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## **Modeling Phosphorus Load Reductions of Agricultural Water Management Practices on a Beef Cattle Ranch**

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**Abstract.** The Watershed Assessment Model (WAM) was applied to Buck Island Ranch, location of the MacArthur Agro-ecology Research Center, near Lake Placid, Florida. This is a 4,200 ha cattle ranch and is operated at full commercial scale allowing researchers to investigate ecological interactions under the economic realities of a working agricultural operation. WAM is a physically-based model that can be used to perform watershed-related hydrological and water quality analyses. It simulates surface and ground water quality based on land use, soil, weather and land management practices. The model uses Geographic Information System (GIS) functions to overlay land use, soils, and rain zones to create a list of unique combinations that are used to estimate the nutrient concentrations in the surface and groundwater flow leaving each source cell. The objective of this study was to determine the potential phosphorus load reduction under various water management alternatives for the most intensively managed portion of the ranch, where 39 proposed structures for on-site water detention are located. The average base load from the ranch is 1.87 mtons per year. It is recommended that a detention depth ranging from 0.25 to 0.5" for pastures should be used to achieve a ranch level phosphorus load reduction of 20%.

**Keywords.** Water Detention BMPs, Water Quality, GIS, Modeling, Agricultural Land Uses

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## Introduction

Buck Island Ranch is located in the Lake Okeechobee watershed (Figure 1). The watershed, which comprises the Lake Okeechobee Protection Plan (LOPP) area, includes 61 drainage basins with a drainage area of 5,500 square miles. Over the past 30 years, Lake Okeechobee has experienced accelerated eutrophication due to excessive phosphorus loading from this watershed (Havens et al., 1996). Phosphorus-containing materials are transported into and out of Lake Okeechobee contributory basins. A portion of the imported phosphorus is exported in basin drainage waters and enters the lake, where it contributes to excessive nutrient enrichment.

During the past 10 years, the assimilative capacity of soils and wetlands for phosphorus in the Lake Okeechobee watershed has been reduced due to the excess net phosphorus import to the watershed (Hiscock et al., 2003). Improvements of phosphorus concentrations and loads to the lake have not occurred in the last decade because external loads have remained high and lake sediments contain thousands of tons of phosphorus that buffer changes in water column total phosphorus, (SFWMD, 2006). Recognizing the limited progress in reducing phosphorus loads to the lake, the 2000 Lake Okeechobee Protection Act (Section 373.4595, Florida Statutes) was passed by the Legislature to establish a restoration and protection program of the lake. In 2001, the Florida Department of Environmental Protection (FDEP) established a Total Maximum Daily Load (TMDL) for total phosphorus entering Lake Okeechobee (FDEP, 2001). The TMDL is 140 metric tons per year, which includes 35 metric tons of phosphorus in rainfall directly falling onto the lake. Based on the five year rolling average from May 2000 to April 2005, phosphorus loading to the lake averages 580 metric tons per year, which is more than four times higher than the TMDL limit. Although P concentrations from beef cattle pastures are lower than from many other land uses, the highest phosphorus loads to Lake Okeechobee historically have originated from cattle pastures because they are the dominant land use in the watershed. As required by the Act, a Lake Okeechobee Protection Plan was completed in January, 2004 (SFWMD, et al., 2004). The Plan contains a phased, watershed-based, comprehensive approach to reduce phosphorus loading to the lake. In order to meet the lake's TMDL by the year of 2015, the Plan outlined the phosphorus load reduction goals achievable under a series of interrelated activities. One of the activities included the evaluation of on-site and tributary water management practices on phosphorus load reduction.

In a previous investigation, the Watershed Assessment Model (WAM) (SWET, 2002) was used to assess the effectiveness of stormwater retention on phosphorus load reduction at the basin level (Zhang and Whalen, 2005). Modeling results indicated that an 18 percent phosphorus load reduction could be achieved with a water detention depth of 0.5 in (1.27 cm) for all pastures (beef, dairy, and abandoned dairy) and 0.25 in (0.64 cm) for non-pasture land uses. The overall objective of this study was to estimate the effectiveness of agricultural water management practices on pasture land uses at the parcel level since pasture land use is the major contributor of phosphorus load in the watershed. Buck Island Ranch, location of the MacArthur Agro-ecology Research Center, near Lake Placid, Florida was selected for this study due to data availability and the extensive research work done at this location. There were four specific objectives to this study. The first was to obtain the current land use and drainage information of the ranch and update the GIS data accordingly. The second was to set up WAM using the ranch data. The third was to calibrate the model based on phosphorus concentration values collected at some drainage ditches. The fourth objective was to evaluate the changes of phosphorus load under different water management alternatives. This study determined relationships between detention depth and phosphorus load reduction for pasture land uses.

