn and Ca-Mg compounds. The implications of this study include a better understanding of farmer perception of BMPs, feasibility of FAV suppression as a method to reduce off-farm P loads, and whether or not the basin-wide implementation of FAV suppression would have a significant effect on EAA P export.
Table 1-1. Summary characteristics of the seven organic soil types in the EAA. Adapted from Bottcher & Izuno (1994).

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Mineral content (%)</th>
<th>Thickness of organic layer (cm)</th>
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<td>&gt;35</td>
<td>&gt;130</td>
<td>Limestone</td>
</tr>
<tr>
<td>Terra Ceia</td>
<td>&lt;35</td>
<td>&gt;130</td>
<td>Limestone</td>
</tr>
<tr>
<td>Pahokee</td>
<td>&lt;35</td>
<td>91-130</td>
<td>Limestone</td>
</tr>
<tr>
<td>Lauderhill</td>
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<td>51-91</td>
<td>Limestone</td>
</tr>
<tr>
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<td>Limestone</td>
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CHAPTER 2
EVERGLADES POLICY REVIEW AND FARMER PERCEPTION OF BEST MANAGEMENT PRACTICES REGULATORY PROGRAM

Introduction

The Everglades Agricultural Area (EAA) is an extremely productive farming region south of Lake Okeechobee in southern Florida, within the extensive Everglades system. It has been the subject of much debate due to the impacts of nutrient enrichment in the Everglades National Park (ENP), resulting in the Everglades Forever Act (EFA) and the EAA Best Management Practices (BMPs) Regulatory Program for reduction of agricultural phosphorus (P) sources (Bottcher & Izuno, 1994). Situated within Palm Beach and Hendry Counties, the EAA is dominated by sugarcane, corn, rice, sod, and winter vegetable farming, adding $1.5 billion from agriculture to Florida’s economy. Because of the high degree of modification of the land cover, land use, and hydrology, restoration efforts of the Everglades system are set at the maximum extent practicable that can accommodate both environmental and agricultural needs. Utilizing BMPs, the South Florida Water Management District (SFWMD), researchers, and the agricultural industry of the EAA are striving to improve downstream water quality and aid ENP restoration (Aillery et al., 2001; National Oceanic and Atmospheric Administration, 2002).

The EAA as a whole must meet the 25% P load reduction goals; some farmers fail to meet the 25% reduction while others surpass it. Because the BMP Regulatory Program has continuously exceeded the 25% reduction of P requirement since its inception 20 years ago (South Florida Water Management District, 2015a), managers need to understand the mechanisms that are driving the program’s success. The EAA is unique compared to many other areas of the world in that BMPs are required by law, so the implementation rate, which is at 100%, does not reflect BMP acceptance and a perceived reduction in risk over time. It would be beneficial for policy and decision makers to understand the motivations behind compliance or
noncompliance by farmers, especially in the face of shifting public opinions and the changing political climate. Gaining an understanding of farmer opinions on the current program can provide insights into why it has been successful, what the specific drivers of the success are, and provide methods for increasing the use of other BMPs.

With the current BMP Regulatory Program, farmers are given a selection of BMP options to implement in order to meet their P abatement requirements. Current BMPs are not tracked for frequency of implementation by EAA farmers and few BMPs have been proposed in response to farmer preference or need. Because EAA farming is dynamic and rotating crops’ needs fluctuate significantly, P sources and pathways shift over season and BMP options need to reflect that variability. In order to estimate the favorability of current BMP options and the need and acceptability of new BMPs, EAA farmers should be consulted on their opinions of the BMP Regulatory Program. This Chapter was to explore the drivers of the BMP Regulatory Program success by implementing a social survey of local farm managers and field workers focused on differentiating between financial incentives, environmental stewardship, and influence of demographic factors like education, age, and race. The hypotheses of this study were: BMP acceptance increased with education level; want for new BMPs increased with income; and agreement with the BMP Regulatory Program decreased with age. Testing these hypotheses was to be achieved through in-person interviews with farmer representatives and a mail-in survey to evaluate farmer opinions of BMPs, the BMP Program, and P enrichment. Initial interviews were conducted, but the mail-in survey had to be replaced with a literature review of farmer surveys conducted around the country.
Methods

Area of Study

South of Lake Okeechobee, the EAA is a smaller subset of the Everglades consisting of 3,000 km² (Izuno, 1989; Miedema, 2014). The EAA was historically sawgrass (*Cladium jamaicense*) marshland because of high rainfall and slow drainage. It was dependent on and shaped by water and fire, experiencing frequent flooding in the wet season and lightening fires in the dry season (Florida Museum of Natural History, 2014). It has a subtropical climate consisting of two seasons: wet and dry. The wet season is from May to October, and is warm and humid, with temperatures averaging in the mid-90s°F (30-35°C). The dry season is from November to April, and is more mild and dry, with temperatures ranging from low 50-70°F (12-25°C) (National Park Service, 2014b). Over 75% of the EAA’s average annual 57 in (145 cm) of rainfall occurs during the wet summer months (National Park Service, 2014b). Rainfall is a significant factor affecting P loads in EAA drainage water because the amount, duration, and frequency of rainfall determines farm drainage (Lang et al., 2010). While the P concentration of the drainage water may remain the same, an increase in the amount of water increases the overall P load.

The EAA is extremely flat, with an average slope of 2 in/mile (3 cm/km) and a maximum elevation of 17 ft (5.1 m) above sea level (United States Geological Survey, 2013). Because of this low slope, water does not drain quickly off of the landscape. At a velocity of 0.2 in/s (0.5 cm/s), it takes water from Lake Okeechobee around 325 days to reach the ENP (Cohen, 2014). The slow velocity of the historic sheet flow allowed for sediment settling, P to be taken up by vegetation and precipitate out with minerals like calcium, and low soil oxidation rates (Noe et al., 2001). Changes in hydrology in the area through drainage have increased flow, movement of sediment and P, and release of stored P through soil oxidation (Newman & Pietro, 2001).
Plant biomass built up slowly over time due to reduced conditions and low decomposition rates in the marshland to create Histosols (Noe et al., 2001). The now-drained, highly organic (>80% organic matter content) soils have released large amounts of P through soil oxidation and decomposition (Lang et al., 2010). Background levels of inorganic P measured from drained EAA soil (0.10 to 0.25 mg P/L) are 10 times higher than samples taken from adjacent swampland (McPherson & Halley, 1996). The EAA contributed large amounts of total phosphorus (TP) downstream, over 202 metric tons/yr, prior to the passage of the EFA in 1994 (Bottcher & Izuno, 1994). Traditionally, the Everglades system had low nutrients (oligotrophic). The EAA contributes enough TP to promote eutrophic conditions, and plants like cattails (*Typha domingensis*) are able to outcompete sawgrass in the protected ENP.

**Everglades Agricultural Area Settlement and Policy Review**

In order to understand the social aspect of the EAA BMP Regulatory Program, the history of the area’s development and demographics must be known. Public opinion towards agriculture and environmental stewardship is dynamic and often at odds. A broad understanding of the pattern of public opinion as shown through policy changes, as well as knowing the economic and cultural climate of the area, will provide insight to the social acceptance of the BMP Regulatory Program and if this type of program, with customized, farm-specific BMPs, should be implemented elsewhere.

**Farmer BMP Program Success and Farmer Opinion Assessment**

The success of the EAA BMP Regulatory Program does not indicate the sustainability of the program because it excludes both the incentives and costs to farmers. A review of financial costs to farmers was conducted to further clarify the quantitative success in P removal reported by the SFWMD annually. Additionally, the motivations for farmers in meeting or exceeding requirements of the EAA BMP Regulatory Program were to be explored using an anonymous
survey study. The design was based on recommended procedures from a literature review on improving farmer response rates to surveys (Pennings et al., 2002), which suggested few questions, review by representative farmers, and mailing during a time of low farming activity. The survey questions were focused on BMPs, and opinions of the EAA BMP Regulatory Program (i.e., does/does not/exceeds/meets expectations, flexible/strict, not/easy to accomplish, approval/disapproval of compliance measures), as well as general demographic information.

The short mail-in survey (Appendix A) included a cover letter explaining the purpose of the research and expected goals to be accomplished with the survey. Follow-up letters were also planned to increase response rate (Pennings et al., 2002), and the biannual farmer BMP training conducted by UF at the Everglades Research and Education Center (EREC) in fall 2016 would be a final attempt at distributing the survey. There was an assumed response rate of between 30-50%, with a target N of around 100, based on mail survey response rate studies (Kaplowitz et al., 2004; Prairie Research Associates, 2015; Fincham, 2008; Hager et al., 2003).

The mail-in survey was constructed with the aid of UF’s Department of Agricultural Education and Communication and was approved by the UF Internal Review Board (IRB) for human studies (nonclinical) (University of Florida Internal Review Board, 2015). After approval by the university, upper-level farm management, lawyers, and extension agents were contacted to review survey questions. Eleven representatives from the three EAA sugar groups and vegetable farmers were consulted on the survey content and specific questions during in-person interviews.

**Everglades Agricultural Area Creation**

The drainage of the once 3 million-acre Everglades system started in the early 1800s to improve transportation and promote agricultural and development activities (Table 2-1) (Anderson & Rosendahl, 1998). Economic development of Florida was dependent on tourists
brought south by Henry Flagler’s railway reaching from Jacksonville to Key West. As the region enjoyed the increasing number of residents and tourists, demands for land and food increased. Land was allocated for wetlands drainage and the construction of a canal between Lake Okeechobee and the EAA (Anderson & Rosendahl, 1998). With the help of Governor Napoleon B. Broward, over 360 km of canals infiltrated the Everglades by 1913 to allow for agricultural expansion. In the 1930s, the canal systems expanded to over 700 km throughout South Florida (Walker, 2001).

The Central and Southern Florida Project of 1948 created the 700,000 acre EAA and five Water Conservation Areas (WCAs) between the EAA and the newly established ENP (Anderson & Rosendahl, 1998). By 1991 there were around 2,113 km² (522,000 acres) of land under agricultural production in the EAA (Army Corps of Engineers & South Florida Water Management District, 2003; South Florida Water Management District, 2014a; National Oceanic and Atmospheric Administration, 2002). At this time, the general atmosphere was to continue draining and development, but with the creation of the Florida State Board of Conservation, the Soil Conservation Act, and the WCAs, the importance of environmental stewardship started to emerge. Florida leaders began recognizing that widespread development was having negative impacts on Florida’s natural attractions.

**Everglades Agricultural Area Policy History**

**Early Restoration Policy (1972-1993)**

Since the 1800s, the Federal and State governments have encouraged and financed extensive drainage canals throughout the Everglades system to promote agriculture, urban growth, industry, and recreation. In the state of Florida and in the United States, the shift towards environmental preservation started in 1970s with the passing of the Clean Air Act (42 U.S.C. §7401) and Clean Water Act (33 U.S.C §§ 1251). In the last few decades, public support of the
preservation of the Everglades has been reflected in state conservation policies, land acquisition for restoration, and billions of dollars allocated for restoration projects. Table 2-2 summarizes federal and state restoration policy between 1972 and 1993. The state struggled to balance the increased development of the Everglades region and protection of the ENP, which resulted in the federal case against the state of Florida, and the designation of the ENP as Endangered from 1993 to 2007 and again in 2010 to present by the UNESCO World Heritage Centre (UNESCO, 2017). In this period, the public had started to turn in favor of protecting the larger Everglades system at the expense of further development. With the passing of the Save Our Everglades Program, the state officially recognized the regional connections of upstate development and impacts on the ENP (Anderson & Rosendahl, 1998).

**Late Restoration Policy (1994-Present Day)**

After the settling of the federal lawsuit against the state which brought in the Environmental Protection Agency (EPA) to protect and maintain the ENP, the state and SFWMD prioritized P and water quality management throughout the greater Everglades region. The Everglades Forever Act (EFA) of 1994 established a 10 ppb P loading into the ENP and Loxahatchee National Wildlife Refuge and a basin-aggregated 25% P load reduction from a designated baseline (1979 to 1988 P monitoring data) (Daroub et al., 2012). Under the EFA’s EAA BMP Regulatory Program, EAA farmers are required to obtain permits to discharge their water into SFWMD canals draining the area. The permits require the farmers to use BMPs to create a farm management plan to reduce P in drainage water and to monitor P exported at each farm drainage pump. Farm management plans require a certain number of BMPs based on an assigned value system. Farmers are able to choose from a list of point-assigned BMPs (Appendix B) for a customized management plan equaling a required total number of points (Kling, 2013). The EFA also required the SFWMD to purchase lands for the development of 34,700 acres of
STAs, which are constructed wetlands that further filter P from waters discharged through EAA canals (South Florida Water Management District, 2014b). The sugar industry of the EAA agreed to help fund STA construction by paying $320 million over 20 years (Clement, 2014).

In 2000, Congress approved the Comprehensive Everglades Restoration Plan (CERP). Developed by the Army Corps of Engineers, CERP is a 40-year, statewide, extensive plan consisting of over 60 individual projects, costing $17 billion so far, and was the largest restoration project in the world at the time of approval (Graf, 2013). Congress passed the Restoring the Everglades, an American Legacy Act (REAL) in 2001 to initiate $7.8 billion in funding for CERP, with a cost-share between federal and state governments approved in 2002 (Committee on Independent Scientific Review of Everglades Restoration Progress, 2014). This plan called for 46,000 acres of STAs to be built by 2003 throughout the EAA to treat agricultural canal waters. In its language, CERP does not foresee restoration to a point where the ecosystem can manage itself, and will therefore require continued energy and maintenance. In 2003, the EFA was amended to extend the deadline of STA construction compliance to 2016.

In 2006, the EPA established a Total Maximum Daily Load (TMDL) for water bodies north of Lake Okeechobee as part of the Lake Okeechobee Protection Plan. The EPA is also in the process of establishing TMDLs for areas south of the Lake, as those areas act as a tributary when pumps back-pump flood waters into the Lake. Waters of the EAA are considered hydrologically different from waters north of Lake Okeechobee, so they required different TMDL standards (Committee on Independent Scientific Review of Everglades Restoration Progress, 2014). In the same year, frustrated with the slow pace of CERP, Florida’s legislature passed the “Acceler 8” program which selected eight CERP projects to prioritize. One of the
projects was the A-1 reservoir meant to store water for environmental, agricultural, and human use located above STA 3-4.

In 2008, Governor Charlie Christ announced the state’s plan to purchase 187,000 acres of U.S. Sugar land in the EAA for $1.75 billion (Army Corps of Engineers, 2012). The plan called for six years of continued farming while purchasing negotiations took place with the goal of restoring natural water flow of around one million acre-feet. By 2010, the land acquisition was reduced to 26,800 acres for $536 million (Army Corps of Engineers, 2012). After an unsuccessful lawsuit by the Miccosukee Tribe in 2009, the state was no longer required to build the A-1 reservoir in the EAA, and instead planned construction of Flow Equalization Basins (FEBs) that would more effectively move water to the STAs on the already acquired land (Army Corps of Engineers, 2012). The SFWMD was required to pay $25 million in penalties for cancelling the A-1 reservoir, lost $282 million in construction costs, and was required to build 42,000 acres of STAs (Army Corps of Engineers, 2012). As of 2012, SFWMD has completed construction of 52,000 acres of STAs, with 6500 additional acres planned over the next 12 years (Schmitz, Kennedy, & Hill-Gabriel, 2013).

**Farmer Best Management Practices Program Success**

The BMP Regulatory Program began in 1994 and was given until 1996 to meet the 25% reduction requirement. The baseline period was established by monitoring flow and TP for the area from October 1, 1978 to September 30, 1988 as defined by the EFA (EFA, 1994; Daroub et al., 2011). Phosphorus reduction compliance is determined by adjusting for hydrologic conditions and comparing the P load of the current water year to the baseline period (EFA, 1994). In the first year, P loads were only reduced by 17%, they increased to 31% reduction in 1995, and by 1996 P reduction reached 68% (Whalen & Whalen, 1996; Anderson & Rosendahl, 1998). The EAA basin has met the 25% reduction requirement every year, except 2007 when
reduction was only 18%, with a 20 year reduction average of 56% (South Florida Water Management District, 2016). Best management practices have prevented 2,900 metric tons of P from flowing south into the Everglades (South Florida Water Management District, 2016).

Because of the high degree of monitoring required by the EFA, measuring the quantitative success of the BMP program is relatively straightforward. However, meeting the legal requirements of P reduction does not indicate the sustainability of the program’s success because it excludes costs to farmers for BMP implementation. For example, there was an annual required Everglades Agricultural Privilege tax of $35/acre/year between 2006-2013. That has since been capped to $25/acre/year for 2014-2026, $20/acre/year for 2027-2029, $15/acre/year 2030-2035, and $10/acre/year for 2036-beyond (Chapter 2013-59, 373.4592, F.S., 2013). The EFA provides incentive credits to encourage BMP performance, which can reduce the Agricultural Tax to a minimum of $24.89 per acre so long as the basin exceeds the 25% P load reduction (South Florida Water Management District, 2014a). Since the BMP program’s creation, the farmers have qualified for the minimum tax rate. There is also a tax relief incentive for individual farmers exceeding 25% P reduction, $0.65/acre/year for each percentage point over 25% reduction (Chapter 2013-59, 373.4592, F.S., 2013). Beyond the cost of farming in the EAA, the annual cost of implementation and monitoring per BMP per acre is estimated to be around $23 for sugarcane, $16-73 for vegetables, and $11-37 for sod (Letson & Milon, 2002).

An economic impact assessment conducted at the request of the state determined the EAA BMP Regulatory Program to be sustainable and did not exert any severe financial impacts to EAA farmers (Letson & Milon, 2002). Best management practices implementation and monitoring are also estimated to create 172 full-time employees in the area, which benefits the local community (Letson & Milon, 2002).
As the program has continuously exceeded the 25% reduction goal since its conception 20 years ago (South Florida Water Management District, 2015), enforcement agencies need to understand the mechanisms driving the program’s success to better refine the current program and provide insight to other states facing similar water quality issues. Farm-specific BMP plans are required by the state under the EFA, but there has been little research on the desire of farmers to exceed requirements. It would be beneficial for decision makers to understand the motivations behind compliance or noncompliance by farmers so that improvements could be made to the program without the need of further government intervention. Understanding farmers’ opinions on the BMP Regulatory Program can provide insight to incentivize farms failing to meet P load average reduction by knowing what is and is not working for those implementing BMPs.

**Everglades Agricultural Area Economy and Demographics**

As of 2013, the area supports around 28,670 agricultural jobs (Bureau of Labor Statistics, 2013). The average annual income is low in the EAA, $30,650 for farm managers and between $13-16,000 for farm workers as of May 2013 (Bureau of Labor Statistics, 2013). The area is classified as “very depressed” economically, with 30 to 50% of families living below the poverty line (Bureau of Labor Statistics, 2013; Army Corps of Engineers; South Florida Water Management District, 2003). It is generalized by high numbers of minority individuals and poor education, with only half of residents reported to graduate from high school and less than 10% with education beyond high school (Army Corps of Engineers; South Florida Water Management District, 2003). The population is relatively low, summing to around 45,000 people (U.S. Census Bureau, 2010b). Population distributions are focused around Belle Glade, South Bay, and Pahokee with these cities housing around 60% of the total population of the EAA (U.S. Census Bureau, 2010a).
Those most affected by the BMP Regulatory Program are people working on farms in the EAA because cost of BMP implementation and maintenance will affect farm profit, and therefore the ability of the farm to employ and pay workers. One of the major concerns for this area is that with increased environmental regulatory requirements, fewer jobs will be available to local residents. Agriculture is the principal source of employment in the EAA, so there may be a link between disapproval of further BMP Regulatory options and households reliant on farming as the primary income. The social survey for this study sought to understand the influence of education on opinions towards the BMP Regulatory Program and impacts of BMP implementation on farm managers and workers financially.

**Everglades Agricultural Area Farmer Groups**

**Sugarcane**

Laws constraining U.S. sugar quotas were abolished in 1974, and the EAA emerged as one of the country’s leading sugar producers, generating around 25% of all domestic sugar (Army Corps of Engineers & South Florida Water Management District, 2003). There are three major sugar corporations, U.S. Sugar Corporation, Florida Crystals Corporation, and Sugar Cane Growers Cooperative, operating six mills and two refineries in the EAA (Army Corps of Engineers & South Florida Water Management District, 2003). The U.S. Sugar Corporation is one of the country’s largest private agro-businesses, cultivating 165,000 acres of land and employing 2,500 people (Army Corps of Engineers & South Florida Water Management District, 2003). It processes 540,000 tons of raw sugar per year, which is 10% of the total sugar in the U.S. (Army Corps of Engineers & South Florida Water Management District, 2003). Florida Crystals Corporation operates three sugar mills and one refinery with 180,000 acres of sugarcane fields. And Sugar Cane Growers Cooperative of Florida is composed of 56 smaller farm operations and is the largest employer in Belle Glade (Army Corps of Engineers & South Florida
Water Management District, 2003). The Co-op produces 300,000 tons of sugar and 15 million gallons of molasses per year, adding $384 million to Florida’s economy (Army Corps of Engineers & South Florida Water Management District, 2003).

**Vegetables**

Although vegetable crops do not account for many acres of production, the EAA is a major producer of winter vegetables (sweet corn, celery, lettuce, radishes, beans, and cabbage) for the United States (Army Corps of Engineers & South Florida Water Management District, 2003). Crops are restricted to winter because of higher sale prices, better irrigation control during Florida’s dry season, and more moderate temperatures. In the EAA, winter vegetables generate over $146 million per year over 39,149 acres (Army Corps of Engineers & South Florida Water Management District, 2003).

