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Characterization and monitoring of on-farm water storage systems in Porter Bayou Watershed, Mississippi

By

Richard L. Kirmeyer III

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Engineering Technology
in the Department of Agricultural and Biological Engineering

Mississippi State, Mississippi

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Characterization and monitoring of on-farm water storage systems in Porter Bayou Watershed, Mississippi

By

Richard L. Kirmeyer III

Approved:

Joel O. Paz
(Director of Thesis)

Mary Love M. Tagert
(Committee Member)

Joseph H. Massey
(Committee Member)

Jeremiah D. Davis
(Graduate Coordinator)

George M. Hopper
Dean
College of Agriculture and Life Sciences

www.manaraa.com

Name: Richard L. Kirmeyer III

Date of Degree: December 14, 2013

Institution: Mississippi State University

Major Field: Engineering Technology

Major Professor: Dr. Joel O. Paz

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Candidate for Degree of Master of Science

The on-farm water storage (OFWS) systems at Metcalf and Pitts farm in Porter Bayou Watershed were monitored for changes in nutrient levels and water withdrawal for irrigation from March 2012 to April 2013. Nitrogen and phosphorus levels were generally higher during the early part of the growing season. The OFWS systems can reduce nitrate and phosphorus in runoff up to 81% and 85%, respectively. However, the systems did not consistently reduce sediment and nutrients especially after significant rainfall and runoff events. The systems provided a total of 130 and 233 acre-feet of recycled water for irrigating crops at Metcalf and Pitts, respectively, during the 2012 growing season. These amounts reflect significant savings in terms of groundwater. This study highlights the advantages of OFWS systems as structural BMPs to reduce nutrient loading into the Gulf of Mexico and to minimize groundwater withdrawals from the Mississippi Alluvial Aquifer.

Keywords: On-farm water storage systems, best management practices, nutrient reduction, water conservation

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DEDICATION

I would like to dedicate this research to the scientists and engineers that have come before me and for those many who will follow. I would also like to dedicate this research to my parents, Richard and Debbie Kirmeyer, and brother Dennis Kirmeyer.

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I would like to acknowledge several individuals who helped me complete this study. Those individuals include my committee members, who have individually helped me work through problems that I faced within my research. My committee members, Dr. Joel O. Paz, Dr. Mary Love M. Tagert, and Dr. Joseph H. Massey, whose encouragement, guidance, and support from the initial to the final level pushed me to complete worthwhile scientific research. I would like to thank Kathleen McCraven, Charles (Trey) Robertson, Kyle Humphrey, Gray Carruth, Sandra Guzman, William McClure, and Ritesh Karki for assisting me in field and lab work. I would like to thank Trinity Long, Paul Rodrigue, and Joey Adams of NRCS, Dr. Dean Pennington of YMD, and Dan Prevost of Delta Wildlife for their assistance in providing information and data for this research.

المنارة للاستشارات

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TABLE OF CONTENTS

CHAPTER

www.manaraa.com

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LIST OF TABLES

www.manaraa.com

LIST OF FIGURES

المنارة للاستشارات

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NOMENCLATURE

AMA	Agricultural Management Assistance Program
AWEP	Agriculture Water Enhancement Program
BMP	Best Management Practice
CPGLP	Conservation of Private Grazing Land Program
CWA	Clean Water Act
DO	Dissolved Oxygen
DP	Dissolved Orthophosphate
EPA	Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
GIS	Geographical Information System
GPS	Global Positioning System
HUC	Hydrologic Unit Code
FOTG	Field Office Technical Guide
LMAV	Lower Mississippi Alluvial Valley
MDEQ	Mississippi Department of Environmental Quality
m	Meters
mg/L	Milligrams per Liter
mm	Millimeters
MRBI	Mississippi River Basin Healthy Watershed Initiative

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MRVA	Mississippi River Valley Alluvial Aquifer
NH	Ammonia
NIFA	National Institute of Food and Agriculture
NO_3	Nitrate
NRCS	Natural Resources Conservation Service
OFWS	On-Farm Water Storage
NPDES	National Pollutant Discharge Elimination System
NPS	Non-Point Source
PS	Point Source
TKN	Total Kjehldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
TWR	Tail Water Recovery
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
YMD	Yazoo Mississippi Delta Joint Water Management District

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CHAPTER I

INTRODUCTION

1.1 General Introduction

The Mississippi Delta is an important cash crop area for the United States because it has the ideal characteristics needed to produce highly productive agricultural land. The Mississippi Delta is located within the Lower Mississippi Alluvial Valley (LMAV) and has the necessary requirements for producing rich cash crops: flat land, fertile soil, and sufficient water. Crops within the LMAV such as rice, corn, cotton, and soybeans combined with livestock to create an annual revenue of about $6.8 billion in 1997 and created roughly 100,000 jobs in 1998 (Black et al., 2004).

Along with very fertile land, the Mississippi Delta sits atop the shallow Mississippi River Valley Alluvial Aquifer (MRVA), which has provided most of the water needed for irrigating crops. However, farmers and landowners are currently faced with two major issues with regard to maintaining and managing agricultural land, namely, nutrient discharge into the Gulf of Mexico and declining groundwater levels. The Delta region’s annual rainfall range from 1150 to 1500 mm. However, the majority of rainfall does not usually fall during growing seasons causing a greater demand for irrigation (Snipes et al., 2005). The LMAV contains over 7 million hectares of irrigated cropland (USDA NASS, 2007), making the LMAV one of the largest areas of irrigated cropland within the United States. Over 90% of the groundwater pumped from the

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MRVA is used for irrigation pumping at a rate of over 9000 gal/day. This pumping rate puts the MRVA third in the nation for daily withdrawal rates (Maupin and Barber, 2005). This extensive use of irrigation over time has put pressure on groundwater supply.

In addition to conserving ground water, state and federal agencies are also focused on reducing the hypoxic zone in the Gulf of Mexico due to the high nutrient loads the Gulf receives from agricultural production areas in the Southeast and Midwest United States. These high volumes of nutrients can make oxygen levels drop lower than 2 mg/L, which is devastating to sea life (Rabalais et al., 2002a). The largest hypoxic zone in the Gulf of Mexico was recorded in 2010 (Rabalais and Turner, 2010). Concerns over water quality and quantity and the cost to produce crops are bringing farmers and government agencies together to collaborate and help establish programs and new management practices that will help farmers while also providing water quality and quantity benefits.

Programs and practices such as the "Mississippi River Basin Healthy Watersheds Initiative (MRBI)" and the "Mississippi Delta Nutrient Reduction Strategies" provide funding and information for new conservation measures also known as Best Management Practices (BMPs) (FTN Associates, 2009). BMPs like On-Farm Water Storage (OFWS) systems are becoming increasingly popular in the Mississippi Delta, offering farmers and landowners the ability to capture surface water for later use rather than relying solely on drilling and using water from groundwater wells. This project was developed to study the effects of OFWS systems and determine if they can simultaneously supplement irrigation needs while also providing downstream nutrient reduction benefits, so that the placement of these systems can be better targeted within a watershed.

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1.2 Objectives

The primary goal of this study was to examine the effects of OFWS systems on downstream water quality in Porter Bayou Watershed. The objectives were a) to conduct an inventory of installed OFWS systems, b) to examine nitrogen and phosphorous concentrations associated with water storage systems, and c) to estimate the amount of surface water from OFWS systems used for irrigation.

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CHAPTER II

LITERATURE REVIEW

2.1 Magnitude of Problem

The Mississippi Delta has approximately 2.8 million acres of agricultural land (YMD, 2010). To maximize economic returns, the attributes that make it such a prime area for row crop production must be protected and conserved. Important to the Delta's success is the Mississippi River and other influential streams that feed from and to the Mississippi River throughout the Delta. The Mississippi River is one of the longest rivers in the world and drains over 40% of the United States. The Mississippi River discharges high volumes of nutrient loads into the Gulf of Mexico. Specifically, 74% of nitrate inputs to the basin originate from agricultural nonpoint sources (Rabalais et al., 2002a). In 2012, North America comprised over 12.9%, 11.6%, and 16.9% of the world's consumption of nitrogen, phosphates, and potash, respectively (FAO, 2012). Alexander et al. (2008) noted that runoff from agricultural lands devoted to crops and pasture contribute over half of the nutrient inputs in aquatic ecosystems. Specifically, areas planted with corn and soybeans are the biggest source of nitrogen loadings (52%), while pasture and range lands are responsible for (37%) of phosphorus delivered into water bodies.

Hypoxic, meaning low oxygen present in water, and anoxic, meaning no oxygen present in water, are commonly used to describe the deepest and darkest parts of oceans

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where there is little to no oxygen. Hypoxic and anoxic conditions are also often used to describe the effects of high nutrient discharges in aquatic ecosystems. These terms are being used more frequently to describe the shallow Gulf water environment that is impaired for dissolved oxygen, causing significant adverse impacts on marine life (Diaz and Rosenberg, 1995; Rabalais et al., 2002b). Large nutrient loads discharged into warm Gulf waters cause algae to increase and multiply. When the algae die and decompose, the decomposition process uses oxygen present in the water, leaving little or none for marine life (U.S. DOI, 2000). The Gulf of Mexico is considered one of the largest oxygen-depleted coastal waters with oxygen levels at less than 2 mg/L (Rabalais et al., 2002a) and a recent study by Rabalais and Turner (2010) found that the summer of 2010 resulted in the largest measured hypoxic zone in the Gulf of Mexico since their research began in 1985.

Most of the highly productive agricultural areas of the Mississippi Delta require irrigation to maximize crop yields and sustain productivity and groundwater is a primary source of water for supplemental irrigations. In addition to concern over non-point source nutrient runoff, declining groundwater levels in the MRVA is another problem in the Delta (Figure 2.1). The MRVA is located in the south central United States underlying parts of Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee and covering approximately 32,000 mi^2 (Ackerman, 1996). Humid eastern states can sometimes support water demands by crops, given that they have an average year of rainfall and that rain falls when needed, but supplemental irrigation is used when crop water demand is not fulfilled by rainfall (Evans and Sadler, 2008; Schaible, 2012). Supplemental irrigation is not necessarily depleting the aquifer when used in the right

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quantity, but the combination of more frequent dry periods and an increasing number of permitted wells over the past decade have placed increased pressure on the aquifer. Putting well use in perspective, in 2010 there were an estimated 1,763,474 irrigated acres using approximately 2,561,794 acre-feet of groundwater with corn and soybeans contributing 1,275,500 acre-feet of the total amount (YMD, 2010). The Yazoo Mississippi Delta Joint Water Management District (YMD) is responsible for the permitting and processing of new wells, as well as modifying existing and renewing previously established wells throughout the MRVA in Mississippi. Majority of water used in Mississippi is by agriculture in the Delta (YMD, 2006) and 2,171 new groundwater well permits were processed between 2010 and 2011 (YMD, 2011 and 2012). The groundwater level in the alluvial aquifer has dropped 8.22 m from 1995 to 2008 (Byrd, 2011).

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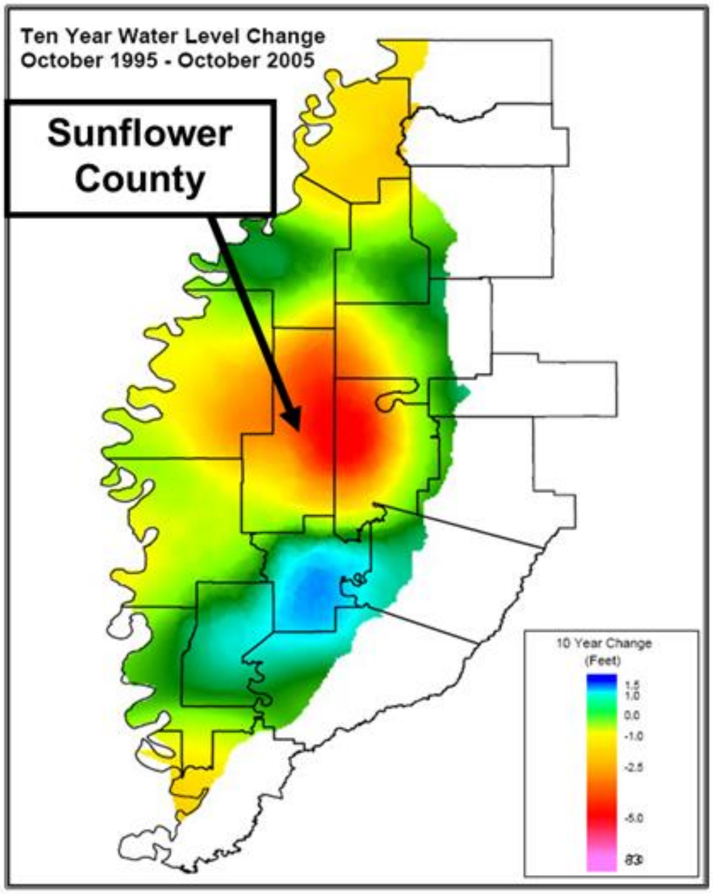

Figure 2.1 Change in water level of the Mississippi Delta Shallow Alluvial Aquifer. (Source: Yazoo Mississippi Delta Joint Water Management District).

2.2 Water Quality Parameters

There are several water quality parameters that are typically measured to determine the health of a water body. The following parameters discussed in this section were the focus of this study. Sediment consists of sands, silts, and clays entering water becoming suspended through numerous ways, such as erosion through upland areas, stream bank erosion, or detachment of streambed particles (Fangmeier el at, 2006). The EPA acknowledges sediment as a large cause for the impairment of surface waters throughout the United States (Gray et al, 2000). The biggest impact of suspended

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sediment on water is optical, and there are two effects (Davies-Colley and Smith, 2001). Suspended sediment reduces the penetration of light into water, thereby limiting photosynthesis by aquatic vegetation (Kirk, 1994), and it also impairs the visual range of aquatic organisms (Vogel and Beauchamp, 1999). This visual impairment can be measured by determining the turbidity of water. Turbidity is the measurement of the clarity of water and it is calculated by determining the amount of light that is able to pass through a column of water. Sediment (clay, silt, and sand), algae, plankton, and microbes all contribute to the level of turbidity in water, and a measure of high turbidity will result in unclear or nontransparent water. However, water with low turbidity or no turbidity will be slightly clear or transparent. In addition to causing optical issues, turbidity also raises the temperature throughout the water column. Particles suspended in water absorb more heat, raising the water temperature. Warmer waters have a lower amount of dissolved oxygen, which can be detrimental for stream quality (U.S. Environmental Protection Agency, 2012c).

Dissolved oxygen (DO) is necessary for the survival of living organisms in water. Water is naturally able to support life by the exchange of gases between the surface of the water and the atmosphere. The DO levels in a water body are typically higher close to the surface, while levels towards the bottom of the water column will be limited, depending on the vertical mixing strength of that body of water. A strong vertical mixing strength will have a higher level of DO that will be carried to the bottom of the water column (Fangmeier, 2006). Temperature also has an effect on DO, with colder water having a higher capacity for holding oxygen rather than warmer waters (U.S. Environmental Protection Agency, 2012c). Living organisms in water are dependent on DO to varying

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degrees. Most aquatic organisms need DO levels above 5 mg/L, and a state of stress usually occurs as levels drop below 5 mg/L. Levels below 2 mg/L over two hours can cause death to certain aquatic species (Kentucky water watch, 2013). If DO is low, dependent organisms will move away from that area. If it is not possible to move away or if they are incapable of moving, they will die from lack of oxygen (Fangmeier, 2006).

Nitrogen (N) and phosphorus (P) are important nutrients which crops need to survive and produce higher yields sufficient to feed a growing population (Brady, 2010). Fertilizers are produced to replenish soils that lack the proper level of nutrients to sustain substantial crop yields. Nitrogen and phosphorus can both be delivered as fertilizers. Nitrogen can present itself in many forms such as the following: nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), ammonia (NH_3), nitrous oxide (N2O), nitric oxide (NO), and nitrogen gas (N_2). These forms change over time as they go through the nitrogen cycle (Fangmeier, 2006). Phosphorus usually presents itself as organic or inorganic phosphates (PO_4^{-3}) (U.S. Environmental Protection Agency, 2012c). It is used in fertilizers such as triple superphosphate ($Ca(H_2PO_4)_2 \cdot H_2O$) (Fangmeier, 2006). These two nutrients are necessary and beneficial when applied in appropriate amounts for a particular site. However, when they are over applied or when certain environmental processes do not allow for complete up-take by plants, run-off and erosion by water carries these nutrients to surface waters (Brady, 2010).

Nitrogen and phosphorus are the main nutrients which cause pollution to surface waters (Brady 2010). Excessive amounts of nitrogen and phosphorus in surface waters can cause eutrophication (U.S. Environmental Protection Agency, 1990). Over half of the lakes and rivers in the United States are impaired due to eutrophication (U.S.

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Environmental Protection Agency, 1996). Water is considered impaired if it does not meet its designated use. Waters can be designated for various uses such as public water supply, irrigation, industry, recreation, or wildlife (U.S. Environmental Protection Agency, 2013). Pollutants, including nutrients, are released into surface waters through either point sources or nonpoint sources. Point source inputs, such as those from industrial treatment plants, can usually be traced, do not have much variability, and can typically be easily controlled and regulated. Nonpoint source inputs have much more variability, and agricultural nonpoint source inputs are usually dependent on seasons. They are much more difficult to monitor and regulate and can negatively affect surface waters (Carpenter, 1998; U.S. Environmental Protection Agency, 2012b).

The EPA has declared that nonpoint sources are the major cause for pollution entering U.S. surface waters (U.S. Environmental Protection Agency, 1990 and 1996). Excessive amounts of nitrates entering the environment have been linked back to failing septic systems, animal feedlots, agricultural fertilizers, manure, industrial wastewaters, sanitary landfills, and garbage dumps (Minnesota Pollution Control Agency, 2008). The EPA set a maximum contaminant level of 10 mg/L for NO_3 in drinking water (U.S. Environmental Protection Agency, 2012c). Phosphorus is usually found attached to sediment particles in water. As long as the phosphorus attached to sediment in water is not disturbed, it is not available for plant use. Certain chemical and biological processes occur, releasing phosphorus into the water and making it available for aquatic plant life (Minnesota Pollution Control Agency, 2008). There has been no established drinking water standard for phosphorus because it has no direct health effect on humans or animals. However, high phosphorus levels in water do cause an indirect health effect. It is

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a major stimulant for toxic algal blooms which can directly affect the health of humans and animals (Carpenter, 1998).

2.3 Federal Law and Incentives

Clean surface waters in the United States are very crucial resources, and avoiding pollution is one of the most cost effective ways of increasing clean water supplies (Carpenter, 1998). The Clean Water Act (CWA) was enacted in 1972 and ensures the protection of U.S. waters from pollutants. The CWA requires the Mississippi Department of Environmental Quality (MDEQ) to complete a triennial review to check and update a state's water quality standards on a routine basis. States are given the authority to assign uses for their surface waters, to create protective water quality standards, and apply an anti-degradation policy. This policy allows a state to keep previous standards which might be more stringent than the current standards (MDEQ, 2007). States' water quality standards are upheld on two components: use classifications and water quality criteria.

Classifications for the state of Mississippi cover uses such as recreation, wildlife, human consumption, agriculture, and industrial (MDEQ, 2007). Water quality standards as outlined in the Water Quality Act of 1987 are then applied based on a waterbody's classified use. The Water Quality Act of 1987 established that the State must identify impaired waters and set limitations for pollutant discharges into such waters. For example, the designated use of the Mississippi River is for fish and wildlife; therefore it must meet the standards to support fish and wildlife (MDEQ, 2007). Failure to comply with Acts such as the CWA can result in civil (fines) and criminal (imprisonment) penalties (Schroeder, 2008).

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The Natural Resource Conservation Service (NRCS) is an agency of the United States Department of Agriculture (USDA) and helps implement management programs to achieve lower levels of nonpoint source pollution in the United States. State agencies such as the MDEQ also help the state of Mississippi develop management plans. These agencies are able to implement management programs through the help of government funding provided by the Farm Bill, which represents the federal government's agriculture and food policy. The 2008 Farm Bill helped create several conservation programs including the Agricultural Management Assistance Program (AMA); Conservation of Private Grazing Land Program (CPGLP); Agricultural Water Enhancement Program (AWEP); Environmental Quality Incentives Program (EQIP); and the Watershed Rehabilitation Program (WRP) (NRCS, 2012b).

The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force developed a goal in 2001 to reduce the size of the Gulf's hypoxic zone to less than 5,000 km^2 by the year 2015 (Task Force, 2001). The 2005-2010 average size of the Gulf hypoxic zone was 17,300 km^2, and the size in 2010 covered 20,000 km^2, far from the 2015 goal of less than 5,000 km^2 (Rabalais and Turner, 2010). A nutrient reduction plan for the Mississippi Delta was developed by a team, led by MDEQ and Delta F.A.R.M., to reduce the amount of nutrients that enter the Gulf of Mexico by implementing best management practices (BMPs). In 2010, the NRCS launched the Mississippi River Basin Healthy Watersheds Initiative (MRBI), which is currently funded from the fiscal years of 2010 through 2013. The MRBI was developed to support conservation practices to help reduce nutrient loading within the watershed, improve water quality in the Basin (NRCS, 2012a), and ultimately help reduce the effects of hypoxia in the Gulf of Mexico. In Mississippi

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watersheds such as Big Sunflower, Deer Steele, Coldwater, and Upper Yazoo, NRCS has been working with landowners and other federal and state agencies to implement the MRBI and other federal cost share programs. Each year, the NRCS will be offering at least $80 million to available corresponding programs such as the Cooperative Conservation Partnership Initiative (CCPI) and Wetlands Reserve Program (WREP) (NRCS, 2012a). These programs have offered farmers and landowners the financial capability to install BMPs.

2.4 Best Management Practices

The use of BMPs has become an increasingly popular conservation strategy within the Mississippi Delta. Increases in population and demand for food, as well as advances in agricultural machinery have left the Delta's soil vulnerable to erosive forces. Row crop production takes more than just good soil, but also requires the use of heavy machinery for land forming, cultivating, planting and harvesting and after continuous use leaves soil loose and prone to erosion. BMPs have been around many years to help farmers and landowners reduce soil loss (Fangmeier, 2006), and as water quality issues become more prominent and new problems arise, new BMPs are developed and implemented to help meet current environmental concerns. Logan (1993) categorized BMPs in three groups: structural, cultural, and management. A structural BMP is a device or something built on site to help control the different aspects of an environmental problem. A cultural BMP would be the way in which one plants or prepares land for crops, and a management BMP includes the application (when, where, and how) of fertilizers, pesticides and irrigation. Some common structural BMPs today are listed as follows: terraces (Fangmeier, 2006), grass filter strips, grass turn rows, vegetated

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waterways, different slotted pipes for drainage (Logan, 1993), wetlands (Bouldin, 2004), and detention ponds (Fiener, 2005). Vegetative strips, rows and waterways are created as buffer zones to help reduce erosion while filtering surface runoff and keeping nutrients and sediment from leaving the farm. De Laney (1995) found that vegetative strips are capable of substantially reducing sediment and nutrients in surface water runoff. Although they have shown positive benefits, vegetative buffer strips are not commonly used within the Mississippi Delta because chemicals can have a tendency to drift when applying herbicides to fields, killing the vegetation in the rows and strips (Trinity Long, Personal communication, 2013).

