Effectiveness of Ranchland Water Retention BMP with Regards to Nutrient Discharges in the Northern Everglades

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Contents

Executive Summary

A ranchland water retention (WR) BMP was evaluated by implementing it at two sites (Site 1 and 2) within a cow-calf ranch located in the south Florida. The ranchland sites consisted of pastures and wetland areas drained by a network of ditches. The WR BMP implemented at each sites used a flashboard riser structure installed at a ditch that drained the site. Boards were added to heights of 1.10 and 0.52 m above the ditch bottom at Site 1 and Site 2, respectively. Pre and post design was used to evaluate the WR BMP at the two sites by comparing flow and water quality data for water years (June-May) under the pre-BMP and post-BMP conditions. At Site 1, three years of pre-BMP data (2005, 2006, and 2012) and five years of post-BMP data (2007, 2008, 2009, 2010, and 2011), were collected to evaluate the effects of the BMP on flow and total nitrogen (TN) and total phosphorous (TP) concentrations and loads. For Site 2, respective data were collected for two pre-BMP periods (2005 and 2012) and six post-BMP periods (2006, 2007, 2008, 2009, 2010, and 2011).

For Site 1, the BMP periods were divided into three types of water years (June 1 – May 31) depending on rainfall: wet (2005 and 2008), dry (2006, 2007, 2010, and 2011), and average (2009 and 2012). Numerical comparisons showed a general decrease in runoff and runoff coefficient for wet, dry, and average water years. Antecedent unsaturated and saturated zone storages and their effect on available water storage and/or the efficacy of the installed BMP were the likely reasons. Mixed results were observed for total nitrogen (TN) and total phosphorus (TP) flow weighted concentrations and rainfall normalized loads. For wet years, when reduction in flows are of special importance for the Northern Everglades region, TP flow weighted concentrations increased by 45% while there was a small (3 to 8%) increase in TP load and rainfall normalized load. The TN flow weighted concentration also showed an increase of 20% while there was a moderate (10 to 15%) decrease in TN load and rainfall normalized TN load. During dry years, runoff as well as TN and TP flow weighted concentrations and rainfall normalized loads decreased. For average rainfall conditions, runoff decreased by 35%, TP load and rainfall normalize load decreased by 46-49%, and TN load and rainfall normalized load decreased by 35-39%. Mixed results for TN and TP are the result of varying hydrological

conditions (e.g., rainfall, available water storage, and inundation area) that existed among the paired pre and post-BMP years.

Since analysis of WR BMP was skewed by dry seasons, dry season data were removed from the analyses. Averages for the average and wet years (termed as "normal" years) were also considered for evaluating the BMP. Averages for the pre- and post-BMP normal years showed 32% decrease in post-BMP runoff and runoff coefficient (runoff/rainfall). The corresponding decrease in TP and TN loads and rainfall normalized loads was 18-25%. Although numerical comparisons of averages for wet and "normal" years showed a general decrease in runoff and nutrient loads during the post-BMP periods, this was not supported by statistical analyses due to large variability in hydrology and water quality data, mainly due to four dry years.

For Site 2, the BMP periods were made up of two types of water years, a wet (2005: pre-BMP and 2008: post-BMP) and average (2012: pre-BMP and 2009: post-BMP) water year. Wet year comparisons showed a general increase (24-30%) in runoff and runoff coefficient during post-BMP years. Wet year TP loads and rainfall normalized loads also increased, by 15 and 25%, respectively, during the post-BMP condition. For average rainfall years (pre-BMP 2 of 2012 and post-BMP 4 of 2009) there was relatively small increase (5 to 10%) in runoff and runoff coefficient. In contrast to flows, all water quality parameters (flow weighted concentrations, loads, and rainfall normalized loads) increased by 30-60% for TN and 36-39% increase in TP. Similar to Site 1, the overall averages for Site 2's hydrologic and nutrient parameters are skewed by the presence of four dry years (2006, 2007, 2010, and 2011) during the eight year monitoring period. Therefore, "normal" year averages were considered instead. Flows increased by 18% and water quality parameters (TN and TP loads and flow weighted concentration) increased by almost 45%. Similar to Site 1, there was statistical significance detected in differences in pre-BMP and post-BMP data (eight years of data) for flow or water quality. This lack of significance was mainly due to large variability in data due to presence of dry conditions in three out of six post-BMP years and no dry conditions during the pre-BMP years.

The WR BMP at Site 1 was also evaluated by using a paired watershed statistical technique by comparing data for a treated watershed (Site 3 which receives flows from Site 1) with control watershed (Site 4) which did not have WR BMP. The paired watershed analyses used all the data

(5 years). Some evidence ($0.05 < p < 0.1$) of a decreased rainfall normalized TP loads and of an increased TN flow weighted concentration was found from the paired watershed analyses.

Based on this study, the following observations can be made:

1. Although water retention on ranchlands using a combination of wetland and pasture as water storage areas has been assumed to be a promising BMP and also a basis for payment for environmental services, data from this project do not provide unequivocal support for the assumed benefit of reduced flows or nutrient loads.

2. The evaluation of WR BMP performed in this study is interim at best. Based on numerical comparisons, results show almost a 30% reduction in flow and 20% reduction in TP loads at one site with a large wetland. At the other site with a smaller wetland and closer to the typical of pastures in the LO basin, the flows and TP loads increased by almost 20% and 45%, respectively.

3. Water retention BMP involves interaction of surface and subsurface water and nutrient processes which when combined with climatic variability, uncertainty in measurements, and unequal number of pre- and post-BMP periods, made it difficult to detect statistically significant changes and/or attribute the changes in flow and nutrient loads to the BMP alone.

4. Use of field-verified hydrologic models that utilizes the available flow and water quality data as well as eddy based ET estimates (largest water flux component) from the two sites can to an extent help increase the confidence in effects of WR on flow. However, evaluating effects on P concentration and loads may not be so easily achievable through the use of models given inherent significant uncertainties in accurately representing P cycling and transport processes.