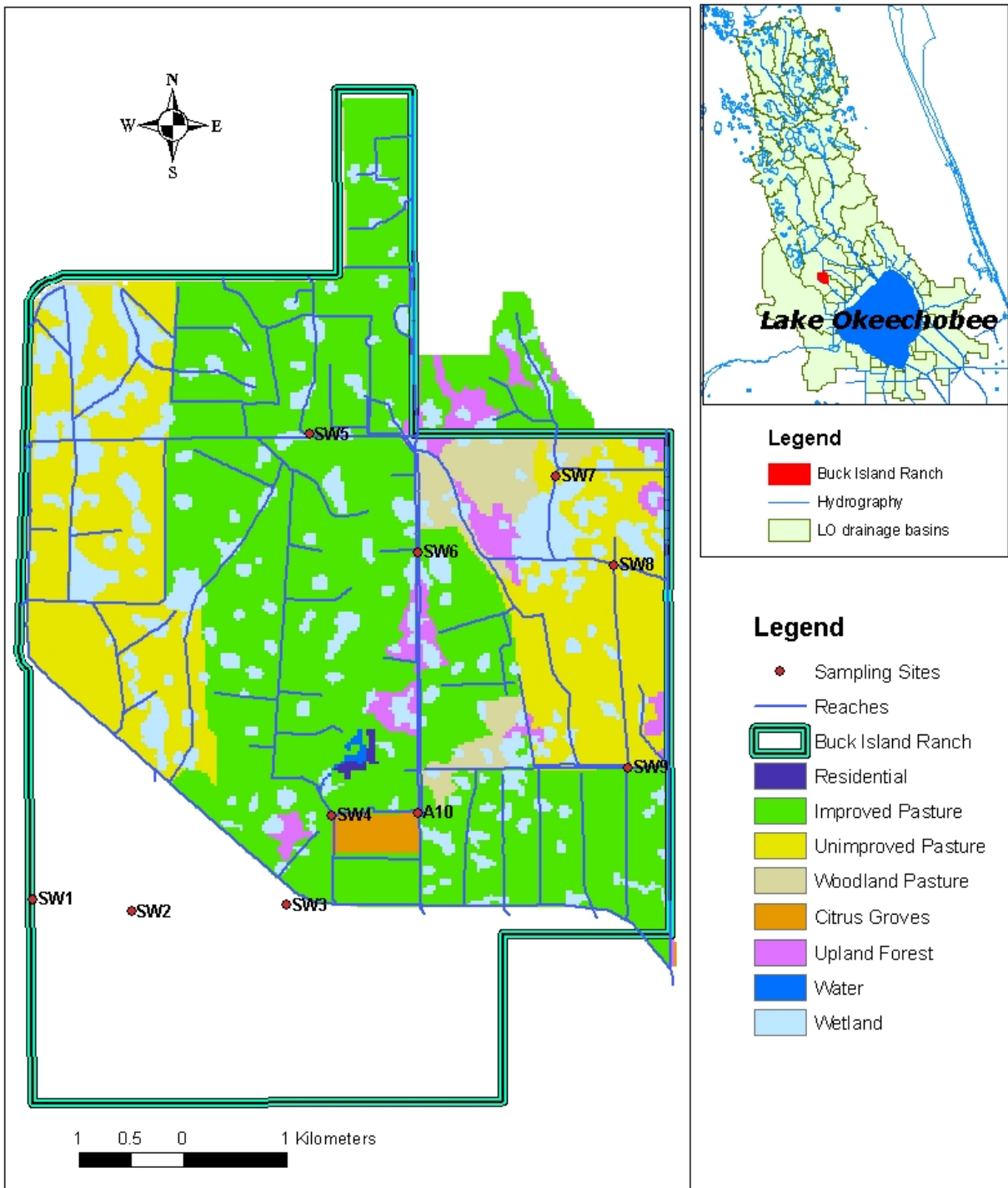


Figure 1. Location and land use map for Buck Island Ranch in the Lake Okeechobee drainage basins

## Buck Island Ranch Description

Buck Island Ranch, the location of the MacArthur Agro-ecology Research Center (MAERC), is a 4,138-ha cattle ranch on a long-term lease to Archbold Biological Station from the John D. and Catherine T. MacArthur Foundation. The Center is dedicated to a mission of long-term research, education and outreach related to the ecological and social value of subtropical grazing lands. The ranch is operated at full commercial scale allowing researchers to investigate ecological interactions under the economic realities of a working agricultural landscape. It also provides researchers the opportunity to evaluate the relationship between economic and ecological factors and how these change over time. A detailed description of the ranch is contained in the website: <http://www.archbold-station.org/ABS/maerc/maerc.htm>.