Terraces and detention ponds serve the same purpose, but are constructed differently. Constructed field terraces act in two ways. First, they reduce the area in which runoff has to gain energy, thereby reducing the capability of carrying large sediment particles in the runoff. Secondly, terraces hold water, giving sediment time to settle before water is released downstream. Terraces are not common throughout the Mississippi Delta because of the topography (Fangmeier, 2006). Detention ponds serve as on-field holding areas for surface runoff so that sediment has time to settle before being released downstream. These ponds also use perforated outlet pipes and vegetated waterways to help reduce pollution downstream (Fiener, 2005). Fiener (2005) showed that detention ponds reduce sediment by 50% and nutrients by roughly 30 to 70%. Ponds have the disadvantage of possible flooding, which would damage crops, and dredging of ponds would probably be needed every year due to sediment build up. Constant inspection would also need to take place to insure systems were running correctly. Other than small financial expenditures and time consuming maintenance, detention ponds are

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cost effective and have shown positive results. Though these BMPs do show significant sediment and nutrient reduction, they still have a low adoption rate. An on-farm water storage system is a relatively new BMP that is starting to receive a lot of attention.

2.5 On-Farm Water Storage System

On-farm water storage (OFWS) systems offer farmers and landowners the flexibility of providing irrigation water and capturing nutrient-rich tailwater from irrigated fields. The benefits associated with OFWS systems include reduced water withdrawals from groundwater wells, reduced loss of sediment and nutrients from on-farm runoff and erosion, and less sediment, nutrients, and chemicals discharged downstream (Shock and Welch, 2011). Since 2010, farmers in the Mississippi Delta have installed OFWS systems through a cost-share program with MRBI and with technical assistance from NRCS. An OFWS system usually includes a reservoir or pond and a tailwater recovery (TWR) ditch (Figure 2.2). The size of the storage reservoir is based on the area to be irrigated, typically using a ratio of 16 acres of irrigated area to 1 acre of reservoir. For example, an irrigated area of 160 acres will have a 10-acre storage reservoir. The depth of water in the pond is 8 feet, which translates to a storage capacity of 80 acre-feet. The on-site water storage systems are commonly designed with small berms, or pads, surrounding the fields to ensure that all runoff from rainfall and irrigation is diverted to a TWR ditch through a series of drainage pipes (Figure 2.3). A pump then moves the water from the recovery ditch to the reservoir where it will remain until used for irrigation purposes. It is a quasi-closed system because tailwater from irrigated fields does not drain into streams, unless there is an extreme event that exceeds the combined

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storage capacity of the TWR ditch and storage pond. In this case, water would flow through an overflow pipe to a nearby stream.

Figure 2.2 A typical on-farm water storage pond (left) used to store water from a tail water recovery ditch (right).

This water storage system provides supplemental irrigation to a 300-acre field in Porter Bayou Watershed, Mississippi.

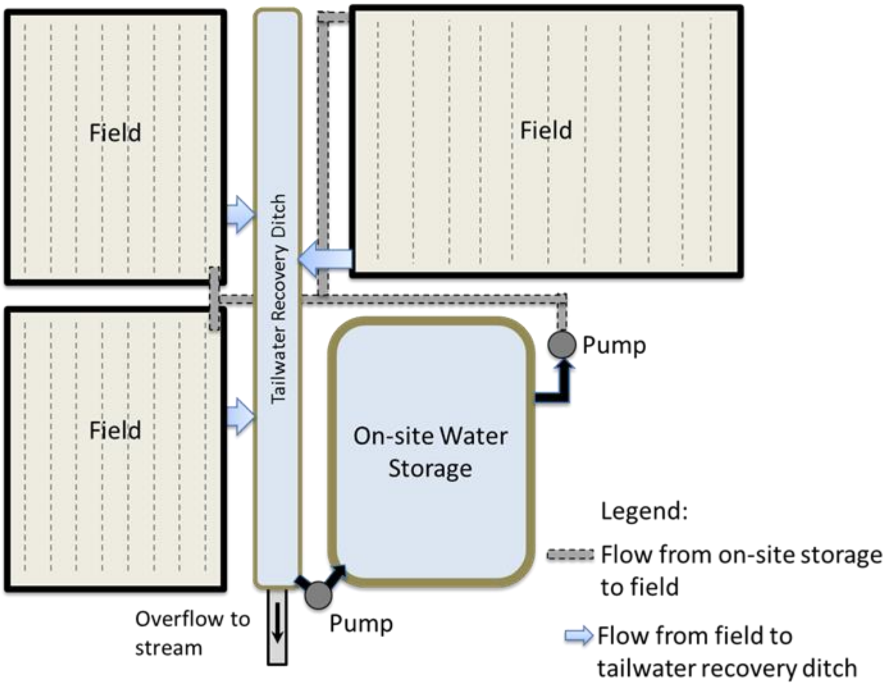

Figure 2.3 Inflow and outflow of water in an on-farm water storage and tailwater recovery system.

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CHAPTER III

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Porter Bayou Watershed

The Porter Bayou Watershed (PBW), located within the Mississippi Delta, was chosen for this study because of the number of OFWS systems that have been installed through the MRBI program. The PBW is a sub-watershed of the Big Sunflower Watershed (HUC 08030207). It has an area of 276.8 km^2 and covers parts of Sunflower and Bolivar counties in Mississippi (Figure 3.1). Roughly 81% of Porter Bayou is cropland while the rest consists of urban development, forest, pastures, waterways, and wetlands (MDEQ, 2011). The PBW is classified as an impaired body of water, which was recorded and placed on the Mississippi Section 303 (d) list of impaired water bodies in 2006 (MDEQ, 2008).

The Mississippi Delta is located within a subtropical climate and sees a majority of its rainfall in the spring and winter, with its average yearly rainfall ranging between 1150 and 1500 mm, and average temperatures around 64°F (Nett, 2004). Porter Bayou discharges into the Sunflower River and was declared impaired due to sediment, organic enrichment, low dissolved oxygen, and nutrients (MDEQ, 2008). A Total Maximum Daily Load (TMDL) report prepared by the Mississippi Department of Environment Quality Office of Pollution Control stated that the implementation of BMPs could be

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used to help reduce the nutrients within the Porter Bayou (MDEQ, 2008). The Big Sunflower River watershed, which includes the PBW, was one of the priority watersheds selected to receive support from the Mississippi River Basins Healthy Watersheds Initiative (MRBI) (NRCS, 2012a). An inventory of OFWS systems in PBW was conducted to provide baseline information regarding the structural characteristics of OFWS systems. The inventory was also used to better understand how field production and agro-ecosystems are impacted by these systems. Two OFWS systems in the PBW were monitored for different nutrient and water quality parameters from March 2012 to April 2013.

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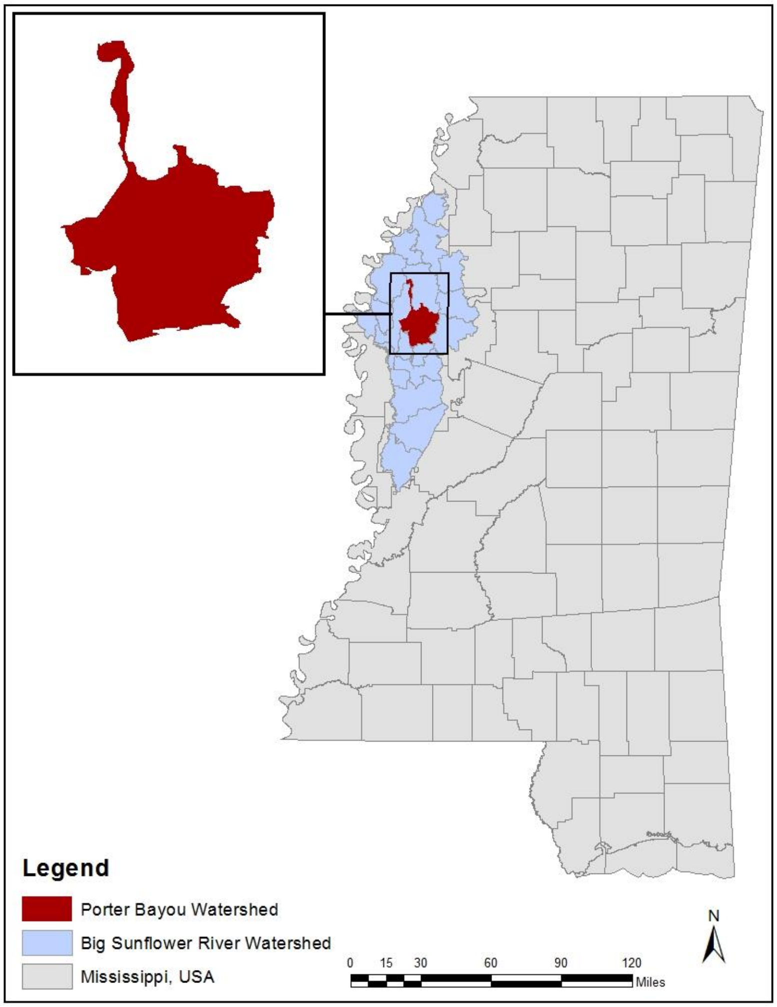

Figure 3.1 Map of Porter Bayou Watershed (HUC 0803020705) located in Big Sunflower River Watershed within Mississippi.

3.1.2 Survey of On-Farm Water Storage Systems in Porter Bayou

In order to address objective one, structural design specifications and management data for several OFWS systems in Porter Bayou watershed were obtained from NRCS in Indianola, MS. Information about installed OFWS systems was collected using a list of descriptors that included dimensions of storage pond and TWR ditch, farm

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size, and crop rotations. Data collected from individual OFWS systems were reviewed at the NRCS field office in Indianola, MS.

3.1.3 Metcalf Farm

The OFWS system at Metcalf farm was constructed and fully operational in 2010. The system has an 818.8 m long TWR ditch and an 11-acre storage pond. Metcalf farm has 245 acres of padded fields, and runoff or tailwater from approximately 77% of total farm land drains into the TWR ditch.

A layout of the fields, TWR ditch, and storage pond at Metcalf farm is shown in Figure 3.2. A small portion of the runoff from a field north of Metcalf farm flows through an inlet and into the TWR ditch. Several underground drainage pipes deliver runoff from the Metcalf fields into the TWR ditch. A 0.9-m diameter culvert is located at the south end of the ditch. The culvert is set at 1.2 meters above the channel bed. If the combined holding capacity of the storage pond and TWR ditch is exceeded, excess water is discharged from the ditch through the outlet and into Porter Bayou. Effluent from the TWR ditch represents part of the headwaters of Porter Bayou, which drains into the Big Sunflower River. Tailwater held in the ditch is transferred from the TWR ditch into the storage pond using a tractor pto-driven pump.

The two fields in the southeast corner of the farm are not a part of the runoff catchment system, but are irrigated using water from the pond. The farm follows a rice and soybean rotation utilizing furrow irrigation (before and after the construction of the OFWS system). The combined capacities of the individual components of the OFWS system can store enough water to irrigate the entire farm (245 acres), with the storage pond providing water to irrigate 205 acres. In addition, water from the TWR ditch can be

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directly pumped to irrigate the remaining 40 acres located in the northwest corner of the farm. The farm also has three available ground water wells that were present and previously used for irrigation needs before the OFWS system was constructed, and they can still be used for irrigation in case of surface water shortage.

Figure 3.2 Boundaries and sampling points of Metcalf OFWS system*.

*System includes fields that are either irrigated by the TWR ditch or reservoir and/or on-farm fields that contribute to the runoff catchment system).

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3.1.4 Pitts Farm

The OFWS system at Pitts farm was constructed in 2010 and became fully operational in 2011. The system has a 1326.6-m long TWR ditch and a 10-acre storage pond. Pitts farm has 200 acres of padded fields, and runoff or tailwater from approximately 100% of the total farm land drains into the TWR ditch.

A layout of the fields, TWR ditch, and storage pond in Pitts farm is shown in Figure 3.3. Runoff from north and east of Pitts farm flows through two inlets into the TWR ditch. Several drainage pipes collect runoff from fields along the length of the ditch and deliver runoff from the fields into the channel. A 1.22-m diameter culvert is located at the end of the ditch and the culvert is set at 1.22 m above the channel bed. Water in excess of the combined storage capacity of the pond and the ditch is discharged through the outlet and into Porter Bayou. Tailwater held in the ditch is transferred from the TWR ditch into the storage pond using a water pump.

The northeast corner field is not irrigated by the system but does contribute runoff to the TWR ditch. The farm is on a corn and soybean rotation and previously utilized a center pivot irrigation system. The farm has used a furrow system since the construction of the OFWS system. The combined capacities of the individual components of the OFWS system can store enough water to irrigate 160 acres of Pitts farm. The remaining 40 acres is irrigated by groundwater. The farm also has two available ground water wells that were used for irrigation prior to the construction of the OFWS system, and these wells can still be used throughout the system for irrigation in case of surface water shortage.

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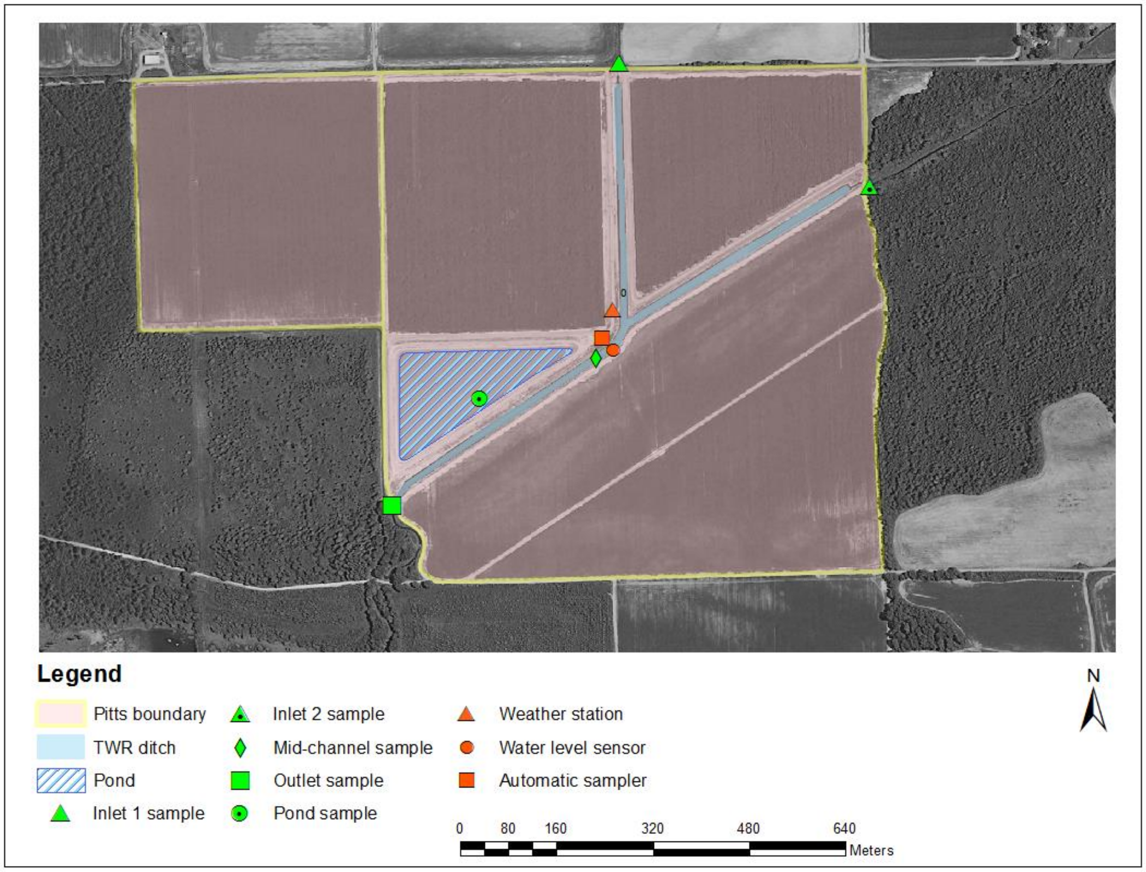

Figure 3.3 Boundaries and sampling points of Pitts OFWS system*.

*System includes fields that are either irrigated by the TWR ditch or reservoir and/or on-farm fields that contribute to the runoff catchment system.

3.2 Field Work

3.2.1 Collection of Data

Water samples were collected from different sites at Metcalf and Pitts farm in order to determine nutrient concentrations and to examine any differences in nutrient levels between influent and effluent water at various times throughout the monitoring period. The sampling points were established before monitoring commenced in March 2012, and grab samples within the OFWS systems were collected at the inlet(s) (area

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before the water entered the TWR ditch), mid-channel (in the approximate center of the TWR ditch), outlet (where the water discharges out of the system), and the pond (where water is transferred for supplemental irrigation purposes) (Figures 3.2 and 3.3).

Samples were collected every third week during the growing season (March – October). A different sampling interval was implemented during the non-growing season (November - February), whereby samples were collected every six weeks. Four grab samples were taken at Metcalf and five grab samples were taken at Pitts Farm. Grab samples were taken at each sampling point in a consistent manner to avoid error. Each bottle was properly labeled so that the samples could be correctly identified once returning to the lab.

In addition to grab samples, 24 samples were taken on each farm using a Teledyne ISCO 6712 automated sampler (Lincoln, NE). Samplers were installed on the channel embankment of both farms to collect water samples in the middle of the TWR canal (Figure 3.2 and 3.3). The sampler was programmed to collect one liter of water every hour for 24 hours during a specified sampling date. The polyethylene wedge bottles containing the water sample were retrieved within one hour after the completion of the auto-sampling event. Samples were placed on ice in coolers and transported from the field to the laboratory. Samplers were installed as a secondary measurement in case a runoff event took place 24 hours before grab sampling. Forty-eight automated samples were collected along with nine grab samples to equal a total of 57 samples for analysis every third week.

A Spectrum Technologies$^{TM.}$ WatchDog 2900ET weather station was installed at both study areas (Figure 3.2 and 3.3). Sensors measured rainfall (in), solar radiation

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(MJ/m^2), wind direction (mph), wind dust (mph), wind speed (mph), air temperature (°F), and dew point temperature (°F). Weather data were recorded every 15 minutes and downloaded to a computer every three weeks. Water level sensors (Global Water model WL 16) were installed on both farms in the TWR ditches to record water level (ft.) and water temperature (°F). Data were recorded every 10 minutes and downloaded to a computer every three weeks when sampling occurred. The precision of measured weather parameters and water levels are shown in Table 3.1 and Table 3.2, respectively.

Table 3.1 Weather station measurements with scientific precision (Spectrum Technologies, 2012)

Parameter	Precision
Air Temperature	± 0.6°C
Dew Point	± 2°C
Evapotranspiration	Not Applicable
Rainfall	± .02 at < 5 cm per hour
Relative Humidity	± .03
Solar Radiation	± .05
Wind Direction	± 4°
Wind Gust	Not Applicable
Wind Speed	± 2 mph

Table 3.2 Pressure transducer with scientific precision (Campbell Scientific Inc., 2012)

Parameter	Precision
Air Temperature	± 0.2°C
Groundwater Level	± .001 (reading)

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3.3 Analytical Methods

Nutrient concentrations and other water quality parameters of samples from the OFWS systems were determined using accepted techniques. All water samples were transferred in coolers filled with ice in order to reduce sample degradation. Upon arrival in the laboratory, water samples were immediately analyzed for pH, conductivity, and dissolved oxygen using the multiparameter Orion Star A2390 meter. The Thermo Scientific Orion Star A2390 meter was calibrated by Thermo Scientific in accordance with International Scientific Organization (ISO) and International Electrotechnical Commission (IEC) standards, (ISO 9001:2000 and ISO/IEC 17025:2005), along with all U.S. Pharamacopeia standards. The Orion Star A2390 meter was re-calibrated before every set of samples to ensure compliance within the calibration standards range.

All water samples were transferred to glass jars and concentrated sulfuric acid was added to preserve the samples. Samples were refrigerated at 4°C in accordance to standard methods (APHA, 1995). The following nutrients were analyzed using specific Hach TNT reagents and measured using a Hach model DR 2800 spectrophotometer: total and reactive phosphorus (TP), nitrate (NO_3-N), ammonia (NH_3-N), and total nitrogen (TN). Turbidity was measured using a Hach model 2100Q portable turbidimeter. The water samples were then sent to the Mississippi State Civil and Environmental Engineering Laboratory for additional analyses, namely, dissolved orthophosphate (DOP), total kjehldahl nitrogen (TKN), and total suspended solids (TSS). Dissolved orthophosphate was determined by the colorimetry method (EPA method 365.2), while total kjehldahl nitrogen was analyzed using (EPA method 351.4). Finally, total suspended solids of water samples were measured using the gravimetric method (EPA method

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160.2). All in-house laboratory analyses previously described are shown below in Table 3.3 along with their scientific precision and range of detection. Low range Hach TNT reagents were used for the initial analysis. Samples with values that were above the low range reagent would be run again with high range reagents to analyze the sample.

Table 3.3 Laboratory measurements with scientific precision and range of detection (Thermo fisher Scientific, 2011; Hach Company, 2007)

Parameter*	**Precision**	**Range of Detection**	
		Lower Limit	**Higher Limit**
Conductivity	Orion Star A3290 ± 0.5	0.00 µS/cm	3,000,000 µS/cm
Rugged Dissolved Oxygen	Orion Star A3290 ± 0.2	0.00 mg/L	20 mg/L
pH	Orion Star A3290 ± 0.002	-2.000	+20.000
Temperature	Orion Star A3290 ± 0.1	-5 °C	105 °C
Turbidity	Hach 2100Q ± .02 (reading)	0 NTU	1000 NTU
TNT Plus LR 835 Nitrate	± 1.00 (mg/L)	0.23 mg/L	13.5 mg/L
TNT Plus HR 836 Nitrate	± 1.00 (mg/L)	5 (mg/L)	35 mg/L
TNT Plus LR 826 Total Nitrogen	± 1.00 (mg/L)	1 mg/L	16 mg/L
TNT Plus HR 827 Total Nitrogen	± 5.00 (mg/L)	5 mg/L	40 mg/L
TNT Plus LR 843 Phosphorus	± 0.15 (mg/L)	0.05 mg/L	1.5 mg/L
TNT Plus HR 844 Phosphorus	± 0.15 (mg/L)	0.5 mg/L	5.0 mg/L
TNT Plus ULR 830 Ammonia	± 0.015 (mg/L)	0.015 mg/L	2.00 mg/L

*LR = low range; HR = high range; ULR = ultra-low range

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CHAPTER IV

RESULTS AND DISCUSSION

4.1 Installed On-Farm Water Storage Systems

Eight OFWS systems were identified within Porter Bayou Watershed and their locations are shown in Figure 4.1. Farm characteristics and design specifications were compiled for these eight OFWS systems in PBW and are presented in Table 4.1-4.4. Eight systems have been installed and operational as of June 2013. The OFWS systems at Metcalf and Pitts farms were monitored as part of this study and are identified by name. The OFWS systems on the other six farms in the PBW are identified as Farm 3, Farm 4, Farm 5, etc. to maintain the privacy of the landowners and farmers. The size of the farms with OFWS systems ranged from 160 to 356 acres. The farms all implemented trapezoidal shaped TWR canals, and they had storage ponds ranging from 10 to 32 acres. All canals had side slopes of 1.5:1 and a bed slope of zero. All systems reviewed consisted of a pond and TWR ditch except Farm 4. This farm did not have both elements because the cost-share program that was used to construct the system did not financially allow for both the TWR ditch and the reservoir to be installed. Also, when these systems were first designed, both the pipes for groundwater wells and the surface water sources were tied together. However, this was not the case for Farm 4 or for new systems that have been recently designed. New systems are being constructed with well and surface pipes separated so that water usage can be better traced and studied. Prior to the

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construction of an OFWS system, four out of seven farms used pivot irrigation systems while two farms utilized furrow irrigation. One farm used flood irrigation. After the OFWS systems were constructed, all farms changed to furrow irrigation with surface water and used groundwater only when necessary. Farms moved to furrow irrigation because it works best with these systems. All drainage areas, except Farm 4, were equal to or less than the farms total acreage. All but two farms had systems that could capture all runoff on the farm. Farm 3 and Metcalf farm were unable to capture runoff from the entire farm because of the layout of the original farm. The system at Metcalf farm captures roughly 67% of the farm's total runoff. Due to the layout of some tracts of land, it was not financially feasible to landform the entire farm for the catchment of all runoff.