5. Given the popularity of dispersed storage and associated concepts such as *Water Farming* on agricultural lands and increased potential risk of nutrient loads as a result of flooding agricultural lands, continued monitoring, combined with the statistical analyses of appropriate data (dry, wet, and average) and hydrologic modeling for the two sites is recommended for improved evaluation of WR on ranchlands of the NE basin.

Introduction

The water retention (WR) BMP evaluation component of the cow-calf BMP project was started in 2005 at the Pelaez Ranch located within the Lake Okeechobee basin. Two sites (Site 1 and 2, Figure 1) located within this beef cattle ranch were selected for quantifying the effects of WR BMP effects on runoff (surface flow volume) and total nitrogen (TN), and total phosphorous (TP) concentrations and loads. Both ranchland sites contain a ditch that was used to drain two pastures containing a wetland. The total areas of ranchland Site 1 and 2 (wetland plus upland areas) are 80.1 and 24.4 ha, respectively.

The WR BMP was implemented at each ranchland site (hereafter, site) by installing a flashboard riser structure at a ditch that drained the wetland-upland areas within the pasture. To achieve water retention, spillage levels at the two sites were raised by 1.10 m and 0.52 m above the ditch bottom at Sites1 and 2, respectively. The baseline condition (hereafter, pre-BMP) represented drainage at the ditch bottom level that existed at the sites prior to the project.

The rise in spillage from ditch bottom at the two sites was based on the acceptability and comfort level of the rancher cooperator. Flow and water quality data collected at the two sites included three pre-BMP periods and five post-BMP periods for Site 1; and two pre-BMP periods and six post-BMP periods for Site 2 (Table 1).

Table 1. Pre- and post-BMP periods for water retention BMP project at Sites 1 and 2.

Site 1	Site 2	Period
pre-BMP1	pre-BMP1	June, 2005-May, 2006
pre-BMP2	post-BMP1	June, 2006-May, 2007
post-BMP1	post-BMP2	June, 2007-May, 2008
post-BMP2	post-BMP3	June, 2008-May, 2009
post-BMP3	post-BMP4	June, 2009-May, 2010
post-BMP4	post-BMP5	June, 2010-May, 2011
post-BMP5	post-BMP6	June, 2011-May, 2012
pre-BMP3	pre-BMP2	June, 2012-May, 2013

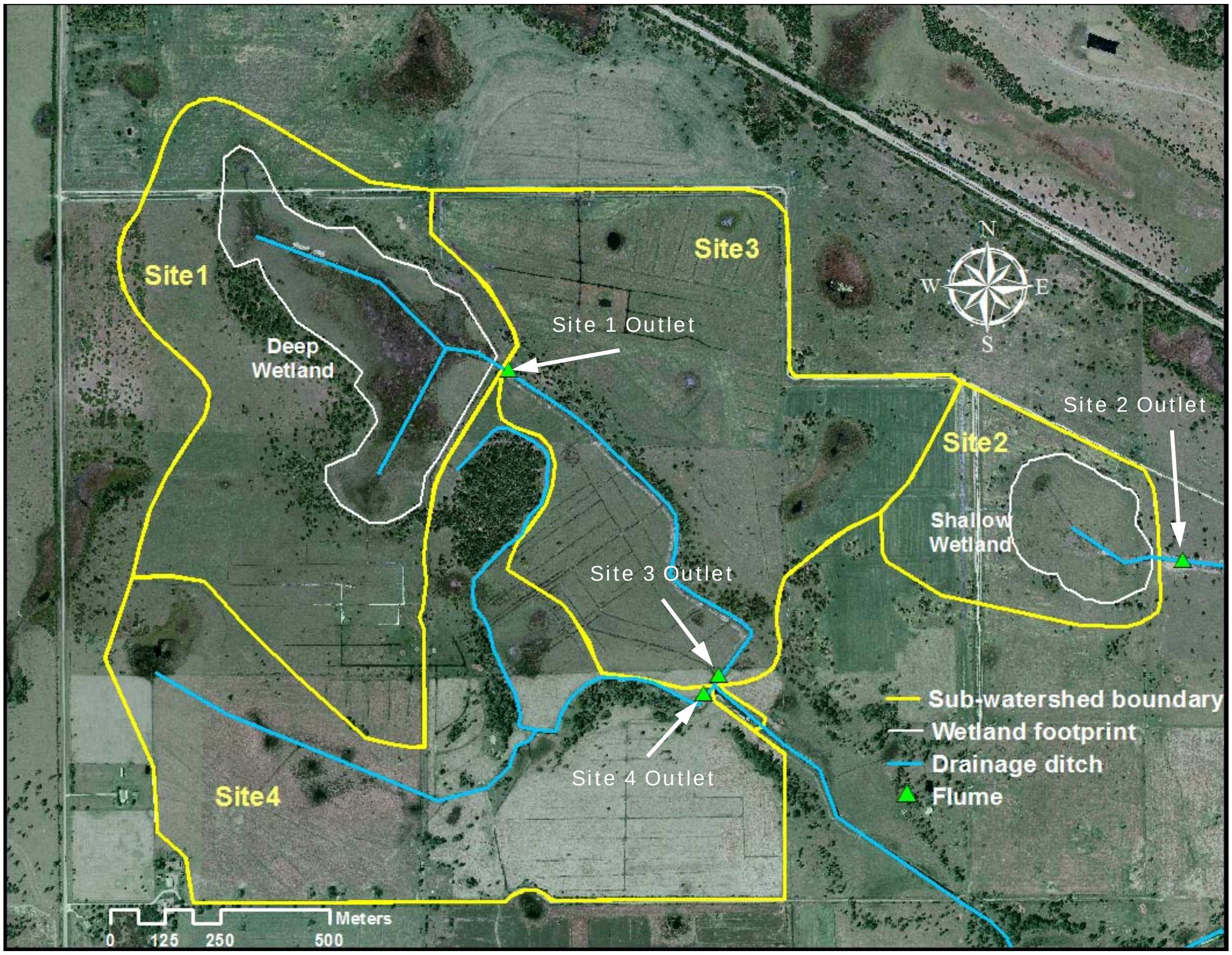


Figure 1. Locations of Sites 1 and 2 within the beef cattle ranch. Yellow lines denote drainage sub-basins for the four separate ranchland sites (wetlands plus upland areas) within the ranch.

