FIELD APPLICATION OF THE REACTIVE STREAM STABILIZATION STRUCTURE (RS2)

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INTRODUCTION

Phosphorus is recognized as a limiting factor for growth of aquatic organisms in surface water bodies especially in lakes and artificial reservoirs. When excess amounts of nutrients (nitrogen and phosphorus) are discharged into the water body, the biomass of phytoplankton starts to increase and shifts to bloom-forming species that may be toxic. As biomass of algae increases, water transparency decreases with taste, odor and water treatment problems a possibility. Microorganisms decompose algae when they die and it causes dissolved oxygen depletion resulting in the death of living organisms, fish kills, and deterioration of aesthetic value of water bodies. This event is called “eutrophication” which is the main cause of water quality “impairment” in the United States (USEPA, 2002).

Therefore, the control of nutrients is a major issue in water resource projects. Nutrient rich, oxygen-starved dead zones in coastal Louisiana have been of increasing interest to those concerned about Gulf of Mexico fisheries. Studies have indicated that at least $4 billion is lost annually as a result of degradation of freshwater resources in the U.S. (Dodds, et al., 2009), thus focusing the necessity to control nutrients on inland waters as well as coastal resources. For the past five years, we have been working on a concept to enhance standard bank stabilization to reduce concentrations of nutrients in the runoff from adjacent agricultural lands. The enhanced bank stabilization system, referred to as Reactive Stream Stabilization (RS-2), has been tested extensively at the pilot scale and recently at a field scale site in Grenada, Mississippi. The RS2 structure was constructed along the Little Bogue Creek in November, 2008. Alum (aluminum sulfate) and organic matter (mulch) were mixed with the soils from the stream bank and installed in a trench parallel with the river and down-gradient from an agricultural field. A summary of the design, construction and initial monitoring results of the RS2 structure at Little Bogue is presented here.

DESIGN AND CONSTRUCTION OF RS2

The RS2 structure was designed according to previous field tests at the Engineering Research Center (ERC) at Colorado State University (CSU) from 2003 to 2006 (Figure 1). In these tests, aluminum-based water treatment residual (WTR) amended sand (15% v/v) was used as the reactive barrier and 95% phosphorus removal was achieved through the barrier (Watson, et al., 2006). The results of these tests indicated that a volume fraction of 10 to 20 % WTR and 15 to 20% organic matter would be adequate for the RS2 structure being designed for the Little Bogue watershed.

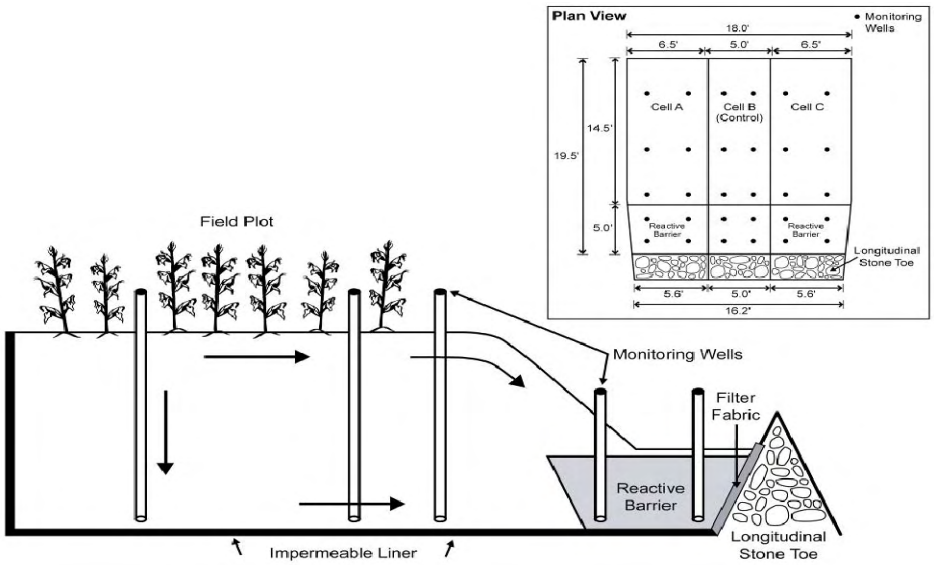

Figure 1 A plan view and a cross section view of the RS2 used in the field test at the ERC of CSU (Watson, et al., 2004).

Due to logistics, aluminum sulfate (Al_2SO_4) was used as a precursor of aluminum hydroxide ($Al(OH)_3$) instead of water treatment residual from a water treatment plant. Eucalyptus mulch was applied to provide organic matter for a carbon source to promote denitrification. The reactive barrier was constructed with a depth of approximately 4 feet, a width of 1 foot and a length of 150 feet (Figure 2). A 75 ft long area adjacent to the barrier was used as a control section since it had no added aluminum or organic matter (OM). Construction of the RS2 was completed on November 19th and 20th, 2008 along the Little Bogue creek where longitudinal peak stone toe protection (LPSTP) already existed (Figure 3). Bags of eucalyptus mulch were mixed with bags of aluminum sulfate and native soils in the trench to develop the reactive barrier zone for P adsorption and denitrification (Figure 4).