The OFWS systems on all but one of the farms were built with funding through NRCS cost-share programs. These farms had to go through a stringent review process before they were approved and accepted. Farm 8 is also located within the PBW but was funded through a program administered by MDEQ. Systems are ranked on various criteria when they apply for funding through NRCS programs. Each system design varies by farm due to a farm's needs and layout, but all are based around the same concept of constructing a TWR ditch first and a reservoir second, if possible and if desired. Farmers and landowners have the opportunity to choose whom they want constructing their system. The financial cost for a system differs because not every farm is alike. Due to privacy issues, the farmer's financial contribution for the construction of the OFWS system was not shared. NRCS did disclose that they have their own system for calculating prices for different aspects of the construction phases and that they are willing to pay 75% of the construction cost, not to exceed $450,000. The farms reviewed in this

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section were funded by several programs such as MRBI, AWEP, and the National Water Quality Initiative (NWQI).

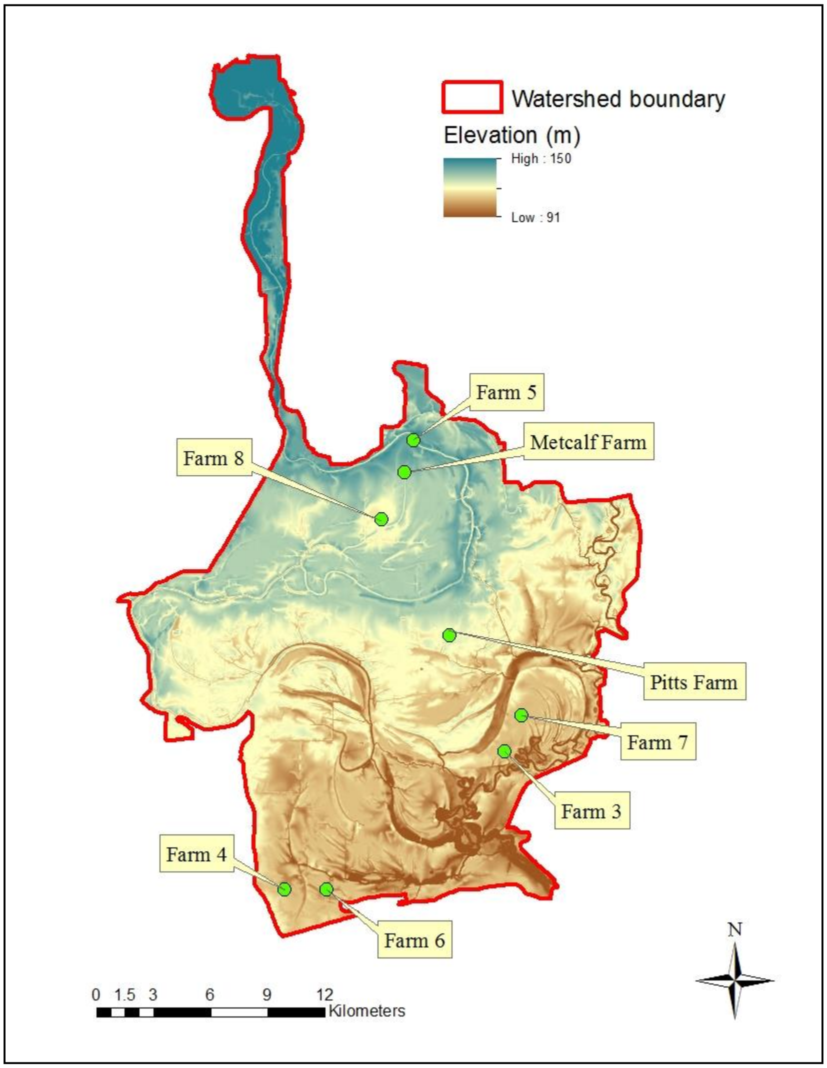

Figure 4.1 Location of installed OFWS systems within Porter Bayou Watershed.

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Table 4.1 Design specifications of installed OFWS systems

Descriptors	Pitts Farm	Metcalf Farm	Farm 3	Farm 4
Location and Size				
Size of Farm	200 acres	245 acres	235.47 acres	308 acres
Drainage Area	200 acres	191 acres	238.9 acres	308 acres
Drainage Area for Outflow	Porter Bayou	Porter Bayou	Sunflower River	Beaver Dam Bayou
TWR Dimensions				
Channel slope	Trapezoid			
Length	1326.6 m	818.8 m	2110.6 m	1493.5 m
Bottom width	7.3 m	3.6 m	4.8 m	9.7 m
Channel bed slope	0			
Side slope	1.5:1			
Depth	1.8 m	1.8 m	2.0 m	1.6 m
Storage Reservoir Dimensions				
Size	10 acres	11 acres	16 acres	N/A
Bottom width	7.9 acres	9 acres	10.2 acres	N/A
Side slope	3:1			

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Table 4.2 Design specifications of installed OFWS systems

Descriptors	Farm 5	Farm 6	Farm 7	Farm 8
Location and Size				
Size of Farm	288.3 acres	356 acres	320 acres	160 acres
Drainage Area	288.3 acres	356 acres	320 acres	450 acres
Drainage Area for Outflow	Porter Bayou of Harris	Beaver Dam Bayou	Benson Break	Porter Bayou
TWR Dimensions				
Channel slope	Trapezoid			
Length	1090.2 m	853.4 m	1463.0	975.3 m
Bottom width	4.8 m	10.9 m	4.8 m	9.1 m
Channel bed slope	0			
Side slope	1.5:1			
Depth	1.8 m	1.8 m	2.1 m	3.0 m
Storage Reservoir Dimensions				
Size	13.8 acres	30.5 acres	32 acres	8 acres
Bottom width	9.8 acres	27.8 acres	19.5 acres	6.5 acres
Side slope	3:1			

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Table 4.3 Farm characteristics and financial cost of OFWS systems.

Descriptors	Pitts Farm	Metcalf Farm	Farm 3	Farm 4
Year of start of operation	2011	2010	2013	2012
Irrigation System				
Before	Pivot	Furrow	Pivot	Pivot
After	Furrow	Furrow	Furrow	Furrow
Crops				
Typical Crop Rotation	Corn and Soybean	Rice and Soybean	Corn and Soybean	Beans, Corn, and Cotton
Crops grown:				
2012	Corn/Beans	Soybeans	Corn	Soybeans
2011	Soybeans	Rice	Soybeans	Soybeans
2010	Soybeans	Soybeans	Corn	Soybeans
Winter crop	None	None	Wheat	None
Programs and Financial Cost				
Programs	MRBI	MRBI	MRBI	Water Quality
Construction Cost	NRCS pays 75% of construction cost not to exceed $450,000.			
Maintenance of TWR and Pond	Varies depending on soil and sediment. Farmer picks up cost of maintenance work.			
Mechanical Pumps and Wells				
Number of existing wells	2	3	2	2
Number of flow meters	4	3	0	3
Wells tied to surface pumps	Yes	Yes	Yes	No
Type of pump to transfer water from TWR to pond	Mixed Flow			
Origin of water for irrigation use				
Before	Well	Well	N/A	Well
After	Mixed (surface water and well water)	Mixed (surface water and well water)	N/A	Mixed (surface water and well water)
Vegetative Cover				
Vegetative cover used to protect the ditch and embankment	Grass Mix	None	Will depend on soil type and season building	Native Warm Season Grasses

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Table 4.4 Farm characteristics and financial cost of OFWS systems.

Descriptors	Farm 5	Farm 6	Farm 7	Farm 8
Year of start of operation	2011	2012	2012	2012
Irrigation System				
Before	Flood	Furrow	Pivot	Furrow
After	Furrow	Furrow	Furrow	Furrow
Crops				
Typical Crop Rotation	Rice and Beans	Beans and Corn	Soybeans	Soybean and Rice
Crops grown:				
2012	Rice	Corn	N/A	Soybeans
2011	Beans	Soybeans	Soybeans	Soybeans
2010	Rice	Wheat	Soybeans	Rice and Beans
Winter crop	None	None	None	None
Programs and Financial Cost				
Programs	MRBI	AWEP	NWQI	319 MRBI EQIP
Construction Cost	NRCS pays 75% of construction cost not to exceed $450,000.			N/A
Maintenance of TWR and Pond	Varies depending on soil and sediment. Farmer picks up cost of maintenance work.			
Mechanical Pumps and Wells				
Number of existing wells	2	2	2	1
Number of flow meters	1	3	3	2
Wells tied to surface pumps	Yes	Yes	Yes	Yes
Type of pump to transfer water from TWR to pond	Mixed Flow	Mixed Flow	Mixed Flow	3,000 GPM
Origin of water for irrigation use				
Before	Wells	Wells	Wells	Wells
After	Mixed (surface water and well water)	Mixed (surface water and well water)	Mixed (surface water and well water)	Mixed (surface water and well water)
Vegetative Cover				
Vegetative cover used to protect the ditch and embankment	Native Warm Season Grasse	Native Warm Season Grasse	None	Bermuda

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4.2 Environmental Conditions

4.2.1 Metcalf Farm Rainfall and Evapotranspiration

The daily rainfall and evapotranspiration are presented in Figures 4.2 and 4.3, respectively. The total rainfall during the 13-month monitoring period was 1156 mm. September had an unusually low amount of rainfall (11 mm) possibly due to a malfunction in the tipping bucket rain gage. Evapotranspiration (ET), which is the sum of evaporation and transpiration, was calculated using the Priestly-Taylor equation (Priestly, 1972). The average ET at Metcalf during the monitoring period was 3.64 mm/day. The maximum ET was 8.41 mm/day which was recorded on July 18, 2012 and the lowest ET was 0.46 mm/day on January 15, 2013. The total ET for the 13-month monitoring period was 1370 mm, which was higher than the total rainfall of 1156 mm measured at Metcalf farm.

A comparison of monthly rainfall and ET values shows a large water deficit when ET is greater than rainfall, during the growing season (Figure 4.4). In particular, ET was considerably higher than rainfall in the months of June (209 mm vs 7 mm) and July (202 mm vs 119 mm). For the entire 2012 growing season (April-October), ET was more than double the amount of rainfall (1121 mm vs 450 mm). In contrast, monthly rainfall values were considerably higher than ET from November 2012 to April 2013. Large amounts of rainfall in the fall and winter months provide sufficient surface water that can be captured by the TWR ditch and stored in the pond for later use.

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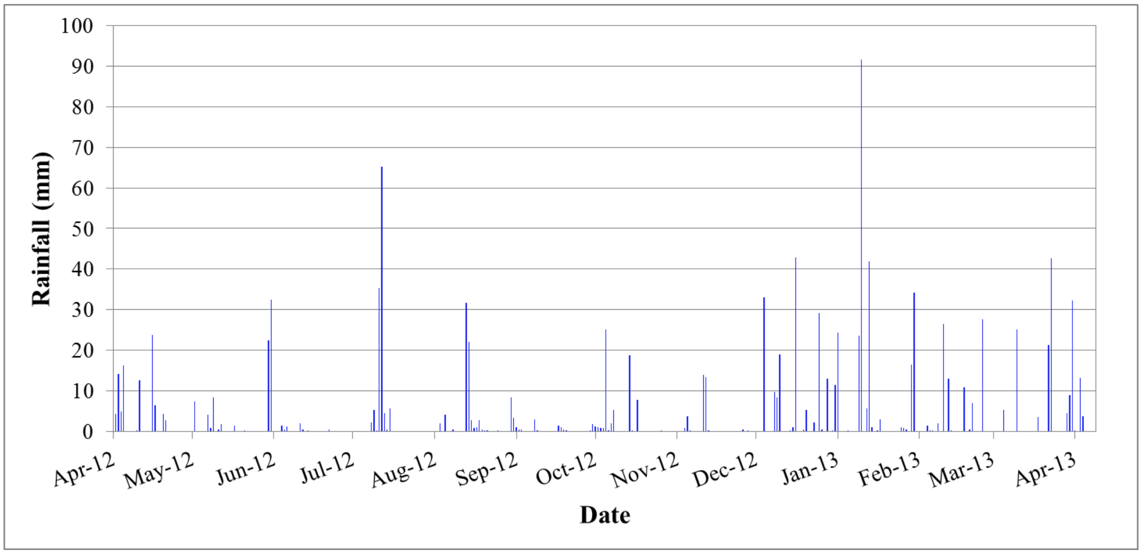

Figure 4.2 Daily rainfall recorded at Metcalf farm during the monitoring period.

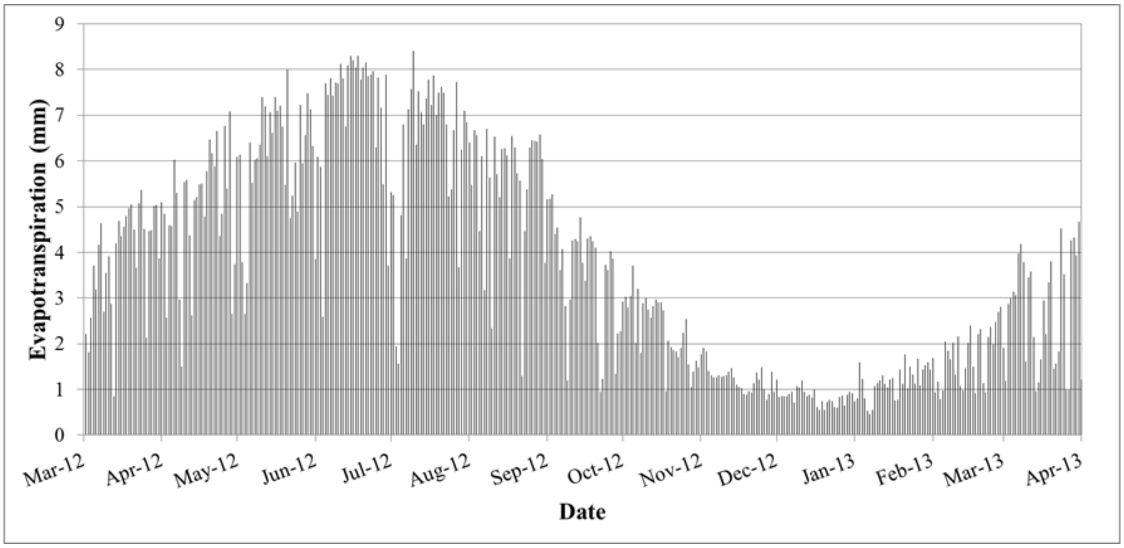

Figure 4.3 Daily evapotranspiration (ET) calculated for the monitoring period at Metcalf farm.

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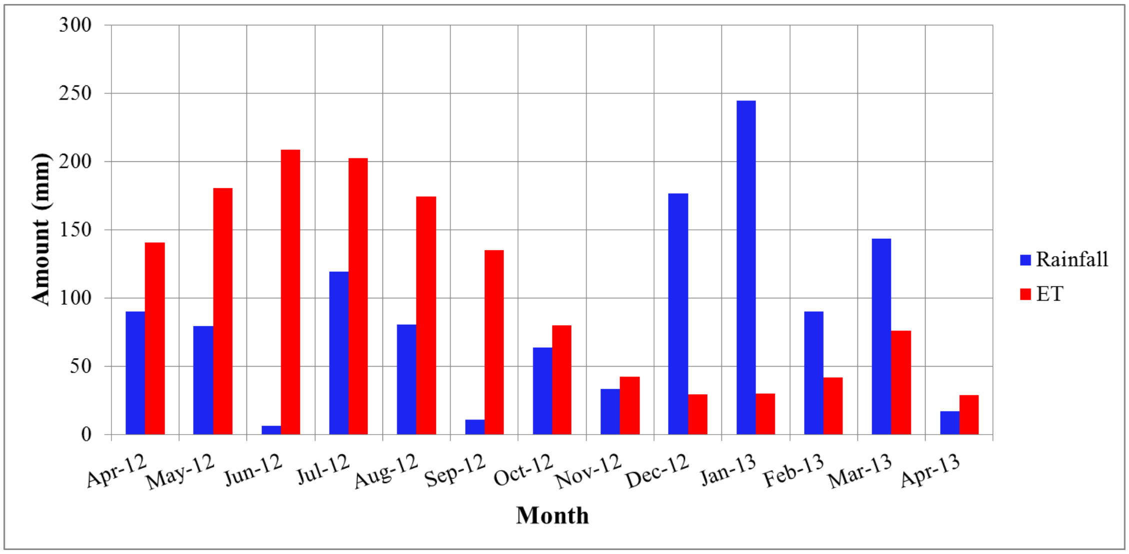

Figure 4.4 Monthly recorded rainfall and ET values at Metcalf farm during the monitoring period.

4.2.2 Pitts Farm Rainfall and Evapotranspiration

The daily rainfall and evapotranspiration are presented in Figures 4.5 and 4.6, respectively. The total rainfall during the monitoring period was 1388 mm. The average ET at Pitts during the monitoring period was 3.61 mm/day. The maximum ET was 8.63 mm recorded on July 18, 2012, and the lowest ET was 0.46 mm on January 15, 2013. The total ET for the 13-month monitoring period at Pitts was 1364 mm, which was slightly lower than the total rainfall of 1388 mm measured at Pitts farm. However, ET was greater than rainfall (1107 mm vs 710 mm) during the 2012-growing season (April-October) (Figure 4.7). Rainfall showed the greatest deficiency when compared to ET during the months of June (217 mm vs 146 mm), July (209 mm vs 123 mm), and May (191 mm vs 82.8 mm). In contrast, monthly rainfall values were considerably higher than ET from December 2012 to March 2013.

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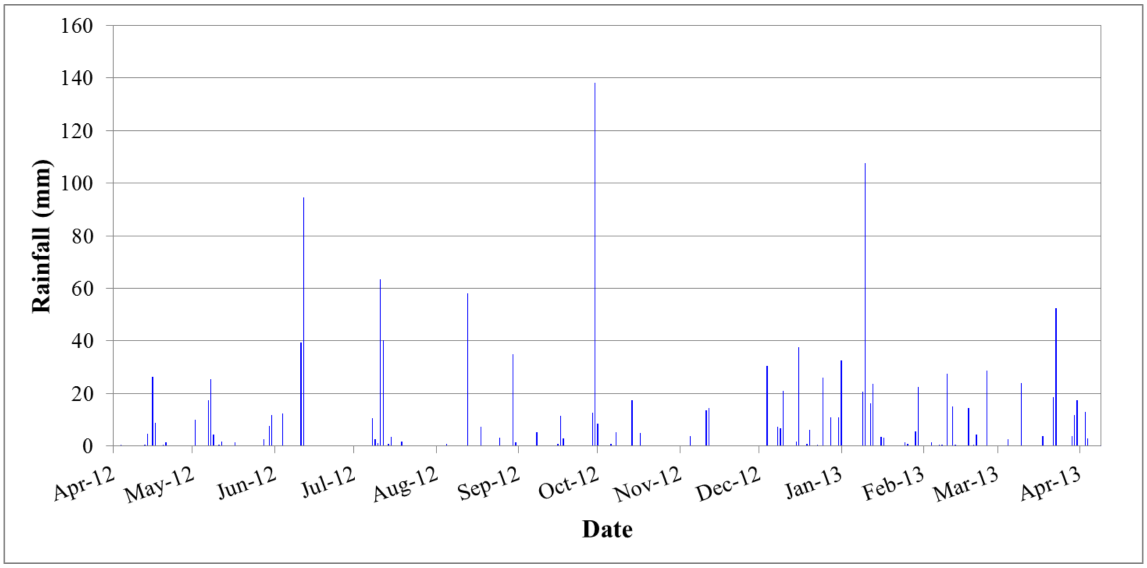

Figure 4.5 Daily rainfall recorded at Pitts farm during the monitoring period.

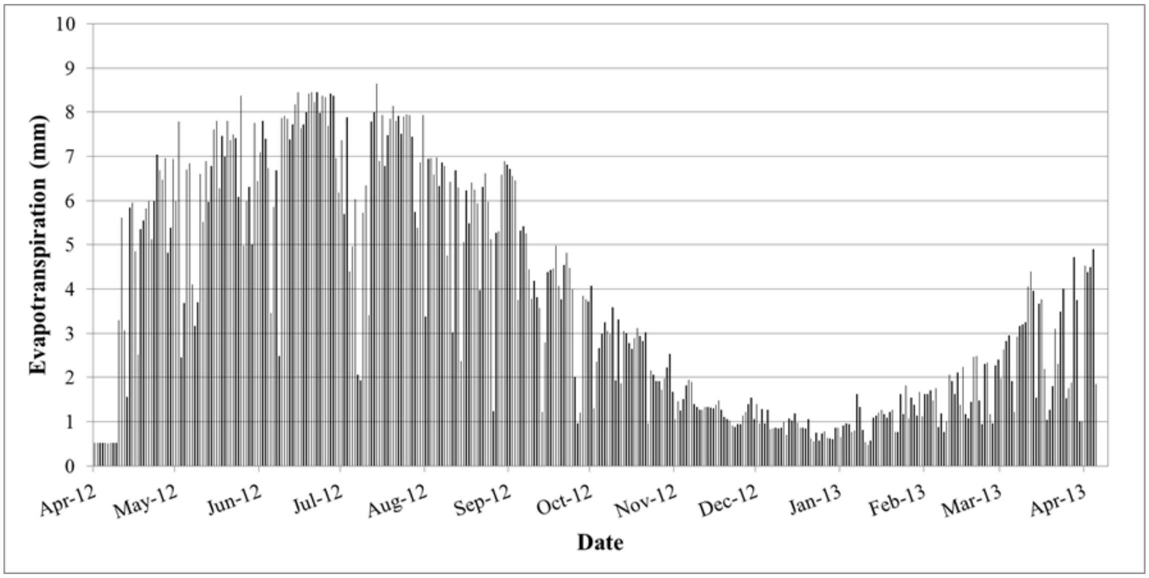

Figure 4.6 Daily evapotranspiration (ET) calculated for the monitoring period at Pitts farm.