WAM was applied to a 3,295-ha area that included all of the improved pastures area of the ranch. The land uses within the modeling area were improved pasture (52%), unimproved/semi-improved pasture (24%), wetland (15%), woodland pasture (4%), upland forest (4%), and citrus (1%). The major soil types include Immokalee (15%), Felda (12%), Brandenton (10%), Valkaria (9%), Myakka (8%), Malabar (7%), Basinger (6%), and Tequesta (5%).

The major drainage canal is the Harney Pond Canal (C-41), surrounding the northern, western and southern boundaries of the modeled area. The nearest rainfall stations were located at the South Florida Water Management District (SFWMD) structures, S70 and S75 (data not shown). Structure S75 is about six km to the east of the ranch and S70 is about five km to the south of the ranch. The rainfall data from both sites were obtained from the SFWMD's DBHYDRO database for the model simulation period of 1991 to 2005.

## Model Description

### *Modeling Approach*

WAM is a Geographic Information System (GIS) based model that allows engineers and planners to interactively simulate and assess the environmental effects of various land use changes and land management practices. The primary reason for using WAM is that it has been calibrated and verified to the northern Lake Okeechobee watershed as a part of the Comprehensive Everglades Restoration Plan (CERP) project for characterizing the hydrology and water quality (HDR Engineering, Inc., 2003).

WAM uses ESRI™ ArcView 3.2a with Spatial Analyst 2.0 to analyze and display model input and output using grids. Grid datasets, as opposed to polygon datasets, spatially represent geographic data as a collection of raster cells. Each cell contains attributes of the dataset, e.g., land use code numbers, which can be overlaid with cells of other grids. The benefit of using grids over polygons includes computational speed and output resolution. Output can be displayed by grid cell as opposed to by subbasin polygon. The cell size is dependant on the desired resolution. In this analysis a grid cell size of 100 feet by 100 feet was chosen with the intent that this would adequately characterize the land use.

The water quality parameters (impact parameters) simulated within the model include: water quantity, soluble nitrogen (N), particulate N, groundwater N, soluble phosphorus (P), particulate P, groundwater P, sediment P, and biological oxygen demand (BOD). GIS datasets of land use, soils and rainfall are used to calculate the combined impact of the watershed characteristics for a given grid cell. Once the combined impact for each unique cell within a watershed is determined, the cumulative impact for the entire watershed is determined by attenuating the constituent to the sub-basin outlets. Constituents are attenuated based upon the flow distances (overland to nearest water body, through wetlands or depressions and within streams to the

sub-basin outlet), flow rates in each related flow path, and the type of wetland or depression encountered. A portion of the flow in each cell is converted to groundwater based on the soil and crop types and amount of imperviousness estimated for each land use. Surface flow that enters depressions is also converted to groundwater. Groundwater is routed to the nearest stream unless directed otherwise.

The hydrologic contaminant transport modeling is accomplished by first simulating all of the unique grid cell combinations of land use, soils, and rainfall by using one of several source cell models including GLEAMS (Knisel, 1993), EAAMOD (Botcher et al., 1998; SWET, 1999), a wetland module, and an urban module (SWET, 2002). These models are called by BUCSHELL.exe based on the land use of the unique combination. The time series outputs for each grid cell is then routed and attenuated to the nearest stream and then through the entire stream network of the watershed. Dynamic routing of flows is accomplished through the use of a route submodel, BLASROUTE.exe, which uses a non-linear reservoir technique (Jacobson et al., 1998). Figure 2 below shows a flow diagram of the hydrologic contaminant transport modeling component of the overall WAM model. More information regarding WAM can be found in the website: <http://www.swet.com>.