Site 1 contains two main drainage ditches that drain the pasture with a large wetland (Figure 1). Drainage from two ditch segments (669 and 332 m in length) converges and flows together for 147 m before exiting Site 1. Soil types at Site1 are Myakka fine sand (7.5 ha), Immokalee fine sand (40.1 ha), Basinger fine sand (21.5 ha), Floridana sand (6.0 ha), and Valkaria sand (5.0 ha). Site 2 contains a single drainage ditch that flows in a south-easterly direction (Figure 1) through the wetland. The soil series within Site 2 include Basinger (13.4 ha) and Immokalee fine sands (11.0 ha). The ranchland areas include improved pasture, wetlands, and patches of pine-palmetto ecosystem. The two major forage types at the two sites are Bahia (*Paspalum notatum)* and Floralta (*Hemarthria altissima*). Site 3 and 4 are located between Site 1 and 2 (Figure 1). Site 3 has a single ditch that originates at the outlet for Site 1and runs in a south-easterly direction. The ditch for Site 3 has embankments that are 10 -15 feet above the ditch invert in some places. Gaps are located along the embankment that allows cattle to cross through the ditch and surface flows to enter the ditch from the surrounding pasture. The pasture has a network of secondary ditches that help drain the pasture. Site 3 has several small wetlands located throughout the pasture that are not directly drained by a primary ditch. Site 4 is located to the south of Site 1 and 3, and has two primary ditches, one that runs in a southerly direction and then joins the other that runs in an easterly direction until it reaches the site outlet (Figure 1). Both ditches help drain the pasture for Site 4 that is spotted with several small wetlands.

Materials and Methods

The WR was implemented by installing a flashboard riser structure at the end of the drainage ditch at each site (Figure 2). The flashboard riser allows water to flow only when the water level exceeds the top elevation of the flashboards. The bottom elevations of Site 1 and 2 were 7.95 and 8.97 m AMSL, respectively (NAVD 88). The elevations of the flashboard riser boards (spillage level) at Sites 1 and 2 were at 9.06 and 9.47 m AMSL, respectively.

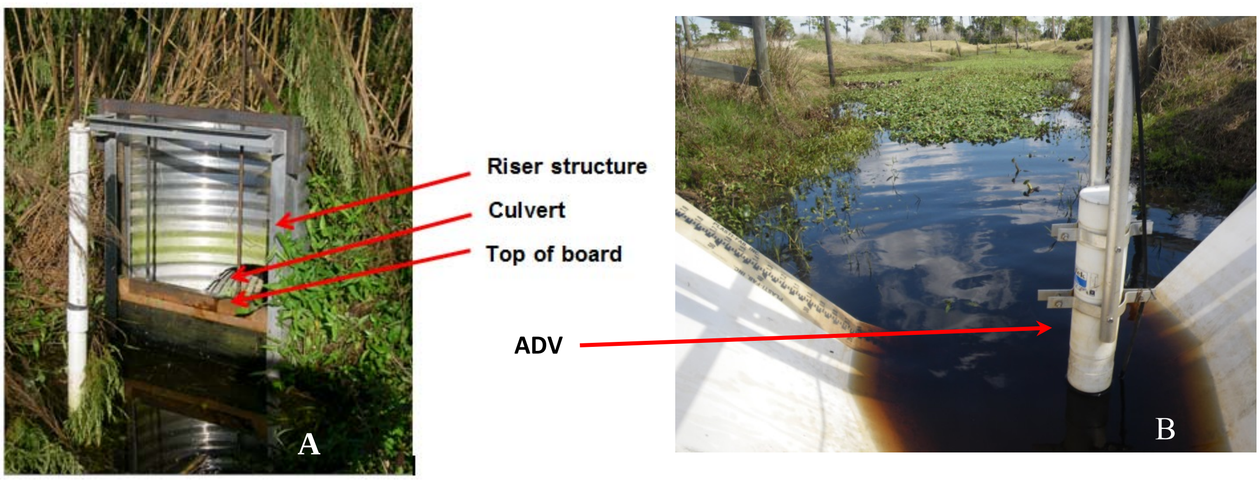


Figure 2. A) Ranchland water retention BMP (flashboard riser with boards) installed at site 2. B) Flume with Acoustic Doppler Velocimeter (ADV) installed.

Trapezoidal flumes fitted with pressure transducers were installed downstream of the flashboard riser and culvert structure to measure flow. In July, 2008 an Acoustic Doppler Velocimeter (ADV) was installed in the flume to improve the accuracy of flow measurement. Wetland stages for each site were monitored using pressure transducers. Auto-samplers were installed at the flume sites to collect water samples that were analyzed for TP, Total Kjeldahl Nitrogen (TKN), ammonia (NH_3-N), and nitrate (NO_3-N). Total N was estimated as TKN + NO_3-N.