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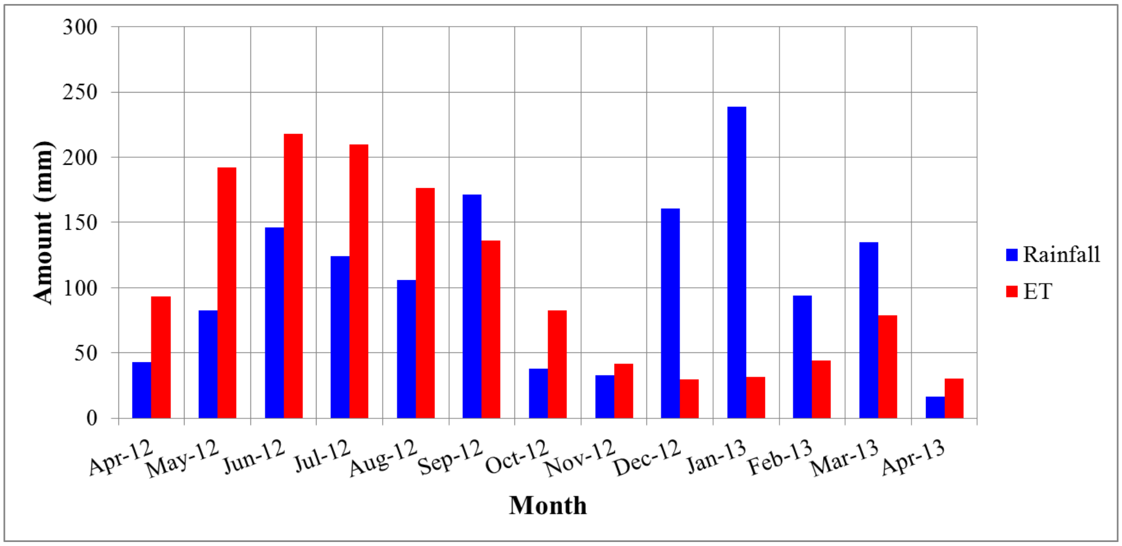

Figure 4.7 Monthly recorded rainfall and ET values at Pitts farm during the monitoring period.

4.2.3 Water Level Data

Water level data was recorded using Global Water sensors model WL 16. Sensors were located mid-channel on both farms. The average water level at Metcalf and Pitts was 0.77 and 1.39 m, respectively. The sensors at both farms only recorded water levels for parts of the monitoring period because of technical problems and human error. Data recorded did show that Pitts had a greater amount of water pass through its system than Metcalf. Even with difficulties, the data that was retrieved from the sensors did show a correlation with recorded rainfall.

Rainfall events in May 2012 at Metcalf farm demonstrate the correlation between rainfall and water level. Total rainfall of 54.86 mm was recorded over two days, on May 30 and 31 (Figure 4.8). The water level in the channel started rising May 30 and peaked at right under 1.8 m on June 1 due to the capacity constraints of the TWR ditch (Figure

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4.9). A sudden drop in water level can be seen on June 1, which is assumed to be the result of pumping water out of the TWR ditch into the pond. The drop in water is not believed to be from natural causes because three days after the peak water had dropped 1.2 m. Patterns can be seen throughout the monitoring period where data was available.

Pitts farm showed similar patterns throughout the monitoring period. Rainfall data recorded during May 30 and 31 showed a total rainfall amount of 42.92 mm (Figure 4.10). This amount of rainfall in two days was reflected in the TWR ditch water level. After two days of rain, the water level drastically increased until it reached the maximum capacity of the TWR ditch (Figure 4.11). The water dropped back to its average water level within two days and this is believed to be from natural discharging of water from the system.

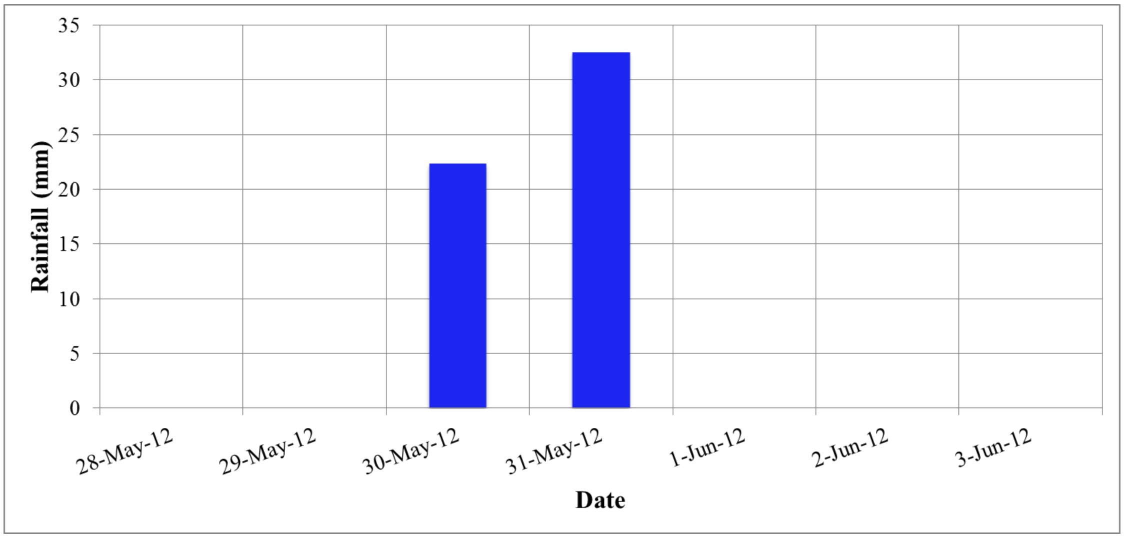

Figure 4.8 Daily rainfall recorded at Metcalf farm May 28 through June 3.

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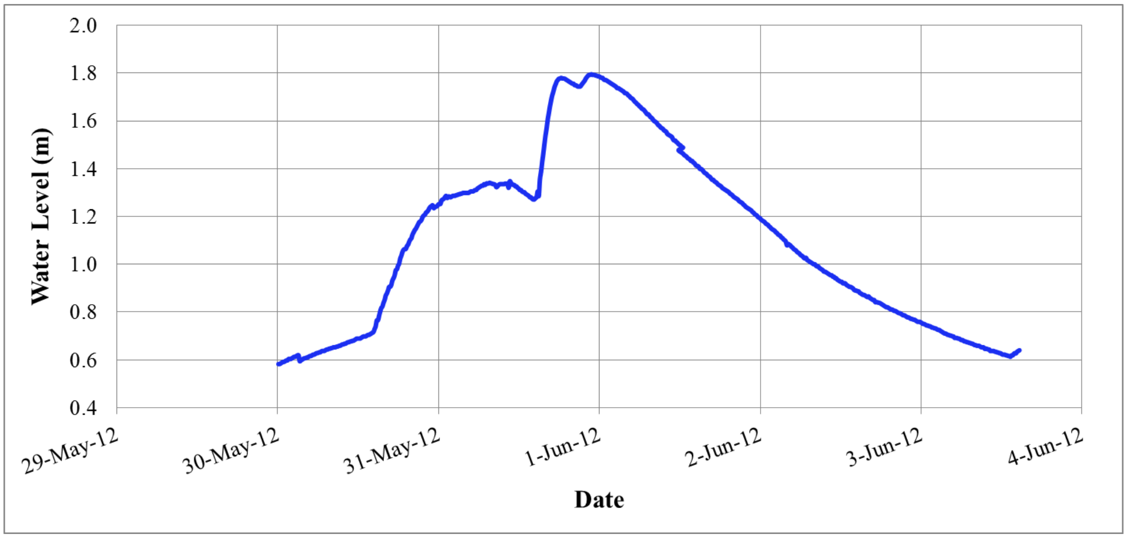

Figure 4.9 Metcalf farm TWR ditch water level for May 30 through June 3.

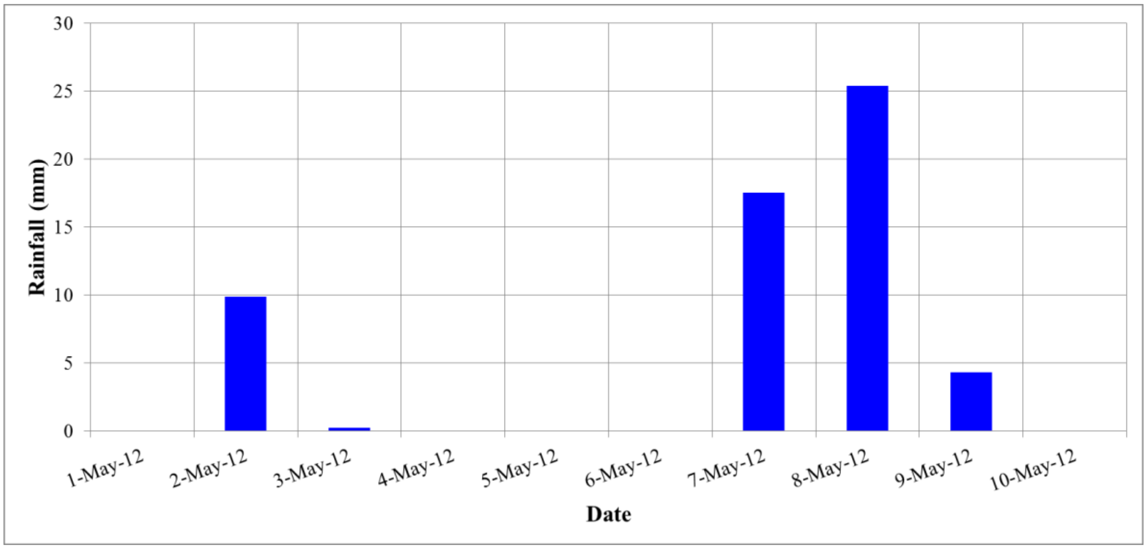

Figure 4.10 Daily rainfall recorded at Pitts farm May1 through May10.

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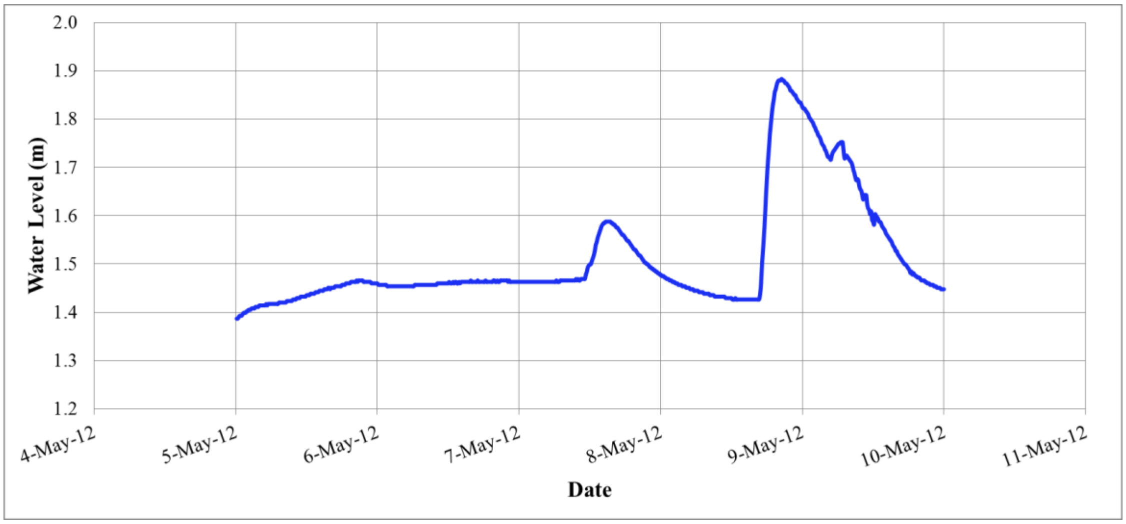

Figure 4.11 Pitts Farm TWR ditch water level for May 4 through May 11.

4.3 Metcalf Farm Water Parameters

4.3.1 pH

The pH is a measure of the level of acidity or alkalinity of a water body, and it is an important water quality parameter that affects the solubility of nutrients. The pH of water samples collected at four sampling points at Metcalf farm ranged from 6.65 to 9.77 (Figure 4.12). The average pH level during the sampling dates in the Metcalf system was 7.75. Samples collected at the inlet (M1), mid-channel (M2), outlet (M3), and pond (MP) had average pH values of 7.54, 7.69, 7.36, and 8.37, respectively. The storage pond showed the highest pH values with elevated concentrations during the months of May, August, and September. Denitrification could have caused these high levels due to reduction of nitrate to nitrogen gas owing to concomitant production of HCO- and OH- (Rust et al., 2000). Overall, the system stayed in a healthy pH range of 6.5 - 8 for aquatic life, with the exception of the pond (U.S. Environmental Protection Agency, 2012c).

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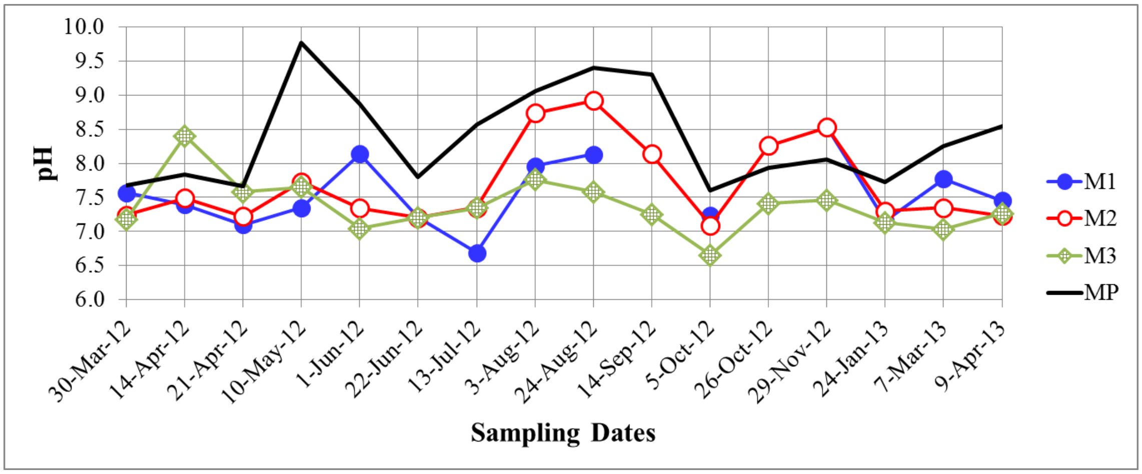

Figure 4.12 Variations in pH levels of water samples collected from the different sampling points at Metcalf's OFWS system.

Sampling points: M1-Inlet, M2-Midchannel, M3-Outlet, and MP-Pond.

4.3.2 Conductivity

The conductivity levels of water samples ranged from 55 to 508 µS/cm (Figure 4.13). These recorded values fall well within the range of conductivity (10 to 1,000 µS/cm) of most fresh water (Chapman, 1996). The average conductivity level during the sampling dates was 178.11 µS/cm. Mean conductivity of water at M1 was 175.45 µS/cm. M2 had an average of 168.00 µS/cm, while MP had an average of 172.58 µS/cm. The water samples collected from M3 had an average conductivity level of 196.07 µS/cm, which is slightly higher than the other three sites. Conductivity seemed to rise starting in May and began to decline at the end of August. The fluctuations in surface water temperatures and the change in nutrient concentrations can cause variations in conductivity levels. Warmer temperatures cause conductivity levels to rise and colder temperatures cause levels to drop (U.S. Environmental Protection Agency, 2012c). As expected, elevated conductivity levels were observed during warmer months and lower

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levels were recorded during colder months. (U.S. Environmental Protection Agency, 2012c).

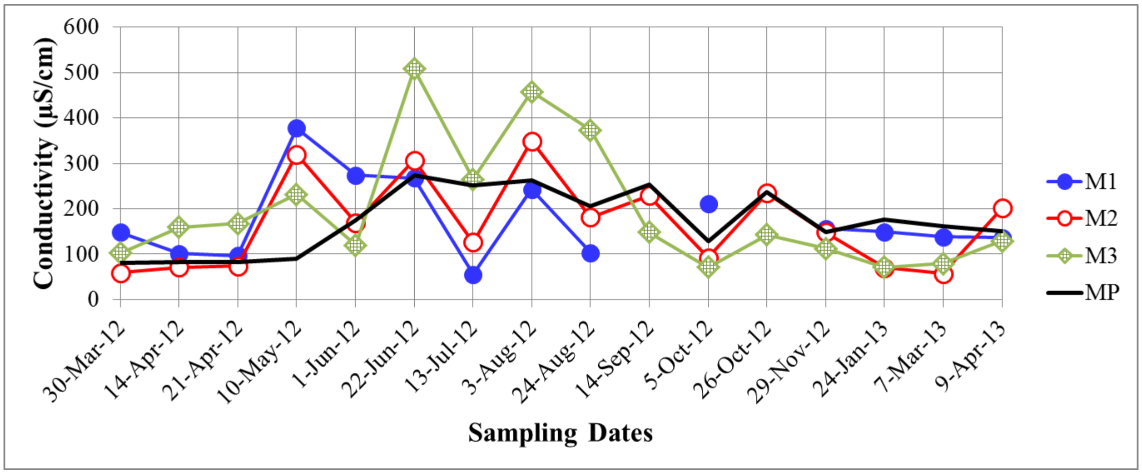

Figure 4.13 Variations in measured conductivity levels of water samples collected from the different sampling points at Metcalf's OFWS system.

4.3.3 Dissolved Oxygen

Dissolved oxygen at Metcalf farm ranged from 6.58 to 14.89 mg/L (Figure 4.14). M1 had an average DO level of 10.03 mg/L, while M2 and M3 had average DO levels of 9.82 mg/L and 9.85 mg/L, respectively. MP had an average DO level of 10.30 mg/L. The average DO concentration throughout the sampling period was 10.00 mg/L. This is considerably higher than the 5 mg/L threshold where aquatic life becomes vulnerable to low levels of DO (Chapman, 1996). In general, average DO levels remained around 9 and 11 mg/L during the monitoring period, with the exception of a few high (14 mg/L) and low levels (6.5 mg/L), none, which pose threats to aquatic life. The outlet of Metcalf had a narrow range of DO values between 9 and 11 mg/L, while M1 and M2 stayed between 6 and 12 mg/L, and the reservoir fluctuated between levels of 7 and 15 mg/L. Higher DO

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concentrations were recorded in the spring and winter, while lower levels were observed in the summer and fall. The monthly trends of low DO during warmer months and higher levels during colder months are a normal trend (U.S. Environmental Protection Agency, 2012c). Algae found in the system likely caused low DO levels in the months of June, July, and September. The process of algal decomposition requires oxygen from surface water (Minnesota Pollution Control Agency, 2008), resulting in a decrease in DO levels of samples in the system. Unusually high DO levels in August were an exception to the normal trend of low DO levels in the summer. A large influx of surface runoff, as evidenced by the increase in water level in the TWR ditch, likely contributed to favorably high DO levels in August. Similarly, the transfer of water from the TWR ditch to the pond may have caused an increase in DO levels in the pond.

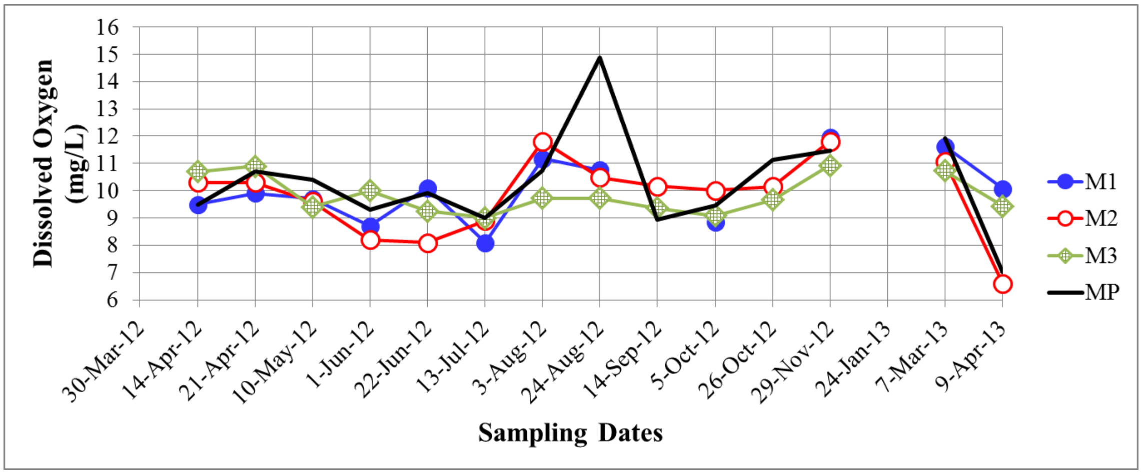

Figure 4.14 Variations in measured dissolved oxygen levels of water samples collected from the different sampling points at Metcalf’s OFWS system.

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4.3.4 Nitrate

The nitrate (NO_3^-) level for water samples collected at the OFWS system at Metcalf farm ranged from 0.25 to 9.84 mg/L (Figure 4.15). The average NO_3^- level throughout the monitoring period in the Metcalf system was 1.46 mg/L, which is below the maximum containment level (MCL) of 10 mg/L set by the EPA (U.S. Environmental Protection Agency, 2012c). In general, NO_3^- levels from all Metcalf sampling points were less than 2 mg/L. The mean NO_3^- levels for specific sampling points were as follows: M1 was 1.26 mg/L, M2 was 1.61 mg/L, M3 was 1.49 mg/L, and MP was 1.47 mg/L. Elevated NO_3^- concentrations were observed on April 21, 2012. Samples from M1, M3, and MP had NO_3^- levels of 9.84 mg/L, 7.52 mg/L, and 4.68 mg/L, respectively. In addition, NO_3^- levels of samples from M2 and M3 collected on June 1 were 3.99 and 5.62 mg/L, respectively. On March 7, 2013 the sample from M2 had 4.97 mg/L NO_3^-, which was higher than levels observed from the other sampling points.

Abnormally high levels of NO_3^- detected on April 21, 2012 likely did not originate within Metcalf farm because fertilizer was not applied on the study area until May and June. It is possible that nitrogen runoff from rice farms located north of Metcalf farm may have contributed to the higher NO_3^- concentrations in water samples taken from M1 in particular, and M3, and MP. Walker and Street (2003) noted that nitrogen is a large part of early rice fertilization. There was a large rainfall accumulation of 37.33 mm during the week (April 14-21), producing a major runoff event prior to the sampling event that could have resulted in the movement of nitrogen-based nutrients from the rice fields and into the TWR ditch at Metcalf farm.