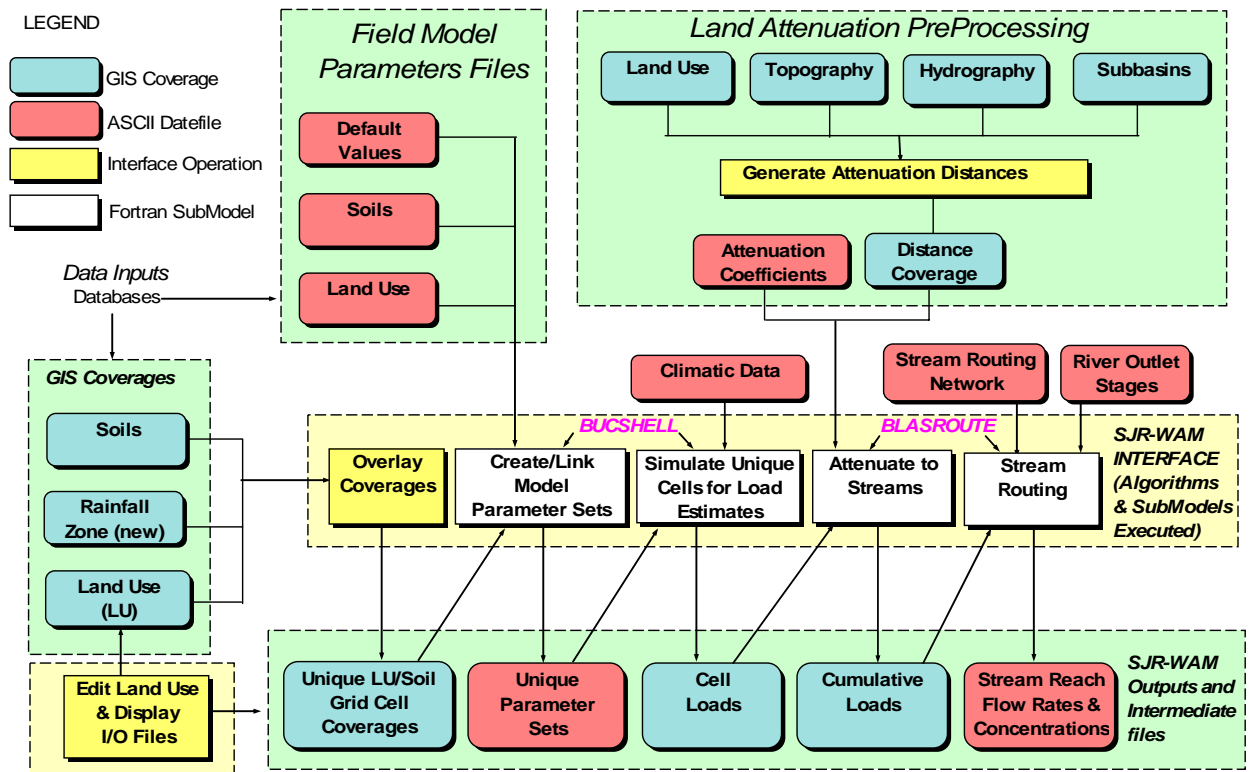


Figure 2. Flow diagram of dynamic modeling components

### WAM Setup

WAM uses the programming language known as Avenue™, which comes with ArcView™, to run the graphical user interface. A separate interface is also available for setting up WAM for a specific watershed. There were two setup procedures followed, as described in the WAM User Manual (SWET, 2002).

The Primary Basin Setup was used to create an ArcView project file for the primary basin, which includes Buck Island Ranch and a small amount of off-site flow that passes through the ranch. The term “primary basin” in WAM refers to a collection of subbasins or basins that typically discharge to a single receiving water body. WAM allows, however, multiple discharge locations. In this case, Buck Island Ranch was set up as a single primary basin with multiple outfalls to adjacent SFWMD canals. The primary basin setup procedure was followed as described in detail in WAM’s User Manual. This procedure includes the following seven steps: 1) create project and view, 2) generate reaches, 3) generate depressions, 4) generate distances, 5) re-assign groundwater, 6) build reach sections, and 7) create default output.

The Watershed Setup procedure was followed to create the main interface for WAM to reflect this geographic region. The main interface, when completed, provides project management tools and a means to select a primary basin to be assessed. In this case, there is only one basin to select. This procedure includes the following four steps, which are described in detail in the User Manual: 1) select base maps, 2) select Best Management Practices (BMPs), 3) setup watershed view, and 4) customize interface layout.

## GIS Datasets

Some of the GIS spatial datasets necessary to set up WAM were extracted from a previous WAM setup in the region associated with the Comprehensive Everglades Restoration Program (CERP) (HDR, 2003). These datasets included land use, soils and topography. Other site-specific information regarding drainage and more recent land use were obtained from the MacArthur Agro-ecology Research Center, an independent, non-profit research facility at the ranch. The spatial datasets were converted, if necessary, to SFWMD’s standard projection, Florida State Plane Feet (East) NAD 83. The land use dataset utilizes the Florida Land Use Cover Classification System (FLUCCS), which is also utilized by WAM. The land use coverage was edited and updated based on information provided by the Center.