Total phosphorus (TP) and nitrogen (TN) concentrations and loads measured in runoff are influenced by rainfall. Direct impact of rainfall with nutrient sources on the soil surface can release nutrients through a different process compared with nutrient sources impacted by saturation excess (ponding and runoff). Rainfall during a dry year is likely to break up and dissolve nutrient sources (e.g., cow manure) slowly by direct contact of rain drops. The dissolved nutrients will not likely travel far from the source since a dry soil matrix will not facilitate nutrient transport. Instead, available nutrients are likely to be taken up by surrounding microorganisms and vegetation. Rainfall events during a wet year are likely to break up and dissolved nutrient sources by a combination of rainfall impact and the effect of saturation (ponding and runoff). Nutrient sources (e.g., cow manure) would be mechanically broken down by the impact of rain drops and eventually dissolve due to frequent or intense rainstorm events. Dissolved nutrients can be leached or transported in runoff; while particulate nutrients will be transported in runoff. Therefore, to better evaluate the BMP (to the extent possible) comparisons of pre- and post-BMP nutrient concentrations and loads were done by the rainfall conditions during specific years by considering wet, dry and average years.

Flow volumes for Site 1 and 2 were estimated using multivariate non-linear regression models as a function of stage for flumes at all sites for the 2005-2007 period. Regression models were developed with the aid of ADV data collected during 2008 to 2011. Evaluation of the WR BMP at the two ranchland sites were based on numerical and statistical comparisons of TP and TN concentrations and loads for pre- and post-BMP periods. Statistical analyses were conducted using Proc GLIMMIX in SAS v9.2 (SAS Institute, Cary, NC) with heterogeneous variance models to compare TP and TN loads and concentrations for the pre- and post-BMP periods. A second statistical technique (paired watershed analyses) was applied where data from controlled and treated watersheds are compared using the Before-After Control-Impact (BACI; Smith 2002) design. The BACI design was used for data from Sites 3 and 4. Site 3 was considered the "treated" site because it receives flows from Site 1. The rest of Site 3's drainage area did not include any intervention to retain water. Site 4, which includes the neighboring watershed (pasture) located south of Site 3 was used as "control" since there was no intervention to retain water.

Results and Discussions

Site 1

Water Dynamics

Annual rainfall measured during the monitoring period, fluctuated around the average annual rainfall for the region (1290 mm, Weatherbase, 2014). Years with above average rainfall were mostly affected by tropical storm systems. During the three pre-BMP periods for Site 1, there were three tropical systems, i.e., hurricane Wilma, and tropical storms Debby and Isaac. Hurricane Wilma impacted the site during 2005 (pre-BMP1) and resulted in 211 mm rainfall which accounted for 14% of the annual total (1474 mm, Table 2), the annual total being 14 % above the regional average. Tropical storms Debby and Isaac impacted the project site during 2012 (pre-BMP3) and released an amount of rainfall that is 27 % of the annual total (1201 mm, Table 2), the annual total being 7 % below the regional average. The total rainfall (906 mm) during the pre-BMP3 period (2006) was 30 % below the regional average and indicates that the ranch experienced drought conditions during 2006.

During the five years of post-BMP period, the site was impacted by a tropical system during 2008, T.S. Fay, which released 250 mm in 24-hr period and a total of 329 mm over seven days; the seven day total being 23 % of the annual total (1405 mm, Table 2), the annual total being 9 % above the annual average. The total rainfall (1277 mm) during the post-BMP3 period is comparable to that of the post-BMP2 period. Although post-BMP 2 and 3 rainfall totals are comparable, the total for post-BMP3 is within 1 % of the regional average, and over half of this total was release during the dry season showing significant differences in seasonal rainfall. Furthermore, the dry season total (662 mm) for the post-BMP3 period was 56 % higher than the dry season regional average (424 mm). The annual rainfall totals for the remaining post-BMP period (post-BMP1, 801 mm; post-BMP4, 822 mm; post-BMP5, 1084 mm) were all below the regional average and indicates that these years were drier than average (Table 2).

Overall, the average rainfall for the pre- and post-BMP periods is comparable, with the pre-BMP period being 11% greater than post-BMP-period. Therefore, the data collected for pre- and post-BMP periods can be used to evaluate the effects of the BMP for the Site 1. Trend for the average runoff totals for the pre-and post-BMP periods were similar to rainfall trend (Table 2); with differences in rainfall (115 mm) and runoff (129 mm) being similar. Post-BMP average runoff reduced by 51% compared to the pre-BMP period. Similar reductions were also observed for the post-BMP average runoff coefficient (0.1) compared to the pre-BMP period (0.2) (Table 2). Although flow at Site 1 reduced during the post-BMP period, this is mainly due to below average rainfall for the three (2007, 2010, 2011) out of five (2007 to 2011) post-BMP periods (Table 2). Next, we compared pre and post-BMP periods with similar rainfall to better evaluate the BMP effects. The years were categorized into average, wet, and dry years.

Based on rainfall, pre-BMP1 (1474 mm) and post-BMP2 (1405 mm) are comparable since they have similar rainfall totals. Also, both years experienced a large tropical storm event that resulted in similar amounts of rainfall (193 mm and 250 mm, respectively). Pre-BMP1 and post-BMP2 are considered wet years since their totals are above (9 -14 %) the regional average (1290 mm). Although post-BMP2 rainfall is only 5 % lower than pre-BMP 1, the corresponding runoff volumes and coefficient during the post-BMP2 are much lower (29 and 26% respectively, Table 2). Runoff totals are relatively high for these pre-BMP1 and post-BMP2 periods (Table 2) because of the frequency and/or the intensity of rainfall, which filled the water storage capacity within the drainage area. The flow reduction (29 %) for post-BMP2 (compared to pre-BMP1) runoff is likely the result of the surface storage created by riser board structures that were installed to hold back flows from this site.

Table 2 shows that the pre-BMP2 period can be compared with the post-BMP4 period since both periods have similar rainfall totals (906 and 802mm, respectively) and can be classified as dry years since their rainfall totals are 30 to 36% below the regional average. Below average rainfall resulted in relatively low runoff totals for these two periods. Limited rainfall for the ranchland area indicates higher available storage for the ranchland compared to years with average rainfall. Therefore, most of the rainfall surplus (after evapotranspiration) during the dry years will contribute to water table recharge. Although a 9 % reduction is observed for the annual rainfall for post-BMP4 compared with pre-BMP2, a disproportionate reduction is observed in runoff (25

%), and to a lesser extent in runoff coefficient (13 %, Table 2). The percent reduction in rainfall for post-BMP4 (compared to pre-BMP2) is less than half the reduction in runoff. Since rainfall cannot account for total reduction seen in runoff, the BMP likely had an impact on runoff by holding back water in the ranchland.