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On June 1, 2012, high NO_3^- levels are observed not at the inlet but rather at the mid-channel and outlet sampling points. On this date, the inlet sampling point showed traces of nutrients. Metcalf soybean crops were planted from May through the second week of June. Planting operations would have been shorter but were extended due to wet field conditions. Liquid chicken litter was inserted in the ground along with the seeds being planted. Generally, chicken litter has a nutrient combination of 3-3-2 (N-P-Potash) (Funderburg, 2009). Heavy rain (54.86 mm) on May 30 and 31 may have facilitated the removal of nutrients from the field and contributed to an increase in NO_3^- at M2 and M3 on June 1, 2012. The March 7, 2013 sampling date exhibited high concentrations at M2 not only for NO_3^- but also for all nitrogen-based nutrients that were analyzed on Metcalf farm. There was no pre-fertilization on the farm, and the sample results for M1 indicate that there was no up-stream activity. There is no logical explanation for the spike in nitrogen-based nutrient levels at the M2 sampling point on this date.

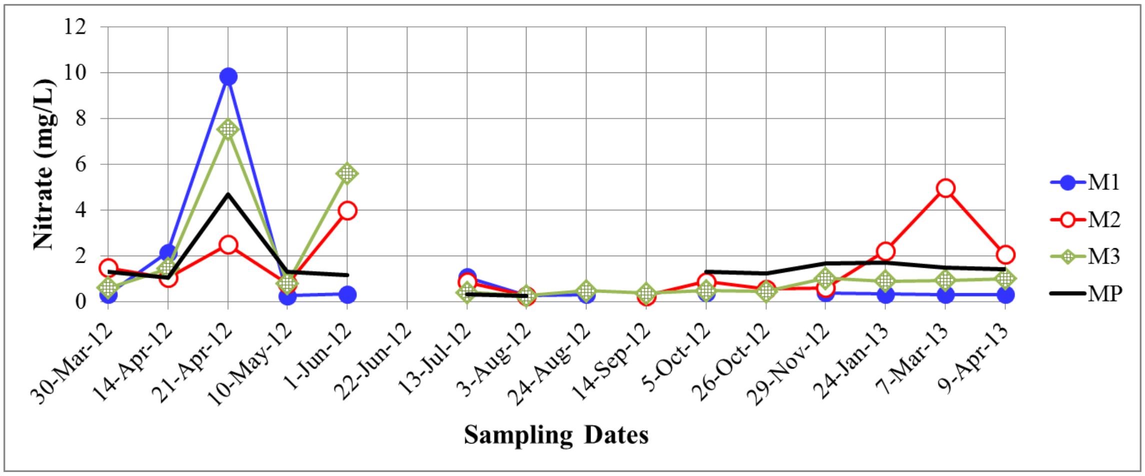

Figure 4.15 Variations in measured nitrate levels of water samples collected from the different sampling points at Metcalf's OFWS system.

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4.3.5 Total Nitrogen

The total nitrogen (TN) level of water samples ranged from 1.07 to 20.70 mg/L (Figure 4.16). The average TN level throughout the monitoring period in the Metcalf system was 3.45 mg/L. In general, TN levels from all sites were less than 5 mg/L. The mean TN levels for specific sampling points were as follows: M1 was 3.82 mg/L, M2 was 3.13 mg/L, M3 was 4.00 mg/L, and MP was 2.93 mg/L. Elevated TN concentrations were observed on April 21, 2012. Samples from M1, M3, and MP had TN levels of 20.70 mg/L, 12.4 mg/L, and 7.55 mg/L, respectively. In addition, there were elevated TN concentrations in samples collected on June 1, 2012 from M2 and M3, respectively, at 6.67 mg/L and 9.98 mg/L. On March 7, 2013 the sample from M2 had 8.47 mg/L TN, which was higher than levels observed from the other sampling points.

Abnormally high levels of TN detected on April 21, 2012 did not likely originate within Metcalf farm because fertilizer was not applied until May and June. Again, as previously stated, it is possible that nitrogen runoff from rice farms located north of Metcalf farm may have contributed to the TN concentrations in water samples taken from M1, M3, and MP (Walker and Street, 2003). Rainfall amounted to 37.33 mm during the week (April 14-21) prior to the sampling event, producing a major runoff event that could have resulted in the movement of nitrogen-based nutrients from the rice fields and into the TWR ditch at Metcalf farm.

Again, the June 1, 2012 sampling date showed higher TN concentrations at M2 and M3 and a low concentration at the inlet, M1. Metcalf soybean crops were planted during the months of May through the second week of June, and liquid chicken litter was inserted in the ground as the seeds were being planted. Heavy rain (54.86 mm) on May

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30 and 31 may have facilitated the removal of nutrients from the field and contributed to an increase in TN at M2 and M3 on June 1, 2012.

The March 7, 2013 sampling date showed a high concentration of TN and other nitrogen-based nutrients at the M2 sampling point on Metcalf farm. Because there was no pre-fertilization on the farm or any apparent up-stream activity, there is no obvious explanation for the elevated concentration at only the M2 sampling point on this date.

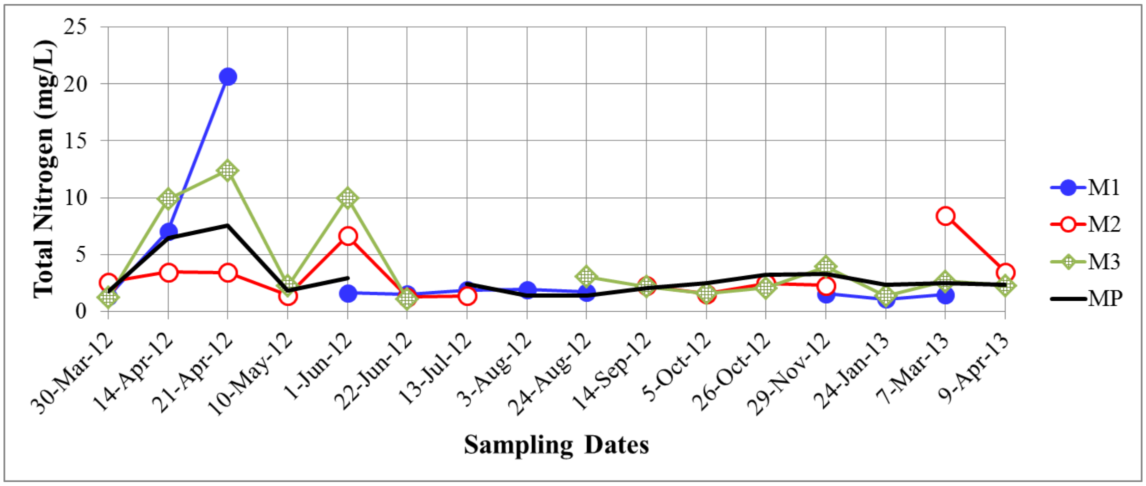

Figure 4.16 Variations in measured total nitrogen levels of water samples collected from the different sampling points at Metcalf's OFWS system.

4.3.6 Ammonia

The ammonia level for grab samples collected at the Metcalf farm ranged from 0.02 to 1.80 mg/L (Figure 4.17). The average NH_3 level throughout the monitoring period was 0.27 mg/L in the Metcalf system. In general, NH_3 levels at all sampling points were less than 0.40 mg/L, which falls on the high end of the safe ammonia level for aquatic life at 0.02 - 0.40 mg/L (Alken-Murray, 2006). The mean NH_3 levels for specific sampling

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points M1, M2, M3, and MP were 0.25 mg/L, 0.30 mg/L, 0.32 mg/L, and 0.22 mg/L respectively. As for the other nitrogen-related constituents, elevated NH_3 concentrations were also observed on April 21, 2012. Samples from M1, M3, and MP had NH_3 levels of 1.8 mg/L, 1.31 mg/L, and 1.00 mg/L, respectively. In addition, the NH_3 level at the sampling point M2 was 1.08 mg/L on June 1, 2012, while M3 had a level of 1.18 mg/L on this date. Finally, sampling point M3 had an NH_3 concentration of 0.30 mg/L on the November 29, 2012 sampling date, and March 7, 2013 experienced a high level of 0.39 mg/L at the M2 sampling point.

Unusually high levels of NH_3 detected on April 21, 2012 did not likely originate within Metcalf farm because fertilizer was not applied until May and June. Again, as previously stated, it is possible that nitrogen runoff from rice farms located north of Metcalf farm may have contributed to the NH_3 concentrations in water samples taken from M1, M3, and MP (Walker and Street, 2003). Rainfall amounted to 37.33 mm during the week (April 14-21) prior to the sampling event, producing a major runoff event that may have resulted in the movement of nitrogen-based nutrients from upstream rice fields and into M1 and M3 at Metcalf farm.

The June 1, 2012 sampling date did not show a large increase at the inlet but did result in high NH_3 levels at M2 and M3. The planting of soybeans and liquid chicken fertilization (May and June) along with heavy rainfall (54.86 mm) on May 30 and 31 may have facilitated the removal of nutrients from the field and contributed to an increase in NH_3 concentrations at M2 and M3 on June 1, 2012.

High NH_3 levels on November 29, 2012 at M3 did not likely originate from within Metcalf farm because no other high levels were observed at the M1, M2, and MP

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sampling points. In addition, there was no water being discharged at the outflow during the time of sampling. Elevated NH_3 concentration at the outlet is believed to originate from an outside source that mixed with the outflow of Metcalf. The March 7, 2013 sampling date showed a high concentration at M2 (1.36 mg/L), as was also the case with the other nitrogen-based nutrients sampled during this date on Metcalf farm. There was no pre-fertilization on the farm or known up-stream activity that might explain the elevated concentration in NH_3 at the M2 sampling point on March 7, 2013.

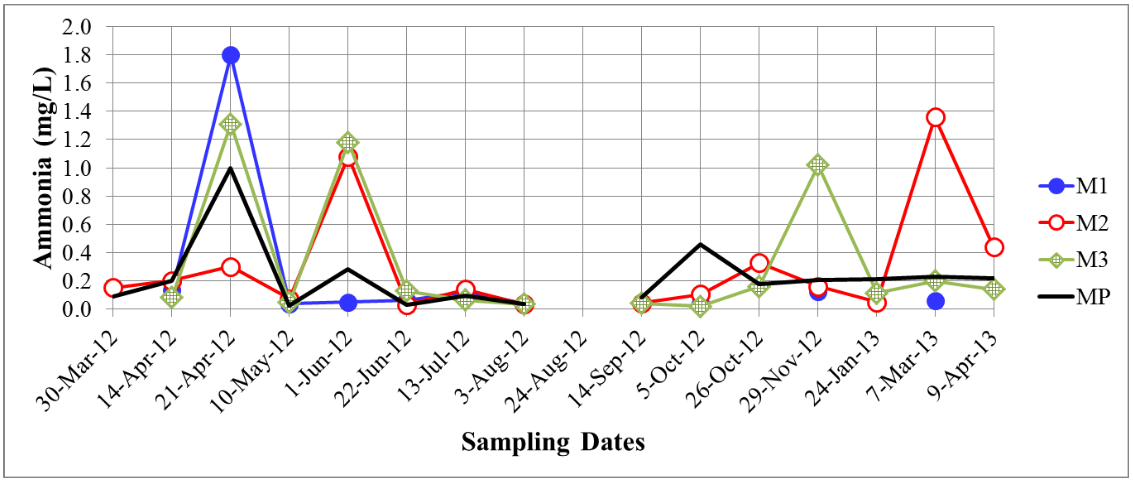

Figure 4.17 Variations in measured ammonia levels of water samples collected from the different sampling points at Metcalf's OFWS system.

4.3.7 Total Phosphorous

The phosphorus level of water samples collected at Metcalf farm ranged from 0.08 to 2.46 mg/L (Figure 4.18). The average TP level throughout the monitoring period in the Metcalf system was 0.46 mg/L. In general, TP levels at all sampling points were less than 0.5 mg/L, but most still exceeded the recommended concentration level of 0.01

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- 0.04 mg/L (U.S. Environmental Protection Agency, n.d.). The mean TP levels for specific sampling points were as follows: M1 was 0.24 mg/L, M2 was 0.64 mg/L, M3 was 0.55 mg/L, and MP was 0.35 mg/L. Elevated TP concentrations were observed on June 1, 2012 at the M2 and M3 sampling points, which showed TP levels of 1.49 mg/L and 1.60 mg/L, respectively. In addition, the TP level at the M3 sampling point was 2.07 mg/L on August, 24, 2012. Finally, the TP concentration at M2 rose to 1.54 mg/L on January 24, 2013 and to 2.46 mg/L on March 7, 2013.

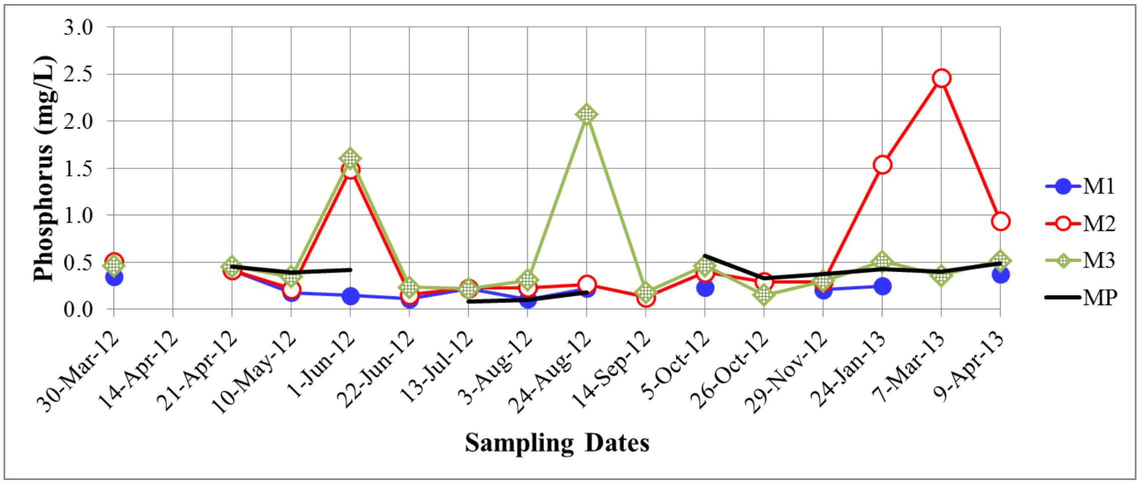

Figure 4.18 Variations in measured phosphorus levels of water samples collected from the different sampling points at Metcalf's OFWS system.

Increased TP concentrations on June 1, 2012 likely originated within Metcalf farm due to chicken litter being applied during May and June and the addition of heavy rain (54.86 mm) on May 30 and 31. This rainfall event may have facilitated the removal of nutrients from the fields and contributed to an increase in TP level at M2 and M3 on June 1, 2012. Contrary to June 1, a high level at M3 during August 24, 2012 did not

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likely originate from within Metcalf farm because no other high levels were observed at M1, M2, and MP sampling points. In addition, there was no water being discharged at the outflow during the time of sampling. The elevated TP concentration at the outlet was believed to originate from an outside source that mixed with the outflow of Metcalf.

January 24, 2013, March 7, 2013, and April 9, 2013 showed high concentrations of TP and other phosphorus-based nutrients sampled during these dates within M2 on Metcalf farm. There was no pre-fertilization on the farm nor was there any up-stream activity, based on observations from M1. However accumulated rainfall from December through April was over 508 mm. A conclusion on why high TP concentrations were observed could be explained through correlation with turbidity and TSS. Heavy rains could have caused phosphorus adsorbed to soil particles to move from the fields, along with the soil, into the TWR ditch, thereby explaining the high concentrations observed at M2.

4.3.8 Turbidity

The turbidity level of water samples ranged from 1.22 to 1000+ NTU (Nephelometric Turbidity Unit) (Figure 4.19). The average turbidity concentration throughout the monitoring period in the Metcalf system was 189.00 NTU. In general, turbidity levels from all sites were less than 400 NTU. The mean turbidity concentrations for specific sampling points were as follows: M1 was 68.90 NTU, M2 was 319.42 NTU, M3 was 164.17 NTU, and MP was 187.50 NTU. Elevated turbidity concentrations were observed on June 1, 2012. Samples from M2, M3, and MP had turbidity levels of 1000+ NTU, 1000+ NTU, and 386 NTU, respectively. In addition, the M2 sampling point had

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spikes in turbidity on January 24, 2012 M2 at 744 NTU and also on March 7, 2013 at 1000+ NTU.

Abnormally high levels of turbidity detected on June 1, 2012 likely originated within Metcalf farm. Fields were tilled and planted during May and June followed by a heavy rainfall event (54.86 mm) on May 30 and 31. The combination of a heavy rain in the midst of planting resulted in a runoff event moving suspended materials from the fields into the TWR ditch, and from there into the pond or through the outlet. January 24, 2013, March 7, 2013, and April 9, 2013 showed high turbidity levels at the M2 sampling point. Rainfall accumulation from December through April was over 508 mm. In addition, crops had been harvested, leaving the ground with little protection from rainfall and a higher propensity for off-site movement of soil, contributing to the rise of turbidity levels in the mid-channel. Higher levels of turbidity were observed during spring and winter, while summer and fall experienced lower levels.

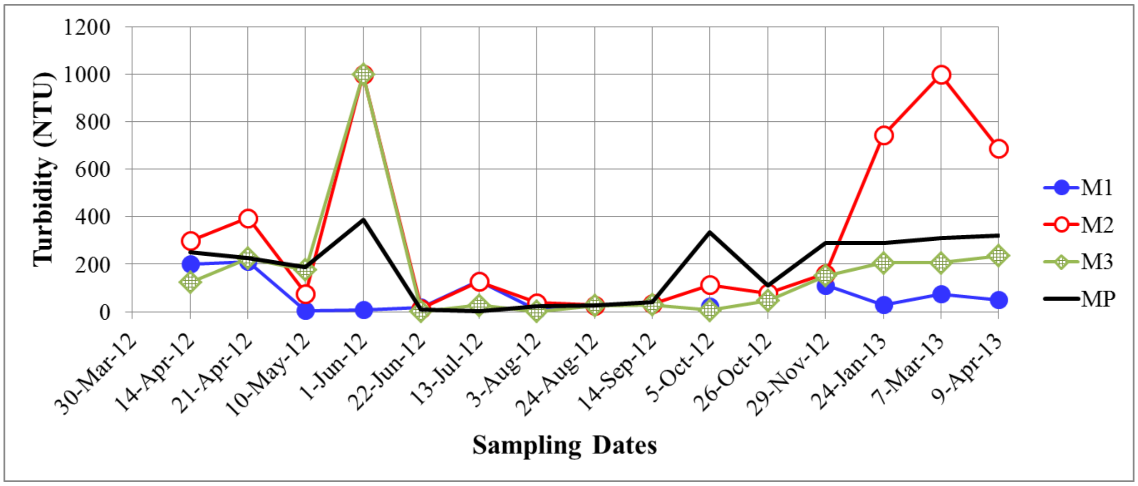

Figure 4.19 Variations in measured turbidity levels of water samples collected from the different sampling points at Metcalf's OFWS system.

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4.3.9 Dissolved Orthophosphate

The dissolved orthophosphate level of water samples collected at Metcalf farm ranged from 0 to 1.47 mg/L (Figure 4.20). The average DP level throughout the monitoring period was 0.17 mg/L. In general, DP levels from all sites were less than 0.30 mg/L. The mean DP levels for specific sampling points were as follows: M1 was 0.14 mg/L, M2 was 0.17 mg/L, M3 was 0.26 mg/L and MP was 0.09 mg/L. Elevated DP concentrations were observed at the M3 sampling point on August 3, 2012 and August 24, 2012. Samples from M3 had DP levels of 0.378 mg/L and 1.48 mg/L, respectively, on those August 2012 dates. In addition, DP levels of samples collected at the M2 sampling point rose to 0.65 mg/L on January 24, 2012, 0.34 mg/L on March 7, 2013, and 0.32 mg/L on April 9, 2013.

High DP concentrations at the outlet on August 3, 2012 and August 24, 2012 did not likely originate within Metcalf farm because the other three sampling points saw no elevated concentrations in DP. In addition, there was no water being discharged at the outlet during these sampling dates. Increased DP concentration at the outlet is believed to originate from an outside source that mixed with the outflow of Metcalf. Also, this could possibly be due to harvesting and the remains of plant tissue, which could have washed into streams from farms that are connected to the outflow of the Metcalf system (U.S. Environmental Protection Agency, 2012c). High levels of DP were also measured at M2 on January 24, 2013 and March 7, 2013. However, there was no fertilization on the farm during this time period, and there were no DP increases at the inlet on these dates. Rainfall accumulated over 508 mm from December through April.

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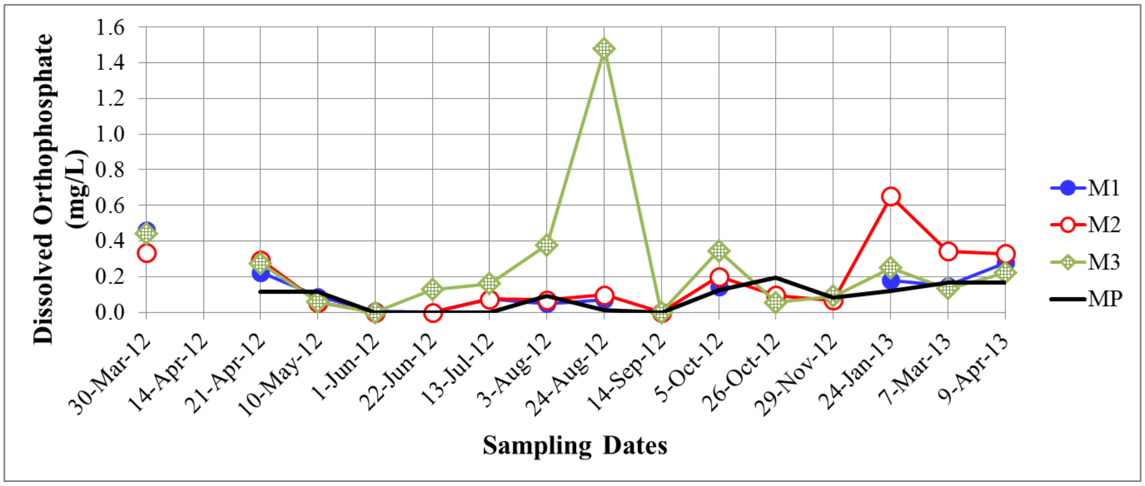

Figure 4.20 Variations in measured dissolved orthophosphate levels of water samples collected from the different sampling points at Metcalf's OFWS system.

4.3.10 Total Kjehldahl Nitrogen

The measured total kjehldahl nitrogen (TKN) level of water samples at Metcalf farm ranged from 0.71 to 10.93 mg/L (Figure 4.21). The average TKN level throughout the monitoring period in the Metcalf system was 3.50 mg/L. In general, most reported TKN levels were less than 4 mg/L. The mean TKN levels for specific sampling points were as follows: M1 was 3.56 mg/L, M2 was 3.29 mg/L, M3 was 3.14 mg/L, and MP was 4.01 mg/L. The TKN level rose to 5.89 mg/L at the M3 sampling point on May 10, 2012. Then, on June 1, 2012, TKN levels rose again to 6.51 mg/L at M2, 5.78 mg/L at M3, and 6.50 mg/L at MP. Abnormally high levels were observed within MP on September 14, 2012 (7.80 mg/L), January 24, 2013 (6.72 mg/L), and March 7, 2013 (8.04 mg/L).