**Rice**

Rice occupies between 25,000 and 27,000 acres in the EAA and is often used as a cover crop and generates over $9 million annually (Army Corps of Engineers & South Florida Water Management District, 2003). Rotating with rice has been shown to reduce soil oxidation during periods of flooding due to high water table requirements and lower P loads off farms (Aillery et al., 2001). Production of rice has therefore been encouraged in the area by researchers, and acres of rice may have risen in recent years (Tootoonchi, 2016).

**Sod**

Sod generates over $30 million on 26,912 acres of land in the EAA (Army Corps of Engineers & South Florida Water Management District, 2003). Growing and harvesting sod is expensive and requires highly specialized equipment, making it a costly crop. Production decreased between 1992 and 2002 by over 58% due to rising costs and more competitive growers in central and northern Florida (Army Corps of Engineers & South Florida Water
Management District, 2003). Sod farms are typically located in low quality soils and experience high subsidence rates (Army Corps of Engineers & South Florida Water Management District, 2003).

**Best Management Practices Regulatory Program Opinion Survey Results**

Of the eleven upper-level farm management representatives interviewed, six were willing to help advance the survey so that it could be distributed to upper and lower-level farm managers and workers. Two others were indifferent to the survey and decided not to comment, and three others were opposed to the survey and any questioning of EAA farmers and workers on their opinions towards the BMP program. Eventually support for the survey was collectively withdrawn and the farmer survey was permanently suspended.

**Discussion**

**Failure of Survey**

Because of the suspension of the survey, the hypotheses for this study could not be tested. There was always risk of farmers refusing to answer survey questions when this study was conceived. The upper-level management of the EAA farming corporations spend a lot of effort promoting the success of the basin’s P abatement using the required BMPs and their mandated funding of BMP research. The methodology of this study, to have farmer-group representatives weigh in on survey questions, was an attempt to ensure that the research kept the farmers’ perspectives in focus and not unintentionally disrupt their land-stewardship campaigns.

Many farmers distrust social science because they fear retribution by environmental groups (Prokopy et al., 2008; Baumgart-Getz et al., 2012). For example, for farmers where BMPs are required, admitting to implementing more BMPs than required could fuel lawsuits that claim the farmers are skewing nutrient abatement results. Or if farmers report implementing the minimum requirements, may prompt groups to call for more restrictions and BMP mandates.
claiming farmers will not exceed minimum requirements on their own. Another possible risk could be that if farmers expressed interest in BMP research and more BMP options, there would be a change in the BMP requirements that would increase current BMP costs. Many farmers have been found to be distrustful of government agencies as well (Gronewold et al., 2012; Cantrill, 2003; McCann & Easter, 1999) as farmers feel pressure to increase production and reduce environmental impacts.

Farmers’ fears are not unfounded. The sugar industry in south Florida and the EAA has been subject to a number of court cases and legal actions by environmental groups due to their land use practices (Rizzardi, 2001). Recently, Earth Justice on behalf of the Sierra Club filed a petition to the EPA to deny U.S. Sugar Corporation an air operation permit renewal on the grounds that the sugarcane burning performed before harvesting is in violation of the Clean Air Act (Marshall & Guest, 2015). The Audubon Society Florida Chapter also sued the sugar industry in 2013 alleging the new farming permits given by SFWMD did not adequately ensure the water quality standards required by the EFA. The Florida Wildlife Federation also sued the Florida Legislature for failing to uphold trust fund money for the acquisition and restoration of conservation lands as mandated by Amendment 1 of the Florida Constitution from November 2014. The Miccosukee Tribe of Florida has also had a number of cases surrounding the water management and farming practices in the EAA. Based on the tumultuous relationship between

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3 Florida Audubon Society v. Sugar Cane Growers Cooperative of Florida, United States Sugar Corporation, Sugar Farms Co-op, and South Florida Water Management District, 171 So. 3d 790, Case No. 2D14-2328 (August 7, 2015).


5 Miccosukee Tribe v. Florida Department of Environmental Protection, 656 So. 2d 505 (Fla. 3d D.C.A. 1995)
Miccosukee Tribe v. Florida Department of Environmental Protection, 677 So. 2d 110 (Fla. 4th D.C.A. 1996)
Miccosukee Tribe of Indians and Friends of the Everglades v. South Florida Water Management District and Florida Department of Environmental Protection, DOAH Case No. 96-3151, ER FALR 98:119 (Florida Department of Environmental Protection Final Order, April 20, 1998)
Miccosukee Tribe v. South Florida Water Management District, 721 So. 2d 389 (Fla. 3d D.C.A. 1998)
the EAA and advocates of the ENP and the pervasive public opinion that agriculture causes significant harm to the environment (Harris & Bailey, 2002), it is not unreasonable that the farmer group upper management and legal teams are wary of social science research.

Other Farmer BMP Implementation Research

Based on the limited sampling of the farmer group representative interviews, it is difficult to draw conclusions of opinions of all EAA farmers towards the BMP Regulatory Program and BMP implementation. There is an extensive pool of research on farmer BMP implementation in other parts of the United States and the world, with a number of meta-analyses assessing farmer BMP adoption reasoning (Prokopy et al., 2008; Pannell et al., 2006; Baumgart-Getz et al., 2012). After analyzing 46 studies spanning 25 years (1982-2007), Baumgart-Getz et al. (2012) found that connection to farmer networks and watershed groups, access to and quality of information, and financial capacity of the farm were the largest factors influencing BMP adoption in the United States. Farmers also perceived BMPs as less of a risk over time, meaning their utility becomes more acceptable the longer they are implemented (Baumgart-Getz et al., 2012). In terms of environmental awareness, the most influential factor in farmer adoption of BMPs was explaining how actions on their specific farms impacts water quality, rather than how agriculture in general can degrade watersheds (Baumgart-Getz et al., 2012). Prokopy et al. (2008) reviewed 55 studies over a 25 year period (1982-2007) and found that education, income, access to information and farmer networks/local agencies, and environmental awareness and attitudes also significantly affect BMP implementation in the United States. Age was negatively significant
with BMP adoption suggesting that older farmers are less likely to use BMPs than younger farmers (Prokopy et al., 2008). Pannell et al. (2006) conducted a review of BMP implementation literature in Australia and found that farmer adoption depended significantly on their perception of whether or not the BMP will achieve the stated goal.

Meta-analyses and individual studies on farmer BMP implementation validate the findings from this study’s limited interviews. Positive farmer attitude and environmental awareness was apparent in this study’s interviews because EAA farmers saw themselves as stewards of their land and they understood the impact their farms had on the environment. Having a continuous feedback loop on environmental management between the farmers and SFWMD through annual P abatement reports helps foster the farmers’ conservationist identities and establish BMPs as the norm (Black et al., 2015; McGuire et al., 2013). Many of the studies agreed that education on the effectiveness of BMPs and environmental quality were significant factors in farmer BMP adoption rate (Black et al., 2015; McGuire et al., 2013; Prokopy et al., 2008; Baumgart-Getz et al., 2012). The BMP Regulatory Program requires an education program, generally hosted by UF at EREC twice per year in English and Spanish, which provides information on the importance of BMPs in the EAA. Without further questioning, the sustainability of the EAA BMP Regulatory Program outside of legal obligation cannot be known.

Conclusions

Social research in an agricultural setting is difficult and complicated, as experienced by this survey study attempt and those mentioned previously. Much of the difficulty in this research stemmed from the fear of legal retribution against the farmers if answers given during the survey could be misconstrued by distrusted groups. In studies portrayed in the literature and in this study, some of that distrust stems from farmer indignation at feeling the blame for environmental issues beyond their area and no responsibility placed on other land uses or urban areas. In the
future, research is needed to analyze the motivation behind BMP implementation beyond the legal requirements in the EAA. The EAA BMP Regulatory Program is seen as a standard of success for state-level agricultural water quality improvement (Kling, 2013). More work should be done to understand benefits and drawbacks to the BMP Regulatory Program, or else the only lesson to be learned is that the best way to improve water quality and farmer BMP use is to mandate it by law.

In the future, in-person interviews would be the best method for collecting information. Survey questions should be reviewed by extension agents or farmers active in research. Anonymity is a key requirement, and questions should be simple, few, and to the point. Those conducting the interviews should make sure to fully disclose the focus of the study and the ultimate goals. Lastly, recording the interviews would not be recommended, as highlighted by Kuehne (2016), because the farmer will feel less pressure to perform and control their answers to fit a specific image.

South Florida’s EAA is a unique area that has been able to adapt to the changing public attitude towards farming. It has one of the few mandated BMP programs in the country and is able to boast unprecedented success in improving water quality. Other research has shown an acceptance of BMPs as functional and necessary in agricultural settings, but the motivations towards BMP implementation in the EAA are still unknown. Future studies may be able to find out if mandated or voluntary BMP programs are the best course of guaranteeing results and if supplemented educational programs, current compensation, and network connectedness are key factors in those programs’ success. Fostering a better relationship between farmers and environmental groups is a difficult, but necessary, feat if this complex system is to be conserved.
Both parties need to make the effort to work together without the threat of litigation for the common goal of improved water quality in south Florida.
Table 2-1. Summary of Everglades Agricultural Area development history (1850-1949)

<table>
<thead>
<tr>
<th>Year</th>
<th>Law, Policy, or Declaration</th>
<th>Purpose</th>
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<td>1850</td>
<td>Swamp Lands Act†</td>
<td>Transferred control of the Everglades region from Federal to State government, with land sales allocated to funding wetland drainage. Created by Governor Napoleon Bonaparte Broward to be in charge of building additional canals, levees, and other drainage infrastructure and established drainage tax districts.</td>
</tr>
<tr>
<td>1907</td>
<td>Everglades Drainage District</td>
<td>Created by Governor Napoleon Bonaparte Broward to be in charge of building additional canals, levees, and other drainage infrastructure and established drainage tax districts.</td>
</tr>
<tr>
<td>1913</td>
<td>General Drainage Act</td>
<td>Allowed for the creation of drainage district upon petition of the landowner.</td>
</tr>
<tr>
<td>1913-1931</td>
<td>EAA Drainage Canals</td>
<td>Canals defining the current-day EAA were built, including the St. Lucie, Miami, North New River, Hillsboro, and West Palm Beach Canals.</td>
</tr>
<tr>
<td>1929</td>
<td>Okeechobee Flood-Control District</td>
<td>Created in response to two major hurricanes in 1926 and 1928. Responsible for the construction and maintenance of flood control structures.</td>
</tr>
<tr>
<td>1930</td>
<td>Herbert Hoover Dike</td>
<td>Dike to prevent future flooding. It encircled the entire lake by the 1960s and included a navigable passage from the St. Lucie River through the Caloosahatchee River.</td>
</tr>
<tr>
<td>1933</td>
<td>Florida State Board of Conservation</td>
<td>Group charged with protecting Florida’s natural resources, replacing the State Shell Fish Commission, the State Department of Game and Fresh Water Fish, and the State Geological Survey.</td>
</tr>
<tr>
<td>1937</td>
<td>Soil Conservation Act</td>
<td>State act creating soil and water conservations districts.</td>
</tr>
<tr>
<td>1939</td>
<td>Southeastern Florida Joint Resources Investigation</td>
<td>Project meant to create a long-range plan of land and water resources development in the state.</td>
</tr>
<tr>
<td>1948</td>
<td>Central and Southern Florida Project†</td>
<td>Provided flood protection and water supply by straightening 103 miles of the meandering Kissimmee River. Also created the 700,000 acre EAA and five Water Conservation Areas. Group took over responsibilities of the Okeechobee Flood-Control District and the Everglades Drainage District. Primary responsibilities were flood control and managing water supply, water conservation, and fish and wildlife. The group became the South Florida Water Management District in 1977.</td>
</tr>
<tr>
<td>1949</td>
<td>Florida Flood Control District</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Anderson & Rosendahl, 1998; Graf, 2013; and Clement, 2014.
† indicates federal law or policy
<table>
<thead>
<tr>
<th>Year</th>
<th>Law</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>Clean Water Act(^1)</td>
<td>Marked national shift in public opinion in the United States towards maintaining environmental integrity. Placed federal pollution discharge limitations into “waters of the United States.” Established the National Pollutant Discharge Elimination System (NPDES) permits to control and monitor discharges and reduce adverse effects of anthropogenic pollutants.</td>
</tr>
<tr>
<td>1972</td>
<td>Florida Water Resource Act</td>
<td>Established five Water Management Districts (WMDs) along hydrologic boundaries, setting a precedent for water management without political lines. The WMDs are authorized to ensure flood control, water quality, and water supply throughout the district. Water quality within each WMD is assessed every five years, with each WMD issuing a status report on health and quality of the basins to the Environmental Protection Agency (EPA).</td>
</tr>
<tr>
<td>1975</td>
<td>Florida Reorganization Act</td>
<td>Established by Governor Bob Graham and recognized that the entire Everglades system was connected and needed protection, not just the ENP. The goal of the program was to restore the Everglades to its 1900 functions by 2000 by reestablishing the Kissimmee River flow, restoring sheet flow south of the EAA, raising roads to allow for sheet flow, and increase flow through Shark and Taylor Slough</td>
</tr>
<tr>
<td>1975</td>
<td>UNESCO Designation(^8)</td>
<td>Everglades National Park (ENP) designated a UNESCO World Heritage Site by the United Nations.</td>
</tr>
<tr>
<td>1981</td>
<td>State Water Policy Act</td>
<td>Created policies for the enhancement of natural ecosystems, restoration, and water conservation.</td>
</tr>
<tr>
<td>1983</td>
<td>Save Our Everglades Program</td>
<td>Mandated the WMDs to establish plans to develop, prioritize, and enact water management strategies to clean and preserve Florida lakes, bays, estuaries, and rivers.</td>
</tr>
<tr>
<td>1984</td>
<td>Warren Henderson Act</td>
<td>Gave the FDER authority to protect wetlands and surface water of the state for public interest.</td>
</tr>
<tr>
<td>1985</td>
<td>Growth Management Act</td>
<td>Required land use activities to prevent water pollution by forming a statewide comprehensive land use plan that utilized pollution prevention facilities.</td>
</tr>
<tr>
<td>1987</td>
<td>Ramsar Wetland(^8) Surface Water Improvement and Management (SWIM) Act</td>
<td>Ramsar Convention recognized the Everglades as a Wetland of International Importance.</td>
</tr>
</tbody>
</table>

Adapted from Anderson & Rosendahl, 1998; Graf, 2013; and Clement, 2014.

\(^1\) indicates federal law or policy
\(^8\) indicates international designation
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>U.S.A. v. SFWMD et al. §1</td>
<td>The State of Florida and the South Florida WMD were charged with violating the state’s water quality standards through increased phosphorus loads into the Everglades under the passage: “In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora and fauna” (Chapter 62-302.530, F.A.C.).</td>
</tr>
<tr>
<td>1989</td>
<td>Everglades National Park Protection and Expansion Act §1</td>
<td>Added nearly 100,000 acres to the ENP and directed the Department of the Army to restore water to improve the ecological integrity of the park.</td>
</tr>
<tr>
<td>1992</td>
<td>Water Resources Development Act §1</td>
<td>Creation of the South Florida Ecosystem Restoration Task Force to be in charge of coordinating federal restoration activities in the Everglades system.</td>
</tr>
<tr>
<td>1989</td>
<td>Settlement Agreement and Consent Decree §1</td>
<td>Settlement of lawsuit against the State of Florida established phosphorus load limits into the ENP and Loxahatchee National Wildlife Refuge and charged the state to meet water quality standards, now administered by the EPA, by 2002.</td>
</tr>
<tr>
<td>1993</td>
<td>Florida Reorganization Act §1</td>
<td>Combined the FDER and the Florida Department of Natural Resources to create the Florida Department of Environmental Protection (FDEP). It required the preparation of a state water plan, with regional pollution control in the form of land use regulation.</td>
</tr>
</tbody>
</table>

Adapted from Anderson & Rosendahl, 1998; Graf; 2013; and Clement, 2014.

† indicates federal law or policy
§ indicates international designation
CHAPTER 3
IMPACTS ON SEDIMENT PROPERTIES AND PHOSPHORUS FRACTIONS FROM SUPPRESSING FLOATING AQUATIC VEGETATION

Introduction

The Everglades Agricultural Area (EAA) is a region south of Lake Okeechobee in southern Florida within the larger Everglades system (Figure 3-1). It is dominated by sugarcane, corn, rice, sod, and winter vegetable farming due to its fertile muck soils (Daroub, et al. 2009). Once formerly sawgrass (*Cladium jamaicense* Crantz) marshes, an intricate series of canals, levees, pumps, and control structures were built to optimize water table levels for agriculture (National Park Service, 2014). Subsurface water flow is the primary mode of drainage and irrigation on these farms through the manipulation of farm canal water levels. Phosphorus (P) applied as fertilizer and released during soil oxidation is carried with agricultural drainage water and is considered one of the leading causes of nutrient enrichment in the downstream Everglades National Park (ENP) (South Florida Water Management District, 2014b).

Phosphorus concentrations entering the ENP have been restricted to 10 ppb (Daroub et al., 2012) and responsibility has been put on the EAA to meet this requirement. A best management practice (BMP) program was established in 1994 by the Everglades Forever Act (Chapter 373, Florida Statutes, Section 373.4592, 1994) requiring a 25% reduction in P loads relative to an agreed-upon baseline from 1979 to 1988 monitoring data, before BMP implementation. The plan requires all farms to implement a farm-specific BMP strategy in order to discharge into state conveyance canals operated by the South Florida Water Management District (SFWMD). Utilizing BMPs, researchers and the $1.5 billion agricultural industry in the EAA are striving to meet restoration goals and improve downstream water quality (Aillery et al., 2001; National Oceanic and Atmospheric Administration, 2002). While the BMP program has been successful in meeting the 25% reduction requirement for 18 consecutive years (South
Florida Water Management District, 2014a), there are still high P concentrations leaving EAA farms and affecting the ENP.

Achieving further reductions in P transport from EAA farms can potentially be achieved by focusing management on floating aquatic vegetation (FAV), which maintains P in a bioavailable form rather than allowing it to precipitate with minerals or absorb with sediments. Floating aquatic vegetation can form mats that block surface water to reduce gas exchange and sunlight penetration (Figure 3-2). In the EAA, 25% of discharged P from the EAA, is generated by in-stream biological growth (Stuck, 1996; Daroub et al., 2005; Daroub et al., 2012). The biological growth most significant to particulate P export is recently deposited material including macrophyte detritus from FAV, filamentous algae, and plankton (Daroub et al., 2012). Not only will suppressing FAV growth reduce detrital matter, it may allow for the transformation of P into more recalcitrant forms through co-precipitation with calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and aluminum (Al) (Figure 3-2). To test the effects of FAV on P removal in farm canals, this study was designed to answer two research questions:

1. Does FAV suppression reduce available P in canal sediments?
2. Does suppressing FAV increase recalcitrant P in canal sediments?

Available P is defined as labile inorganic P$_i$ and humic-fulvic bound organic P$_o$, and recalcitrant P is defined as Ca-Mg bound P$_i$ and residue P from the P fractionation method.

Overall, this study hypothesizes that FAV suppression will have a positive effect on the ability of agricultural canal sediment to retain P in the EAA through co-precipitation into denser compounds. The objectives established to test the research questions and overall hypothesis were:

1. Measure and compare sediment properties and total P in farm canals suppressing and allowing FAV growth.
2. Determine differences in canal sediment P pools between farms with and without FAV suppression using sequential P fractionation.

Materials and Methods

Experimental Design

Research was conducted on eight farms in the EAA, with four treatment-control pairs (Figure 3-3). Farms were paired for similarities in discharge volume, crop type, acreage, canal dimensions, soil depth, drainage velocity, pumping-to-rainfall ratio, and P load history. The study took place between 2011 and 2016, with a calibration period from 2011 to 2013, and the experimental period spanning May 2013 to June 2016, when FAV suppression was implemented. The funding agency prevented the seeding or supplying of FAV beyond what naturally occurred in control farms due to concern that it would unintentionally increase the total P discharged from those farms. Because the EAA farmers must legally reduce their total P loads under the Everglades Forever Act, the funding agency did not want to impinge on the farmers’ ability to meet their requirements. To overcome this obstacle, the experimental design was modified to test a threshold of 25% FAV cover in treatment farms, which was considered an economically feasible threshold for farmers, and normal farm practices. Treatment farms used spot-spraying of herbicides (Diquat and Rodeo) to prevent canal FAV coverage greater than 25%, while control farms implement normal canal FAV management. Normal management ranged from suppressing FAV to allowing full coverage with few mass spray events to lower cost and time allocation.

Soil cores were sampled from each farm twice a year, before (April) and after (November) the wet season, at three different transects A, B, and C (Figure 3-4). Cores were then separated into 0-2.5 cm and 2.5-5.0 cm depth sections, and tested for total P, pH, wet and dry bulk density, organic matter content, and the top 0-2.5 cm underwent P-fractionation.
Farm Description

There were four farm pairs consisting of one treatment and one control farm canal. Table 3-1 summarizes each farm pair characteristics, like size, crop type, and number of pumps. Four farms are located in the S5A basin and four in the S6 basin. Farm pair 4, consisting of treatment farm 4702 and control farm 4701, required an extra calibration year due to a poor regression relationship needed to determine the treatment and control designations.