Hydrologic reaches and subbasins were also obtained from the Center. The hydrologic reaches included canals, ditches and furrows. Reaches with depths of one meter or more were used as model reaches. The subbasin information included only the subbasins for the proposed detention areas. Subbasins for the remainder of the ranch were delineated based on the previous WAM setup for CERP, topography, review of aeriels and input from the Center. In total, 47 subbasins and 167 hydrologic model reaches were assigned.

## Rainfall

Rainfall datasets were created from monitoring information obtained from SFWMD monitoring sites. The nearest stations are S70 and S75, which were also used in the WAM modeling performed for CERP (HDR, 2003), but were updated to include rainfall up to 2005. Two rainfall zones were created to spatially assign the rainfall data based on Theissen’s method.

## Boundary Conditions

This project provided a rare opportunity to use the WAM model at varying spatial scales. The WAM modeling effort associated with CERP (HDR, 2003) was performed at a much larger and broader scale than the modeling performed for Buck Island Ranch. Though less detailed, e.g., cell sizes were one hectare, the model output covered the entire C-40 and C-41 Basins including all of the canals surrounding the northern, western and southern boundaries of the ranch. Output from the previous modeling effort was used to generate boundary conditions that include time-series information for canal stages and constituent concentrations.

## Depressions

Depressions are one of the three geographic features (wetlands, streams and depressions) that WAM uses to route runoff and attenuate flow. Areas that drain to depressions are attenuated differently than areas that drain via surface water to the streams. Runoff entering depressions converts to groundwater with very little phosphorus re-emerging in the streams. Depressions are basically isolated wetlands with no outfall. The ditched wetlands may detain water, but can still discharge. WAM recognizes the wetland and uses it as an attenuation feature. It does the same with depressions, but the attenuation is much greater since it goes to groundwater before re-emerging in the streams. The model was run and resulted in very few depressions converting surface runoff to groundwater. This is not surprising considering the amount of ditching that has occurred on the site.

## Attenuation Distances

WAM attenuates water quality parameters in the runoff based on distances and the type of geographic feature the runoff passes through (upland, wetland, depression and stream). The WAM Primary Basin Setup includes an algorithm to develop a series of ASCII grids for this purpose. ArcView™ Spatial Analyst distance functions are employed to determine both distance and attributes of the feature that is found. For example, when the closest wetland is found, the wetland FLUCCS number can also be returned. In addition, a grid of wetland distances to streams can be accessed to provide the distance to the next feature.

## Methods

For the purpose of assessing stormwater detention for various pastures at the ranch, WAM was applied to the 3,295-ha described above. To better represent the ranch condition, the model was calibrated using the measured total phosphorus concentrations collected monthly at seven locations throughout the modeling portion of the ranch. During the model calibration process, modifications to the input files were made including changes to the wetland parameter file to better match with collected data.

The stormwater detention alternatives were designed to allow users to determine the benefit of providing water storage for phosphorus load reduction via flow volume reduction and phosphorus concentration improvement. WAM was used to assess stormwater retention for three pasture land uses that are suitable to detain water for the ranch. These land uses include improved, unimproved/semi-improved and woodland pastures. In WAM, stormwater storage can be simulated by defining a detention depth which is the ratio of detention volume to land use area.

The 10-year average values of detention volume and phosphorus loads from the simulation with detention practices were compared to the baseline condition for each land use to determine the volume and load reduction efficiency. Baseline condition is defined as the long term average conditions without additional detention practices in the basin. The stormwater detained is assumed to be stored in the low-lying areas and ditches in the specified land use of the basin, not the entire area of each land use. Therefore, the detention depth at the low-lying areas should be much greater than the simulated detention depth. The low-lying areas could be a pond at the downstream end or an existing wetland with a detention structure.

Detention depths of 0.25 inch and 0.50 inch were simulated using WAM to assess the phosphorus load reduction by detaining stormwater runoff within the three land uses. The potential phosphorus load reductions under different combinations of detention depths were evaluated.