The high levels of TKN detected on May 10, 2012 did not likely originate within Metcalf farm because a high level was only detected at M3. However, the high TKN

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levels measured on June 1, 2012 were a result of on-farm activity. The inlet had a low TKN level on this date, while all other sampling points showed high TKN levels. The June 1 sampling date fell during fertilization and just after a large rainfall event of 54.86 mm over the two-day period of May 30 and 31. This rainfall event may have facilitated the removal of nutrients from the fields and contributed to an increase in TKN at M2, M3, and MP. High levels observed within MP would be from water that has entered the system and been pumped from the channel into the pond.

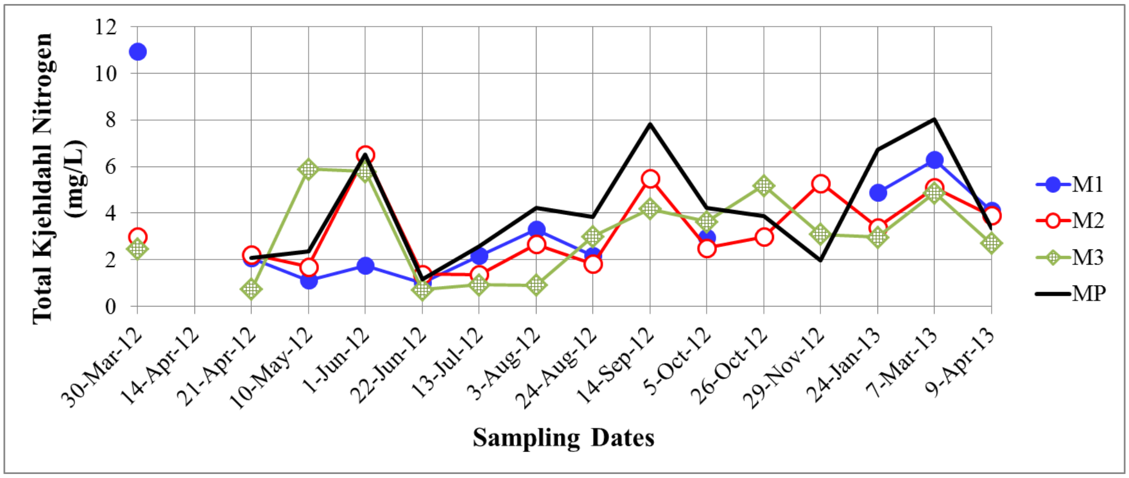

Figure 4.21 Variations in total kjehldahl nitrogen levels of water samples collected from the different sampling points at Metcalf's OFWS system.

4.3.11 Total Suspended Solids

The measured total suspended solids concentration of water samples ranged from 0 to 1000+ mg/L (Figure 4.22). The average TSS level throughout the monitoring period in the Metcalf system was 197.54 mg/L. In general, most TSS levels were less than 400 mg/L. The mean TSS concentrations for specific sampling points were as follows: M1 was 41.56 mg/L, M2 was 337.69 mg/L, M3 was 185.74 mg/L, and MP was 204.39 mg/L.

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Elevated TSS levels were observed June 1, 2012. Samples from M2 and M3 had TSS concentrations of 1123.50 mg/L and 1353.6 mg/L, respectively. In addition, the TSS concentration of sample M2 collected on March 7, 2013 was 1550.50 mg/L.

Abnormally high TSS concentrations detected June 1, 2012 likely originated within Metcalf farm. Planting took place during May and June, with a heavy rainfall event of 54.86 mm over a two-day period of May 30 and 31. The combination of a heavy rainfall event while planting could have facilitated the removal of TSS from the fields and contributed to an increase in TSS levels at M2 and M3 on June 1, 2012.

However, only the M2 sampling point had a high TSS level on March 7, 2013. This high level likely originated from within Metcalf farm because increased concentrations were not detected at the other three sampling points. There were no significant rainfall events prior to this sampling date, so there is no obvious explanation for why TSS levels were high at only the M2 sampling point. TSS values seem to be highest when the soil is bare and loose (pre-planting and post-harvest) and when rainfall is able to come in direct contact with bare ground (Fangmeier, 2006).

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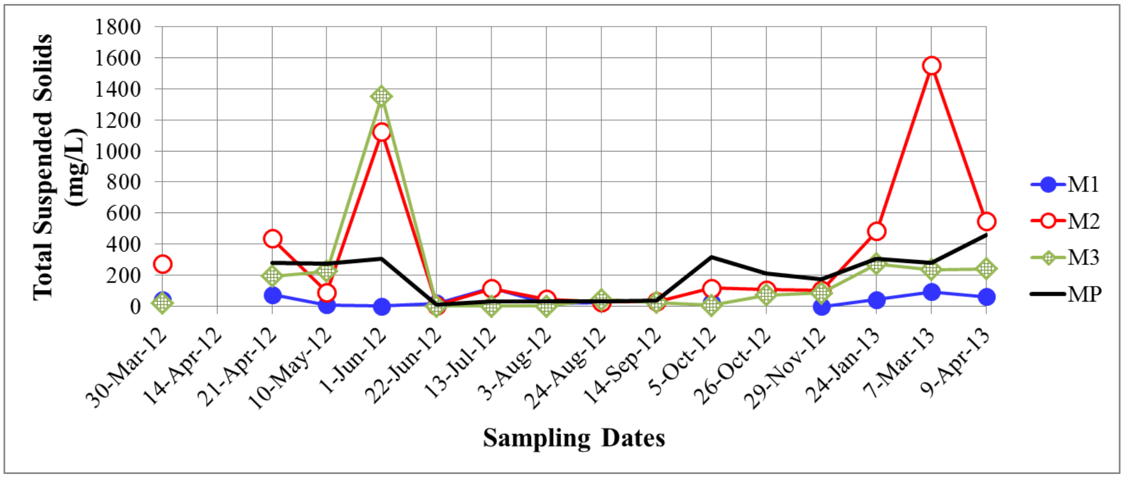

Figure 4.22 Variations in measured total suspended solid levels of water samples collected from the different sampling points at Metcalf's OFWS system.

4.4 Pitts Farm Water Parameters

4.4.1 pH

The pH of water samples collected from five sampling points at Pitts farm ranged from 6.83 to 9.26 (Figure 4.23). The average pH level throughout the monitoring period at Pitts Farm was 7.88. The mean pH level at the first inlet (P1) was 8.029, second inlet (P4) was 7.52, mid-channel (P2) was 7.82, outlet (P3) was 7.82, and the pond (PP) was 8.23. Similar to pH results at Metcalf farm, the pond showed the highest values of pH. These high values could possibly be due to denitrification (Rust et al., 2000). Even though the pond values are slightly over what the EPA recommends as a healthy level of pH, a majority of the samples stayed between a healthy pH range of 6.5 to 8 (U.S. Environmental Protection Agency, 2012c).

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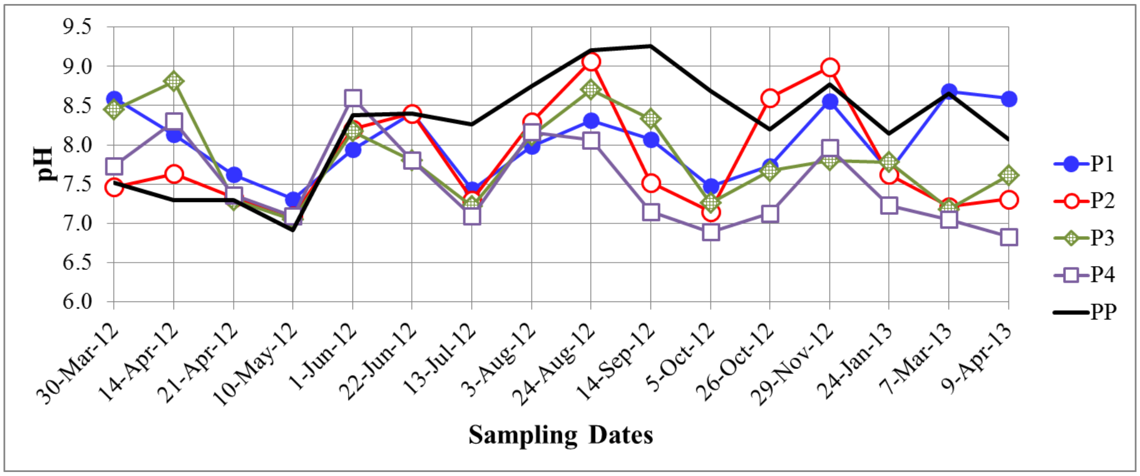

Figure 4.23 Variations in measured pH levels of water samples collected from the different sampling points at Pitts' OFWS system.

Sampling points: P1-1st Inlet, P2-Midchannel, P3-Outlet, P4-2nd Inlet, and PP-Pond.

4.4.2 Conductivity

The conductivity level of water samples collected at Pitts farm ranged from 53.8 to 712 µS/cm (Figure 4.24). These recorded values fall well within the range of conductivity (10 to 1,000 µS/cm) of most fresh water (Chapman, 1996). The average conductivity level during the monitoring period was 232.6 uS/cm. Mean conductivity of water at P4 was 230.4 µS/cm, P2 was 212.4 uS/cm, P3 was 214.3 uS/cm, PP was 221.2 uS/cm, and the highest mean was P1 with 284.8 uS/cm. Overall, the system experienced higher conductivity values during the warmer months and lower values during the colder months. There was only one exception to this trend, which was recorded July 13, 2012 and showed very low values at P1, P2, P3 and P4. Comparing data to Metcalf farm, results recorded at Pitts were higher overall.

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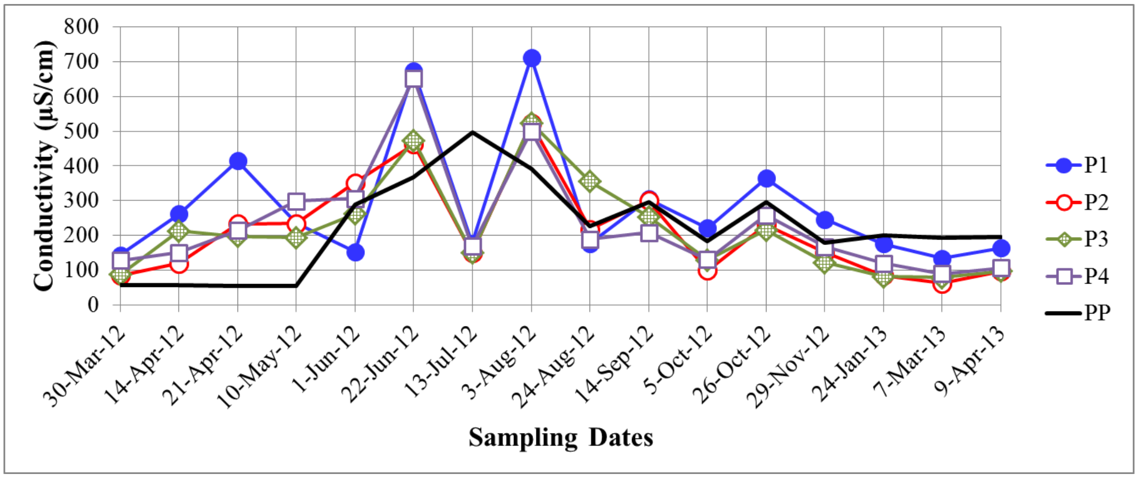

Figure 4.24 Variations in measured conductivity levels of water samples collected from the different sampling points at Pitts' OFWS system.

4.4.3 Dissolved Oxygen

The dissolved oxygen level of water samples collected at Pitts farm ranged from 7 to 12.5 mg/L (Figure 4.25). P1 had an average DO level of 9.9 mg/L, the P4 average was 9.4 mg/L, the P2 average was 10 mg/L, the P3 average was 9.9 mg/L, and the PP average was 10.3 mg/L. The average DO concentration throughout the sampling period was 9.9 mg/L, high above the 5 mg/L level where aquatic life becomes vulnerable to low levels of DO (Chapman, 1996). Low levels were generally observed in the summer and fall, while spring and winter experienced higher levels. Abnormally low DO levels seen Sept 14-October 26, 2012 could have possibly been due to algae within the system. Algae were observed in the system throughout September and October. DO levels tend to be lower than normal during the presence of algae because of the use of DO during the life cycle of the algae (Minnesota Pollution Control Agency, 2008).

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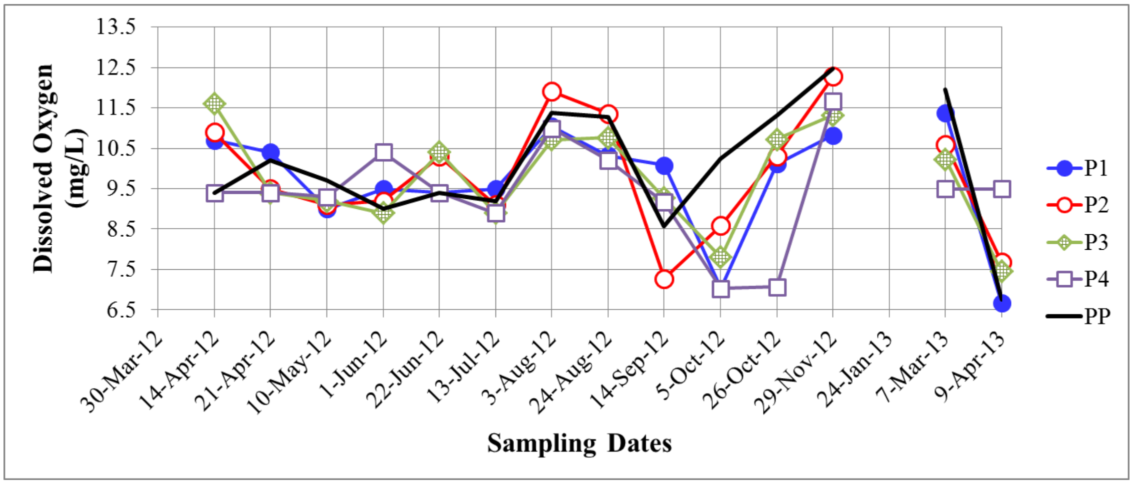

Figure 4.25 Variations in measured dissolved oxygen levels of water samples collected from the different sampling points at Pitts' OFWS system.

4.4.4 Nitrate

The nitrate level of water samples at Pitts farm ranged from 0.23 to 23.60 mg/L (Figure 4.26). The average NO_3^- level throughout the monitoring period in Pitts system was 1.74 mg/L, which is below the maximum containment level (MCL) of 10 mg/L set by the EPA (Fangmeier, 2006). In general, NO_3^- levels from all sites were less than 2 mg/L. The mean NO_3^- levels for specific sampling points were as follows: P1 was 0.98 mg/L, P2 was 2.10 mg/L, P3 was 1.48 mg/L, P4 was 3.38 mg/L, and PP was 0.87 mg/L. Elevated NO_3^- concentrations were observed on April 21, 2012. Sample P4 had an NO_3^- level of 23.6 mg/L. In addition, NO_3^- levels of samples from P4, P2, P3, P1, and PP collected on May 10, 2012 were 12.60 mg/L, 12.50 mg/L, 9.97 mg/L, 4.92 mg/L, and 2.73 mg/L, respectively. On March 7, 2013, the sample from P2 had 3.43 mg/L NO_3^-, which was higher than levels observed from the other sites during this sampling date.

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The abnormally high NO_3^- concentration detected at P4 on April 21, 2012 did not likely originate within Pitts farm because no other high levels were observed at P1, P2, P3, and PP sampling points. It is possible that farms located east of Pitts farm may have contributed to the NO_3^- concentrations in water samples taken from P4. Contrary to April 21, high levels on May 10, 2012 likely originated on-farm. Nitrogen fertilizer was applied the second and fourth week of May, and rainfall amounted to 47.24 mm three days prior to the sampling date. This may have produced a major runoff event resulting in the movement of nitrogen-based nutrients from on-farm fields into the system along with incoming nutrients from the inlets at P1 and P4.

March 7, 2013 showed a high concentration in P2 for NO_3^- and all nitrogen-based nutrients that were analyzed on Pitts farm during the monitoring period. There was no pre-fertilization on the farm, nor was there any up-stream activity, based on observations at P1 and P4. There is no apparent explanation for the fluctuation in NO_3^- on March 7, 2013.

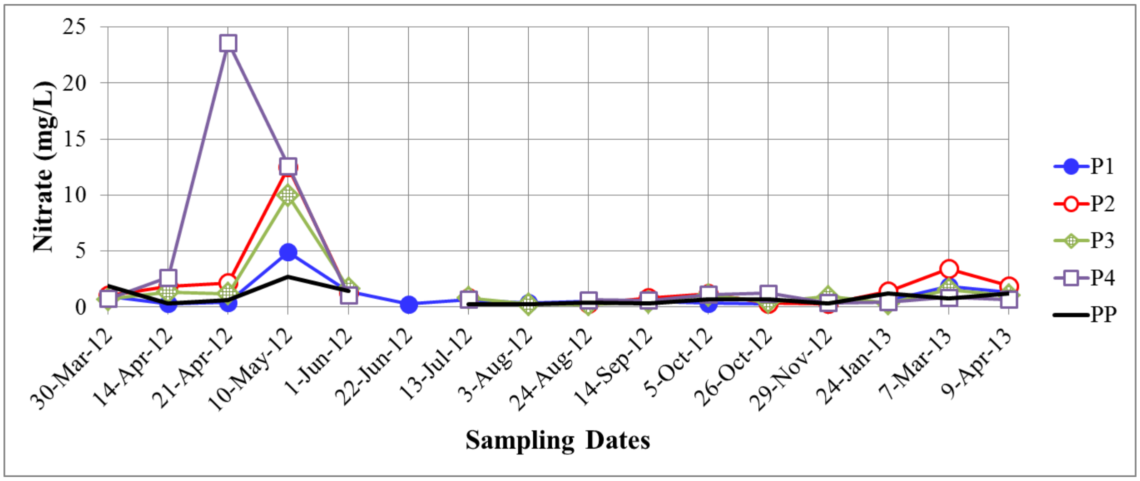

Figure 4.26 Variations in measured nitrate levels of water samples collected from the different sampling points at Pitts' OFWS system.

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4.4.5 Total Nitrogen

The total nitrogen level of water samples ranged from 1.04 to 29.50 mg/L (Figure 4.27). The average TN level throughout the monitoring period in the Pitts system was 3.52 mg/L. In general, TN levels from all sites were less than 5 mg/L. The mean TN levels for specific sampling points were as follows: P1 was 2.49 mg/L, P2 was 3.83 mg/L, P3 was 2.92 mg/L, P4 was 6.20 mg/L, and PP was 2.34 mg/L. Increased TN concentrations were observed at P4 on April 14 and 21 of 2012. Samples from P4 had TN levels of 10.80 and 29.50 mg/L, respectively. In addition, TN levels of samples from P4, P2, P3, and P1 collected on May 10, 2012 were 18.6 mg/L, 16.1 mg/L, 13 mg/L, and 8.77 mg/L, respectively. On March 7, 2013 the sample from P2 had a TN concentration of 7.47 mg/L, which was higher than levels observed from the other sites.

Abnormally high levels of TN detected on April 14 and 21 of 2012 did not likely originate within Pitts farm because high levels were not seen at P1, P3, or PP sampling points. There was a slightly elevated TN concentration at P2, which is most likely from TN beginning to make its way through the system. It is possible that farms located east of Pitts farm may have contributed to the TN concentrations in water samples taken from P4. Contrary to April 14 and 21, high levels on May 10, 2012 likely originated on-farm. Nitrogen fertilizer was applied the second and fourth week of May, and rainfall amounted to 47.24 mm three days prior to the sampling date. This may have produced a major runoff event resulting in the movement of nitrogen-based nutrients from on-farm fields along with incoming nutrients from P1 and P4.

March 7, 2013 showed a high concentration in P2. There was no pre-fertilization on the farm or any up-stream activity, based on observations at the inlet sampling

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locations (P1 and P4). Thus, there is no conclusion on the cause of TN fluctuation on March 7, 2013.

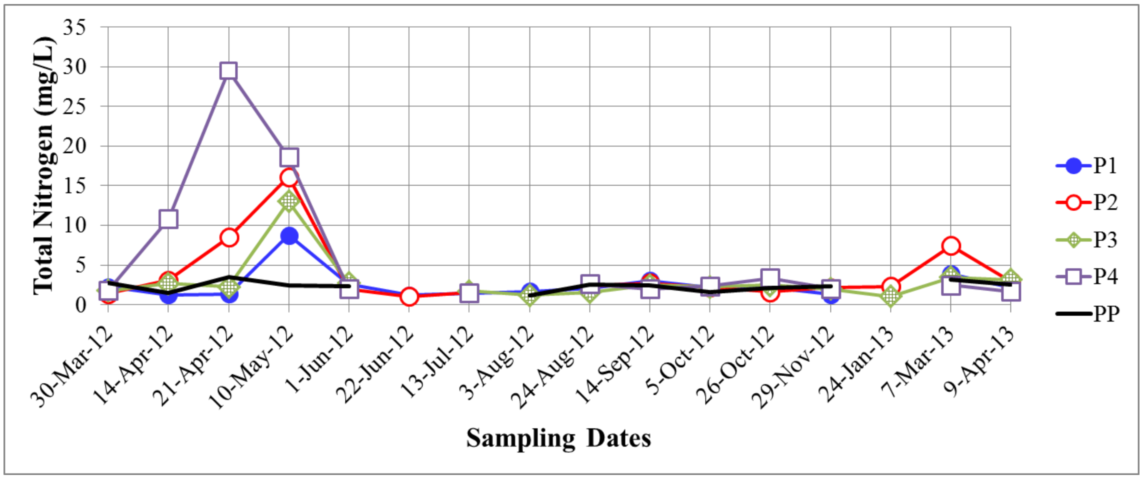

Figure 4.27 Variations in measured total nitrogen levels of water samples collected from the different sampling points at Pitts' OFWS system.

4.4.6 Ammonia

The ammonia level of water samples ranged from 0.02 to 1.49 mg/L (Figure 4.28). The average NH_3 level throughout the monitoring period in the Pitts system was 0.21 mg/L. In general, NH_3 levels from all sites were less than 0.5 mg/L. The mean NH_3 levels for specific sampling points were as follows: P1 was 0.14 mg/L, P2 was 0.28 mg/L, P3 was 0.29 mg/L, P4 was 0.22 mg/L, and PP was 0.14 mg/L. High NH_3 values were observed at P4 on April 14 and 21 of 2012. Samples from P4 had NH_3 levels of 0.68 and 0.72 mg/L, respectively. In addition, NH_3 levels of samples from P2, P3, P4, and P1 collected on May 10, 2012 were 1.49 mg/L, 1.36 mg/L, 0.79 mg/L, and 0.69 mg/L, respectively. On October 26, 2012 sample P3 had a value of 0.78 mg/L, and on March 7, 2013 sample P2 had 7.47 mg/L NH_3.