Pre-BMP3 and post-BMP3 are comparable years since both have similar rainfall totals (1200 and 1277 mm, respectively, Table 2) which are close to the regional average. Although rainfall totals were close on annual basis, distributions of rainfall for the wet (June – Oct) and dry (Nov-May) seasons were different. Pre-BMP3 had a wetter (927 mm) than average wet season (864 mm) and a drier (274 mm) than average dry season (424 mm). In contrast, post-BMP3 experienced a drier wet season (615 mm) and wetter dry season (662 mm). For pre-BMP3, the majority of runoff occurred during the wet season when the available water storage was limited; and little runoff occurred during the dry season when available water storage was high. This seasonality in flows is typical of south Florida. For post-BMP3, runoff was unusually high since there was sufficient rainfall throughout the water year (June-May) to maintain a water table relatively close to the surface which resulted in frequent runoff. Although the post-BMP3 annual rainfall total is 6 % less than that of pre-BMP3, the annual runoff total and runoff coefficient for post-BMP3 is 35 % and 38 % higher, respectively than that of pre-BMP3. This disproportionate reduction in runoff is likely due to low available water storage (surface and subsurface) during the post-BMP3 period.

The data for wet and average years were averaged and compared to evaluate the WR BMP effects. This comparison was termed as "normal" average considering that the need to reduce the excessive flows and nutrient loads is critical for these conditions. The normal years were pre-BMP 2005 and 2012, and post-BMP 2008 and 2009. For the "normal" years, pre- and post-BMP rainfall averages were similar (1338 and 1341 mm, respectively). However, post-BMP runoff (35 %) and runoff coefficient (33 %) have noticeably decreased compared to that of pre-BMP averages indicating effectiveness of the WR BMP in reducing the surface flows.

In summary, numerical values of runoff for average and wet years indicate a reduction in surface flows due to the WR BMP. However, the efficacy of WR will be diminished for wet years when the available water storage for the ranchland is depleted, especially with successive storms.

Table 2. Rainfall and runoff depths for pre- and post-BMP periods (June-May) at Site 1.

Period	Year	Rainfall (mm)*	Runoff depth (mm)	Runoff Coefficient
pre-BMP1	2005	1474	392.48	0.27
pre-BMP2	2006	906	73.08	0.08
pre-BMP3	2012	1201	292.51	0.24
Pre-Average		**1193**	**253**	**0.20**
Pre-Average Normal		**1338**	**342**	**0.26**
post-BMP1	2007	801	16.36	0.02
post-BMP2	2008	1405	277.39	0.20
post-BMP3	2009	1277	189.32	0.15
post-BMP4	2010	822	54.49	0.07
post-BMP5	2011	1079	84.17	0.08
Post-Average		**1077**	**124**	**0.10**
Post-Average Normal		**1341**	**233**	**0.18**

*Regional average rainfall = 1290 mm

Phosphorus and Nitrogen Concentration and Load

Comparison of both pre-BMP1 and post-BMP2 periods, both wet years, showed increases in mean concentration, flow weighted concentration, load, and rainfall normalized loads for TP by 82, 45, and 8 %, respectively during the post-BMP 2 period (compared to pre-BMP1; Tables 3 and 4). The pre-BMP1 TP mean concentration (0.61 mg/L) was lowest of the monitoring period and was likely due to a dilution effect from the highest runoff and rainfall observed for the monitoring period. Post-BMP2 mean concentration and flow-weighted concentrations for TN also increased by 134 and 20 %, respectively; but load and rainfall normalized load showed a decrease of 15 and 10 %, respectively, compared with pre-BMP1 (Table 3). The post-BMP2 mean concentration (8.37 mg/L) for TN was highest for the monitoring period and was likely due to the high levels of organic and mineralized N that was delivered by surface flows to the ditch outlet during T.S. Fay.

Pre-BMP2 and post-BMP4 were dry years. Post-BMP4 mean concentration, flow weighted concentration, load, and rainfall normalized load for TP decreased by 8, 66, 74, and 71 %, respectively, compared with pre-BMP2 (Tables 3 and 4). The dry conditions experienced during pre-BMP2 and post-BMP4 resulted in the lower mineralization of P from soil, which can be seen in the relatively low mean (0.72 - 0.78 mg/L) and flow weighted concentrations (0.22 – 0.64 mg/L). The reduction in TP concentration for post-BMP4 is also reflected in the TP load and rainfall normalized load. Post-BMP2 mean concentration and flow-weighted concentrations for TN increased by 262 %, but flow weighted concentration, load and rainfall normalized load decreased by 28, 47 and 41 %, respectively, compared with pre-BMP2 (Tables 3 and 4). An increase in the post-BMP4 TN concentration is the result of the unusually low TN concentration (1.6 mg/L) observed for pre-BMP2; the lowest for the entire monitoring period. Such a low concentration is likely the result of limited delivery of TN nutrients to the ditch due to low mineralization of organic N as well as N leaching (organic and inorganic N) under dry conditions.

Pre-BMP3 and post-BMP3 were average rainfall years. Post-BMP3 mean concentration, flow weighted concentration, load, and rainfall normalized load of TP all decreased by 26, 17, 46 and 49 %, respectively, compared with pre-BMP3 (Tables 3 and 4). The flow weighted concentration for post-BMP3 TN almost remained unchanged when compared with that of pre-BMP3. Otherwise, the TN mean concentration, load, and rainfall normalized load all decreased by 5, 35, and 39 %, respectively. These results are similar to flow which showed a decrease for these two year pairs.