FAV Survey and Sampling

Farm canals were surveyed every two weeks for percent FAV cover over the entire canal. The total FAV coverage was visually estimated for the entire canal length. Samples of FAV were collected every two months from two locations within the canal and dried for one week at 50°C to calculate wet and dry biomass and moisture content, then ground and analyzed for FAV tissue total P.

The predominant FAV species found in the experimental canals were water lettuce (Pistia stratiotes L.), duckweed (Lemna minor), filamentous algae (Spirogyra sp.), alligatorweed [(Alternanthera philoxeroides (Mart. Griseb.)], and torpedograss (Panicum repens). Filamentous algae is a submerged aquatic vegetation that becomes buoyant in later stages of life and forms mats similar to water lettuce. Alligatorweed and torpedograss are emergent aquatic vegetation but grow across the water surface forming mats similar to water lettuce. All species were considered FAV during the FAV surveys because they intermingled in mats blocking the water surface. All but duckweed and filamentous algae were sprayed with herbicide in treatment canals.

Canal Sediment Sampling

Sediment core samples (25.0 cm long and 7.0 cm diameter, Figure 3-4) were taken twice yearly, at the end of the dry (April) and wet (November) seasons at transects A, B, and C, using a
piston core sampling device designed at UF/IFAS EREC. There were ten sampling dates during the five year experiment, from three transects of eight farms, for a total 240 core samples. Cores were sub-sectioned into 0-2.5 cm and 2.5-5.0 cm groups and stored in plastic, screw-top containers at 4ºC until further analyses.

**Canal Sediment Properties Analyses**

Each sub-sectioned sample was mixed thoroughly and analyzed for pH, organic matter, total P, and wet and dry bulk density. Samples for pH were analyzed using a 1:2 soil to water ratio and measured using a Thermo Orion (model 720) pH meter according to EPA method 9045D (EPA, 2004). Wet and dry bulk density (without pre-treatment sieving) and organic matter content by loss on ignition were determined according to Soil Survey Laboratory Methods Manual (2004). Sediment samples for total P were ashed at 550ºC for four hours and ground before analysis according to the Anderson (1974) modification of EPA method 365.4 (EPA, 2003).

**X-Ray Diffraction Analysis**

X-ray diffraction is an analytical method examining the diffraction angle of x-rays from crystalline materials whose atoms are arranged in regular patterns. X-rays will always be deflected at a unique angle for each substance, creating a unique fingerprint even in non-pure substances, which allows for identification of individual minerals, and their relative intensity based on the number of times their unique angle was counted.

Sediment core samples from December 2013 and April 2014 at the 0-2.5 cm and 2.5-5.0 cm groups were analyzed using X-ray diffraction (XRD). Sample mounting and cation saturation procedures were modified from those described by Harris and White (2008). One gram NaCl was added to washed samples to promote flocculation; the addition of NaCl was harmless and ultimately unnecessary, but continued through all samples to maintain consistency.
As described by Harris and White (2008), the XRD analysis was conducted using a computer-controlled x-ray diffractometer (Ultima IV X-Ray Diffractometer, Rigaku Corporation, Japan) equipped with a stepping motor and graphite crystal monochromator. Scans from 2-60° 2θ were administered at a rate of 2 degrees 20 per min using Cu Kα radiation. Results were given as relative XRD peak intensity graphs with d-spacings for each mineral identified.

**Canal Sediment Mineral Analysis**

Oxalate extractable mineral concentrations of iron (Fe$_{ox}$) and aluminum (Al$_{ox}$) were measured according to the Acid Ammonium Oxalate in Darkness- Tamm’s Reagent method from Soil Science Society of America Methods of Soil Analysis (Sparks et al., 1996). Extractable Ca, Mg, and manganese (Mn) were measured using the Soil Survey Laboratory Methods Manual. 2004. R. Burt (ed.) Soil Investigation Report No. 42. Version 4. Two grams of sediment were weighed into 50 ml centrifuge tubes with 20 mL 1 N ammonium acetate (NH$_4$OAc) at pH 7. Samples were then shaken on a mechanical shaker for 30 minutes continuously, and intermittently for 6 hours. Samples were centrifuged at 6000 rpm for 10 minutes and filter through 0.45 micrometer membrane. Samples were acidified with concentrated nitric acid and sent to the Analytical Research Laboratory in Gainesville, FL to be analyzed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPAES).

**Sequential P-Fractionation Analysis**

Determination of P pools was done using a Hedley-modified sequential P fractionation method developed by Reddy et al. (1998b). A 0.3 g air-dry weight of sample was sequentially extracted with 1 M KCl, 0.1 M NaOH, 0.5 M HCl, and 6.0 M HCl solutions, with each addition followed by shaking, centrifuging at 6000 rpm for 10 minutes, filtration, and analysis (Figure 3-5). The KCl-P$_i$ was determined by adding 20 mL 1.0 M KCl and shaking for 2 hours before
centrifuging and filtering. The extract collected was stored at 4°C until analysis using a Spectronic 20 Genesys spectrophotometer.

Next, 20 mL of 0.1 M NaOH was added to the sample and shaken for 17 hours before centrifuging and filtering. The extract collected was stored at 4°C until analysis. For NaOH-P, 5 mL of extract was pipetted into separate scintillation vials with 7 drops of 12 N HCl concentrate. For NaOH-P, 5 mL of the same NaOH filtrate was pipetted into conical flasks with 1 mL 11 N sulfuric acid and 0.4 g potassium persulphate. Samples were digested at 125°C for 3 hours, 380°C for 4 hours, and cooled to 100°C where 10 mL of DI water was added. The samples were then analyzed for total P. NaOH-Po was calculated by subtracting NaOH-P concentrates from NaOH-Pi concentrates.

The HCl-Pi was determined by adding 20 mL 0.5 M HCl to each sample and shaking for 24 hours. The sample was then centrifuged and filtered and stored at 4°C until analysis. Inorganic P fractions were analyzed using a Spectronic 20 Genesys spectrophotometer.

The residual P was determined by ashing in a muffle furnace at 550°C for 4 hours, then adding 20 mL of 6.0 M HCl. Samples were placed on a hot plate at 100-120°C until dry, then raised to 260-280°C for 30 minutes. The samples were cooled to room temperature, 2.25 mL of 6 M HCl was added to each sample, and samples were placed on hot plate and brought to a boil. Samples were filtered and the extract was analyzed for total P.

**Equilibrium Phosphorus Concentration**

The Equilibrium Phosphorus Concentration (EPC0) was calculated by determining the sorption isotherm according to Delaune et al. (2013), using 0.01 mol L⁻¹ KCl solution containing 0, 0.01, 0.10, 1.00, 5.00, 10.00, 20.00, 50.00 mg P/L as KH₂PO₄. Tubes were shaken on a mechanical shaker for 24 hours, centrifuged, and filtered through 0.45 micrometer filter. The
filtrate was analyzed for soluble reactive phosphorus (SRP) on a continuous flow Auto Analyzer 3 (Seal Analytical Inc., Mequon, WI, USA).

Linear regression statistics were then performed on the SRP values to determine \( EPC_0 \) using the formula (Pant et al., 2002):

\[
S = KC - S_0
\]  

where:

- \( S = \) P sorbed in solid phase (mg/kg)
- \( K = \) P sorption coefficient
- \( C = \) P concentration in solution after shaking 24 h (mg/L)
- \( S_0 = \) P originally sorbed by sediments, which is the y-intercept

The \( EPC_0 \) is the P concentration where net \( S = 0 \), or the value of \( C \) on the x-axis when \( y = 0 \).

To estimate the sediment P storage capacity, linear Langmuir isotherm calculations were performed for each transect to find the maximum P sorption (\( S_{max} \)). The linear Langmuir isotherm uses the Langmuir Equation, originally derived to describe adsorption of gases to solids, in the form (Reddy et al., 1998a):

\[
\frac{C}{S} = \frac{1}{k \cdot S_{max}} + \frac{C}{S_{max}}
\]

where:

- \( C = \) concentration in solution after shaking 24 h (mg/L)
- \( S = \) P sorbed in solid phase (mg/kg)
- \( S_{max} = \) Maximum P sorption (mg/kg)
- \( k = \) sorption constant of P bonding energy (L/mg)

A regression of \( C/S \) vs \( S_{max} \) was plotted, with the slope equaling \( 1/S_{max} \) and the intercept \( 1/(k \cdot S_{max}) \). The sorption constant \( k \) is the reciprocal of EPC at half saturation, and as it increases,
there is an increase in sediment P bonding energy (Olsen & Watanabe, 1957). \( S_{\text{max}} \) estimates the sediment P storage capacity.

**Statistical Analyses**

Statistical analyses were performed using SigmaPlot 13.0 (Systat Software, Inc., San Jose California USA). T-tests and Wilcoxon signed-rank tests were used to analyze data sets between treatment-control designations. Pearson correlations were done to assess the relationships between FAV coverage, sediment properties, P fractions, and minerals.

**Results**

**Percent FAV Cover**

The experimental design dictated that treatment farms were to have less than 25% FAV coverage, while FAV coverage on control farms were left to the management of the farm. All treatment data pooled (3103, 0401, 4702, and 6117) averaged 18% FAV coverage during the course of the experiment (May 2013-June 2016), with a range of 19-53%. However, due to our inability to manipulate FAV cover in control farms, the pooled control farms (3102, 2501, 4701, and 1813), FAV cover also averaged 18%, and ranged from 19-53%. Treatment and control farms pooled did not have significantly different FAV cover (Figure 3-10A).

Most treatment farms had FAV cover over 25% at some survey point during the experiment (Figures 3-6-9A). Farm pair 6117-1813 rarely had FAV cover, with control farm 1813 (Figure 3-9B) averaging 3% cover and treatment farm 6117 (Figure 3-9A) averaging 19% cover, with no significant difference between treatments (Figure 3-14A). Farm pair 3103-3102 both had periods of time with FAV cover higher than the 25%, with average cover as 31% in control farm 3102 (Figure 3-6B), and treatment farm 3103 (Figure 3-6A) averaging 16% over the course of the experimental period. The pair 3102 (C)-3103 (T) was significantly different in percent FAV cover (Figure 3-11A). Farms 0401 and 2501 (Figure 3-7AB, respectively) did not
significantly differ in percent cover (Figure 3-12A), averaging 23% for treatment farm 0401, and 18% for control farm 2501. Farm 4702 (Figure 3-8A) is the only treatment farm that maintained less than 25% cover, averaging 7% cover during the course of the experiment, and control farm 4701 (Figure 3-8B) mostly maintained cover above 25%, averaging 35%, upholding the experimental design. The farm pair significantly differed in percent FAV cover (Figure 3-13A). A higher percent FAV coverage was observed in warmer months for all farms.

**Sediments**

**Properties**

Sediments sections (0-2.5 cm and 2.5-5.0 cm) were analyzed for pH, percent organic matter, wet bulk density (BD), dry BD, and total P. Table 3-2 summarizes the values for each sampling period by year and farm pairs. Sample values were averaged over transects and sediment sections because there was no statistical significant difference between sections.

Pooled total P did significantly vary between all treatment and all control farms, averaging 974 mg/kg in treatment farms and 1,125 mg/kg in control farms (Figure 3-10B). The lack of significance between treatment-control designations may be attributable to the wide range and high degree of variability found in sediment total P sampling, with a range of 536 and 1,728 mg/kg between all farms during the experimental period.

The average pH of the sediments was 7.43 in pooled treatment farms, and 7.40 in pooled control farms, and did not statistically differ (Figure 3-10C). Percent organic matter averaged 40% in pooled treatment farms, and 38% in pooled control farms, and did not significantly differ by treatment or control (Figure 3-10D). The loss on ignition method to determine organic matter at high temperatures risks loss of carbonates as well as organic carbon (Heiri, Lotter, & Lemcke, 2001). The high carbonate content of the sediment, and any loss thereof during organic matter measurement, may have reduced any statistical variation in organic matter content attributed to
the experimental conditions. Wet and dry BD were both significantly different between treatment and control (Figures 3-10EF, respectively), averaging 1.12 g/cm\(^3\) and 0.38 g/cm\(^3\) in treatment farms and 1.09 g/cm\(^3\) and 0.30 g/cm\(^3\) in control farms for wet and dry BD, respectively. For both wet and dry BD, control farm canals had lower BD, meaning the sediment was more flocculent and easily transportable.

When separating into treatment and control farm pairs, some followed the experimental design better than others, as mentioned above. Farm pair 3103-3102 significantly differed in percent FAV cover (Figure 3-11A), with control farm 3102 having on average 31% FAV coverage compared to 16% in 3103, generally following the experimental design, but this was not maintained throughout the entire experimental period. Despite differences in FAV cover, there were no significant difference in total P (Figure 3-11B) between the control 3102 (average 1235 mg P/kg) and treatment 3103 (average 1275 mg P/kg). There were also no significant differences in sediment pH (7.39 (C), 7.39 (T)), percent organic matter (37% (C), 38% (T)), or wet BD (1.15 g/cm\(^3\) (C), 1.12 g/cm\(^3\) (T)) and dry BD (0.41 g/cm\(^3\) (C), 0.37 g/cm\(^3\) (T)) (Figure 3-11C-F).

Farm pair 0401-2501 had an FAV cover averaging 23% for treatment farm 0401 and 18% for control farm 2501, and therefore did not follow the experimental design. Sediment total P was extremely variable (ranging from 770 to 1,441 mg P/kg), and therefore the average values of 1049 (C) and 929 mg P/kg (T) were not meaningfully different or statistically significant (Figure 3-12AB, respectively). Sediment pH was very similar for both farms (7.37 (C), 7.50(T)) (Figure 3-12C) and not significantly different. No significant differences were found between the sediment organic matter (37% (C), 33% (T)) for this farm pair as well, likely due to high levels of variation (Figure 3-12D). There were, however, significant differences in wet BD (1.09 g/cm\(^3\)
(C), 1.15 g/cm$^3$ (T)) and dry BD (0.25 g/cm$^3$ (C), 0.42 g/cm$^3$ (T)) between 0401 and 2501 (Figure 3-12EF, respectively). Control farm 2501 had lower BD than treatment farm 0401, indicating that the treatment farm canal sediments were heavier than the control farm.

Farms 4701 and 4702 had a significantly different percentage of FAV cover, following the experimental design, with control farm 4701 averaging 35% FAV cover and treatment farm 4702 containing an average of 7% cover (Figure 3-13A). Control farm 4701 had significantly higher sediment total P, averaging 1,057 mg P/kg, than treatment farm 4702, which averaged 732 mg P/kg over the course of the experiment (Figure 3-13B). Similar to other farm pairs, pH (7.43 (C), 7.41(T)) was not significantly different (Figure 3-13C). Sediment organic matter was significantly different, with control farm 4701 averaging 37% and treatment farm 4702 averaging 47% (Figure 3-13D). The origin of the organic matter is unknown, but the higher FAV cover and sediment total P in control farm 4701 suggests the organic matter content of the sediment may not be originating from recently deposited FAV detrital matter. Wet BD was significantly different within the farm pair, averaging 1.07 and 1.11 g/cm$^3$ for 4701 (C) and 4702 (T), respectively (Figure 3-13E). Dry BD was also significantly different, with control farm 4701 having lower BD (average 0.254 g/cm$^3$) than treatment farm 4702 (average 0.332 g/cm$^3$) (Figure 3-13F). Despite having lower organic matter, 4701 (C) had lower dry BD and therefore lighter, less dense sediment as compared to the treatment farm. This could be a result of the higher FAV coverage in control farm 4701 dropping detrital matter with high P on the sediment surface, which has not been incorporated enough into the sediment to alter the organic matter content, but takes up enough volume in the top 5.0 cm to alter the BD.

Farm pair 1813 and 6117 did not behave according to the experimental design. While there was a significant difference in FAV coverage, control farm 1813 had an average of 3%
FAV cover and treatment farm 6117 averaged 19% (Figure 3-14A). Sediment total P also significantly differed between the two farms, with control farm 1813 averaging 1,153 mg P/kg and treatment farm 6117 averaging 987 mg P/kg (Figure 3-14B). Measurements taken during the calibration period in 2012 (data not shown), demonstrated that total P between the pair varied greatly, which may account for the significance of the statistical analysis. There were no significant differences in pH (7.43 (C), 7.40 (T)) and sediment organic matter (39% (C), 41% (T)) within the pair (Figure 3-14CD, respectively), or for wet and dry BD (Figure 3-14EF, respectively). Control farm 1813 had lower wet and dry BD (1.08 and 0.29 g/cm$^3$) than treatment farm 6117 (1.15 and 0.43 g/cm$^3$). Similar to total P, this difference could stem from an inherent difference in farm canal properties rather than a result of the experimental conditions.

**XRD**

Sediment samples from December 2013 and April 2014 were subjected to the XRD analysis. The resulting diffractograms (Appendix C) show the intensity peaks and unique d-spacing values for each crystalline substance in the samples. The d-spacing values are derived from Bragg’s Law (d = $\lambda / 2 \sin \theta$) and are used as a means of identifying minerals in the sample. A summary of the relative abundance of minerals present in each canal is found in Table 3-3. The most dominant minerals identified from d-spacing values were calcite (calcium carbonate, CaCO$_3$), quartz (SiO$_2$), and palygorskite ((Mg, Al)$_2$Si$_4$O$_{10}$(OH)•4(H$_2$O)). Limestone (calcium carbonate) is the bedrock of the EAA, so the dominance of calcite was expected. Other minerals identified were sepiolite (Mg$_4$Si$_6$O$_{15}$(OH)$_2$•6H$_2$O), dolomite (CaMg(CO$_3$)$_2$), aragonite (calcium carbonate, CaCO$_3$), and kaolinite (Al$_2$Si$_2$O$_5$(OH)$_4$). The sediments were dominated by Ca, Mg, and Al minerals, and there were no mineral forms of P, such as apatite (Ca$_5$(PO$_4$)$_3$(F,Cl,OH)), detected. This could mean that P-bearing minerals are below XRD detection limits or that P is primarily present as an adsorbed component.
**Mineral content**

To determine the amount of available minerals for P precipitation, sediment samples from December 2014 and April 2016 (depth 0-2.5 cm) were analyzed for extractable minerals known to potentially co-precipitate with P. The results of the oxalate extractable Fe and Al (Fe$_{ox}$ and Al$_{ox}$) and extractable Ca, Mg, and Mn are shown in Table 3-4. Extractable Ca was present in the highest amount in all sediment samples (10,542-15,084 mg Ca/kg). The large pool of extractable Ca is consistent with the relative abundance of minerals present in the sediment samples, as calcite (calcium carbonate) dominated all samples. Extractable Mg and Fe$_{ox}$ were the next highest available minerals (1,011-2,322 mg Mg/kg and 840-2,236 mg Fe/kg, respectively). Magnesium is a component of many of the minerals present in the sediments, like palygorskite. Very little Mn was present (three orders of magnitude less than other tested minerals) in the sediments, which was expected as it is a micronutrient and tends to be deficient in the EAA (Wright et al., 2012; Craft & Richardson, 1997).

**P-fractionation**

The labile, inorganic P$_i$ pool is an important factor for plant growth and water column P, and it is considered the most mobile, bioavailable form (Reddy et al., 1995) (Figure 3-5). The next most reactive pool is Fe-Al oxides bound P$_i$ pool and the organic humic-fulvic bound P$_o$ pool. The Ca-Mg bound P$_i$ pool is considered biologically unavailable, or recalcitrant under most natural conditions (Reddy et al., 1995). The last fraction, the residual P, is considered highly recalcitrant.

There were no significant differences by treatment-control designations for any fraction of P when analyzed over all farms and sampling. The variation was too high due to the high variation in many different sediment properties, (e.g. legacy P values). Additionally too few data points were collected to provide meaningful statistical differences between sampling periods on
individual farms. Instead, farm pairs were evaluated by comparing sampling periods over the course of the experiment.

Table 3-5 summarizes the P pools over the experimental period for each farm pair. The labile \( P_i \) was the smallest fraction for all farms, averaging 20 mg P/kg in control farms and 15 mg P/kg in treatment farms. There were no significant differences for any farm pair for labile \( P_i \). The largest pool for all farms was the Ca-Mg bound \( P_i \), which averaged 432 mg P/kg in treatment farms and 490 mg P/kg in control farms. Because of the dominant presence of Ca and Mg minerals, the large pool of extractable Ca and Mg, and the regional pH, the Ca-Mg bound \( P_i \) was expected to be the largest fraction. There was only one farm pair with significantly different Ca-Mg bound \( P_i \), with control farm 4701 having higher values (437 mg P/kg) than treatment farm 4702 (286 mg P/kg). This may be attributed to the overall difference in total P between 4701 and 4702, where 4701 was significantly higher. Other fractions, Fe-Al bound \( P_i \) (69 mg P/kg (C), 57 mg P/kg (T)), humic-fulvic bound \( P_o \) (88 mg P/kg (C), 86 mg P/kg (T)), and residue P (207 mg P/kg (C), 201 mg P/kg (T)) had no significant differences over all farms or between farm pairs.

Because of the inherent differences in total P for all the farm canal sediments, comparing the actual value of measured P fractions is not possible. Instead, normalizing the values allow for comparisons among the farms. Table 3-5 also shows the fractions as percentages of the total P below the P concentration in mg P/kg. The differences between all fractions by treatment and control were not significantly different with the average labile \( P_i \), equaling 2% (ranging from 1-6%), Fe-Al bound \( P_i \) averaging 8% (range 3-15%), humic-fulvic bound \( P_o \) averaging 11% (range 2-17%), Ca-Mg bound \( P_i \) averaging 56% (range 36-74%), and residue P averaging 24% (range 14-51%). When separated by treatment control pairs, the percentages of P fractions are similar
between farms pairs 3102-3103 (Figure 3-15A), 0401-2501 (Figure 3-16B), 4701-4702 (Figure 3-16A), and 1813-6117 (Figure 3-16B).