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High levels of NH_3 detected on April 14 and 21 of 2012 did not likely originate within Metcalf farm because high levels were not observed at P1, P3, P2, and PP sampling points. It is possible that farms located east of Pitts farm may have contributed to the high NH_3 concentrations in water samples taken from P4. Contrary to April 14 and 21, unusually high levels of NH_3 on May 10, 2012 did likely originate on-farm. Nitrogen fertilizer was applied the second and fourth week of May, and there was rainfall amounting to 47.24 mm three days prior to the sampling date. This may have produced a major runoff event resulting in the movement of nitrogen-based nutrients from on-farm fields along with incoming nutrients from P1 and P4.

A high NH_3 level observed on October 26, 2012 at P3 most likely originated from an outside source mixing into Pitts outflow. March 7, 2013 showed a high NH_3 concentration at the P2 sampling point. However, there was no pre-fertilization on the farm or any known up-stream activity, based on observations from P1 and P4. There is no explanation for the NH_3 fluctuations at P2 on March 7.

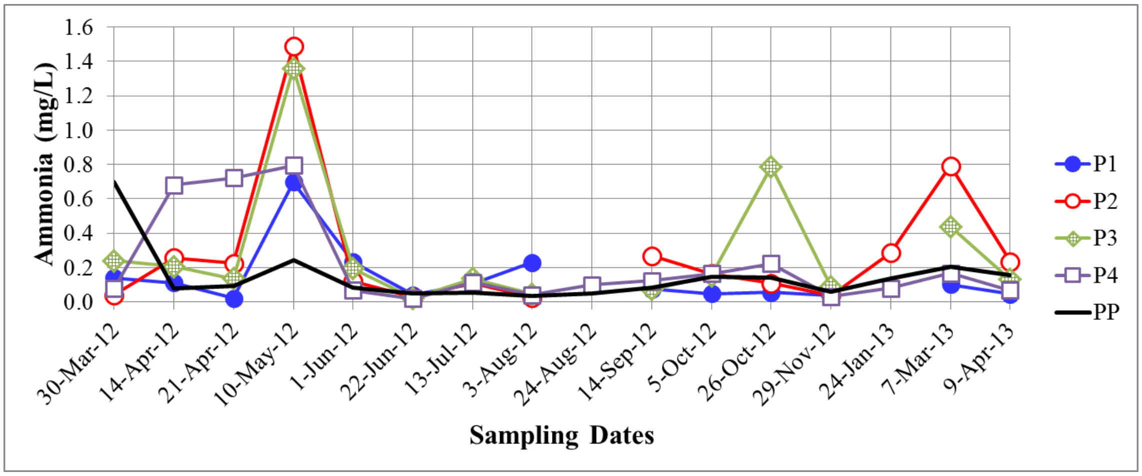

Figure 4.28 Variations in measured ammonia levels of water samples collected from the different sampling points at Pitts' OFWS system.

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4.4.7 Total Phosphorus

The total phosphorus level of water samples ranged from 0.05 to 1.39 mg/L (Figure 4.29). The average TP level throughout the monitoring period in the Pitts system was 0.38 mg/L. In general, TP levels from all sites were less than 0.6 mg/L, still generally exceeding the recommended concentration level of 0.01 - 0.04 mg/L as stated by the EPA (n.d.). Mean TP level at P1 was 0.36 mg/L, P2 was 0.45 mg/L, P3 was 0.39 mg/L, P4 was 0.39 mg/L, and PP was 0.30 mg/L. Elevated TP values were observed on May 10, 2012, which was during fertilization, and rainfall amounted to 47.24 mm three days prior to the sampling event. This may have produced a major runoff event that washed phosphorus-based nutrients from on-farm fields along with incoming nutrients from P1.

In addition, TP levels of samples collected after harvest began to exhibit random fluctuations in concentrations. This could be an effect of harvesting and the remains of organic phosphorus enriched plant tissue, which could have washed into streams. Once organic phosphorus enters water and begins decomposing from biological processes it is then returned back to inorganic phosphorus. This biological phosphorous activity could be the cause of random fluctuations that are seen throughout the end of the monitoring period (U.S. Environmental Protection Agency, 2012c).

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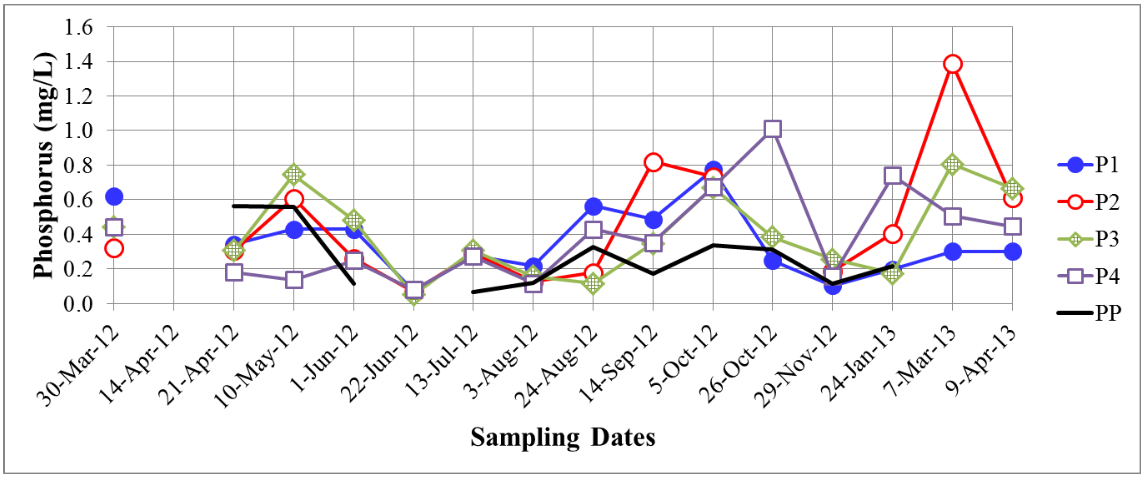

Figure 4.29 Variations in measured phosphorus levels of water samples collected from the different sampling points at Pitts' OFWS system.

4.4.8 Turbidity

The turbidity level of water samples collected at Pitts farm ranged from 3.29 to 486 NTU (Figure 4.30). The average turbidity level in the system throughout the monitoring period was 127 NTU. In general, turbidity levels from all sites were less than 200 NTU. The mean turbidity levels for specific sampling points were as follows: P1 was 72.94 NTU, P2 was 147.8 NTU, P3 was 151.25 NTU, P4 was 124.78 NTU and PP was 140.65 NTU. Increased turbidity concentrations not exceeding 400 NTU were observed between April and May of 2012.

In addition, turbidity values began to increase after harvest. This was most likely because the ground had no protection from rainfall, giving rainfall a higher possibility to cause soil erosion and contribute to the rise of turbidity levels. Highest values occurred during the spring, fall, and winter months when rain was plentiful. Recorded rainfall for

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June through August was 375.9 mm and September through April rainfall was 886.46 mm.

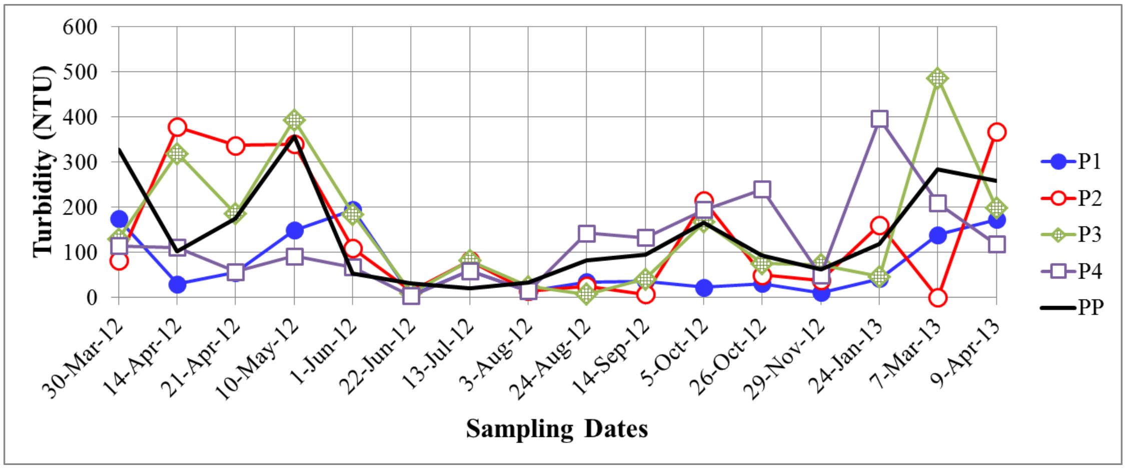

Figure 4.30 Variations in measured turbidity levels of water samples collected from the different sampling points at Pitts' OFWS system.

4.4.9 Dissolved Orthophosphate

The dissolved orthophosphate level of water samples ranged from 0 to 0.61 mg/L (Figure 4.31). The average DP level throughout the monitoring period in the Pitts system was 0.16 mg/L. In general, DP levels from all sites were less than 0.2 mg/L. The mean DP levels for specific sampling points were as follows: P1 was 0.18 mg/L, P2 was 0.19 mg/L, P3 was 0.16 mg/L, P4 was 0.18 mg/L, and PP was 0.07 mg/L. High DP levels were observed after harvest. High levels were observed on August 24, 2012 at P1 (0.46 mg/L), on September 14, 2012 at P2 (0.49 mg/L) and P1 (0.33 mg/L), on October 5, 2012 at P1 (0.61 mg/L), P2 (0.41 mg/L), P3 (0.40 mg/L), and P4 (0.34 mg/L), on October 26, 2012 at P4 (0.57 mg/L), and on March 7, 2013 at P2 (0.48 mg/L)

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August 24 and October 26, 2012 did not likely originate on-farm because high DP concentrations were only detected at P1 and P4, the inlet sampling locations. However, high DP concentrations presents on September 14 and October 5, 2012 and March 7, 2013 did likely originate on-farm because high levels of DP were detected within the farm in the TWR ditch. This could be an effect of harvesting and the remains of organic phosphorus-enriched plant tissue, which could have washed into streams. Once organic phosphorus enters water and begins decomposing from biological processes, it is then returned back to inorganic phosphorus. This biological phosphorous activity could be the cause of the DP fluctuations that were seen throughout the end of the monitoring period (U.S. Environmental Protection Agency, 2012c).

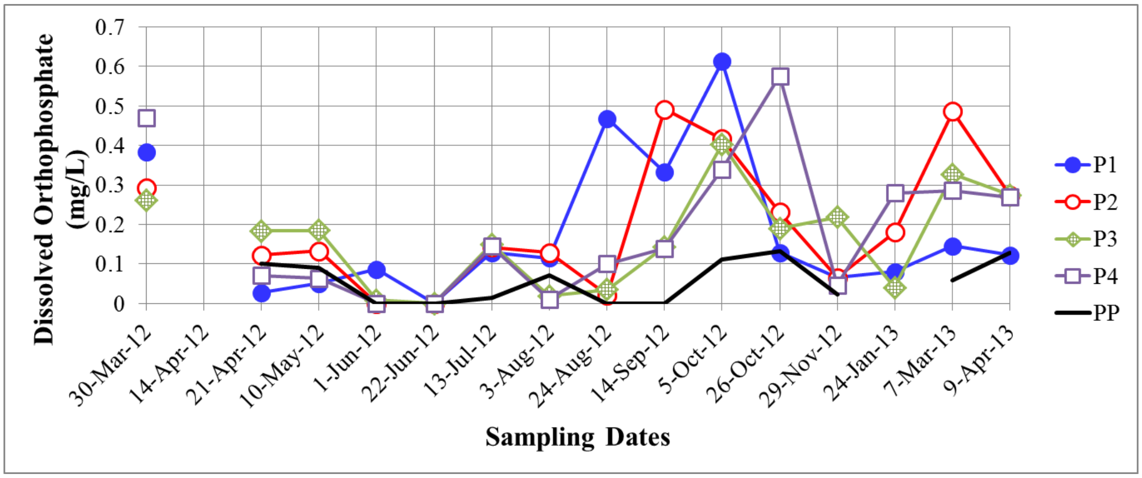

Figure 4.31 Variations in measured dissolved orthophosphate levels of water samples collected from the different sampling points at Pitts' OFWS system.

4.4.10 Total Kjehldahl Nitrogen

The total kjehldahl nitrogen level of water samples ranged from 0 to 9.25 mg/L (Figure 4.32). The average TKN level throughout the monitoring period in the Pitts

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system was 2.97 mg/L. In general, TKN levels from all sites were less than 4 mg/L. The mean TKN levels for specific sampling points were as follows: P1 was 2.82 mg/L, P2 was 2.78 mg/L, P3 was 3.37 mg/L, P4 was 2.80 mg/L, and PP was 3.07 mg/L. Elevated TKN values were observed after fertilization and again after harvest. The highest TKN level was experienced on June 1, 2012 at the outlet P3 (9.25 mg/L). This most likely originated from an outside source because P2, P1, P4, and PP show very little traces of TKN. In addition, on September 14, and October 5, 2012 and January 24, 2013, lower TKN levels in the TWR ditch combined with higher levels at one or both of the inlets show that the source of the TKN seems to originate from outside the system. However, higher TKN levels in the TWR ditch with lower levels at the inlet on August 24 and November 29 indicate that TKN spikes appear to have originated from on-farm activities.

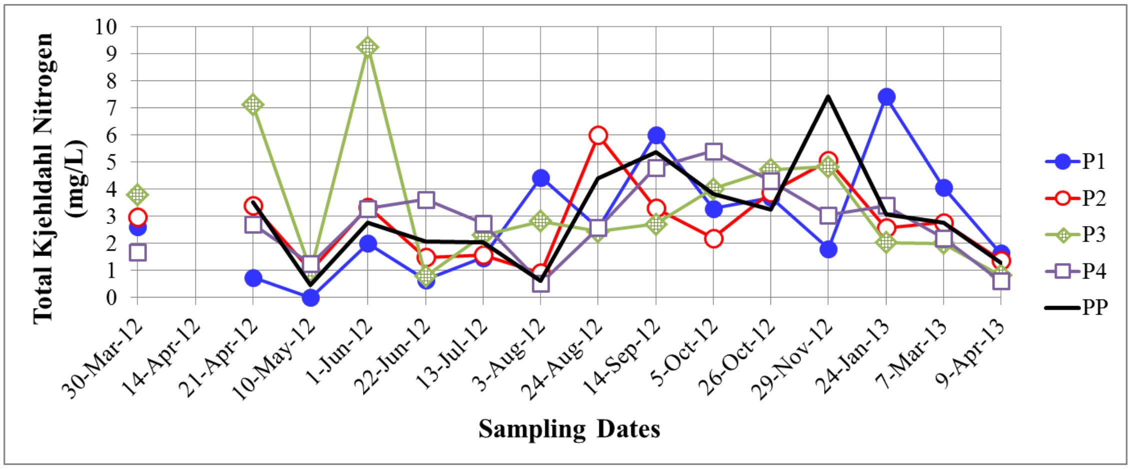

Figure 4.32 Variations in total kjehldahl nitrogen levels of water samples collected from the different sampling points at Pitts' OFWS system.

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4.4.11 Total Suspended Solids

The measured total suspended solids concentration of water samples ranged from 0.6 to 847.5 mg/L (Figure 4.33). The average TSS level throughout the monitoring period in the Pitts system was 150.17 mg/L. In general, a majority of TSS levels were less than 200 mg/L. The mean TSS levels for specific sampling points were as follows: P1 was 79.88 mg/L, P2 was 172.74 mg/L, P3 was 142.04 mg/L, P4 was 155.36 and PP was 200.84 mg/L. Increased TSS levels were observed at the PP sampling site on April 21 and May 10, 2012. Samples from PP had highest TSS concentrations of 464 mg/L and 491.5 mg/L, respectively, on April 21 and May 10. In addition, TSS concentrations of sample P2 and P3 collected on March 7, 2013 were 847.5 mg/L and 428.5 mg/L, respectively.

April 21 and May 10 high levels at PP seem to have originated from pumping into the pond. Overtime, TSS could build up from the continuous pumping to fill the pond. High levels observed March 7 most likely originated on site because of the high TSS level seen at P2, while little traces of TSS were detected at the inlet sampling sites, P1 and P4. TSS values seem to be highest when the soil is bare and loose (pre-planting and post-harvest) and rainfall is able to come in direct contact with bare ground (Fangmeier, 2006).

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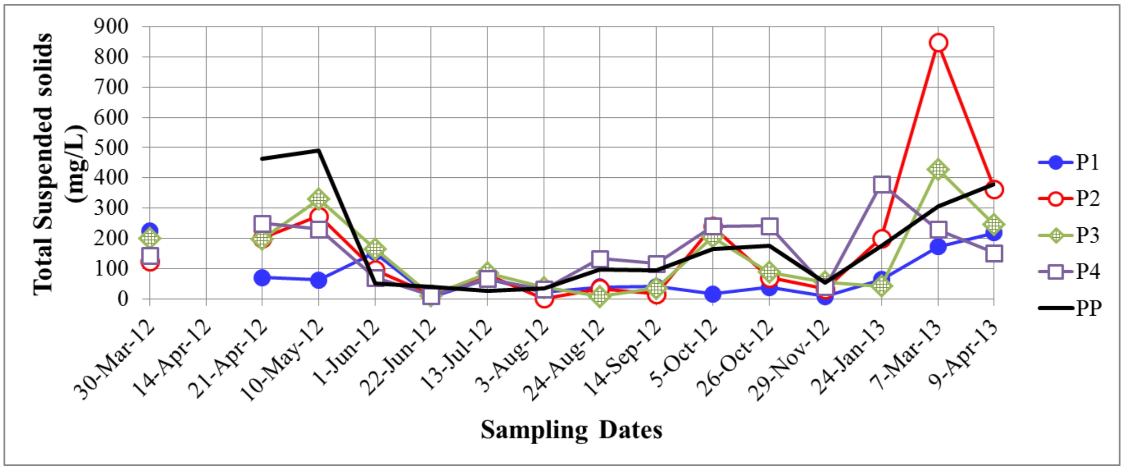

Figure 4.33 Variations in measured total suspended solids levels of water samples collected from the different sampling points at Pitts' OFWS system.

4.5 Reduction Efficiency

The percentage of nutrient reduction efficiency for Metcalf and Pitts farm is presented in Tables 4.5 and 4.6, respectively. Each table shows the percentage increase and reduction of NO_3, TN, TP, DP, and TSS from the mid-channel to the outlet of each farm. Each sampling date within the tables was chosen because there was water observed flowing out of the outflow so a reduction analysis could be calculated.

The effectiveness of the OFWS systems in reducing nutrients from discharging downstream varied with the magnitude of rainfall that fell on and up stream of the farms, the volume of water present within the TWR ditch at the beginning of the rainfall event, and the mixing of off-farm streams that flow into the outflow of the systems. Significant rainfall events that were too large for the systems to handle did not allow systems to reduce the amount of nutrients discharged downstream. However, when the water level in the TWR ditch was low and able to retain a majority of the runoff from the fields, the system was able to reduce the nutrients effectively. The detainment of water on-farm

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gives nutrients and sediment time to settle and not be released downstream (U.S. Environmental Protection Agency, 2012a). The systems were also effective during small rainfall events and dry periods. Concerning the outlet, there are streams that feed into Metcalf and Pitts outlet that are not a part of the farms. It should be noted that increases in nutrient levels that were observed at the outlets of these systems could be due to streams carrying nutrients from upstream and mixing at the outlets of Metcalf and Pitts.

Table 4.5 Metcalf OFWS system nutrient reduction efficiency.

Date	**Nitrate**	**Total Nitrogen**	**Total Phosphorus**	**Dissolved Orthophosphate**	**Total Suspended Solids**
10-May-12	1% Increase	58% Increase	57% Increase	3.5% Reduction	148% Increase
1-Jun-12	40.8% Increase	49% Increase	7% Increase	No increase or reduction	20% Increase
22-Jun-12	26% Increase	15% Reduction	50% Increase	Increase*	80% Reduction
13-Jul-12	51% Reduction	42% Reduction	3% Reduction	113% Increase	98% Reduction

*M2 had zero mg/L of DP and M3 had 0.127 mg/L

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Table 4.6 Pitts OFWS system nutrient reduction efficiency.

Date	Nitrate	Total Nitrogen	Total Phosphorus	Dissolved Orthophosphate	Total Suspended Solids
1-Jun-12	30% Increase	35% Increase	86% Increase	No increase or reduction	71% Increase
22-Jun-12	10% Reduction	10% Reduction	24% Reduction	5.6% Increase	23% Reduction
13-Jul-12	2% Reduction	11% Increase	5% Increase	85% Reduction	8% Increase
3-Aug-12	54% Increase	73% Increase	24% Increase	66% Increase	6,150% Increase
5-Oct-12	1% Reduction	2% Increase	8% Reduction	77% Reduction	15% Reduction
7-Mar-13	54% Reduction	53% Reduction	42% Reduction	32% Reduction	49% Reduction
9-Apr-13	44% Reduction	6% Increase	9% Increase	0.37% Increase	32% Reduction

4.6 Automated Sampler Data

4.6.1 Metcalf Auto-Sampler

Nitrogen and phosphorus based nutrient analyses for samples collected by an automated sampler located within the mid-channel of Metcalf farm is represented in Figures 4.34 and 4.35, respectively. Rainfall data three days prior to sampling is represented in Figure 4.36.The auto-sampler collected 24 samples, one sample per hour. However, only odd numbered samples were analyzed so that time and cost could be lowered for analyses.

The May 10, 2012 sampling date was chosen for Metcalf farm. The weather station recorded 13.2 mm of rainfall three days prior to May 10. May 9 alone recorded 8.3 mm of rainfall. Sampling began at 10:00 a.m. on May 9 and finished on May 10 at 10:00 a.m. with a 24-hour sampling period (one sample per hour). Nutrient data was

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similar throughout the sampling period with the exception of TKN. Nutrients seem to be the highest during the first hour of sampling and then began decreasing until nutrients leveled off and held constant. High levels during the first hour were most likely the tail end of the rainfall event and as samples continued to be gathered runoff ceased to flow into the TWR ditch while sediment and nutrients began to settle.