In general, year-to-year comparisons used to evaluate the BMP revealed mixed results. However, the overall average for pre- and post-BMP periods show an increase in TP and TN mean (22 and 50 %, respectively) and flow weighted concentrations (5 and 7 %, respectively); and a decrease in post-BMP loads (46.4 and 46.3 %, respectively) and rainfall normalized loads (46 and 45 %, respectively) for TP and TN when compared to that of the pre-BMP period (Table 3 and 4). The comparison of overall average is skewed by the presence of two dry years during the post-BMP period compared to one dry year during the pre-BMP period.

For normal years (Table 3 and 4), the overall average for pre- and post-BMP periods show a relatively small increase in TP mean concentration (8%) and flow weighted concentrations (14%) and a decrease in TP load by 18%. The TN mean and flow weighted concentrations increased by 45 and 10% respectively. However, the TN load which is the most important parameter with regards to contributions of ranchlands to the lake, reduced by 24%. Statistical analyses were conducted to determine if the observed reductions by the BMP are significant.

Results from the statistical analyses performed by the Proc GLIMMIX procedure showed no evidence of a difference (α = 0.1) between pre- and post-BMP averages for annual runoff depth, and runoff coefficient; annual TP and TN mean concentrations, flow weighted concentrations, loads and rainfall normalized loads for Site 1 using monthly data. The absence of any significant differences is likely the result of a large variability in monthly values used to conduct statistical analyses. Additional data combined with separate analyses for the average and wet conditions may help increase the chances of finding statistically significant differences. Numerical comparisons at Site 1 support the positive effect of WR BMP on flows and TP loads.

Table 3. Total Phosphorus (TP) and Nitrogen (TN) mean, and flow-weighted concentrations for pre- and post-BMP periods at Site 1.

BMP-Period	Year	Mean Total Nitrogen Concentration (mg/L)	Mean Total Phosphorus Concentration (mg/L)	Total Nitrogen Flow Weighted Concentration (mg/L)	Total Phosphorus Flow Weighted Concentration (mg/L)
Pre-BMP1	2005	3.57	0.61	2.88	0.75
Pre-BMP2	2006	1.60	0.78	2.02	0.64
Pre-BMP3	2012	6.30	1.29	3.16	0.78
Pre-Average		**3.82**	**0.89**	**2.69**	**0.72**
Pre-Average (wet, average)		**4.94**	**0.95**	**3.02**	**0.77**
Post-BMP1	2007	3.40	1.20	2.94	1.25
Post-BMP2	2008	8.37	1.11	3.47	1.09
Post-BMP3	2009	5.96	0.95	3.17	0.65
Post-BMP4	2010	5.79	0.72	1.45	0.22
Post-BMP5	2011	5.23	1.49	3.30	0.59
Post-Average		**5.75**	**1.09**	**2.87**	**0.76**
Post-Average (wet, average)		**7.17**	**1.03**	**3.32**	**0.87**

Table 4. Total Phosphorus (TP) and Nitrogen (TN) loads and rainfall normalized loads for pre- and post-BMP periods at Site 1.

BMP-Period	Year	TN Load (kg/ha)	TP Load (kg/ha)	TN Load_Rainfall Normalized (kg/ha/cm)	TP Load_Rainfall Normalized (kg/ha/cm)
Pre-BMP1	2005	11.29	2.95	0.08	0.020
Pre-BMP2	2006	1.48	0.47	0.02	0.005
Pre-BMP3	2012	9.23	2.27	0.08	0.019
Pre-Average		**7.33**	**1.90**	**0.057**	**0.015**
Pre-Average (wet, average)		**10.26**	**2.61**	**0.08**	**0.019**
Post-BMP1	2007	0.48	0.20	0.01	0.003
Post-BMP2	2008	9.64	3.03	0.07	0.022
Post-BMP3	2009	6.00	1.23	0.05	0.010
Post-BMP4	2010	0.79	0.12	0.01	0.001
Post-BMP5	2011	2.77	0.50	0.03	0.005
Post-Average		**3.94**	**1.02**	**0.031**	**0.008**
Post-Average (wet, average)		**7.82**	**2.13**	**0.058**	**0.016**

Site 2

Water Dynamics

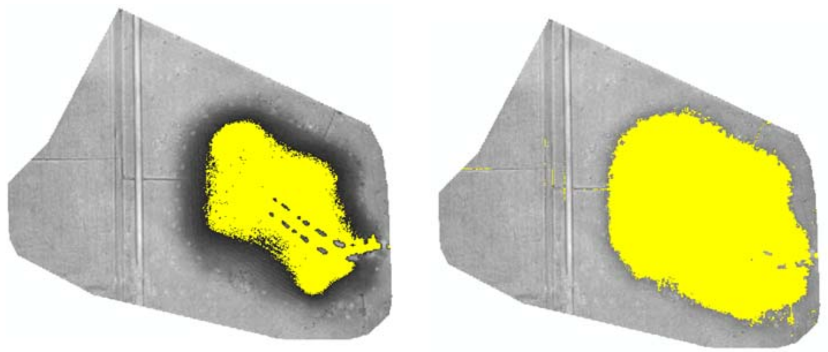
Similar to Site1, data analyses for Site 2 was done based on rainfall conditions. However, here was no pre-BMP year with dry condition, hence the comparisons were conducted for the average and wet conditions. Wet year comparisons were done for the pre-BMP 1 and post-BMP 3 pair while average year pair was pre-BMP2 and post-BMP4 (Table 5).