Scenario One included a water detention depth of 0.25 inch runoff for unimproved and woodland pastures and no detention changes for improved pasture and other land uses. Scenario Two increased the water detention depth to 0.50 inch for unimproved and woodland pastures but no detention changes for improved pasture and other land uses. Scenario Three included a water detention depth of 0.25 inch for all three pasture types and maintained no detention changes for other land uses. Scenario Four maintained a water detention depth to 0.25 inch for improved beef pasture and increased the detention depths to 0.50 inch for other two pastures.

## Results and Discussion

### Model Calibration

The model calibration results for total phosphorus concentrations at seven sites were reviewed and results at three sites are presented below. The model made reasonable prediction for site SW4 where improved pasture is the major land use for the drainage area (Figures 3). Several high phosphorus concentration values were observed at the site and the model produced low estimates for these months. However, the model provided reasonable estimates for all other months. For site SW4, the measured and the simulated average phosphorus concentration values are 0.547 mg/L and 0.511 mg/L respectively. Figure 4 presents the model prediction at site SW7 where the major land use is woodland pasture. For this site, the measured and the simulated average phosphorus concentration values are 0.083 and 0.079 mg/L respectively. Figure 5 shows the model prediction at site SW8 where the major land use is unimproved pasture. For this site, the measured and the simulated average values are 0.080 and 0.076 mg/L respectively. Based on data collected at those seven locations, the average phosphorus concentrations are 0.452 and 0.082 mg/L for improved and unimproved/woodland pastures respectively.