**Correlations**

**Extracted element subset data**

Pearson correlations were conducted to assess the relationship between extractable element content, sediment properties, and P fractions only for samples from December 2014 and April 2016 (depth 0-2.5 cm). The results from this test showed significant, positively correlated relationships between Fe$_{ox}$ concentration and total P, Al, Mg, and Ca-Mg bound P$_i$ (Table 3-6). Iron concentrations were inversely related to total P and Ca-Mg bound P and positively correlated with Al$_{ox}$ and Mg concentrations. This suggests that as the sediment concentrations of Fe$_{ox}$ increased, binding of P with Ca-Mg became more favorable. Aluminum concentration was negatively correlated with labile P$_i$ and Ca-Mg bound P$_i$, suggesting that labile P$_i$ and Ca-Mg bound P$_i$ decreased as Al$_{ox}$ in the sediment increased. Aluminum was also positively correlated with Fe$_{ox}$ and organic matter content.

Extractable Ca concentration was positively significantly correlated with Mg, Mn, and organic matter, and negatively correlated with Ca-Mg bound P$_i$. Magnesium concentrations were also negatively correlated with Ca-Mg bound P$_i$ and positively correlated with organic matter, Fe$_{ox}$, Ca, and Mn. As the fraction of P bound to Ca-Mg increased, concentrations of extractable Ca and Mg in the sediment decreased. Manganese had a positive relationship with Ca and residue P, but was not correlated with any other factors.

The correlation analysis shows that labile P is influenced by Al$_{ox}$ content rather than Fe$_{ox}$, Ca, Mg, or Mn. Iron-aluminum and humic-fulvic bound P was also not influenced by mineral content. Phosphorus bound to Ca-Mg were influenced by mineral content of the sediment, especially Fe$_{ox}$, Al$_{ox}$, Ca, and Mg. The pH range for highest P availability is between 5.5 and 7.0,
with P binding with Ca-Mg at greater than 7.0 and P binding with Fe-Al below 5.5 (Brady & Weil, 2008). For these samples, pH ranged from 7.16 to 7.82 with an average of 7.43. While the range and average pH are within the optimal Ca-Mg binding range, there is a decrease in labile \( P_i \) and Ca-Mg bound \( P_i \) with increased pH. That is due to the positive relationship labile \( P_i \), Fe-Al bound \( P_i \), humic-fulvic bound \( P_o \), and Ca-Mg bound \( P_i \) have with total P.

**All sample data correlation**

Another Pearson correlation analysis was performed on all samples to determine if the percentage of FAV cover had an effect on sediment properties, total P, or P fractions (Table 3-7). The only factors that were correlated with percent FAV cover were wet BD and residue P. Both were positively correlated, meaning as percent FAV cover increased, so did wet BD and residue P. Sediment pH was negatively correlated with Fe-Al bound \( P_i \), so as pH went down, the amount of P bound with Fe-Al increased. Organic matter was negatively correlated with wet and dry BD and Ca-Mg bound \( P_i \). Higher amounts of organic matter tend to result in lower BD because BD is a measure of soil weight within a specific volume (Brady & Weil, 2002). Organic matter is lighter than mineral soil particles causing lower BD than if that space were filled with more mineral particles. The negative correlation of BD with organic matter fits this trend.

Wet and dry BD were negatively correlated with labile \( P_i \). Wet BD was also negatively correlated with Fe-Al bound \( P_i \). While labile \( P_i \) was not correlated with organic matter, the negative relationship with wet and dry BD may be indirectly from the organic matter content. Total P was only correlated with Ca-Mg bound \( P_i \), with an increase in total P resulting in increasing Ca-Mg P."
**EPC and $S_{\text{max}}$**

Table 3-8 summarizes the EPC$_0$ and $S_{\text{max}}$ values for all transects from experimental farms. Phosphorus adsorption is favored when EPC is less than SRP, and P release is favored when EPC is greater than SRP. $S_{\text{max}}$ values give the maximum P absorptive capacity of the soil.

For treatment farm canal 3103, EPC$_0$ values averaged 1.09 mg P/L. This value is within the range of previous studies in the Lake Okeechobee basin where EPC$_0$ of stream sediments ranged from 0.03 to 4.76 mg P/L and wetland soils ranged from 0.03 to 9.06 mg P/L (Reddy et al., 1995). EPC$_0$ of the larger SFWMD canals ranged an order of magnitude lower from 0.02 to 0.11 mg P/L (Das, 2010). $S_{\text{max}}$ values for 3103 was 756 mg P/kg. For control farm 3102, EPC$_0$ value was 0.56 mg P/L, and $S_{\text{max}}$ values was 1,180 mg P/kg. This means that treatment farm 3103 requires higher canal water SRP to retain P in canal sediments than control farm 3102. Control farm 3102 also has a higher capacity for P sorption than treatment farm 3103.

Treatment farm 0401 had an average EPC$_0$ of 0.32 mg P/L, and an $S_{\text{max}}$ value of 1,238 mg P/kg. Control farm 2501 had an EPC$_0$ value of 0.19 mg P/L, and an $S_{\text{max}}$ value of 807 mg P/kg. The treatment farm again had higher EPC$_0$ values than the control farm, but higher P maximum sorption. That means the treatment farm will release P sooner than the control farm as SRP values decrease.

For treatment farm 4702, average EPC$_0$ was 0.59 mg P/L, while control farm 4701 had an EPC$_0$ value of 0.53 mg P/L. The $S_{\text{max}}$ value for 4702 was 817 mg P/kg and 1,613 mg P/kg for 4701. While the concentration of SRP at which the canal sediment will act as a source was not different, maximum P adsorption was higher for control farm 4701.

In treatment farm 6117, average EPC$_0$ was 1.48 mg P/L with an average $S_{\text{max}}$ value of 594 mg P/kg. Control farm 1813 average EPC$_0$ was 0.58 mg P/L and $S_{\text{max}}$ was 1,365 mg P/kg.
The average EPC$_0$ of 6117 was nearly three times that of 1813, and the average S$_{\text{max}}$ was over two times less than 1813.

Equilibrium phosphorus concentrations were determined using a batch adsorption isotherm experiment using varying P spike concentrations. Extracted SRP values were plotted against the amount of P retained or released calculated as the difference in added P concentration minus the SRP value for each sample. The EPC$_0$ is then the point at which the y-intercept equals 0. Phosphorus adsorption is favored when EPC is less than SRP, and P release is favored when EPC is greater than SRP. Table 3-9 summarizes the EPC$_0$ and S$_{\text{max}}$ values for all transects from experimental farms.

**Discussion**

**Percent FAV Cover**

Overall this experiment was designed to compare effects of FAV suppression in farm canals. Because FAV seeding was not an option, one of the most pervasive problems throughout the experiment stemmed from low FAV cover in the control farms being managed by the farmers.

Statistical analyses of farm conditions based on treatment-control designations may have had skewed results because the percent FAV cover did not always follow the experimental design. A percent FAV cover threshold was tested using all canal sediment data, but no threshold value was found to significantly affect sediment total P. Farm pair 4702 and 4701 was the best representative pair of the experimental design, with percent FAV cover of the treatment farm remaining below 25% and the control farm generally above 25%.

**Sediments**

The objectives of this study were to evaluate the effects of FAV suppression on canal sediment properties, total P, and fractions of P. The most significantly affected factors by FAV
suppression were BD and total P. Organic matter was originally thought to be highly impacted by FAV suppression because of the loss of additional detrital matter once FAV was removed. Organic matter content is inherently high for these sediments because the soils are of the Histosol series, so changes in organic matter content due to FAV suppression may have been negligible or diluted. Our data indicates that bulk density of the sediment was a better indicator of the effect of FAV suppression on sediment properties, possibly as a result of the detrital matter not breaking down quickly and taking up more space in the top 5 cm of sediment. As FAV biomass dies and becomes incorporated into the sediment, the plant material takes up more space and reduces the mass to volume ratio. While organic matter was not significantly correlated with FAV cover, it was with BD. That means bulk density may be a more immediate indicator of FAV suppression affects, while organic matter may be affected on a longer time scale. The fact that treatment farm canals that were suppressing FAV coverage had higher bulk density than control farms allowing FAV growth shows that sediment in treatment farms was denser. This supports part of the overall hypothesis that FAV suppression results in heavier, less transportable sediments.

Similar to organic matter, our data suggested that sediment pH was not affected by suppressing or allowing FAV coverage. The EAA farm canals are dug down to the limestone bedrock to increase P sorption capacity. The limestone (calcium carbonate) bedrock in the EAA increases the pH from otherwise acidic Histosols soils. The large pool of limestone may account for there being no significant differences in sediment pH related to FAV suppression. However, when correlating to the other sediment properties, there was a significant negative relationship between pH and Fe-Al bound P. This supports the idea that an increase in pH results in a decrease in P bound with Fe and Al (Nur & Bates, 1979). Although the Fe-Al bound P fraction
was not included as recalcitrant or available P in research Question 3-1 or 3-2, it does partially reject the overall hypothesis that FAV suppression will result in P co-precipitation into denser compounds.

Total P is another inherent quality of sediment. There was no correlation with total P and percent FAV cover, so the significantly higher total P in control farms compared to treatment farms may not be a result of FAV suppression or growth. Instead, the significant differences may be a result of the legacy P stored in the canal sediments. Total P values rely strongly on the land use activities within the canal’s watershed (Das, 2010), i.e., crop type on the farm. Other crop types were present in small amounts, such as corn, rice, vegetables, and sod, some of which require more fertilizers and lower water tables than sugarcane. Additionally, the crop types before the experimental period are unknown and cannot be taken into consideration. The variability of total P in the experimental farms may be a result of legacy P from the unknown farming activities previous to this study. Because of this, total P cannot be used as a factor to support or reject the overall hypothesis that FAV suppression increases P retention by canal sediments.

The EPC is the P concentration where no retention or release between the sediments and water column occurs (Das et al., 2012; Reddy et al., 1998a). Knowing the EPC can determine the capacity of the sediment to store P, and whether P has the potential to flux from sediments into the water column or be fixed from the water column to sediments. In general, treatment farms had higher EPC₀ values than control farms, meaning they require higher canal water SRP to retain P in canal sediments. With FAV suppression, if farmers reduced the SRP in their canal waters lower than the EPC₀ of the sediments, their canals will act as a source of P rather than a sink. Control farms also had higher S_max values than treatment farms, meaning they can absorb
higher values of P than farms suppressing FAV. These results do not support the overall hypothesis that suppressing FAV would have a positive effect on canal sediment ability to retain P.

The sediment P fractions tested two proposed research questions. First, does FAV suppression reduce available P in canal sediments, with available P defined as labile P\textsubscript{i} and humic-fulvic bound P\textsubscript{o}? There were no significant differences between labile P\textsubscript{i} fractions and humic-fulvic P\textsubscript{o} fractions when comparing treatment and control farms or individual farm pairs. Labile and humic-fulvic P were two of the smallest fractions, accounting for 1-6% and 2-17%, respectively, which may account for the lack of significance when suppressing FAV. Labile P\textsubscript{i} was negatively correlated with BD, which suggests there might be an indirect relationship with FAV because treatment farms had higher BD than control farms. Humic-fulvic bound P\textsubscript{o} had no significant changes between FAV suppression and growth and was not correlated with any other factor. These results cannot support or reject research Question 3-1 that FAV suppression would reduce available P in canal sediments.

The research Question 3-2 asked if FAV suppression would increase recalcitrant P in canal sediments, with recalcitrant P defined as Ca-Mg bound P\textsubscript{i} and residue P. There were no significant differences between treatment and control farms for either Ca-Mg bound P\textsubscript{i} or residue P. There was a significant difference in farm pair 4702-4701, with treatment farm 4702 having lower Ca-Mg bound P\textsubscript{i} values than control farm 4701, but when the measured P data were normalized into percent total P, there were no significant differences. While Ca-Mg bound P\textsubscript{i} was not correlated with percent FAV cover, residue P had a significant positive correlation. That means, as percent FAV cover decreased, residue P decreased as well. This partially rejects research Question 3-2 that suppressing FAV increases recalcitrant P in canal sediments. The
relationship may not be a direct effect of FAV suppression on recalcitrant P, but a result of the overall difference in the sediments’ legacy P.

**Conclusion**

It was hypothesized that data from the P fractionation analysis would show differences in P fractions between treatment and control farms with FAV suppressed. Under this hypothesis, it was expected that FAV suppression would produce denser, more recalcitrant P and decrease available P. Although there was no support of P becoming less available by binding with Fe-Al or Ca-Mg, there was support that suppressing FAV increased the BD of sediments. The generation of denser sediment may retain more P within the canal by reducing sediment particle-absorbed P transport out of farm canals during pumping events.

More time is required to fully understand impacts of FAV suppression because changes to inherent sediment properties, like organic matter content, pH, or total P, require not only more time but more sampling periods within the year. Also, better control of FAV coverage between treatment and control farms would result in clearer relationships with sediment properties. It is possible that canal pumping regimes or other unknown factors may be influencing how P binds in the sediment. In the future, studies on canal sediments will need to focus on other factors that may impact P sorption, like measuring redox potential at the sediment surface, testing alternate percent cover thresholds, or altering mineral concentrations.

Controlling the growth of FAV at pump stations is a practice already implemented by some farmers to benefit flow during drainage and irrigation. This study hoped to show that suppressing FAV growth in the entirety of the canals in the EAA would help farmers reduce their P loads by retaining P held in sediments. Ultimately, this study provides a snapshot of the changes occurring within canal sediments when FAV is suppressed. It does not reveal the impacts of FAV suppression on P loads out of the canal, which is the ultimate goal of P
management tools in the EAA. Canal sediment properties may not be the best indicator of FAV suppression as a P load reducing practice because the effects are slow to materialize. While the conditions in the canals are better understood following this study, work is needed to assess the P discharged during drainage events, in both the water and the discharged particulate sediment. Only with that data will the effectiveness of FAV suppression as a means to reduce P loads be known.
Figure 3-1. Map of south Florida showing the larger Everglades system. The Everglades Agricultural Area (EAA) is shown south of Lake Okeechobee. (Map created by Anne Sexton.)
Figure 3-2. Potential floating aquatic vegetation (FAV) effects on canal functions, with complete FAV coverage and no coverage. With full coverage sunlight and gas exchange is impeded, detrital matter accumulation increases, and floc sediment generation and loss increase during water movement, as compared to clear canal.
Figure 3-3. Map of experimental farms in the Everglades Agricultural Area (EAA). Each farm pair is labeled and similarly colored. All farms are south east of Lake Okeechobee. (Map created by Anne Sexton).
Figure 3-4. Farm canal sediment sampling schematic. Transects A, B, and C are sampled twice per year for sediment cores.

Figure 3-5. Schematic of modified Hedley P fractionation. Fractions are defined by their ease of extractability, with labile P being the most mobile and residue P the most recalcitrant.
Figure 3-6. Percent floating aquatic vegetation (FAV) cover from April 2014 to June 2016 for farms 3103 and 3102. A) Cover for farm 3103. B) Cover for farm 3102. The 25% designated threshold is shown as a red line. (T) denotes treatment farm and should have values below the red marker. (C) denotes control farm and percent coverage was not under experimental control.
Figure 3-7. Percent floating aquatic vegetation (FAV) cover from April 2014 to June 2016 for farms 0401 and 2501. A) Cover for farm 0401. B) Cover for farm 2501. The 25% designated threshold is shown as a red line. (T) denotes treatment farm and should have values below the red marker. (C) denotes control farm and percent coverage was not under experimental control.
Figure 3-8. Percent floating aquatic vegetation (FAV) cover from April 2014 to June 2016 for farms 4702 and 4701. A) Cover for farm 4702. B) Cover for farm 4701. The 25% designated threshold is shown as a red line. (T) denotes treatment farm and should have values below the red marker. (C) denotes control farm and percent coverage was not under experimental control.
Figure 3-9. Percent floating aquatic vegetation (FAV) cover from April 2014 to June 2016 for farms 6117 and 1813. A) Cover for farm 6117. B) Cover for farm 1813. The 25% designated threshold is shown as a red line. (T) denotes treatment farm and should have values below the red marker. (C) denotes control farm and percent coverage was not under experimental control.
Figure 3-10. Box plots of sediment properties comparing all treatment and all control farms. A) Percent FAV cover. B) Total P. C) pH. D) Organic matter. E) Wet bulk density. F) Dry bulk density. All factors were compared over all treatment farms and all control farms for the study period. Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 3-11. Box plots of sediment properties for farm pair 3102 (C) and 3103 (T). A) Percent FAV cover. B) Total P. C) pH. D) Organic matter. E) Wet bulk density. F) Dry bulk density. All factors were compared over all treatment farms and all control farms for the study period. Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 3-12. Box plots of sediment properties for farm pair 2501 (C) and 0401 (T). A) Percent FAV cover. B) Total P. C) pH. D) Organic matter. E) Wet bulk density. F) Dry bulk density. All factors were compared over all treatment farms and all control farms for the study period. Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 3-13. Box plots of sediment properties for farm pair 4701 (C) and 4702(T). A) Percent FAV cover. B) Total P. C) pH. D) Organic matter. E) Wet bulk density. F) Dry bulk density. All factors were compared over all treatment farms and all control farms for the study period. Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 3-14. Box plots of sediment properties for farm pair 1813 (C) and 6117 (T). A) Percent FAV cover. B) Total P. C) pH. D) Organic matter. E) Wet bulk density. F) Dry bulk density. All factors were compared over all treatment farms and all control farms for the study period. Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 3-15. Percent P fractions for farm pairs 3103 and 3102, and 0401 and 2501. A) Farm pair 3102-3103. B) Farm pair 0401-2501. (T) denotes treatment farms, while (C) denotes control farms. P= phosphorus, Ca = calcium, Mg= magnesium, Fe= iron, and Al= aluminum. Dry season = December-April. Wet season = May-November.
Figure 3-16. Percent P fractions for farm pairs 4102 and 4701, and 6117 and 1813. A) Farm pair 4702-4701. B) Farm pair 6117-1813. (T) denotes treatment farms, while (C) denotes control farms. P= phosphorus, Ca = calcium, Mg= magnesium, Fe= iron, and Al= aluminum. Dry season = December-April. Wet season = May-November.
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T = treatment; C = control; SFWMD = South Florida Water Management District
Table 3-2. Averaged percent FAV cover and sediment properties by season for each farm. Units are % for FAV cover and organic matter, g/cm³ for wet and dry bulk density (BD) and mg/kg for Total phosphorus (P). Control farms are designated with a (C), and treatment farms with a (T).

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Table 3-3. Minerals present in canal sediments averaged over transects. Relative abundance of each mineral is given from 0-100, with 100 equaling the most dominant mineral and 0 shows not present.

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<th>Farm</th>
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<th>Dolomite</th>
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Note: Values are a qualitative ranking of relative abundance, not quantitative measurements.
Table 3-4. Oxalate extractable Fe and Al, and extractable Ca, Mg, and Mn from December 2014 and April 2016 (depth 0-2.5 cm) sediment samples

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<td>Fe\text{ox} (mg/kg)</td>
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<td>786</td>
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<td>830</td>
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<td>600</td>
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<td>Ca (mg/kg)</td>
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Table 3-5. Averaged sediment P fractions in mg/kg and percent of total by season for each farm

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<td>Labile P&lt;sub&gt;i&lt;/sub&gt;</td>
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<td>210</td>
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<td>201</td>
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<td>30</td>
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<td>(6)</td>
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<td>(3)</td>
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<td>(3)</td>
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<td>84</td>
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<td>40</td>
<td>103</td>
<td>96</td>
<td>45</td>
</tr>
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<td>(5)</td>
<td>(10)</td>
<td>(9)</td>
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</tr>
<tr>
<td>Humic-Fulvic bound P&lt;sub&gt;i&lt;/sub&gt;</td>
<td>(14)</td>
<td>(5)</td>
<td>(16)</td>
<td>(6)</td>
<td>(13)</td>
<td>(6)</td>
<td>(8)</td>
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<tr>
<td>Ca-Mg bound P&lt;sub&gt;i&lt;/sub&gt;</td>
<td>331</td>
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<td>624</td>
<td>427</td>
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<td>715</td>
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<td>112</td>
<td>156</td>
<td>116</td>
<td>178</td>
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<td>(14)</td>
<td>(23)</td>
<td>(17)</td>
<td>(17)</td>
<td>(14)</td>
</tr>
</tbody>
</table>

* indicates significant difference within treatment and control pair by averaged P fraction over time.
Table 3-6. Pearson correlation of oxalate extractable Fe and Al, and extractable Ca, Mg, and Mn, sediment properties, and P fractions for samples Dec 2014 and April 2016.