For the wet pairs, despite a small decrease (5 %) in post-BMP 3 (wet) rainfall (1405 mm), compared with pre-BMP1 (1474 mm, wet), both runoff as well as runoff coefficient increased by 24 and 30%. This is opposite of what was observed at Site 1 where there was a decrease in flows for wet years. For the average rainfall pairs, pre-BMP2 and post-BMP4, rainfall during the post-BMP 4 at Site 2 was 6% higher than pre-BMP2 and the corresponding increase in runoff was similar (10 %). There seems to be a small to significant (24-30%) increase in flows during the post-BMP periods, a likely effect of the WR BMP due to reduced available storage for large rainfall events. Consider for example, the inundation area of the wetland after an extreme rainfall event during pre- and post-BMP periods. The inundation area for the post-BMP3 (16 ac) was 500 % greater than that for the pre-BMP1 period (3 ac). Figure 4 shows the maximum daily inundated areas observed for the pre-BMP1 and post-BMP3 periods. The inundated area observed a day after Hurricane Wilma (October 24, 2005; rainfall = 192 mm) during the pre-BMP1 period was lower than the maximum inundation observed after the Tropical Storm Fay (August 18-19, 2008; rainfall = 253 mm) during the post-BMP periods. A larger inundation area indicates lower available storage for subsequent rainfall events leading to greater runoff depths for post-BMP3 period.

Although overall, averages for the pre- and post-BMP periods show that a decrease in rainfall (22 %) for the post-BMP period (compared with the pre-BMP period) has a corresponding decrease in runoff depth (49 %) and runoff coefficient (43 %), this inference is skewed by four dry years 2006, 2007, 2010 and 2011 during the post-BMP periods (post-BMP1, post-BMP2, post-BMP5, and post-BMP6, respectively) which makes this comparison is inappropriate for evaluating the WR BMP (Table 5). When dry years are removed from the analyses, the post-BMP rainfall (1341 mm) not only moves closer to regional average (1290 mm) but also almost same as for the pre-BMP rainfall (1338 mm). Although there was negligible difference (3 mm) in average rainfall totals of "normal" pre and post post-BMP periods, the post-BMP runoff (volume and rainfall normalized volume) increased by almost 20% indicating an increase in runoff due to WR BMP (Table 5).

Table 5. Rainfall and runoff depths for pre- and post-BMP periods at Site 2.

Period	Year	Rainfall (mm)	Runoff depth (mm)	Runoff Coefficient
pre-BMP1	2005	1474	342	0.23
pre-BMP2	2012	1201	266	0.22
Pre-Average		**1338**	**304**	**0.23**
post-BMP1	2006	906	19	0.02
post-BMP2	2007	801	19	0.02
post-BMP3	2008	1405	424	0.30
post-BMP4	2009	1277	293	0.23
post-BMP5	2010	822	83	0.10
post-BMP6	2011	1084	95	0.09
Post-Average		**1049**	**155**	**0.13**
Post-Average (wet, average)		**1341**	**359**	**0.27**



Pre-BMP1 maximum inundation (24 October, 2005)

Post-BMP3 maximum inundation (20 August, 2008)

Figure 3. Maximum inundations during pre-BMP1 and post-BMP3 periods at Site 2.

Phosphorus and Nitrogen Concentration and Load

Similar to the analyses for water dynamics, nutrient parameters are compared for years with similar rainfall (wet, dry, and average). For wet conditions (pre-BMP1, 2005; post-BMP 3, 2008), post-BMP mean concentrations increased for TP and TN (24 and 34 %, respectively), but flow weighted concentrations decreased by 7 and 19 %, respectively (Table 6). Post-BMP3 TP loads and rainfall normalized loads increased by 15 and 25 %, respectively, compared with pre-BMP1values (Table 7). There was almost no change in post-BMP3 TN loads and rainfall normalized loads. The observed increases in mean concentration, loads, and rainfall normalized loads of TP during post-BMP3 period (Table 6 and 7) are consistent with corresponding increases in flows and were likely due to increased inundation from holding water behind the riser board structure which increased the surface water connectivity of the pasture with the wetland. This increased connectivity may have caused surface transport being the preferred mode of movement of particulate as well as dissolved P. In the case of low inundation under baseline conditions, particulate P will remain in localized areas while the dissolved P will move vertically through the soil before returning through drainage ditch in the wetland. Subsurface movement of P through the soil before coming out through the drainage ditch to the Site 2 outlet will involve much longer time which in turn will also result in reduced dissolved P concentration due to its sorption while it travels through the soil profile. A similar increase in TN being absent is likely from extensive denitrification due to saturated conditions especially during the wet season (June-October). Particulate N is likely the dominant form of N delivered to the drainage ditch during periods of extensive pasture inundation.

During the average rainfall conditions of pre-BMP 2 (2012) and post-BMP 4 (2009), flows were estimated with ADV which reduces the uncertainty in TN and TP loads due to differences in measurement errors between flume-based flow equation and ADV based flows. All TP parameters showed an increase in post-BMP4 period (compared with pre-BMP2); TP mean concentrations (44%), flow weighted concentrations (85 %), loads (102 %), and rainfall normalized loads (67%) increased (Tables 6 and 7). Corresponding increases in TN were 20, 104, 125, and 100% for the mean and flow weighted concentrations and loads and rainfall normalized loads. While the post-BMP4 rainfall was 6% higher than pre-BMP2, which could explain part of the increase in TP and TN parameters, the disproportionate large increases in these parameters is a strong indication of un-intended adverse impacts of WR BMP at Site 2. Increases in nutrient concentrations and loads were likely due to increased surface connectivity which made surface flow the preferred mode of transport of N and P and lower surface storage volume compared to Site 1.

Overall averages for the post-BMP period (compared to the pre-BMP period) increased for TP and TN mean concentrations (30 and 19%, respectively) and flow weighted mean concentrations (36 and 60%, respectively), but decreased for loads (39 and 37%, respectively) and rainfall normalized loads (38 and 33 %, respectively). However, averages for the post-BMP period are skewed by the presence of three dry years (2006, 2007 and 2010) and are not comparable to averages for the pre-BMP period. When dry years were removed from the analyses to consider "normal" years, the post-BMP (compared the pre-BMP period) mean and flow weighted TP concentrations showed an increase of 34 and 31 %, respectively. Both TP loads and normalized loads also increased by approximately 45%. The corresponding increases in TN mean and flow weighted concentration were 28 and 34% while both TN loads and normalized loads increased by 46% during the post-BMP periods compared to pre-BMP periods (Tables 6 and 7). These results show that during average to wet years when the excessive flows to the Lake Okeechobee are most damaging, there is a risk of increased flows as well as loads of TP and TN from WR BMP implemented at ranches similar to Site 2.