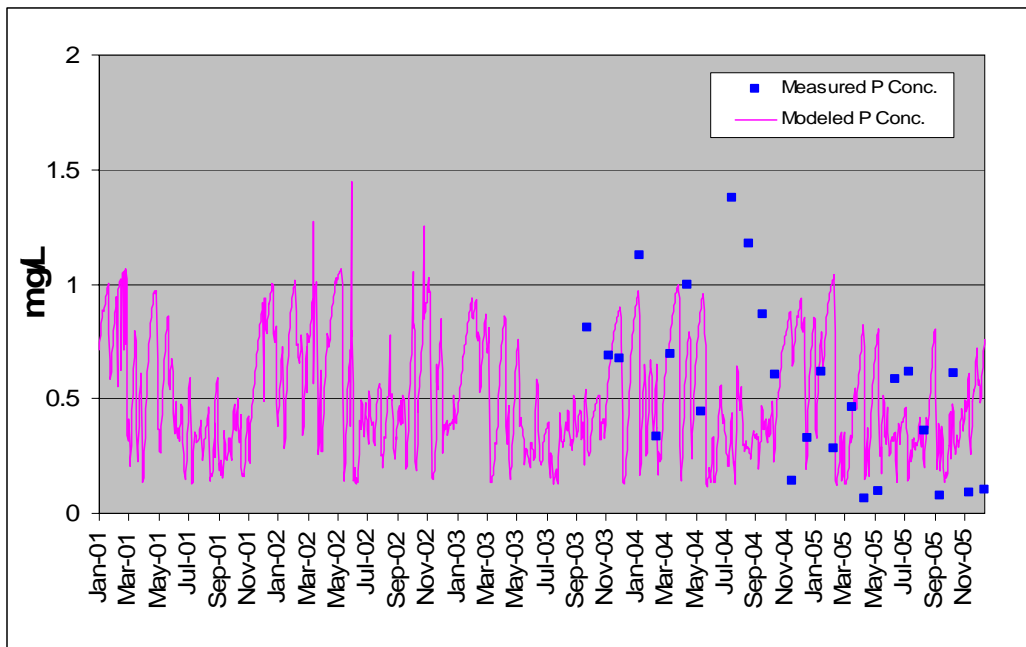


Figure 3. P concentration comparison at SW4, Reach 68, improved pasture

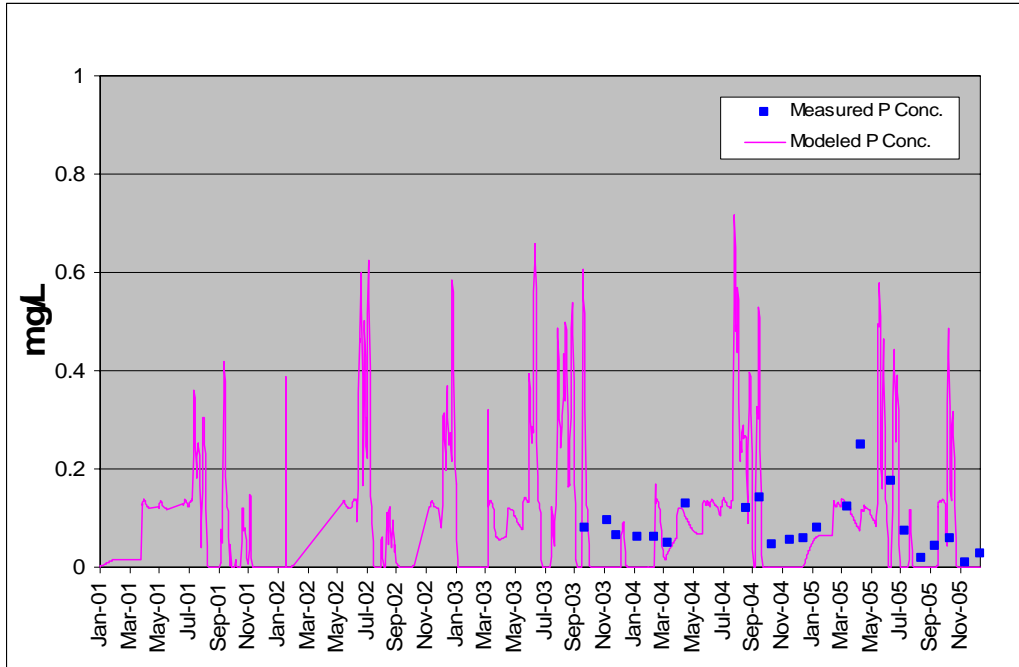


Figure 4. P concentration comparison at SW7, Reach 157, woodland pasture

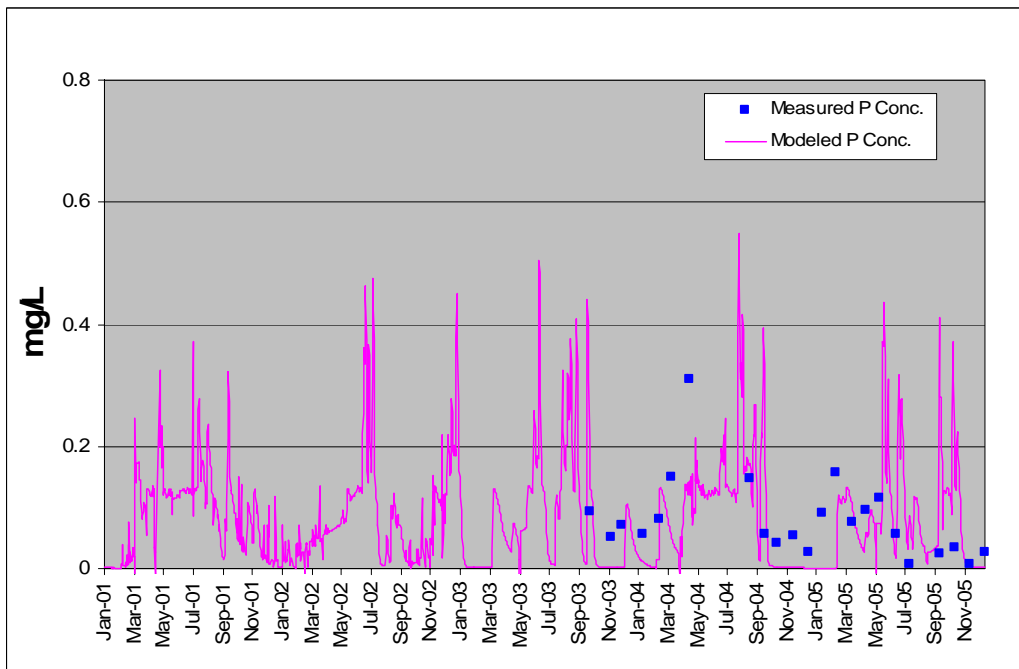


Figure 5. P concentration comparison at SW8, Reach 154, unimproved pasture

## Model Predictions

The total drainage area for the modeled portion of the ranch was 3,295 ha (Table 1). The base load under current condition is 1,871 kg based on the model simulation results of 1996 to 2005. An estimated 4% and 7% load reductions could be obtained with Scenarios One and Two which detain 0.25 and 0.5 inch depth of water respectively for unimproved and woodland pastures (Table 1). An estimated 16% and 19% load reductions could be obtained with Scenarios Three and Four which detain 0.5 inch depth of water for unimproved and woodland pastures and 0.25 inch depth of water for improved pasture (Table 1). The model output suggests that recommended detention depths that range from 0.25 to 0.5 inch of runoff could be implemented to achieve a ranch level of 20% phosphorus load reduction. Phosphorus load reductions of 71, 128, 291, and 348 kg of phosphorus per year could be achieved under these four scenarios respectively (Table 1).