<table>
<thead>
<tr>
<th></th>
<th>Fe Conc (mg/kg)</th>
<th>Al Conc (mg/kg)</th>
<th>Ca Conc (mg/kg)</th>
<th>Mg Conc (mg/kg)</th>
<th>Mn Conc (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>0.08</td>
<td>0.15</td>
<td>-0.03</td>
<td>-0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
<td>0.13</td>
<td>0.29</td>
<td>0.51</td>
<td>0.33</td>
<td>0.14</td>
</tr>
<tr>
<td>Bulk Density (g/cm³)</td>
<td>-0.09</td>
<td>0.00</td>
<td>-0.23</td>
<td>-0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>Total P (mg/kg)</td>
<td>-0.29</td>
<td>-0.19</td>
<td>-0.31</td>
<td>-0.25</td>
<td>-0.11</td>
</tr>
<tr>
<td>KCl-P (mg/kg)</td>
<td>-0.22</td>
<td>-0.31</td>
<td>-0.07</td>
<td>-0.08</td>
<td>-0.14</td>
</tr>
<tr>
<td>NaOH-Pi (mg/kg)</td>
<td>-0.09</td>
<td>0.07</td>
<td>-0.01</td>
<td>-0.10</td>
<td>0.17</td>
</tr>
<tr>
<td>NaOH-Po (mg/kg)</td>
<td>0.03</td>
<td>0.09</td>
<td>0.10</td>
<td>-0.31</td>
<td>0.17</td>
</tr>
<tr>
<td>HCl (mg/kg)</td>
<td>-0.39</td>
<td>-0.29</td>
<td>0.11</td>
<td>-0.40</td>
<td>0.19</td>
</tr>
<tr>
<td>Residue P (mg/kg)</td>
<td>0.18</td>
<td>-0.01</td>
<td>-0.06</td>
<td>-0.01</td>
<td>0.31</td>
</tr>
<tr>
<td>Fe Conc (mg/kg)</td>
<td>0.29</td>
<td>0.27</td>
<td>0.34</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Al Conc (mg/kg)</td>
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<td></td>
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<tr>
<td>Ca Conc (mg/kg)</td>
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<td></td>
</tr>
<tr>
<td>Mg Conc (mg/kg)</td>
<td></td>
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</tbody>
</table>

The pair(s) of variables with positive correlation coefficients and P values below 0.05 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.05, one variable tends to decrease while the other increases. For pairs with P values greater than 0.05, there is no significant relationship between the two variables.

* p < 0.05, ** p < 0.01, *** p < 0.001
Table 3-7. Pearson correlation of FAV cover, sediment properties, and P fractions over all sediment samplings

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Organic Matter</th>
<th>Wet Bulk Density</th>
<th>Dry Bulk Density</th>
<th>Total P</th>
<th>Labile P&lt;sub&gt;i&lt;/sub&gt;</th>
<th>Fe-Al Bound P&lt;sub&gt;i&lt;/sub&gt;</th>
<th>Humic Fulvic Bound P&lt;sub&gt;0&lt;/sub&gt;</th>
<th>Ca-Mg Bound P&lt;sub&gt;i&lt;/sub&gt;</th>
<th>Residue P</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Cover</td>
<td>-0.087</td>
<td>-0.109</td>
<td>0.303</td>
<td>0.246</td>
<td>-0.01</td>
<td>-0.312</td>
<td>-0.080</td>
<td>0.108</td>
<td>-0.088</td>
<td>0.54</td>
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<td></td>
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</tr>
<tr>
<td>pH</td>
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</tr>
<tr>
<td>Organic Matter</td>
<td>-0.404</td>
<td>-0.492</td>
<td>-0.123</td>
<td>0.102</td>
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</tr>
<tr>
<td>Wet Bulk Density</td>
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<td>-0.549</td>
<td>-0.397</td>
<td>0.007</td>
<td>0.041</td>
<td>0.194</td>
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<tr>
<td>Dry Bulk Density</td>
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<td>-0.108</td>
<td>-0.442</td>
<td>-0.256</td>
<td>0.101</td>
<td>0.315</td>
<td>0.156</td>
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<td>Total P</td>
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<td>-0.054</td>
<td>-0.132</td>
<td>0.408</td>
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<tr>
<td>Labile P&lt;sub&gt;i&lt;/sub&gt;</td>
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<td></td>
<td>0.185</td>
<td>0.026</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Humic Fulvic Bound P&lt;sub&gt;0&lt;/sub&gt;</td>
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<tr>
<td>Ca-Mg Bound P&lt;sub&gt;i&lt;/sub&gt;</td>
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The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

* p < 0.50, ** p < 0.01, *** p < 0.001
Table 3-8. Equilibrium phosphorus concentration (EPC₀) and Sₘₐₓ for experimental farm canals over all transects and by farm average.

<table>
<thead>
<tr>
<th>Farm</th>
<th>Transect</th>
<th>EPC₀ (mg/L)</th>
<th>R² (%)</th>
<th>Sₘₐₓ (mg/kg)</th>
<th>R² (%)</th>
<th>Farm</th>
<th>Transect</th>
<th>EPC₀ (mg/L)</th>
<th>R² (%)</th>
<th>Sₘₐₓ (mg/kg)</th>
<th>R² (%)</th>
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<td>3103</td>
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<td>(T)</td>
<td>B</td>
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<td>93</td>
<td>833</td>
<td>98</td>
<td>(C)</td>
<td>B</td>
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<td>99</td>
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<td>79</td>
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<tr>
<td></td>
<td>C</td>
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<td>95</td>
<td>667</td>
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<td>C</td>
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<td>Farm Average</td>
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<td>714</td>
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<td>B</td>
<td>0.96</td>
<td>99</td>
<td>1429</td>
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<td>Farm Average</td>
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<td>817</td>
<td>66</td>
<td>Farm Average</td>
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</tr>
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<td>94</td>
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<td>Farm Average</td>
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<td>594</td>
<td>90</td>
<td>Farm Average</td>
<td></td>
<td>0.58</td>
<td>94</td>
<td>1365</td>
<td>81</td>
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</table>
CHAPTER 4
IMPACTS FROM SUPPRESSING FLOATING AQUATIC VEGETATION ON CANAL WATER PHOSPHORUS AND DISCHARGE SEDIMENTS

Introduction

Waters discharged from the Everglades Agricultural Area (EAA) have been identified as a contributor to the elevated phosphorus (P) levels in the Everglades National Park (Sievers et al., 2003) and prompted the Best Management Practices (BMP) program for farmers to reduce discharges of P under the Everglades Forever Act.

Phosphorus can have a number of fates in aquatic systems, including plant uptake, sorption to sediments, and precipitation (Menon and Holland, 2014). Up to half of all P discharged from the EAA is as particulate P (PP), due to the strong absorption of P to suspended solids (Izuno and Rice, 1999). It has been observed that PP primarily originates from plant material, with detrital matter from floating aquatic vegetation (FAV), filamentous algae, and plankton as the most prominent source (Stuck, 1996; Izuno and Rice, 1999; Daroub et al., 2005; Daroub et al., 2012). After initial uptake and removal of P from the water column, FAV acts as a source of P following death and decomposition of detrital matter (Menon and Holland, 2014).

Due to the influence of macrophytic detrital matter on P loads discharged from the EAA, this study focused on suppressing FAV as a possible tool to help farmers further reduce P loads from EAA farm canals as mandated by the Everglades Forever Act of 1994.

Suppression of FAV in farm canals may limit production of low density, labile sediments, which are easily transported, along with P, off farm when water is being discharged to larger municipal canals that eventually reach the Everglades (Figure 3-3). Additionally, suppression of FAV growth may provide more opportunities for P to enter less labile pools, such as through co-precipitation with minerals that will remove P from the water column. This study had three research questions:
1. Does FAV suppression reduce P load from farm canals?
2. Does suppressing FAV reduce particulate P (PP) from farm canals?
3. Does suppressing FAV reduce total P in discharged sediments?

This study hypothesizes that FAV suppression will reduce P loads, water PP, and discharged sediment total P. To test the research questions in this study, the objectives were to:

1. Evaluate effects of FAV suppression in treatment farms versus control farms on canal water P species.
2. Determine differences in discharged sediment P pools between farms with and without FAV suppression using sequential P fractionation.

**Materials and Methods**

**Experimental Design**

Research was conducted on eight farms in the EAA, with four treatment-control pairs as described in Chapter 3 (Figure 3-3; Table 3-1). The study took place between 2011 and 2016, with the calibration period from 2011 to 2013, and the experimental period starting in May 2013. Treatment farms use spot-spraying of herbicides (Rodeo and Diquat) to prevent canal FAV coverage greater than 25%, while control farms implement normal canal FAV management. Normal management ranged from suppressing FAV to allowing full coverage with few mass spray events, at the discretion of the farm management.

**FAV Survey and Sampling**

Farm canals were surveyed every two weeks for percent FAV cover over the entire canal. Sight estimates were used to approximation total canal coverage. When percent FAV cover was greater than 25% in treatment canals, herbicide was applied to suppress cover. The predominant FAV species found in the experimental canals were water lettuce (*Pistia stratiotes*), duckweed (*Lemna minor*), filamentous algae (*Spirogyra* sp.), alligatorweed (*Alternanthera philoxeroides*), and torpedograss (*Panicum repens*). Filamentous algae is a submerged aquatic vegetation that becomes buoyant in later stages of life and forms mats similar to water lettuce. Alligatorweed
and torpedograss are emergent aquatic vegetation but grow across the water surface forming mats similar to water lettuce. All species were considered FAV during the FAV surveys because they intermingled in mats blocking the water surface. All but duckweed and filamentous algae were sprayed with herbicide in treatment canals.

**Water Sampling and Analysis**

Discharge water composite samples were collected on a flow-weighted basis via refrigerated auto-samplers at each farm during pumping events and retrieved within 24 h of collection (Figure 4-1). Discharge water samples were kept on ice in coolers until transported to the laboratory for analysis.

Discharge water samples were analyzed for total P, total dissolved P (TDP), and soluble reactive P (SRP) by a continuous segmented flow analyzer (AutoAnalyzer 3, Seal Analytical Inc., Mequon, WI, USA) according to EPA method 365.1 (EPA, 2003). Samples for SRP and TDP were filtered through 0.45 µm membrane filters (Durapore, EMD Millipore Corp., Darmstadt, Germany) prior to P analyses. Samples for total P and TDP were preserved with sulfuric acid and digested by the ammonium-persulfate method (EPA, 2003) prior to analyses. Results for PP and dissolved organic P (DOP) were calculated according to Equations 4-1 and 4-2, respectively:

\[
PP = TP - TDP \tag{4-1}
\]

\[
DOP = TDP - SRP \tag{4-2}
\]

where PP = particulate P (mg/L), TP = total P (mg/L), TDP = total dissolved P (mg/L), DOP = dissolved organic P (mg/L), and SRP = soluble reactive P (mg/L).

Total suspended solids (TSS) concentrations were determined gravimetrically (APHA, 1998). Calcium (Ca) concentrations for water samples were analyzed with an inductively coupled plasma-optical emission spectrophotometer (ICP-OES 5300 DV, Perkins Elmer,
Waltham, MA, USA) used with an AS93 plus auto-sampler (Perkins Elmer) after acidification with nitric acid.

**Discharged Particulate Sediment Sampling and Analysis**

In order to estimate the P leaving farm canals during drainage events and contributing to the farms’ overall P loads, discharged particulate sediments were collected (Figure 4-1). During drainage events, autosamplers connected to two settling tanks captured discharged sediments. Samples were settled for 24 h, decanted, and transported to the laboratory for analysis. In the laboratory, samples underwent an additional settling and decant step after 24 h and 2 h in settling cones, prior to storage in plastic containers at 4°C.

After mixing each sectioned sample thoroughly, subsamples were taken to determine pH, organic matter, and total P. Measurement for pH were completed using a 1:2 soil to water ratio and using a Thermo Orion electrode pH meter (Model 720) (EPA 9045D). Organic matter was determined by loss on ignition (Soil Survey Laboratory Methods Manual, 2004). Total P was determined according to Anderson (1974) and EPA method 365.4 (EPA, 2003) after samples were ashed at 550°C for four hours and ground with a pestle and mortar.

**Sequential P-Fractionation Analysis**

Determination of P pools was done using a P fractionation sequence modified from the Hedley method by Reddy et al. (1998b). The modified fractionation scheme (KCl-NaOH-HCl) was used as described in Chapter 3.

**Statistical Analyses**

Statistical analyses were performed using SigmaPlot 13.0 (Systat Software, Inc., San Jose California USA). T-tests and Wilcoxon signed-rank tests were used to analyze data sets between treatment-control designations. Pearson correlations were done to assess the relationships
between FAV coverage, canal conditions, and canal water P species. Significance was assigned at p-value ≤ 0.05.

**Results**

**Percent FAV Cover**

As discussed in Chapter 3, percent FAV cover was not well maintained under the treatment (<25% cover) and control (>25% cover) requirements. Canals under treatment designations were not always kept under 25% cover and control canals had variable coverage from less than 5% to over 50%. Because of this, discharge water was not analyzed by aggregated treatment and control groups. Instead, treatment-control farm pairs were individually analyzed, and a percent FAV cover threshold value was tested based on water quality data.

**Discharged Canal Water**

Discharge canal water samples were collected during pumping events. Data were averaged by month and statistically analyzed using t-tests to compare treatment-control farm pairs. Some conditions, like rainfall, flow, and velocity, were similar among all farms. The average rainfall in treatment farms was 0.12 inches, and the average in control farms was 0.13 inches. The average discharge flow in treatment farms was 1.91 Mgallons, and the average in control farms was 2.69 Mgallons. The average velocity in treatment farms was 0.02 m/s and in control farms was 0.01 m/s, with an average maximum velocity of 0.03 m/s in both treatment and control farms.

Total P in the discharge water averaged 0.16 mg/L in treatment farms and 0.12 mg/L in control farms. Total dissolved P averaged 0.07 mg/L and 0.06 mg/L in treatment and control farms. The average PP in treatment farms was 0.08 mg/L, and the average in control farms was 0.09 mg/L. Soluble reactive P averaged 0.06 mg/L in treatment farms and 0.05 mg/L in control farms.
farm canals was 0.01 mg/L. The P load in treatment farms was 1.31 kg/month, and the average in control farms was 1.81 kg/month.

The average discharge water pH in treatment farms was 7.81, and the average in control farms was 7.72. The average Ca concentration was in treatment farms was 117.70 mg/L, and the average in control farms was 102.92 mg/L. The average TSS in treatment farms was 20.57 mg/L, and the average in control farms was 18.97 mg/L.

**Farm pair 3103 (T) - 3102 (C)**

Results from the statistical comparison of canal water characteristics for treatment farm 3103 and control farm 3102 are found in Figure 4-2, and for P speciation Figure 4-3. In farm pair 3103 (T) and 3102 (C), average FAV cover was lower in the treatment farm (16%) than the control farm (31%), and was significantly different. There were no significant differences in P speciation between treatment and control farms for averages of total P (0.19 mg/L (T) and 0.21 mg/L (C)), TDP (0.08 mg/L (T) and 0.10 mg/L (C)), PP (0.10 mg/L (T) and 0.11 mg/L (C)), SRP ((0.07 mg/L (T) and 0.09 mg/L (C)), or DOP (0.01 mg/L for T and C). The P load in 3103 (2.39 kg/month) was not significantly different from 3102 (2.97 kg/month).

Average pH was significantly higher in the treatment farm (7.80) than the control farm (7.63). The average Ca concentration was significantly higher in the treatment farm (122.58 mg/L), as compared to the control (103.38 mg/L). The TSS averaged 23.10 mg/L in the treatment farm, and was not significantly different from the average TSS in the control farm (22.42 mg/L).

**Farm pair 0401 (T) - 2501 (C)**

Results from the statistical comparison of canal water characteristics for treatment farm 0401 and control farm 2501 are found in Figure 4-4, and for P speciation Figure 4-5. In farm pair 0401 (T) and 2501 (C), average FAV cover was higher in the treatment farm (23%) than the
control farm (18%) and was not significantly different. There were no significant differences in P speciation between treatment and control farms for averages of total P (0.15 mg/L (T) and 0.14 mg/L (C)), TDP (0.07 mg/L (T) and 0.07 mg/L (C)), PP (0.08 mg/L (T) and 0.07 mg/L (C)), SRP ((0.06 mg/L (T) and 0.05 mg/L (C)), or DOP (0.01 mg/L for T and C). Average P load in 0401 was 1.15 kg/month, and the average in 2501 was 1.75 kg/month. There was no significant difference between 0401 and 2501 P load.

Average pH was significantly higher in the treatment farm (7.85) than the control farm (7.68). The average Ca concentration was significantly higher in the treatment farm (119.31 mg/L), as compared to the control (101.50 mg/L). The TSS averaged 26.59 mg/L in the treatment farm, and was not significantly different from the average TSS in the control farm (22.03 mg/L).

**Farm pair 4702 (T) - 4701 (C)**

Results from the statistical comparison of canal water characteristics for treatment farm 4702 and control farm 4701 are found in Figure 4-6, and for P speciation Figure 4-7. In farm pair 4702 (T) and 4701 (C), average FAV cover was statistically significantly lower in the treatment farm (7%) than the control farm (35%). There were no significant differences in P speciation between treatment and control farms for averages of total P (0.10 mg/L (T) and 0.12 mg/L (C)) or DOP (0.00 mg/L for T and C). There were significant differences in TDP (0.04 mg/L (T) and 0.03 mg/L (C)), PP (0.05 mg/L (T) and 0.09 mg/L (C)), and SRP ((0.04 mg/L (T) and 0.02 mg/L (C)). Treatment farm 4702 was significantly higher in TDP and SRP, and significantly lower in PP, than control farm 4701. There was no significant difference in P load between 4702 (0.40 kg/month) and 4701 (0.52 kg/month).

Average pH in the treatment farm (7.74) was not statistically different from the control farm (7.76). The average Ca concentration in the treatment farm (119.83 mg/L) was not
significantly different than the control farm (111.54 mg/L). The TSS averaged 15.59 mg/L in the
treatment farm, and was not significantly different from the average TSS in the control farm
(20.61 mg/L).

**Farm pair 6117 (T) - 1813 (C)**

Results from the statistical comparison of canal water characteristics for treatment farm
6117 and control farm 1813 are found in Figure 4-8, and for P speciation Figure 4-9. In farm pair
6117 (T) and 1813 (C), average FAV cover was higher in the treatment farm (19%) than the
control farm (3%) but was not significantly different. Treatment farm 6117 had significantly
higher values than control farm 1813 for all five P species, total P (0.18 mg/L (T) and 0.12 mg/L
(C)), DOP (0.015 mg/L (T) and 0.012 mg/L (C)), TDP (0.08 mg/L (T) and 0.06 mg/L (C)), PP
(0.10 mg/L (T) and 0.06 mg/L (C)), and SRP ((0.06 mg/L (T) and 0.05 mg/L (C)). There was no
significant difference in P load between 6117 (1.37 kg/month) and 1813 (1.19 kg/month).

Average pH in the treatment farm (7.79) was not statistically different from the control
farm (7.81). The average Ca concentration in the treatment farm (123.86 mg/L) was significantly
higher than the control farm (100.89 mg/L). The TSS averaged 22.84 mg/L in the treatment
farm, and was significantly different from the average TSS in the control farm (14.21 mg/L).

**Percent FAV Coverage Threshold**

Statistical analyses of farm conditions based on treatment-control designations may not
provide the most comprehensive results of the real impact of FAV suppression because the
percent FAV cover did not always follow the experimental design. A percent FAV cover
threshold was tested using all canal water data, and 5% FAV coverage was found to be a
statistical point at which FAV cover affected P species and some canal conditions that may
impact P removal.
Below the 5% FAV threshold, discharge water total P (0.14 mg/L) (Figure 4-10A), PP (0.08 mg/L) (Figure 4-10C), and DOP (0.001 mg/L) (Figure 4-10E) were significantly lower than total P (0.16 mg/L), PP (0.09 mg/L), and DOP (0.002 mg/L) above 5%. There was no significant difference in TDP (Figure 4-10B) or SRP (Figure 4-10D) in discharge water at the 5% FAV cover threshold. There was also no significant differences in the water pH (Figure 4-11A) or TSS (Figure 4-11C). Calcium concentration (Figure 4-11B) was significantly higher above the 5% FAV cover threshold.

**Correlation Analysis**

A Pearson correlation analysis was conducted on monthly averages of discharge water samples to compare P species and canal conditions (Table 4-1). The percentage of FAV cover was not significantly correlated with any P species. Discharge water total P was negatively correlated with average air temperature, solar radiation, and pH. Total P was also positively correlated with TSS and flow. Similarly, discharge water PP was negatively correlated with solar radiation, and positively correlated with TSS. Discharge water TDP was also negatively correlated with average temperature and pH, and positively correlated with rain and flow. Discharge SRP was positively correlated with rain and flow, and negatively correlated with pH. Discharge water DOP was negatively correlated with solar radiation, and positively correlated with flow.

As air temperatures in the area decreased and there was less sunlight, for example during winter conditions, discharge water total P, PP, TDP, and DOP increased. And as TSS and flow increased, there was an increase in total P, PP, TDP, SRP, and DOP. These relationships could represent FAV mats dying back in the winter months and releasing stored P into the water column (Granéli & Solander, 1988).
Phosphorus load was positively correlated with total P, TDP, SRP, and DOP. As the P species increase, the P load also increases. This is expected because P load is calculated from total P and flow. Velocity was not significantly correlated to any P species, suggesting that the speed of water movement was not as important as the volume. These relationships suggest that hydrology, like rain and flow, is highly influential.

**Discharge Sediments**

Discharge sediments were collected in the 2015 wet season and 2016 dry season. A total of 33 samples were collected from all eight farms during pumping events. Samples were analyzed by treatment and control designations and by wet versus dry season. Drainage pumps are primarily used during the wet season (April-Nov). Dry season (Dec-March) samples may provide insight into the flocculent sediment discharged after the FAV growing season and dieback period.