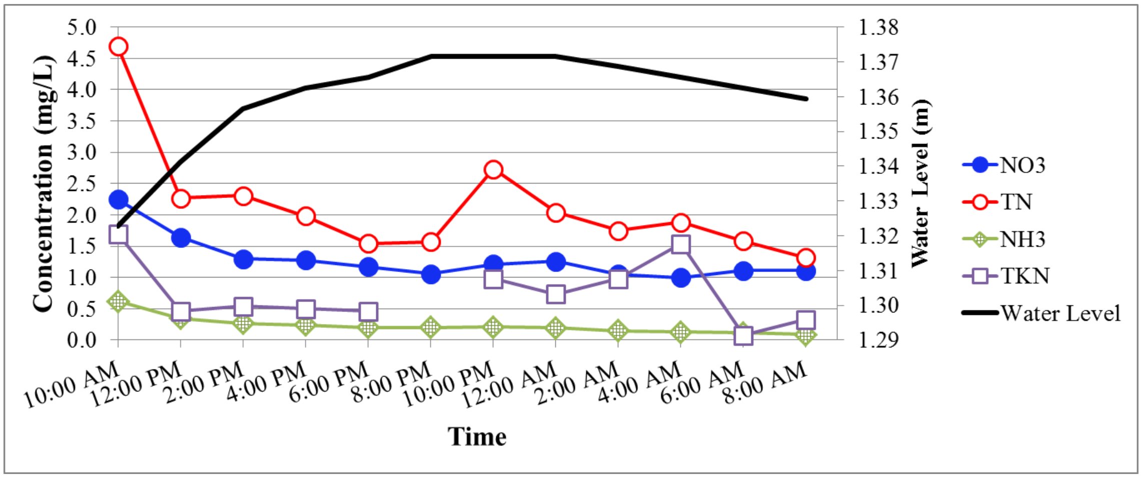

Figure 4.34 Nitrogen-based water sample analyses collected by auto-sampler and recorded water depth within TWR ditch on Metcalf Farm (May 9 and 10).

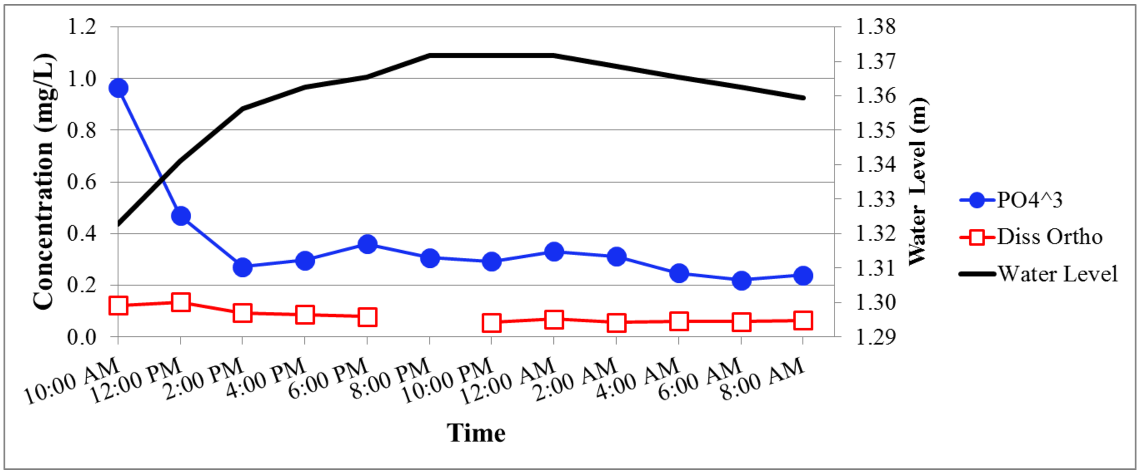

Figure 4.35 Phosphorus-based water sample analyses collected by auto-sampler and recorded water depth within TWR ditch on Metcalf Farm (May 9 and 10).

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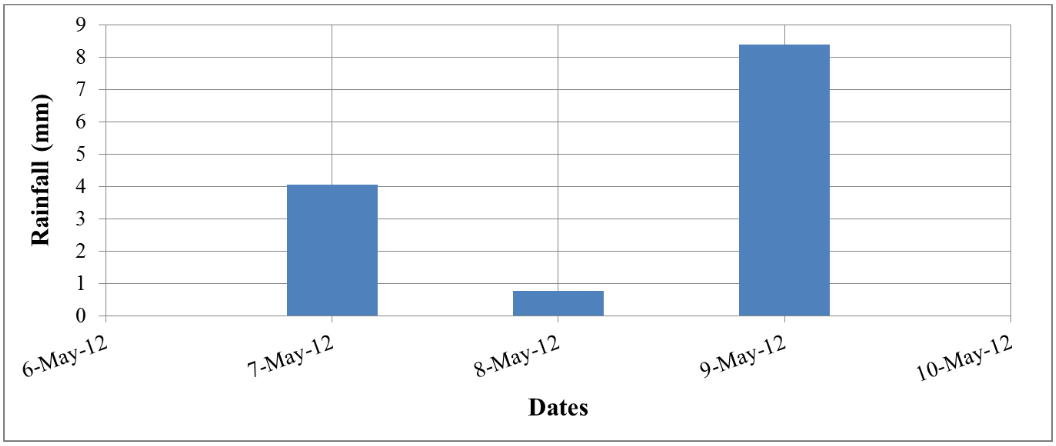

Figure 4.36 Daily recorded rainfall at Metcalf farm May 6 through May 10.

4.6.2 Pitts Auto-Sampler

Nitrogen and phosphorus based nutrient analyses collected by an automated sampler located within the mid-channel of Pitts farm are represented in Figures 4.37 and 4.38, respectively. Rainfall data two days prior to sampling is represented in Figure 4.39. The auto-sampler collected 24 samples, one sample per hour. However, only odd numbered samples were picked to analyzed to save time and expense.

The June 1, 2012 sampling date was chosen for Pitts farm. The weather station recorded 19.3 mm of rainfall during the two days prior of June 1st. May 31 alone saw 11.6 mm of rainfall. Water level showed a low depth (1.53 m) at the end of May 30 but dropped back down to1.43 m by mid-day May 31. Water level rose a second time on the afternoon of May 31 to almost 1.6 m but began declining shortly thereafter. Sampling began at 10:00 a.m. on May 31 and finished on June 1 at 10:00 a.m. with a 24-hour sampling period (one sample per hour). Nutrient data was similar throughout the sampling period. All nutrients showed a rise in concentration at 4:00 p.m. on May 31st.

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More than likely this was when the heaviest rainfall occurred causing the largest runoff event during the 24-hour sampling period. Nutrients levels then dropped after 4:00 p.m. and showed a short elevated concentration around 8:00 p.m. After 8:00 p.m. levels began to slowly decline and level off. These analyses showed how quickly nutrients can be moved during a runoff event.

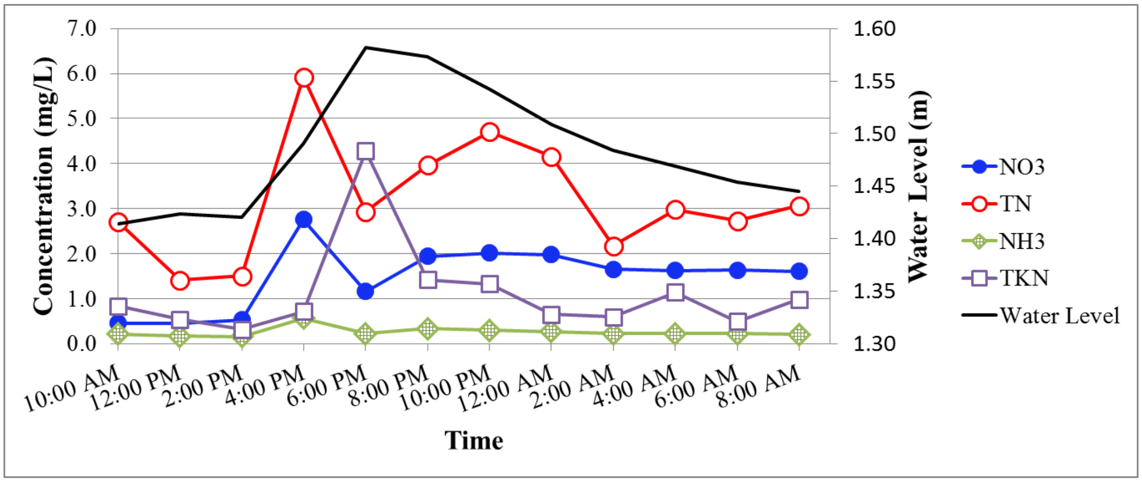

Figure 4.37 Nitrogen-based water sample analyses collected by auto-sampler and recorded water depth within TWR ditch on Pitts farm (May 31 and June 1).

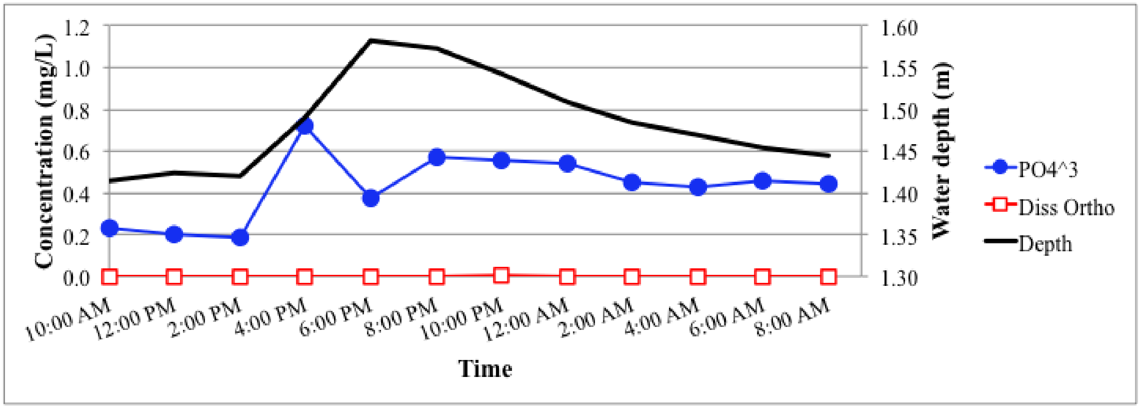

Figure 4.38 Phosphorus-based water sample analyses collected by auto-sampler and recorded water depth within TWR ditch on Pitts farm (May 31 and June 1).

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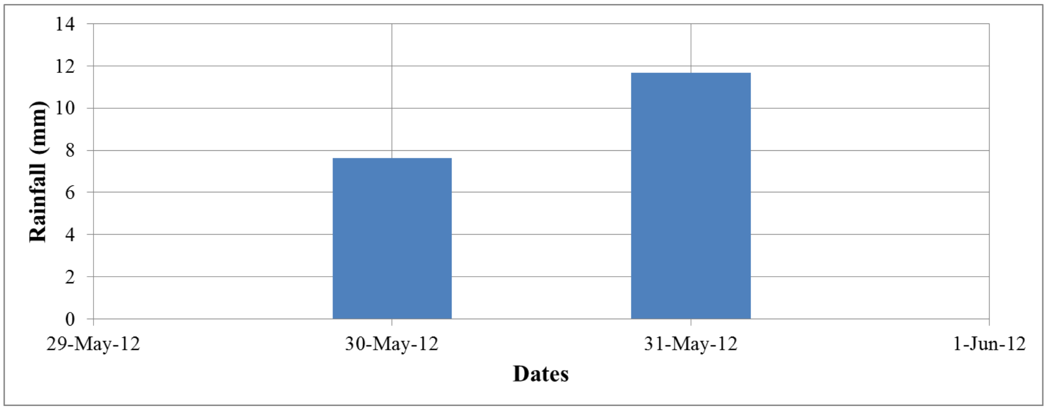

Figure 4.39 Daily recorded rainfall at Pitts farm May 29 through June 1.

4.7 Seasonal Water Consumption

4.7.1 Metcalf Flow Meter

Metcalf farm was one of the first OFWS systems constructed by NRCS within Sunflower County, Mississippi. A pipe flow meter was installed to monitor water withdrawal from the pond. The cumulative volume of water used for irrigation based on flow meter readings from the pond at Metcalf farm is presented in Figure 4.40.

Surface water was not utilized until after crops were planted. Irrigation of soybean plants commenced in June 2012. A majority of water used during the monitoring period was applied in late July and early August, corresponding to increased crop water demand during this period of high growth rate. Irrigation ceased after harvest operations in September 2012. The average amount of water needed for soybean production within the Mississippi Delta is 0.9 acre-feet of water per acre of soybean planted (Powers, 2007). Metcalf farm consisted of 245 acres of planted soybeans, which meant that a total of 220.5 acre-feet was needed to sustain soybean production. A total of 130 acre-feet of

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water from the pond was used for supplemental irrigation during the 2012 growing season, and the balance (90.5 acre-feet) was fulfilled by rainfall.

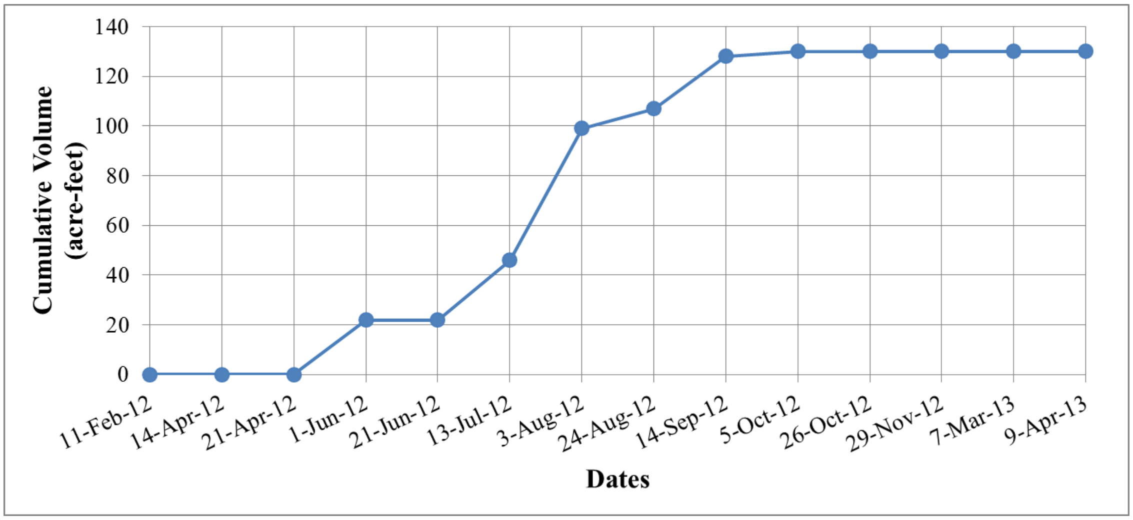

Figure 4.40 Volume of water pumped from the storage pond at Metcalf farm and used for irrigation during the monitoring period.

4.7.2 Pitts Flow Meter

Two pipe flow meters were monitored on Pitts farm, one located at the mid-channel and the second near the pond. The flow meter located at the mid-channel recorded the amount of water that was pumped from the TWR ditch to the pond for storage (Figure 4.41). The initial transfer of water from the ditch to the pond was made in March 2012. A total of 241 acre-feet was pumped into the pond during the monitoring period.

The flow meter located near the pond recorded the amount of water that was pumped from the pond into the fields for irrigation (Figure 4.42). Based on the typical seasonal irrigation demand of soybean (0.9 acre-feet of water per acre of soybean), a total

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of 200 acre-feet of water was needed to irrigate 160 acres of planted soybean at Pitts farm. A cumulative volume of 183 acre-feet of water from the pond was used for irrigation. The amount is equivalent to 59.6 million gallons of water that was not pumped from the MRVA. However, this was not the total amount of water used for irrigation during the 2012 growing season. The system of pumps and pipes at Pitts farm allowed the farmer to irrigate his field by directly pumping water from the TWR ditch. It is important to note that direct pumping of water from the ditch for irrigation was only possible when the pond was full and there were large amounts of water in the ditch. This practice provided another source of irrigation water, besides pumping water from the pond, and also helped reduce energy costs associated with re-lifting. No data was collected regarding the volume of water drawn directly from the TWR ditch for irrigation. Therefore, it is assumed that the total amount of groundwater savings was considerably higher than what was recorded (183 acre-feet) by the flow meter near the pond.

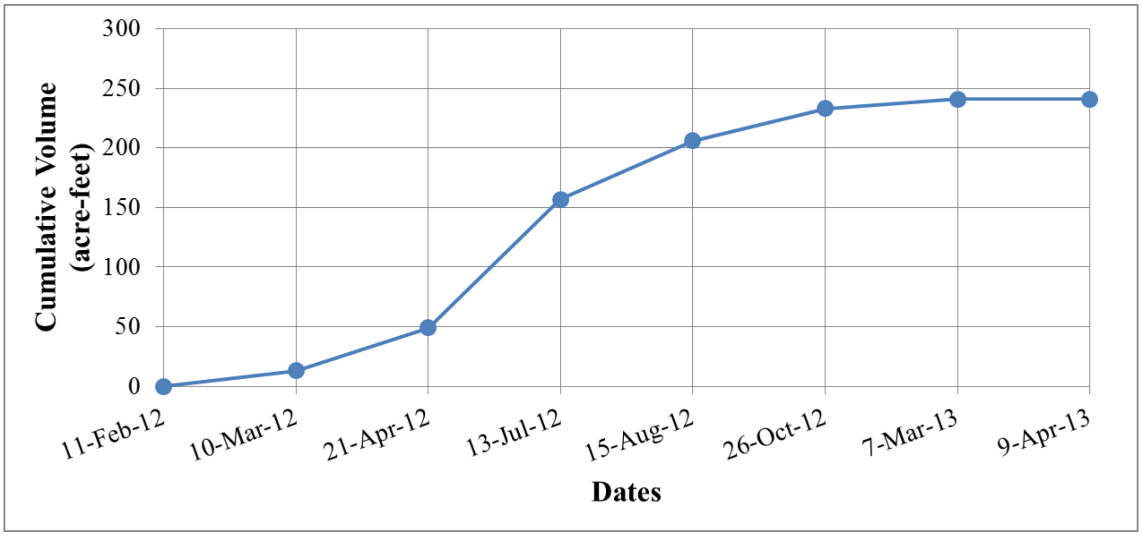

Figure 4.41 Volume of water transferred from the TWR ditch to the storage pond at Pitts farm during the monitoring period.

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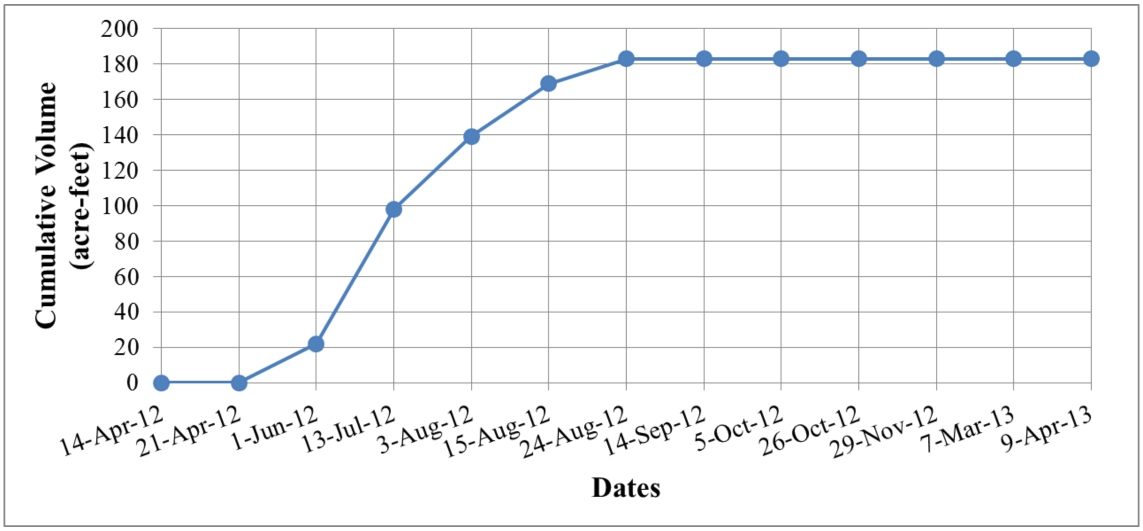

Figure 4.42 Volume of water pumped from the storage pond at Pitts farm and used for irrigation during the monitoring period.

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CHAPTER V

CONCLUSION

5.1 General Conclusion

The main goal of this study was to examine the nutrient reduction potential of OFWS systems in Porter Bayou Watershed. Eight OFWS systems have been constructed in PBW primarily as a means to capture and use runoff for irrigating crops. These systems were constructed with technical assistance from NRCS and MDEQ, and funded through MRBI and other cost-share programs. In general, OFWS systems have moderately-sized drainage areas (191-450 acres) from which runoff is captured by TWR ditches. Water from the systems can be used to irrigate an average of 251 acres of farmland. Water collected from different sampling points within the OFWS systems at Metcalf and Pitts farm were monitored for different water quality indicators from March 2012 and April 2013.

Nitrogen and phosphorus levels of water samples were generally higher during the early part of the growing season. The effectiveness of the OFWS systems in reducing nutrients from the effluent was varied, possibly due to three factors, namely 1) the magnitude of rainfall and resulting runoff events, 2) the volume of water in the TWR ditch prior to the onset of runoff events, and 3) the mixing of effluent from different fields downstream. Large rainfall events overwhelmed the systems, causing a failure in reducing the amount of nutrients discharged downstream. However, when the water level

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in the TWR ditches was low, the system was able to detain surface runoff and allow sediment to settle in the TWR ditch or pond, thereby reducing nutrient levels in the effluent. The key to reducing nutrients downstream is to keep the TWR ditch as low as possible at all times, allowing for maximum holding capacity and detention time during runoff events caused by rainfall or irrigation. The lack of data on the water quality conditions prior to the installation of OFWS systems at the two farms limited the scope of this study on current impacts of the BMP on nutrient concentrations. The two systems monitored were fairly new and thus, data also could have been influenced by the age of the systems.

Runoff captured by both OFWS systems was used for irrigation during the 2012 growing season, thus saving considerable amounts of groundwater. Research estimated that a minimum of 130 acre-feet of surface water was pumped from the OFWS at Metcalf farm, and a minimum of 183 acre-feet was used at Pitts farm. A total of 313 acre-feet was pumped from the storage ponds, which translates to 101 million gallons of water that was not withdrawn from the Mississippi River Alluvial Aquifer. Considering the rainfall variability in the Delta region, the results of this study underscore the importance of OFWS systems as structural BMPs for water conservation, providing surface water for irrigation, and reducing the dependence of agricultural production on groundwater.

5.2 Future Recommendation

This study highlighted the effect of hydrologic events on the transport of nutrients and sediments into surface waters. Researchers must be aware of the impact that time and placement of water sample collection has on data analysis. Future studies on monitoring OFWS systems must include a refinement of field collection procedures that takes into

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account the onset of rainfall and peak runoff events, antecedent water level condition of the TWR ditch, and stream velocity. An area of research that can be investigated is the impact of nutrient levels of irrigation water pumped from the storage pond on soil nutrient concentrations and overall field-level nutrient balance. This may have significant implications specifically, on how farmers implement their nutrient management strategies and, more broadly, on the magnitude of nutrient loads into the Gulf of Mexico. Also, farmers and landowners must implement an appropriate plan to maintain and manage OFWS systems in order to prevent erosion of the side slopes of ditches and ponds. Poor maintenance will lead to siltation and reduce the capacity of these systems.

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