Table 1. Estimated phosphorus load reductions under various detention depths for Buck Island Ranch

Land Use and Detention Depth	Area (ha)	Base load (kg)	Load with Detention (kg)	Change (kg)	Change (%)
<b>Scenario One</b>					
Improved Pasture, 0"	1,707	1271.8	1271.8	0	0
Unimproved Pasture, 0.25"	780	351.2	288.2	63.0	18
Woodland Pasture, 0.25"	122	60.9	52.5	8.4	14
Others	686	186.9	186.9	0	0
<b>Total</b>	<b>3295</b>	<b>1871</b>	<b>1799</b>	<b>71</b>	<b>4</b>
<b>Scenario Two</b>					
Improved Pasture, 0"	1,707	1271.8	1271.8	0	0
Unimproved Pasture, 0.5"	780	351.2	238.7	112.5	32
Woodland Pasture, 0.5"	122	60.9	45.1	15.8	26
Others	686	186.9	186.9	0	0
<b>Total</b>	<b>3295</b>	<b>1871</b>	<b>1743</b>	<b>128</b>	<b>7</b>
<b>Scenario Three</b>					
Improved Pasture, 0.25"	1,707	1271.8	1052.2	219.6	17
Unimproved Pasture, 0.25"	780	351.2	288.2	63.0	18
Woodland Pasture, 0.25"	122	60.9	52.2	8.4	14
Others	686	186.9	186.9	0	0
<b>Total</b>	<b>3295</b>	<b>1871</b>	<b>1580</b>	<b>291</b>	<b>16</b>
<b>Scenario Four</b>					
Improved Pasture, 0.25"	1,707	1271.8	1052.2	219.6	17
Unimproved Pasture, 0.5"	780	351.2	238.7	112.5	32
Woodland Pasture, 0.5"	122	60.9	45.1	15.8	26
Others	686	186.9	186.9	0	0
<b>Total</b>	<b>3295</b>	<b>1871</b>	<b>1523</b>	<b>348</b>	<b>19</b>

## Summary and Conclusion

This study applied the Watershed Assessment Model (WAM) to Buck Island Ranch for the evaluation of the phosphorus load reduction potential under four water management alternatives. WAM was developed by Soil and Water Engineering Technology, Inc. (SWET, 2002) for assessing the effectiveness of various BMPs in reducing phosphorus load from surface runoff. The model was applied to the northern Lake Okeechobee watershed as a part of the Comprehensive Everglades Restoration Plan (CERP) project. The model was applied to this ranch and calibrated using data collected from 2002 to 2005. WAM was used to assess stormwater retention for three pasture land uses that are suitable to detain water on site including improved, unimproved, and woodland pastures. Various detention depths were modeled to achieve an on-site retention deduction by approximated 20%.

There are seven ditch monitoring sites in the modeled area. The modeling results for total phosphorus concentrations at these sites were reviewed. The model provided a good match with measured phosphorus concentration values. Based on data collected from October 2002 to December 2005, the average phosphorus concentrations in runoff are 0.452 and 0.082 mg/L for improved and unimproved pastures, respectively.

The average base load from the ranch is 1.87 mtons per year. Scenario One included a water detention depth of 0.25 inch for unimproved and woodland pastures. An estimated 4% load reduction could be obtained. Scenario Two increased water detention depth of 0.5 inch to these two pastures and an estimated 7% load reduction would be achieved. Scenario Three changed water detention depth to 0.25 inch for all three pasture types and an estimated 16% load reduction would be achieved. An estimated 19% load reduction would be achieved with a detention depth of 0.25 inch for beef pastures, 0.5 inch for unimproved and woodland pastures under Scenario Four. It is recommended that a detention depth ranging from 0.25 to 0.5 inch should be used to achieve a ranch level phosphorus load reduction of 20%.

The watershed phosphorus control program uses a multifaceted approach to reduce phosphorus loads through continued implementation of existing regulations and BMPs, development and implementation of improved BMPs, improvement and restoration of the hydrologic functions of the natural and managed systems, and use of alternative technologies for nutrient reduction. Numerous activities and projects in the watershed are currently being planned and implemented. These activities include regional construction projects, on-site BMP implementation, restoration of isolated wetlands, and the continuation of research and monitoring to ensure the projects have been designed and implemented successfully. The results of this study could be used to guide water management alternative evaluations on other beef cattle ranches in the Lake Okeechobee watershed.

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