The percent FAV cover was not significantly different between treatment and control farms during the period of discharge sediment collection (Figure 4-12A). There was also no significant difference in FAV cover when wet season was compared to dry season (Figure 4-13A). In treatment farms, average total P in discharged sediments was 2396 mg/kg (range 1,138 to 5,600 mg/kg), significantly higher than in control farms, which averaged a total P of 1,745 mg/kg (range 968 to 3,317 mg/kg) (Figure 4-12B). Compared to canal sediment (Chapter 3), total P discharged from the canals during drainage events was almost two times greater than canal sediment. In the wet season, total P averaged 2,167 mg/kg (range 968 to 3,237 mg/kg), which was significantly higher than dry season average total P of 1,927 mg/kg (range 1,117 to 5,600 mg/kg) (Figure 4-12C).

In treatment canals, organic matter averaged 53% (range 33 to 69%) in discharged sediments, while in control farms it averaged 47% (range 29 to 68%), and results were not
significantly different (Figure 4-12C). Compared to canal sediment (Chapter 3), organic matter in discharged sediment was greater than canal sediments, which averaged 39%. In the wet season, organic matter averaged 46% (range 29 to 69%), while in the dry season it averaged 54% (range 39 to 69%) and was significantly different (Figure 4-13C).

There was no significant difference in discharge sediment pH between treatment (7.20) and control (7.18) farms (Figure 4-12D). In the wet season, pH averaged 7.18 and in the dry season pH averaged 7.23, and was also not significantly different (Figure 4-13D). Discharged sediments had a lower average pH compared to the average canal sediment pH 7.42 (Chapter 3).

**Discharge Sediment P Fractionation**

The labile P was the smallest fraction for all farms. There was a significantly higher amount of labile P in treatment farms (183 mg/kg) than control farms (70 mg/kg) (Figure 4-14A). Iron-aluminum bound P values averaged 355 mg/kg in treatment farms and 272 mg/kg in control farms. There was a significant difference between canals for the Fe-Al bound P pool (Figure 4-14B), with treatment canals having significantly higher values than control canals. Humic-fulvic bound P averaged 353 mg/kg in treatment farms and 177 mg/kg in control farms. The largest pool was the Ca-Mg bound P, which averaged 845 mg/kg in treatment farms and 573 mg/kg in control farms. There were no significant differences in treatment versus control canals in humic-fulvic bound P (Figure 4-14C) or Ca-Mg bound P (Figure 4-14D). Residue P averaged 390 mg/kg in treatment farms and 222 mg/kg in control farms. There was a significant difference between canals for the residue pool (Figure 4-14E), with treatment canals having significantly higher values than control canals.

Similar to the canal sediment P data from Chapter 3, the discharged sediment data was normalized into percent of total P in order to compare the values. Discharge sediment labile P averaged 6% of the total P, while in the canal sediment the average labile P was 2%. Iron-
aluminum $P_i$ averaged 19% in the discharged sediments, as compared to 8% in canal sediment. Humic-fulvic bound $P_o$ in discharged sediments averaged 15% and averaged 11% in canal sediment. In discharge sediments, Ca-Mg bound $P_i$ averaged 42%, and the pool averaged 56% in canal sediments. Finally, residue $P$ in discharged sediments averaged 17%, and canal sediments averaged 24% residue $P$. Discharge sediment was higher in labile $P$ and lower in recalcitrant $P$ than canal sediments.

**Discussion**

**Percent FAV cover**

This experiment was designed to assess the effects of FAV suppression on P removal in EAA farms. Treatment farms were expected to have FAV cover suppressed below 25% coverage, whereas control farms were left to the management of the farmer. Percent FAV cover did not differ significantly when analyzing between all treatment and control farms. It also did not differ between the wet and dry season. Because FAV seeding was not an option, one of the most pervasive problems throughout the experiment stemmed from a lack of appropriate FAV cover in treatment and control farm canals. Additionally, while water lettuce was the most common FAV in the canals, some species, notably duckweed and filamentous algae, were counted towards overall percent coverage but were not sprayed with herbicide due to their transient nature. That meant treatment farms were not always kept below the 25% cover.

Due to the inconsistency of FAV cover within the treatment and control designations, statistically analyzing the results by the measured percent FAV cover (rather than an assumed range) gave more reliable results in relations to effects of FAV presence or absence. While the 25% FAV cover was tested as a threshold for its effect on discharge total $P$, it was not statistically significant. Threshold values from 0 to 45% FAV cover, in 5% increments, were tested, and 5% was the only value to have a significant impact on a proportion of discharge $P$. 
species. Canal discharge sediments and canal sediments were also tested for an FAV percent cover threshold, but no coverage value was significant with respect to total P or other species of P.

**Canal Discharged Water**

Analyzing the P load from canals, there were no significant differences between canals when evaluating by treatment-control designations, within farm pairs, or using the 5% FAV cover threshold. The dominant factor controlling P load is the amount of water pumped off-farm, rather than manipulation of FAV cover. Because there were lower total P concentrations in the FAV suppressed farms, if both treatment and control farms had pumped the same volume, the significant difference in P load should be maintained. More extensive analysis needs to be conducted to assess the most significant factors affecting P load, but because FAV suppression had no significant influence, there was no support for research Question 4-1 that FAV suppression would reduce P load.

When looking at the water leaving the canals, there were significantly lower concentrations of total P and PP values when percent FAV cover was below 5%. This supports research Question 4-2 that suppressing FAV will result in lower PP discharged from canals.

The relationship between the canal water and sediment is essential to assessing the cycling of P in these farm canals. Canal P is carried by water, adsorbed to sediment, taken up by FAV, and precipitated with minerals. When assessing P removal by FAV uptake, there may be a change in the portion of P absorbed to sediment and P in the water column. The EPC values calculated in Chapter 3 ranged from 0.19 to 1.48 mg/L, meaning that as the concentration of P at the sediment-water interface decreases below the EPC value, the sediment has a higher potential to release sediment absorbed P into the water column. For all farm canals, EPC values were higher than total P and SRP values, signifying that the canal sediments had the potential to
release P into the water column. Treatment farms tended to have higher EPC values than control farms (Table 3-9), so lowering the canal water P concentrations may have resulted in more P released from these sediments. The sediment P and EPC values, which may be a result of the long-time P sediment loading due to agricultural practices in the historically oligotrophic area, may be affecting water P concentrations beyond the impact of FAV suppression. This influence may be the reason statistical comparisons between treatment and control farms resulted in higher values for some treatment canals. Because analyzing by FAV cover thresholds took away the EPC variable by mixing all farms, and therefore all EPC values, together, the FAV suppression effect on water quality was apparent.

**Discharged Sediment**

Discharge sediments were higher in total P and P fractions than canal sediments (Chapter 3). Wet season total P was higher than dry season total P, and treatment canals were higher than control farms. Research Question 4-3, stating that suppressing FAV will reduce total P in discharged sediment, cannot be supported or rejected because too few data points were collected to result in statistical significances. The 5% FAV cover threshold was tested but there were too few data points collected for the analysis to be representative. Because PP from canal bottoms discharged with canal water has been found to be composed of up to 50% newly deposited detrital matter (Stuck, 1996; Izuno and Rice, 1999; Daroub et al., 2005; Daroub et al., 2012), more data points should be collected in the future to be able to determine whether or not FAV suppression on a 5% threshold affects total P in discharge sediment.

**Conclusion**

The percent cover designation for this experiment was set as a level considered reasonable for farmers to achieve (<25%), but the percent cover actually found in the two designations did not accurately represent the treatment designation or true control conditions.
Flaws in the experimental design, namely the lack of FAV cover control in treatment farms and restrictions on seeding FAV in control farms, resulted in farm canal designations being unrepresentative of FAV effects on water properties. The 5% coverage threshold will better guide future management strategies for suppressing FAV. If farms are to be evaluated in a paired design in the future, the experimental design needs to be restructured so that control farms have zero FAV cover and treatment farms are maintained at higher coverage to analyze overall impacts of FAV suppression. Also, many farmers allow FAV coverage up to 100% with a mass herbicide application before pumping to increase water flow efficiency. In the future, samples should be taken before, within 24 hrs, 48 hrs, and during the first pumping after a mass herbicide application to assess whether or not it is affecting discharge water P concentrations and P load.

Farmers are evaluated on discharged canal water total P for assessing P load reductions from the EAA basin, but another important contributor to P load is the discharge sediments. Discharged sediment was higher in total P and organic matter than canal sediments because the lightweight, flocculent sediment carried with the moving canal water is most likely derived from nutrient-rich detrital matter. Also, as shown in Chapter 3, some canal sediments are innately higher in total P values than others, so their discharged sediments would be expected to also be higher in total P. More discharge sediment samples need to be collected in order to analyze effects of FAV suppression on sediments leaving canals on a farm by farm basis.

Canal water was more reactive to changes in FAV cover than sediments, with lower total P and PP concentrations when suppressing FAV. The fact that the P load for each canal was not affected by FAV suppression may be a result of stronger influences by hydrology, like flow, velocity, or rain. Although P load was not reduced with FAV suppression, the reduction in total P and PP concentrations can give farmers a way to improve their water quality on a per volume
basis. Canal management by farmers may need to focus more on volume of discharge water if their goal is to reduce P load, which was corroborated by relevant literature from the area. While past research has shown the importance of PP on P load, that relationship was not seen in this discharge water data. A multivariate analysis should be performed to assess what factors influence P load, as well as P species concentrations. Ultimately, this study found that suppressing FAV cover to less than 5% did reduce total P and PP concentrations in water discharged from canals and lowered the dissolved P in ambient canal waters. This reduction, in conjunction with other BMPs and data from mass herbicide application events, may incentivize farmers to adopt the practice of year-round FAV suppression.
Figure 4-1. Farm water and discharged sediment sampling schematic. Transects A, B, and C were for ambient water every two weeks when pumps are not on. Discharged water samples were taken at pump house every time pump was active. Discharged sediment samples were also collected during pumping.
Figure 4-2. Box plots of canal discharge water conditions of farms 3102 and 3103. A) Percent FAV cover. B) Total P load. C) pH. D) Calcium concentration. E) Total suspended solids. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 4-3. Box plots of canal discharge water P species of farms 3102 and 3103. A) Total P concentration. B) Total dissolved P concentration. C) Particulate P concentration. D) Soluble reactive P concentration. E) Dissolved organic P concentration. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus. (C) = control farm, (T) = treatment farm.
Figure 4-4. Box plots of canal discharge water conditions of farms 2501 and 0401. A) Percent FAV cover. B) Total P load. C) pH. D) Calcium concentration. E) Total suspended solids. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 4-5. Box plots of canal discharge water P species of farms 2501 and 0401. A) Total P concentration. B) Total dissolved P concentration. C) Particulate P concentration. D) Soluble reactive P concentration. E) Dissolved organic P concentration. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus. (C) = control farm, (T) = treatment farm.
Figure 4-6. Box plots of canal discharge water conditions of farms 4701 and 4702. A) Percent FAV cover. B) Total P load. C) pH. D) Calcium concentration. E) Total suspended solids. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farm, (T) = treatment farm.
Figure 4-7. Box plots of canal discharge water P species of farms 4701 and 4702. A) Total P concentration. B) Total dissolved P concentration. C) Particulate P concentration. D) Soluble reactive P concentration. E) Dissolved organic P concentration. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus. (C) = control farm, (T) = treatment farm.
Figure 4-8. Box plots of canal discharge water conditions of farms 1813 and 6117. A) Percent FAV cover. B) Total P load. C) pH. D) Calcium concentration. E) Total suspended solids. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farms, (T) = treatment farms.
Figure 4-9. Box plots of canal discharge water P species of farms 1813 and 6117. A) Total P concentration. B) Total dissolved P concentration. C) Particulate P concentration. D) Soluble reactive P concentration. E) Dissolved organic P concentration. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus.
Figure 4-10. Box plots of discharge water P species with less than and greater than 5% FAV cover. A) Total P concentration. B) Total dissolved P concentration. C) Particulate P concentration. D) Soluble reactive P concentration. E) Dissolved organic P concentration. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. N = 102 FAV <5%, N = 209 FAV >5%. P = phosphorus.

Figure 4-11. Box plots of discharge water properties with less than and greater than 5% FAV cover. A) pH. B) Calcium concentration. C) Total suspended solids. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. N = 102 FAV <5%, N = 209 FAV >5%.
Figure 4-12. Box plots of discharge sediment properties by treatment and control. A) Percent FAV cover. B) Total P concentration. C) Organic Matter. D) pH. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. (C) = control farms, (T) = treatment farms.
Figure 4-13. Box plots of discharge sediment properties by season. A) Percent FAV cover. B) Total P concentration. C) Organic Matter. D) pH. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, FAV = floating aquatic vegetation. Dry season = December-April, Wet season = May-November.
Figure 4-14. Box plots of discharge sediment P fractionation by treatment and control. A) Labile P. B) Fe-Al bound P. C) Humic-fulvic bound P. D) Ca-Mg bound P. E) Residue P. T-tests were performed to determine significant differences in treatment and control groups, as designated by (a) and (b). Boxes represent the median and interquartile range, whiskers represent the 10th and 90th percentiles, and dots represent values outside the 10th and 90th percentiles. P = phosphorus, Fe = iron, Al = aluminum, Ca = calcium, Mg = magnesium. (C) = control farms, (T) = treatment farms.
Table 4-1. Pearson correlation of FAV cover, P species, and canal conditions from May 2013 to June 2016

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<th>PP</th>
<th>SRP</th>
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Top: Correlation coefficient; middle: N number of data points; bottom: p-value (significance < 0.05). * p < 0.05, ** p < 0.01, *** p < 0.001
P = phosphorus; TDP = total dissolved P; PP = particulate P; SRP = soluble reactive P; DOP = dissolved organic P; TSS = total suspended solids; Ca = calcium
CHAPTER 5
QUANTIFYING FLOATING AQUATIC VEGETATION SUPPRESSION IMPACTS ON PHOSPHORUS CYCLING IN EVERGLADES AGRICULTURAL AREA IRRIGATION AND DRAINAGE CANALS

Introduction

The Everglades Agricultural Area (EAA) is subject to unique regulations regarding phosphorus (P) abatement in discharged water from farm canals. The Everglades Forever Act of 1994 requires farmers to work with researchers to establish new methods of reducing P loads, so as to meet P abatement requirements. Suppression of floating aquatic vegetation (FAV) in farm canals is a method that was tested for its ability to affect P in canal sediment (Chapter 3) and discharge water (Chapter 4). While canal sediment did not respond to FAV suppression, canal water did show a reduction in total P and particulate P (PP) concentrations in discharged waters. Reduction in total P concentration in discharge water shows promise in the ability of this practice to reduce P exported from the EAA basin.

To test whether this method could be effective beyond the study farms, development of a means to simulate this relationship via hydrologic models is promising. Models allow for the study of systems that would otherwise be impossible or impractical. A model may be very simple and composed of one equation, or it may contain multiple equations designed to replicate complex relationships (Castaings et al., 2009). Simulations are conducted by using the model to better understand a system by conducting experimental changes and evaluating the changes in key variables (Jørgensen, & Bendoricchio, 2001). It is difficult to quantitatively measure FAV impacts on P cycling through direct measurement (Eid et al., 2016), but a model can synthesize the measured parameter data within the experimental canals and estimate impacts. The simplified relationship of FAV and P cycling in the farm canals is depicted in Figure 5-1 derived from experimental conditions from Chapter 4. Six data parameters were selected to represent these
processes: FAV coverage, FAV biomass total P, discharge water total P, flow, P load, and sum P load. Sum P load is the sum of P load over a month, while P load is the average P load within a month. The inclusion of both parameters was an attempt to capture any variation by month that may have occurred.

There are few models available that attempt to simulate FAV nutrient cycling, with those existing focusing on carbon (Eid et al., 2016) or eutrophication potential (Volpert, 2010). This study aims to identify hydrological factors controlling FAV suppression effects on P cycling in EAA farm canal water by creating multivariate linear equations based on measured data that reflect changes in key parameters. The formulation of these equations will be useful in that they can be integrated into larger watershed models, like the Soil and Water Assessment Tool (SWAT) developed by USDA Agricultural Research Service (Arnold et al., 1998; Neitsch et al., 2005), which currently restrict P cycling to erosion/sedimentation rate and algal growth.

Methods

Input Data

FAV surveying and sampling

Field data was collected from May 2013 to June 2016 in EAA drainage canals, as described in Chapters 3 and 4. Percent FAV cover was recorded every two weeks, with FAV biomass samples collected every two months and analyzed for total P. Biomass samples were collected, weighed for wet weight, and dried at 55°C for one week. Dry FAV were again weighed for dry weight, then ground and samples sent to the Analytical Research Laboratory in Gainesville, FL for leaf tissue P concentration analysis using EPA method 200.7 (EPA, 2003).

Water sampling and analysis

Discharge and ambient water was collected as described in Chapter 4. Samples were analyzed for total P, total dissolved P (TDP), and soluble reactive P (SRP). Particulate P was
calculated by subtracting TDP from total P, and dissolved organic P (DOP) was calculated by subtracting SRP from TDP. Total suspended solids (TSS), calcium (Ca), and pH was also measured for each water sample collected.

**Environmental conditions**

Rainfall data were collected at each farm pump station, as well as flow volume and average and maximum velocity. Phosphorus load was calculated by multiplying measured total P concentration data by flow volume. Daily solar radiation and minimum, average, and maximum temperature data was retrieved from the University of Florida’s Institute of Food and Agricultural Sciences (UF/IFAS) Florida Automated Weather Network (FAWN) database (https://fawn.ifas.ufl.edu/data/) from the Belle Glade, FL weather station.

**Statistical Analyses**

Correlation and regression statistical analyses were performed on collected data using SigmaPlot 13.0 (Systat Software, Inc., San Jose California USA) and SAS 9.3 (SAS Institute, Inc., Cary, NC USA). Descriptive statistics were calculated for all variables in the study, including number of samples (N), mean, standard deviation, median, minimum, and maximum (Table 5-1). A Pearson correlation coefficient analysis was performed to assess the strength of the linear relationship between variables (Ott & Longnecker, 2004). The Pearson correlation coefficient is determined by dividing the covariance of the two variables by the product of their standard deviations. A negative value means there is a negative linear relationship, while a positive value denotes a positive linear association between the two variables.

Once the correlation analysis was completed, a multivariate linear regression analysis was performed for each of the six selected parameters for farm pair 4701-4702 and all farm aggregated data. The parameters were chosen as functions representing impacts on canal P cycling due to FAV. Farm pair 4701-4702 was selected because it best represented high FAV
cover and low FAV cover for the entirety of the experiment. Multivariate linear regression is a statistical method used when wanting to test multiple response variables, or dependent variables, over one or more predictors, or independent variables. This type of analysis allows for the viewing of numerous dependent variables of interest within the same larger data set as related to each other. The multivariate regression analysis results in linear equations with independent variables correlated with the dependent variables and correlation coefficients. Multivariate linear regression analyses were performed for each of the six dependent parameters (percent FAV coverage, FAV biomass total P, discharge water total P, flow, P load, and sum P load) using the experimental data variables.

**Sensitivity Analysis**

A sensitivity analysis was then performed to identify the factors that significantly influence outputs and quantify the influence (Cariboni et al., 2007). A sensitivity analysis is done by changing the parameters within the equation model and observing the corresponding change in selected data variables, following the Equation 5-1 (Jørgensen & Bendoricchio, 2001):

\[
S = \left( \frac{\partial P}{\partial x} \right) / \left( \frac{\partial x}{x} \right) 
\]

where \( S \) is the sensitivity, \( P \) is the parameter being tested, and \( x \) is the data variable of interest. This equation uses partial derivatives (\( \partial \)), which is defined as the derivative of multiple variables when all variables but the variable of interest are fixed during the differentiation (Jørgensen & Bendoricchio, 2001). It looks at how large the change in output data for one variable is when holding all other variables within the parameter equation fixed.

The analysis compares the response rates of variables of interest to changes in input. Because the independent data used as the input variables are measured in different units or on
different scales, input variables are normalized by dividing the difference in range by the input change, as shown in Equation 5-2:

$$S = [(Max_x - Min_x) / \bar{x}]$$  \hspace{1cm} (5-2)

where $S$ is the sensitivity and $x$ is the variable of interest. Combining Equations 5-1 and 5-2 into Equation 5-3 results in the normalized sensitivity of the equation parameter to the variable of interest.

$$S = \left[\frac{(Max_p - Min_p) / \bar{P}}{(Max_x - Min_x) / \bar{x}}\right]$$  \hspace{1cm} (5-3)

where $S$ is the sensitivity, $P$ is the equation parameter being tested, and $x$ is the variable within the equation. Ultimately, the sensitivity analysis creates a ratio of a normalized change in the dependent variable to the normalized change in the independent variable. This ratio can range widely, depending on the data relationship. This calculation is repeated for each variable within the parameter equation and shows to what the parameter being tested is most sensitive. The resulting number shows by how much the parameter is affected by the variable, which can be compared to the other variables included in the parameter equation. The variable with the highest sensitivity value is the most influential.