Results from the statistical analyses performed by the Proc GLIMMIX procedure showed no evidence of a differences (α = 0.1) between pre- and post-BMP averages for annual TP and TN mean concentrations, flow weighted concentrations, loads and rainfall normalized loads for Site 2. Similar to Site 1, the absence of any significant differences is likely the result of a large variance in monthly values used to analyze annual values.

Table 6. Total Phosphorus (TP) and Nitrogen (TN) mean, and flow-weighted concentrations for pre- and post-BMP periods at Site 2.

BMP	Year	Mean TN Concentration (mg/L)	Mean TP Concentration (mg/L)	TN Flow Weighted Concentration (mg/L)	TP Flow Weighted Concentration (mg/L)
Pre-BMP1	2005	3.56	1.05	2.95	1.76
Pre-BMP2	2012	2.89	1.11	2.18	1.26
Pre-Average		**3.23**	**1.08**	**2.56**	**1.51**
Post-BMP1	2006	2.13	1.00	1.55	1.10
Post-BMP2	2007	6.53	2.67	11.43	4.71
Post-BMP3	2008	4.76	1.30	2.40	1.64
Post-BMP4	2009	3.47	1.60	4.45	2.33
Post-BMP5	2010	2.55	0.87	2.40	1.20
Post-BMP6	2011	3.66	1.00	2.34	1.33
Post-Average		**3.85**	**1.41**	**4.10**	**2.05**
Post-Average Normal		**4.12**	**1.45**	**3.43**	**1.99**

Table 7. Total Phosphorus (TP) and Nitrogen (TN) loads for pre- and post-BMP periods at Site 2.

BMP	Year	TN Load (kg/ha)	TP Load (kg/ha)	TN Load Rainfall Normalized (kg/ha/cm)	TP Load Rainfall Normalized (kg/ha/cm)
Pre-BMP1	2005	10.08	6.03	0.07	0.04
Pre-BMP2	2012	5.80	3.37	0.05	0.03
Pre-Average		**7.94**	**4.70**	**0.06**	**0.03**
Post-BMP1	2006	0.30	0.21	0.00	0.00
Post-BMP2	2007	2.14	0.88	0.03	0.01
Post-BMP3	2008	10.18	6.94	0.07	0.05
Post-BMP4	2009	13.04	6.81	0.10	0.05
Post-BMP5	2010	1.98	0.99	0.02	0.01
Post-BMP6	2011	2.24	1.27	0.02	0.01
Post-Average		**4.98**	**2.85**	**0.04**	**0.02**
Post-Average Normal		**11.61**	**6.88**	**0.09**	**0.05**

BACI Analysis

The paired watershed technique was applied to the data for the treated (Site 3) and control (Site 4) sites (Figure 1). Site 3 had a BMP implemented during years 2007 to 2011 of the monitoring period in the upstream part of the watershed (Site 1) while Site 4 had no BMPs. The BACI analyses were performed using an additive model that was applied to the GLIMMIX procedure in SAS v9.2 (SAS Institute, Cary, NC). Eight years (2005-2012) of monthly TP and TN mean concentrations, flow weighted concentrations, loads, and rainfall normalized loads data were used in the analyses.

Results of the analyses showed that there is some evidence ($p < 0.0843$) of an increase in TN flow weighted concentrations. There was no evidence of any change for the remaining nutrient parameters. It should be noted that BACI analyses is also to some extent affected by the large variability in the data, especially due to inclusion of three dry years, one during the pre-BMP years (pre-BMP2) and two during post-BMP years (post-BMP 1 and 4).

Conclusions

Based on this study, the following observations can be made:

6. Although water retention on ranchlands using a combination of wetland and pasture as water storage areas has been assumed to be a promising BMP and also a basis for payment for environmental services, data from this project do not necessarily support these assumptions regarding reduced flows or nutrient loads.

7. Water retention BMP involves interaction of surface and subsurface water and nutrient processes which when combined with climatic variability, makes it difficult to attribute the observed changes in water and P dynamics to WR BMP alone.

8. Long-term data comprising multiple years of pre- and post-BMP periods was collected to detect statistically significant changes due to WR BMP implementation. Although eight years of monitoring data was used to quantify WR BMP effects, the nature of the project combined with the unequal number of pre- and post-BMP periods and large climatic variability (2 wet years, 4 dry years, and 2 average years) combined with uncertainty in flow and load estimates made it difficult to draw conclusions on the BMP effectiveness.

9. The evaluation of WR BMP performed in this study is interim at best. Based on numerical comparisons, results show almost a 30% reduction in flow and 20% reduction in TP loads at one site with a large wetland. At the other site with smaller wetland and closer to the typical of pastures in the LO basin, the flows and TP loads increased by almost 20% and 45%.

10. Use of field-verified hydrologic models that utilizes the available flow and water quality data as well as eddy based ET estimates (largest water flux component) from the two sites can to an extent help increase the confidence in effects of WR on flow. However, evaluating effects on P concentration and loads may not be so easily achievable through the use of models given inherent significant uncertainties in accurately representing P cycling and transport processes.

11. Given the popularity of dispersed storage and associated concepts such as *Water Farming* on agricultural lands and increased potential risk of nutrient loads as a result of flooding agricultural lands, additional monitoring, combined with the statistical analyses of appropriate data (dry, wet, and average) and hydrologic modeling for the two sites is recommended for improved evaluation of WR on ranchlands of the NE basin.

References

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