**Results**

Based on the model design (Figure 5-1), six parameters were selected to represent how FAV influences P cycling in EAA farm canals: percent FAV coverage, FAV biomass total P, discharge water total P, flow, P load, and sum P load. Inflow of P (Figure 5-1[1]) is a measured value (mg/L) and considered as the variable ambient total P. The inflow value includes all P sources, like organic matter oxidation, erosion/sedimentation, fertilizers, P flux from sediment, or atmospheric deposition that may be difficult to measure individually. Phosphorus uptake (Figure 5-1[2]) by FAV is defined as the parameter FAV biomass total P and is measured in mg/kg. Percent FAV cover (Figure 5-1[3]) is the overall FAV cover in the canal and is
considered to represent FAV growth. Both FAV biomass total P and percent FAV cover are considered the factors directly affecting canal environment and P cycling. Phosphorus release (Figure 5-1[4]) occurs with changes to FAV biomass and FAV cover, but it was not a measured value and was considered a represented function within the data variable ambient water total P. Sorption and desorption of P with the canal sediments was not measured in this study and was considered a represented function within the data variable ambient water total P. Future work should reanalyze the data to include P flux from sediments to see if it is a dominant variable or one that is already captured by the ambient total P data variable. Phosphorus outflow (Figure 5-1[7]) is the main parameter of concern and was estimated with three parameters. The first, discharge water P concentration (mg/kg), was a measured value. From this value, average P load (in kg) per month was calculated by multiplying by flow during pumping. The third parameter, P load sum, was the total P load per month. Data variables considered to influence these parameters were temperature (average, minimum, and maximum), rain, solar radiation, P inflow (ambient water total P), flow, and velocity of discharge canal water (average and maximum).

**Pearson Correlation Coefficient Analysis**

The Pearson correlation coefficient analysis was performed to determine which variables were significantly correlated with each of the six parameters. The results of the analysis are in Table 5-2. Each of the six parameters had correlating variables interrelating to each other, and all relationships found to be statistically significant were positive relationships. Percent FAV cover was significantly positively correlated with FAV biomass total P, temperature (average, minimum, maximum), and solar radiation. As temperature and solar radiation increased, percent FAV cover and P uptake also increased. Floating aquatic vegetation have higher growth rates and P uptake with warmer temperatures (Boyd, 1971; Menon & Holland, 2014) and higher solar radiation (Eid et al., 2016), so the positive correlation of temperature, solar radiation, and FAV
TP with percent FAV cover supports results found in the literature (Boyd, 1971; Menon & Holland, 2014; Eid et al., 2016).

The FAV biomass total P parameter was positively significantly correlated with temperature (average, minimum, and maximum). As the temperature increases, promoting plant growth (Dewald & Lounibos, 1990), total P stored in the plant tissues increases. Biomass total P also was positively correlated with percent FAV cover, discharge water total P, P load, and P load sum. Some species of FAV, like the dominant water lettuce in the study canals, have increased growth and biomass P with increased nutrient load (Howard & Haley, 1997). The positive relationship between FAV biomass and discharge total P reflects the relationship found in the literature that FAV P uptake increases with nutrient concentration in the water (Howard & Haley, 1997). Biomass FAV total P also was positively significantly correlated with flow, which may be a result of refreshed sources of P flowing through the suspended roots or it could be a secondary relationship of flow with discharge total P.

Flow was positively significantly correlated with discharge total P, P load, and sum P load. As flow increased, total P concentration also increased. Because P load and P load sum were calculated from flow and total P concentration, the statistical significance of these variables is circular and disregarded. Flow was also positively significantly correlated with temperature (average, minimum, and maximum), rain, and FAV biomass total P. The growing season, with higher temperatures, is also the rainy season, which is when higher rates of canal pumping occurs. Flow increased in the warmer months with increased rain with higher concentrations of total P in the canal water. Flow was also positively significantly correlated with average and maximum velocity. That meant, as the volume of water per unit time increased, the speed at which the water moved increased.
Discharge water total P was positively significantly correlated with FAV biomass total P, inflow total P, and flow. As FAV biomass P decreased, discharge water total P decreased as well. That could be because the inflow total P also decreased, so as the P concentration in the canals went down, the P uptake into FAV biomass and P discharged with drainage water decreased as well. That means the P concentration of discharge water is dependent on influx of P coming into the canal and the volume of water leaving the canals. Discharge water total P was used to calculate P load and P load sum, so the significance of these two variables was excluded as significant.

Phosphorus load and sum P load were both significantly positively correlated with rain and average and maximum velocity. As the amount of rain and speed of water discharged increased, the P load and P load sum also increased. There was also a significant positive correlation with FAV biomass total P. That means as the uptake of P by FAV decreased, the P load and P load sum also decreased. These two variables were most related to the amount of rain and average velocity of water leaving the canals. Flow and discharge water total P were used to calculate P load and P load sum and were therefore excluded as significant.

**Multivariate Linear Regression Analysis**

To assess the influence of the variables correlated with the six key parameters, a stepwise multivariate linear regression analysis was conducted. The goal of the multivariate regression analysis was to create equations that represent the effects of FAV on P cycling in EAA canals. To do this, the regression analysis was performed over all farms, then on farm pair 4701 (C) and 4702 (T) which best represented FAV suppression in treatment farm and growth in control farm (Chapter 4). The resulting parameter equations for all farms is in Table 5-3, farm 4701 (C) in Table 5-4, and farm 4702 (T) in Table 5-5. Correlations were weaker when considering all farms, as opposed to individual treatment farm and control farm which was expected because of the
high variability in the different farm characteristics and conditions, as discussed in Chapters 3 and 4. All variables correlated to parameters were positively correlated, except in treatment farm 4702 where crop (sugarcane) was negatively correlated with discharge water total P.

For parameter sum P load, rain and velocity were important variables for all farms ($R^2 = 0.63$) and the control ($R^2 = 0.80$) and treatment ($R^2 = 0.94$) farms. This suggests that the nutrient transport is closely associated with hydrology and flow hydraulics. Some previous work done in the EAA basin also concluded that P load is most influenced by rainfall, pumping velocity, and pumping to rainfall ratios (Lang et al., 2010). Similarly for parameter P load, rain and velocity were highly correlated in all farms ($R^2 = 0.63$) and the control ($R^2 = 0.81$) and treatment ($R^2 = 0.94$) farms. When considering over all farms, inflow P was also an important variable associated with sum P load and P load.

Rain was the most highly associated variable for the flow parameter in all farms ($R^2 = 0.40$), control farm 4701 ($R^2 = 0.51$), and treatment farm 4702 ($R^2 = 0.97$). Because rain is required for farmers to turn their pumps on, it was expected for rain to be correlated with flow. In treatment farm 4702 suppressing FAV, P load and velocity were also associated with flow. This again reiterates that nutrient transport was closely associated with hydrology.

In all farms, variables inflow P and FAV biomass total P made up the linear equation that best determined the parameter discharge total P ($R^2 = 0.18$). Control farm 4701 allowing farmer-management of FAV, percent FAV cover and inflow P were the associated variables accounting for discharge total P ($R^2 = 0.87$). In treatment farm 4702 suppressing FAV, crop type (sugarcane) was the only associated factor with discharge total P ($R^2 = 0.11$). Percent FAV cover was highly correlated with discharge P in the control farm where FAV was not suppressed.
Percent FAV cover was correlated with solar radiation and FAV biomass total P over all farms ($R^2 = 0.44$). This follows the Pearson correlation analysis and published literature, that solar radiation and nutrient uptake affect FAV growth (Center & Spencer, 1981). In both the treatment farm 4702 and control farm 4701, percent FAV cover was correlated with FAV biomass total P ($R^2 = 0.25$ and $0.76$, respectively). When suppressing FAV, the correlation between FAV cover and FAV total P is significant but weak ($R^2 = 0.25$), which means FAV suppression affected the relationship with FAV biomass total P.

The FAV biomass total P (FAV total P) was weakly correlated ($R^2 = 0.05$) with maximum temperature over all farms. When suppressing FAV in treatment farm 4702, FAV biomass total P was weakly correlated with percent FAV cover ($R^2 = 0.25$). And in control farm 4701 allowing FAV growth, FAV biomass total P was highly correlated ($R^2 = 0.95$) with average temperature and percent FAV cover. Biomass total P of FAV is closely associated with percent FAV cover, which is then correlated with temperature and solar radiation.

From these equations, it seems FAV biomass total P, or P uptake, is more influenced by air temperature, and percent FAV cover is more associated with solar radiation. Again, this agrees with what was found in the literature that temperature increases nutrient uptake (Howard & Haley, 1997), and solar radiation is an important factor in leaf area and plant growth (Center & Spencer, 1981; Eid et al., 2016). When FAV is suppressed, the relationships break down and percent FAV cover and FAV biomass total P are only weakly associated with each other. When FAV is allowed to grow, discharge total P is correlated with percent FAV cover, but P load and P load sum are not. Phosphorus load and sum P load were highly related with rain and velocity, suggesting the hydrology in the area is more important than FAV management.
Sensitivity Analysis

All farms equations

The results from the sensitivity analyses for the six parameter equations over all farms are found in Table 5-6. The resulting number is the ratio of the parameter to the data variable, as shown in Equation 5-3. Parameter sum P load had three independent data variables, maximum velocity, rain, and ambient water total P. Maximum velocity had a sensitivity of 0.959, rain was 0.165, and ambient water total P was 0.167. That means sum P load was five to six times more sensitive to maximum velocity than rain and ambient water total P, making maximum velocity the dominant independent data variable.

Parameter P load also had three independent data variables, maximum velocity, rain, and ambient water total P. Maximum velocity had a sensitivity of 0.961, rain was 0.173, and ambient water total P was 0.168. Similar to sum P load, P load was five to six times more sensitive to maximum velocity than rain and ambient water total P, making maximum velocity the dominant independent data variable.

Parameter flow had one independent variable, rain. Rain had a sensitivity of 1.011. With no other data variables in the equation, rain was the dominant independent data variable affecting the flow output.

For the parameter discharge water total P, there were two independent data variables, ambient water total P and FAV total P. Ambient water total P had a sensitivity of 0.457 and FAV total P was 0.152. Discharge water total P was three times more sensitive to ambient water total P than FAV total P, making ambient water total P the dominant independent data variable.

Parameter percent FAV cover had two independent data variables, solar radiation and FAV total P. Solar radiation had a sensitivity of 0.845 and FAV total P was 0.757. Percent FAV
cover was slightly more sensitive to solar radiation than FAV total P, making solar radiation the dominant independent data variable.

Lastly, parameter FAV total P had one independent data variable, maximum temperature. Maximum temperature had a sensitivity of 6.628. With no other data variables in the equation, maximum temperature was the dominant independent data variable affecting output FAV total P.

**Control farm 4701 equations**

The results from the sensitivity analyses for the six parameter equations for control farm 4701 are found in Table 5-7. Parameter sum P load had two independent data variables, average velocity and rain. Average velocity had a sensitivity of 0.972 and rain was 0.236. Sum P load was four times more sensitive to average velocity than rain, making average velocity the dominant independent data variable.

Parameter P load also had two independent data variables, average velocity and rain. Average velocity had a sensitivity of 0.976 and rain was 0.263. Similar to sum P load, P load was three times more sensitive to average velocity than rain, making average velocity the dominant independent data variable.

Parameter flow had one independent data variable, rain. Rain had a sensitivity of 1.100. With no other data variables in the equation, rain was the dominant independent data variable affecting output flow.

Parameter discharge water total P had two independent data variables, ambient water total P and percent FAV cover. Ambient water total P had a sensitivity of 0.742 and percent FAV cover was 0.887. Discharge water total P was slightly more sensitive to percent FAV cover than ambient water total P, making percent FAV cover the dominant independent data variable.
Parameter percent FAV cover had one independent data variable, FAV total P. Floating aquatic vegetation total P sensitivity was 1.312. With no other data variables in the equation, FAV total P was the dominant independent data variable affecting percent FAV cover.

Lastly, parameter FAV total P had two independent data variables, average temperature and percent FAV cover. Maximum temperature had a sensitivity of 4.773 and percent FAV cover was 1.085. Floating aquatic vegetation was four times more sensitive to average temperature than percent FAV cover, making average temperature the dominant independent data variable.

**Treatment farm 4702 equations**

The results from the sensitivity analyses for the six parameter equations for treatment farm 4702 are found in Table 5-8. Parameter sum P load had two independent data variables, average velocity and rain. Average velocity had a sensitivity of 0.975 and rain was 0.231. Sum P load was four times more sensitive to average velocity than rain, making average velocity the dominant independent data variable.

Parameter P load also had two independent data variables, average velocity and rain. Average velocity had a sensitivity of 0.975 and rain was 0.231. Similar to sum P load, P load was four times more sensitive to average velocity than rain, making average velocity the dominant independent data variable.

Parameter flow had four independent data variables, rain, P load, average velocity, and maximum velocity. Rain had a sensitivity of 0.389, P load was 1.003, average velocity was 0.295, and maximum velocity was 0.102. Flow was two to three times more sensitive to P load than rain and average velocity, and nine times more sensitive than maximum velocity, making P load the dominant independent variable.
Parameter discharge water total P had one independent data variable, sugarcane. Sugarcane had a sensitivity of 0.192. With no other data variables in the equation, sugarcane was the dominant independent data variable affecting output discharge water total P.

Parameter percent FAV cover had one independent data variable, FAV total P. Floating aquatic vegetation total P sensitivity was 0.888. With no other variables in the equation, FAV total P was the dominant independent variable affecting percent FAV cover.

Lastly, parameter FAV total P also had one independent variable, percent FAV cover. Percent FAV cover sensitivity was 0.827. With no other variables in the equation, percent FAV was the dominant independent variable affecting percent FAV cover.

**Discussion**

From the equations generated using the multivariate linear regression analysis, it seems FAV biomass total P (P uptake) is more influenced by air temperature, and percent FAV cover is more associated with solar radiation. This again agrees with what was found in the literature that temperature increases P uptake (Howard & Haley, 1997), and solar radiation is a primary factor in leaf area and plant growth (Center & Spencer, 1981; Eid et al., 2016). When FAV is suppressed, the relationships break down and percent FAV cover and FAV biomass total P are associated only with each other. When FAV is allowed to grow, discharge total P is correlated with percent FAV cover, but P load and sum P load are not. When FAV is suppressed, FAV cover is no longer a correlating factor in discharge total P, which was expected when there is no FAV with which to have a relationship. Phosphorus load and sum P load were highly related with rain and velocity for all regression analyses, suggesting the hydrology in the area the most important factor when trying to manage P load.

The sensitivity analysis was able to assess the variables to which the six parameters representing FAV impacts on P cycling are most sensitive. Discharge water total P was the most
interesting parameter when comparing between treatment farm 4702 and control farm 4701. When not suppressing FAV growth in control farm 4701, discharge water P is most sensitive to percent FAV cover, with discharge water P increasing with increasing percent FAV cover. When suppressing FAV cover, crop type (sugarcane) became the most influential variable. These results demonstrate that discharge water total P is most sensitive to percent FAV cover, rather than ambient water total P (P inflow).

In general the variables affecting the other five parameters were the same for equations from all farms, control farm 4701, and treatment farm 4702. Percent FAV cover was most sensitive to FAV total P and solar radiation, and FAV total P was most sensitive to percent FAV cover and temperature. Sum P load and P load were most sensitive to velocity, or the speed at which water was being discharged from the canal. This agrees with the results from the Pearson correlation analysis and results from Chapter 4 wherein flow and velocity were correlated with P load. Flow was most affected by rain over all farms and control farm 4701. In treatment farm 4702, rain was the second most influential variable to flow, with flow being most sensitive to P load, which was then correlated with rain and velocity.

The results from the multivariate regression analysis showed a positive linear relationship with discharge total P and percent FAV cover. Statistical analyses in Chapter 4 showed reductions in discharge total P when FAV was suppressed below 5%. The sensitivity analyses from this study indicated that discharge water total P was most sensitive to percent FAV cover when FAV was allowed to grow, and that relationship broke down when FAV was suppressed. This supports the findings from Chapter 4 that discharge water total P concentration can be reduced by suppressing FAV growth. Also, the sensitivity analysis showed that P load was most
sensitive to velocity. In terms of application, farmers can be directed to reduce discharge water total P by suppressing FAV, and decrease P load by reducing their pumping velocity.

**Conclusions**

The next steps to be taken in this study will be to validate the developed equations for each parameter. The validation procedure will use two to three years of the measured data to test how well the modified equations fit the conditions measured in the real world. After validation is completed, the equations can be incorporated into larger hydrological models, like the SWAT or the Watershed Assessment Model (WAM).

These large-scale models currently do not consider FAV as a factor in P cycling in water bodies and generally represent P cycling with algal growth and erosion/sedimentation rates. Without having the parameter equations to show the relationship between FAV and P cycling, there would be extensive modifications to model structure and code required to incorporate the findings from this study into the larger models. These parameter equations make it much more feasible to simulate the processes in larger models and allow the modeling community to better represent these factors affecting water quality.

The goal of this study was to generate equations that would best represent the relationship between FAV and P cycling so that, with future refinement of the equations, the modeling community can incorporate them into large-scale hydrologic models. The parameters chosen in this study and the equations generated set the foundation for this goal in the near future. Once the basic relationship is validated, future work can be done to continue refining the equations and expand them beyond the EAA basin.
Figure 5-1. Schematic of P cycling in EAA farm canals as related to FAV.
Table 5-1. Summary statistics of model equation variables

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<td>Rain (inches)</td>
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<td>Solar Radiation (w/m²)</td>
<td>296</td>
<td>205</td>
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<td>122</td>
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<td>FAV Cover (%)</td>
<td>264</td>
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<td>12</td>
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<td>Sum P Load (kg)</td>
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<td>Maximum Velocity (m/s)</td>
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Table 5-2. Pearson correlation coefficients analysis results for six key parameters.

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<th>Flow</th>
<th>Discharge Total P</th>
<th>P load</th>
<th>Sum P Load</th>
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<td>Temperature Ave (F)</td>
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<td>*</td>
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<td>Temperature Min (F)</td>
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<td>*</td>
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<td>Temperature Max (F)</td>
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<td>Solar Radiation (w/m2)</td>
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<td>-0.02</td>
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<td>FAV Cover (%)</td>
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<td>-0.05</td>
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<td>-0.07</td>
<td>-0.06</td>
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<td>FAV Biomass Total P (mg/kg)</td>
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<td>0.17</td>
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<td>0.24</td>
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<td>Ambiant Water Total P (mg/L)</td>
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<td>Flow (Mgallons/minute)</td>
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<td>Discharge Water Total P (mg/L)</td>
<td>0.07</td>
<td>0.31</td>
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<td>***</td>
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<tr>
<td>P load (kg)</td>
<td>-0.07</td>
<td>0.24</td>
<td>0.86</td>
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<td>***</td>
<td>***</td>
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<td>Sum P Load (kg)</td>
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<td>0.85</td>
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</tbody>
</table>

Top: Correlation coefficient; middle: N number of data points; bottom: p-value (significance < 0.05). * p < 0.05, ** p < 0.01, *** p < 0.001
P = phosphorus; TDP = total dissolved P; PP = particulate P; SRP = soluble reactive P; DOP = dissolved organic P; TSS = total suspended solids; Ca = calcium
Table 5-2. Continued.

<table>
<thead>
<tr>
<th>Velocity (m/s)</th>
<th>0.08</th>
<th>-0.04</th>
<th>0.64</th>
<th>-0.02</th>
<th>0.48</th>
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<td>Maximum</td>
<td>0.02</td>
<td>-0.01</td>
<td>0.42</td>
<td>-0.03</td>
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<td>Crop</td>
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<td>-0.07</td>
<td>-0.03</td>
<td>0</td>
<td>-0.03</td>
<td>-0.03</td>
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<tr>
<td>(Sugarcane) (%)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Top: Correlation coefficient; middle: N number of data points; bottom: p-value (significance < 0.05). * p < 0.05, ** p < 0.01, *** p < 0.001

P = phosphorus; TDP = total dissolved P; PP = particulate P; SRP = soluble reactive P; DOP = dissolved organic P; TSS = total suspended solids; Ca = calcium
Table 5-3. All farms multivariate regression equations

<table>
<thead>
<tr>
<th>Parameter Equation</th>
<th>R-Squared</th>
<th>R-Squared (Adjusted)</th>
<th>RMSE</th>
<th>F-value</th>
<th>Pr &gt; F</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Load Sum = -9.229 + 78.992 Inflow P + 67.669 Rain + 144.3 Maximum Velocity</td>
<td>0.6254</td>
<td>0.6070</td>
<td>17.641</td>
<td>33.95</td>
<td>&lt;.0001</td>
<td>65</td>
</tr>
<tr>
<td>P Load = -0.3063 + 2.6051 Inflow P + 2.2539 Rain + 38.062 Maximum Velocity</td>
<td>0.6280</td>
<td>0.6097</td>
<td>0.5833</td>
<td>34.32</td>
<td>&lt;.0001</td>
<td>65</td>
</tr>
<tr>
<td>Flow = -40578 + 1.83E7 Rain</td>
<td>0.4025</td>
<td>0.4005</td>
<td>2.07E6</td>
<td>198.08</td>
<td>&lt;.0001</td>
<td>296</td>
</tr>
<tr>
<td>Discharge Total P = 0.0707 + 0.4096 Inflow P + 112E-7 FAV Total P</td>
<td>0.1847</td>
<td>0.1456</td>
<td>0.0726</td>
<td>4.75</td>
<td>0.0138</td>
<td>137</td>
</tr>
<tr>
<td>FAV Cover = -9.018 + 0.0741 Solar Radiation + 0.0084 FAV Total P</td>
<td>0.4361</td>
<td>0.4277</td>
<td>14.839</td>
<td>51.82</td>
<td>&lt;.0001</td>
<td>137</td>
</tr>
<tr>
<td>FAV Total P = -6378.8 + 82.954 Temperature Maximum</td>
<td>0.0478</td>
<td>0.0407</td>
<td>1438.4</td>
<td>6.78</td>
<td>0.0103</td>
<td>137</td>
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</tbody>
</table>

RMSE = root mean square error; P = phosphorus; FAV = floating aquatic vegetation

Table 5-4. Control farm 4701 multivariate regression equations

<table>
<thead>
<tr>
<th>Parameter Equation</th>
<th>R-Squared</th>
<th>R-Squared (Adjusted)</th>
<th>RMSE</th>
<th>F-value</th>
<th>Pr &gt; F</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Load Sum = -3.2618 + 48.043 Rain + 2076.4 Velocity</td>
<td>0.7976</td>
<td>0.7681</td>
<td>11.936</td>
<td>27.59</td>
<td>&lt;.0001</td>
<td>17</td>
</tr>
<tr>
<td>P Load = -0.1178 + 1.5289 Rain + 71.529 Velocity</td>
<td>0.8055</td>
<td>0.7777</td>
<td>0.3977</td>
<td>28.99</td>
<td>&lt;.0000</td>
<td>17</td>
</tr>
<tr>
<td>Flow = -242180 + 1.26E7 Rain</td>
<td>0.5083</td>
<td>0.4919</td>
<td>1.30E6</td>
<td>31.01</td>
<td>&lt;.0001</td>
<td>32</td>
</tr>
<tr>
<td>Discharge Total P = -0.0332 + 0.0035 FAV Cover + 0.3163 Inflow P</td>
<td>0.8687</td>
<td>0.7812</td>
<td>0.035</td>
<td>8.5554</td>
<td>18.89</td>
<td>0.0048</td>
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<tr>
<td>FAV Cover = 4.2829 + 0.0087 FAV Total P</td>
<td>0.7589</td>
<td>0.7188</td>
<td>8.5554</td>
<td>45.29</td>
<td>0.0006</td>
<td>8</td>
</tr>
<tr>
<td>FAV Total P = -8682.3 + 119.21 Average Temperature + 82.665 FAV Cover</td>
<td>0.9477</td>
<td>0.9407</td>
<td>436.26</td>
<td>45.29</td>
<td>0.0006</td>
<td>8</td>
</tr>
</tbody>
</table>

RMSE = root mean square error; P = phosphorus; FAV = floating aquatic vegetation

Table 5-5. Treatment farm 4702 multivariate regression equations

<table>
<thead>
<tr>
<th>Parameter Equation</th>
<th>R-Squared</th>
<th>R-Squared (Adjusted)</th>
<th>RMSE</th>
<th>F-value</th>
<th>Pr &gt; F</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Load Sum = -1.1174 + 20.779 Rain + 1093.5 Velocity</td>
<td>0.9446</td>
<td>0.9414</td>
<td>4.5137</td>
<td>290.03</td>
<td>&lt;.0001</td>
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<tr>
<td>P Load = -0.0357 + 0.6965 Rain + 35.626 Velocity</td>
<td>0.9414</td>
<td>0.938</td>
<td>0.1518</td>
<td>273.33</td>
<td>&lt;.0001</td>
<td>37</td>
</tr>
<tr>
<td>Flow = -76786 + 1.24E6 Rain + 2.05E6 P Load + 4.07E7 Velocity - 5.72E6 Maximum Velocity</td>
<td>0.9731</td>
<td>0.9698</td>
<td>2.69E5</td>
<td>289.58</td>
<td>&lt;.0001</td>
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<tr>
<td>Discharge Total P = 0.1251 - 0.0004 Crop (Sugarcane)</td>
<td>0.1068</td>
<td>0.0642</td>
<td>0.0313</td>
<td>2.51</td>
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<td>FAV Cover = 2.593 + 0.0099 FAV Total P</td>
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<td>FAV Total P = 228.84 + 25.487 FAV Cover</td>
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<td>715.65</td>
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<td>0.0404</td>
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RMSE = root mean square error; P = phosphorus; FAV = floating aquatic vegetation
Table 5-6. Sensitivity analysis results for all farms six parameter equations

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<th>Sum P Load</th>
<th>P Load</th>
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<th>Discharge</th>
<th>FAV Total P</th>
<th>FAV Cover</th>
<th>FAV TP</th>
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<td>Max Velocity</td>
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<td>Ambient Total P</td>
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<td></td>
<td>0.152</td>
<td>0.757</td>
<td>0.845</td>
</tr>
<tr>
<td>FAV Cover</td>
<td></td>
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<td>0.152</td>
<td>0.757</td>
<td>0.845</td>
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<tr>
<td>FAV TP</td>
<td></td>
<td></td>
<td></td>
<td>0.152</td>
<td>0.757</td>
<td>0.845</td>
</tr>
<tr>
<td>Solar Radiation</td>
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<tr>
<td>Ave Temperature</td>
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<td></td>
<td></td>
<td>0.152</td>
<td>0.757</td>
<td>0.845</td>
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<tr>
<td>Max Temperature</td>
<td></td>
<td></td>
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<td>0.152</td>
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<tr>
<td>P Load</td>
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<td></td>
<td></td>
<td>0.152</td>
<td>0.757</td>
<td>0.845</td>
</tr>
<tr>
<td>Crop (Sugarcane)</td>
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<td></td>
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<td>0.757</td>
<td>0.845</td>
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Values shown for variables contained in parameter equations. The higher the value, the more sensitive the parameter is to that variable.

Table 5-7. Sensitivity analysis results for control farm 4701 six parameter equations

<table>
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<tr>
<th>Sum P Load</th>
<th>P Load</th>
<th>Flow</th>
<th>Discharge</th>
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<th>FAV Cover</th>
<th>FAV TP</th>
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<tbody>
<tr>
<td>Ave Velocity</td>
<td>0.972</td>
<td>0.976</td>
<td>0.236</td>
<td>0.263</td>
<td>1.100</td>
<td>0.742</td>
</tr>
<tr>
<td>Max Velocity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain</td>
<td>0.236</td>
<td>0.263</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Total P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAV Cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAV TP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Radiation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Temperature</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>P Load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop (Sugarcane)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values shown for variables contained in parameter equations. The higher the value, the more sensitive the parameter is to that variable.

Table 5-8. Sensitivity analysis results for treatment farm 4702 six parameter equations

<table>
<thead>
<tr>
<th>Sum P Load</th>
<th>P Load</th>
<th>Flow</th>
<th>Discharge</th>
<th>FAV Total P</th>
<th>FAV Cover</th>
<th>FAV TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave Velocity</td>
<td>0.975</td>
<td>0.975</td>
<td>0.231</td>
<td>0.231</td>
<td>0.295</td>
<td>0.102</td>
</tr>
<tr>
<td>Max Velocity</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Rain</td>
<td>0.231</td>
<td>0.231</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Total P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAV Cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAV TP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Radiation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.827</td>
</tr>
<tr>
<td>Max Temperature</td>
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<td></td>
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<td></td>
<td></td>
<td>0.888</td>
</tr>
<tr>
<td>P Load</td>
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<td></td>
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<td></td>
<td>1.003</td>
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<tr>
<td>Crop (Sugarcane)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.192</td>
</tr>
</tbody>
</table>

Values shown for variables contained in parameter equations. The higher the value, the more sensitive the parameter is to that variable.
CHAPTER 6
CONCLUSIONS

This study strove to provide a holistic understanding of current and future BMP use by combining social and hard sciences to understand if farmers would implement FAV suppression as a practice if it was found to reduce P discharged from EAA farms. Farmer interviews were meant to give a realistic view of farmers’ views on BMPs and whether they would implement new practices if recommended. Field experiments assessed the effectiveness of FAV suppression as a way to reduce P discharged from canals. Creation of FAV-suppression and P cycling equations from measured data will allow for the inclusion of these relationships in large-scale hydrology models.

Social research in an agricultural setting is difficult and complicated, as experienced by the survey study attempt. South Florida’s EAA is a unique area that has been able to adapt to the changing public attitude towards farming. It is has one of the few mandated BMP programs in the country and is able to boast unprecedented success in improving water quality. Much of the difficulty in this research stemmed from the fear of legal retribution against the farmers if answers given during the survey could be misconstrued by distrusted groups. In the future, research does need to be conducted to analyze the motivation behind BMP implementation beyond the legal requirements in the EAA. The EAA BMP Regulatory Program is seen as a standard of success for state-level agricultural water quality improvement (Kling, 2013). More work should be done to understand benefits and drawbacks to the BMP Regulatory Program, or else the only lesson to be learned is that the best way to improve water quality and farmer BMP use is to mandate it by law.

Controlling the growth of FAV at pump stations is a practice already implemented by some farmers. This study hoped to show that suppressing FAV cover would affect canal

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sediment and discharge water in a way that reduces P leaving the canals. Canal sediment properties may not be the best indicator of FAV suppression effects on P cycling because the effects are slow to materialize. More time is required to fully understand impacts of FAV suppression because changes to inherent sediment properties, like organic matter content, pH, or total P, require not only more time but more sampling periods within the year. Canal discharge water was more sensitive to changes in FAV cover than sediments, with lower total P and PP concentrations when suppressing FAV. Discharge sediment may play a larger role in P load and discharge water total P concentration because of its higher total P and organic matter. More discharge sediment samples need to be collected with discharged canal water in order to analyze effects of FAV suppression on sediments leaving canals on a farm by farm basis.

The fact that the P load for each canal was not affected by FAV suppression is a result of greater influences by flow and velocity on P load. The identification of representative parameters and their associated variables simulating FAV effects on P cycling gave a better understanding of how FAV affected the P discharged from the canals. Hydrology was the most influential factor controlling P load, but FAV suppression did reduce P concentrations in discharge water. The generation of these parameters and their equations creates the opportunity for these processes, with future refinement, to be incorporated into large-scale hydrologic models.

The main flaw in the experiment was the inability to maintain above and below 25% FAV cover. The lack of FAV cover suppression in treatment farms and restrictions on seeding FAV in control farms resulted in farm canal designations being unrepresentative of FAV effects on water properties. If farms are to be evaluated in a paired design in the future, the experimental design needs to be restructured so that control farms have zero FAV cover and treatment farms are seeded to full coverage to analyze overall impacts of FAV suppression.
Correction of the experimental design, either by fully seeding and suppressing FAV in farm pairs, or by focusing on maintaining a specific percent cover threshold, is the primary change if data are to be continued to be collected. Also, because many farmers allow FAV coverage up to 100% with a mass herbicide application before pumping to increase water flow efficiency, an experiment needs to be conducted to assess the impacts of this practice on water quality. Samples should be taken before, within 24 hrs, and 48 hrs of mass herbicide application to assess whether or not this method of FAV suppression will affect P concentrations of canal water without pumping, discharge water P concentrations, and P load. These data can be compared to the results from this study to assess whether or not suppressing FAV will differ from the water quality resulting from current FAV management.

Ultimately, this study found that suppressing FAV cover to less than 5% did reduce total P concentrations in water discharged from canals, and that percent FAV cover did significantly influence discharge water P concentration. This reduction and relationship may incentivize farmers to adopt the practice of year-round FAV suppression.
Hello,

Included in this letter is an **anonymous, short survey** being conducted by the Everglades Research and Education Center (EREC) and the University of Florida (UF/IFAS) to evaluate your opinions on nutrient management and the 40E63 Works of the District Best Management Practice (BMP) Permit Program in the Everglades Agricultural Area.

**The purpose of this survey is to better understand the experience of those implementing the current BMP requirements under the Everglades Forever Act, including factors influencing BMP choices, benefits and drawbacks of BMP implementation, and suggestions for improving the program.** Once responses are evaluated, this research can better inform as to what challenges farmers are facing in making the BMP Program successful and suggestions for improving farmer participation and Program effectiveness.

If aged 18 or older, please complete the attached survey. Your participation in this anonymous survey is voluntary and only summary results will be published. Your full participation would be greatly appreciated, although you do not have to answer any questions you do not wish.

If you have any questions about this survey, you may contact the principal investigator (see below) or the faculty advisor Samira Daroub (telephone 561-993-1593, email sdaroub@ufl.edu). There are no direct benefits or risks to you for participating in the study. For questions about your rights as a research participant, contact the University of Florida Institutional Review Board (telephone 352-392-0433).

Thank you for your participation!

Sincerely,

Anne Sexton  
Ph.D. Candidate, Principal Investigator  
University of Florida, Soil and Water Sciences Department  
Everglades Research and Education Center  
3200 E. Palm Beach Rd., Belle Glade, FL 33430  
Telephone 850-980-2848, email aes9922@ufl.edu
### SECTION 1: BEST MANAGEMENT PRACTICE SELECTION AND IMPLEMENTATION

#### 1. How familiar are you with the following terms?

<table>
<thead>
<tr>
<th>Term</th>
<th>Not at all familiar</th>
<th>Slightly familiar</th>
<th>Somewhat familiar</th>
<th>Moderately familiar</th>
<th>Extremely familiar</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Stormwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Best Management Practices (BMPs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) EAA BMP Program</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) Phosphorus load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e) Nutrient enrichment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f) Floating aquatic vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 2. Please answer the following Yes or No questions.

<table>
<thead>
<tr>
<th>Question</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Do you agree BMPs reduce the amount of phosphorus entering water bodies?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Would you like to see more BMP options count toward your farm BMP plan?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) Would you like to see fewer BMP options count toward your farm BMP plan?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) Do you think your farm’s BMP plan is effective in reducing phosphorus loads?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e) Does the implementation of BMPs fit well into your current farm management?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f) Have you seen benefits in your production from BMP implementation?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g) Have you seen benefits to your farm operation from BMP implementation?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3. How do you select BMPs for your farm? (select all that apply)

- [ ] Target hot spots
- [ ] Site specific
- [ ] Same BMPs for all farm fields
- [ ] Preventative measure
- [ ] Crop specific
- [ ] High BMP diversity on farm
- [ ] Ease of implementation
- [ ] Other (Please list)
  ____________________________________________________________

#### 4. Does your farm exceed the BMP permit 25 point minimum?

- [ ] No
- [ ] Yes

**If yes, why?** (Please check all that apply)

- [ ] Monetary incentive
- [ ] Extra BMPs have been recommended
- [ ] BMPs help farmers as stewards of the land
BMPs improve farm profitability
Anticipation of increased BMP requirements
Pressure from other farmers
Other (Please list) ______________________
I don’t know

5. Does your farm implement other management practices that currently do not count towards the listed farm BMP points?
   No
   Yes

6. Does your farm currently manage floating aquatic vegetation?
   No
   Yes

   If no, why not?
   ________________________________
   I don’t know

   If yes, how does your farm manage floating aquatic vegetation? (Please check all that apply)
   Bank-to-bank coverage before herbicide use
   Spot spray herbicide
   Mechanical collection
   Other (Please list) ______________________
   I don’t know

7. Why do you think the BMP Program has been successful?
   __________________________________
   __________________________________
   I don’t know

8. In your opinion, what is the contribution of each group to the success of the BMP Program?
   South Florida Water Management District ______%
   UF/IFAS ______%
   Farmers ______%
   ______ 100%

9. What difficulties have you encountered implementing a BMP plan on your farm? (select all that apply)
   Decrease in profit
   Increase of implementation/maintenance cost
   Increase in man power/time to implement or maintain
   Decrease in farm management flexibility
   Other (Please list)
10. What do you think is the major impediment to improve BMP implementation?
   _____ Money
   _____ Lack of BMP options
   _____ Time
   _____ Other (Please list) ______________________
   _____ BMP knowledge

11. List up to two things you think would improve the effectiveness of the BMP Program:
   1. ____________________________________________________________
      ____________________________________________________________
   2. ____________________________________________________________
      ____________________________________________________________

SECTION 2: AGRICULTURAL OPERATION AND DEMOGRAPHIC INFORMATION

1. How many acres is the farm where you work? (if known)
   _____ acres

2. How many years have you owned, operated, or worked on a farm in the EAA?
   _____ years

3. What crops are typically grown on the farm where you work? (Please check all that apply)
   __________________________
   Crop Type
   _____ Sugar Cane
   _____ Sweet Corn
   _____ Vegetables
   _____ Rice
   _____ Sod
   _____ Other (Please list)
   _____ I don’t know

4. What is your job title/description? (Farm Manager, Tractor Operator, Nutrient Analyst, etc.)
   ____________________________________________________________

5. What is your gender?
   _____ Male   _____ Female

6. What is your age?
   _____ 18-28   _____ 29-39   _____ 40-   _____ 51-61   _____ > 61
   ___ 50
7. What is your race/ethnicity?

- Asian
- Black or African American
- Hispanic or Latino
- Native American
- White or Caucasian
- Other

8. What is your level of education? (Please choose the highest level)

- Some high school
- High school
- Some college
- Associate’s degree
- Bachelor’s degree
- Master’s degree
- Doctorate degree
# APPENDIX B

## BEST MANAGEMENT PRACTICES AND ASSIGNED POINTS FOR EVERGLADES AGRICULTURAL AREA FARMS

<table>
<thead>
<tr>
<th>BMP</th>
<th>PTS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NUTRIENT CONTROL: MINIMIZE MOVEMENT OF NUTRIENTS OFF-SITE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrient Application Control</td>
<td>2½</td>
<td>Controlled application of nutrients; banding, controlled application</td>
</tr>
<tr>
<td>Nutrient Spill Prevention</td>
<td>2½</td>
<td>Formal spill protocols: storage, handling, transfer, and education/instruction</td>
</tr>
<tr>
<td>Rotational Vegetable Planting</td>
<td>2½</td>
<td>Rotation planting of high P/low P demand crops to avoid P build up</td>
</tr>
<tr>
<td>Plant Tissue Analysis</td>
<td>2½</td>
<td>Determines plant nutrient requirements via tissue testing</td>
</tr>
<tr>
<td>Soil Test Based Fertilization</td>
<td>5</td>
<td>Determine soil P requirements and follow standard recommendations</td>
</tr>
<tr>
<td>Split Nutrient Application</td>
<td>5</td>
<td>Applying split P without exceeding total recommendation</td>
</tr>
<tr>
<td>Slow Release P Fertilizer</td>
<td>5</td>
<td>Specially treated fertilizer</td>
</tr>
<tr>
<td>Reduced P Fertilization</td>
<td>5</td>
<td>P application rate is at least 30% below recommendation</td>
</tr>
<tr>
<td><strong>WATER MANAGEMENT: MINIMIZE THE VOLUME OF OFF-SITE DRAINAGE DISCHARGE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>½ Inch Detained</td>
<td>5</td>
<td>Delay discharge: based on measuring daily rain events using a rain gauge</td>
</tr>
<tr>
<td>1 Inch Detained</td>
<td>10</td>
<td>Delay discharge: based on measuring daily rain events using a rain gauge</td>
</tr>
<tr>
<td>Improved Infrastructure</td>
<td>5</td>
<td>Re-circulate water; fallow field flood; increase water detention</td>
</tr>
<tr>
<td>Water Table Management</td>
<td>5</td>
<td>Optimizing drainage and irrigation schedules to decrease discharge</td>
</tr>
<tr>
<td><strong>PP AND SEDIMENTS: MINIMIZE MOVEMENT OF PARTICULAT MATTER AND CANAL SEDIMENTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any 2</td>
<td>2½</td>
<td></td>
</tr>
<tr>
<td>Any 4</td>
<td>5</td>
<td>Leveling fields • Slow drainage velocity near pumps</td>
</tr>
<tr>
<td>Any 6</td>
<td>10</td>
<td>Grassed swales/field ditch connections • Ditch bank berms • Canal cleaning program</td>
</tr>
<tr>
<td>Any 8</td>
<td>15</td>
<td>Aquatic weed control • Field ditch drainage sumps • Barriers at discharge locations • Ditch bank stabilization • Sediment sump/trap in canals • Soil stabilization through infrastructure improvements • Cover crops • Culvert bottoms above ditch bottoms • Vegetated ditch banks</td>
</tr>
<tr>
<td>Other BMPs</td>
<td>TBD</td>
<td>BMPs proposed by permittee and accepted by SFWMD</td>
</tr>
</tbody>
</table>

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APPENDIX C
X-RAY DIFRACTOGRAM OUTPUTS FOR SEDIMENT SAMPLES

Figure C-1. Diffractogram of transects A, B, and C for farm 3103 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
Figure C-2. Diffractogram of transects A, B, and C for farm 3102 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
Figure C-3. Diffractogram of transects A, B, and C for farm 0401 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
Figure C-4. Diffractogram of transects A, B, and C for farm 2501 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
Figure C-5. Diffractogram of transects A, B, and C for farm 4702 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
Figure C-6. Diffractogram of transects A, B, and C for farm 4701 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
Figure C-7. Diffractogram of transects A, B, and C for farm 6117 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
Figure C-8. Diffractogram of transects A, B, and C for farm 1813 mineral composition for December 2013 (a) and April 2014 (b). Minerals include palygorskite (P), calcite (C), sepiolite (S), quartz (Q), dolomite (D), aragonite (A), and kaolinite (K).
LIST OF REFERENCES


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Everglades Forever Act (EFA), Sec. 373.4592, Florida Statutes. (1994).


Zeiger, C. F. (1967). Biological control of alligatorweed with Agasicles n. sp. in Florida. Hyacinth Control Journal, 6, 31-34.
BIOGRAPHICAL SKETCH

Anne received her Bachelor of Arts degree in environmental science from Oglethorpe University in 2011. She went on to receive a Master of Arts in urban and environmental policy and planning from Tufts University in 2013. She completed her Doctor of Philosophy in soil and water sciences from the University of Florida in 2017.