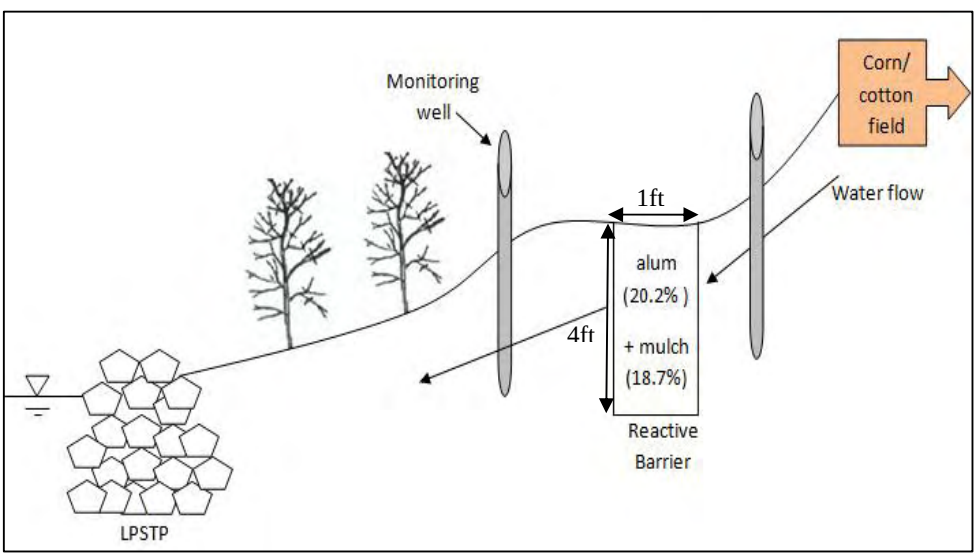

Figure 2 Design concept of Reactive Stream Stabilization (RS2) along Little Bogue Creek

Figure 3 The RS2 test site before constructing the RS2.

Figure 4 Mixing alum and mulch with soils in the RS2 barrier.

To enhance infiltration of rain and surface runoff into the barrier, a small berm was built streamward of the trench and a gully on the top bank was restored. Excessive soils on the barrier, the berm and the repaired gully were removed and top soils were flattened and seeded

with winter rye grass and mulched hay (Figure 5). Six monitoring wells were installed on January 12th, 2009. Three of them were placed on the streamside bank and the 3 on the field side bank of the reactive barrier to monitor nutrient transport through the barrier (Figure 6).

Five months after the RS2 construction, the first sampling was conducted on May 2nd and 3rd in the test and control areas. Water samples were collected from the RS2 monitoring wells and from up-, mid- and down-stream river sites to begin to develop a database for determining the impact of RS2 on the stream water quality. Soil samples were taken from the trench and the adjacent stream banks in the test and control areas (Figure 7). A second sampling was carried out on July 3rd, 2009.

Figure 5: View of Little Bogue site after RS2 construction.

Figure 6: Monitoring wells on the field side of the RS2 barrier.

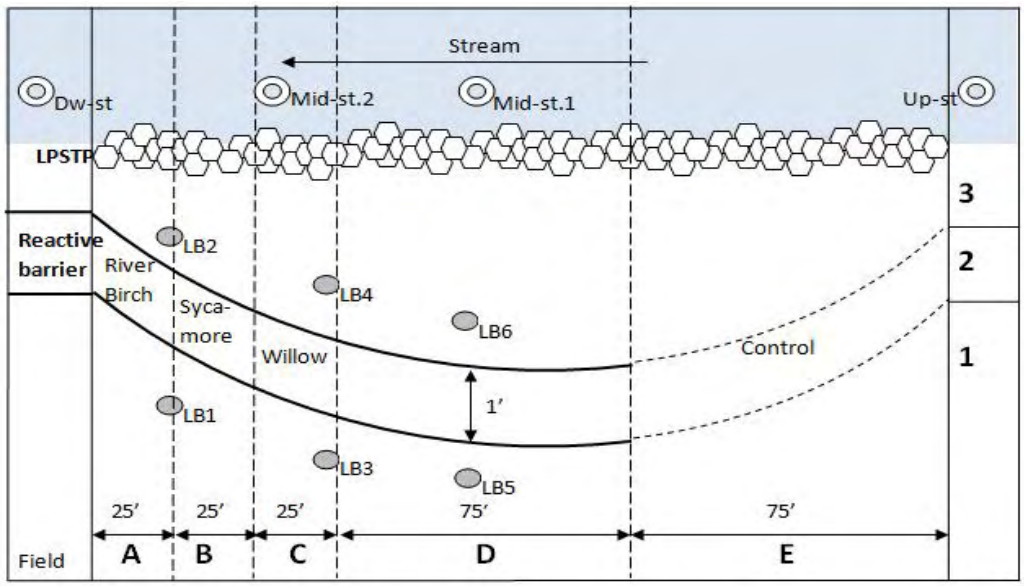

Figure 7 Plan view of sampling sites in the RS2 test area on the Little Bogue Creek.

INITIAL MONITORING RESULTS

Samples were collected according to the diagram shown in Figure 7. Sampled soils were classified and total phosphorus (TP), total organic carbon (TOC), total nitrogen (TN) and aluminum (Al) were measured in soil samples and TP, dissolved reactive phosphorus (DRP), TN, nitrate and TOC were determined for water samples.

Soil Classification Air dried and well-ground soils were passed through 2mm and a 75µm sieves to be characterized. The classified sand, silt and clay were weighed and percentages calculated. Based on standard definitions, the soil samples were classified into the categories shown in Table 1.

Table 1 Soil classification in the RS2 study and control areas.

	RS2 Study Area				Control Area
	A	B	C	D	
Field	Silty Clay	Silt Loam	Silty Clay	Silty Clay Loam	Silty Clay
Barrier (16")	Silt Loam	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay
Barrier (36")	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam
Bank	Silty Clay	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam

55% of soil samples were silty clay, 35% were silty clay loam and the remaining was silt loam. Silty clay soil contains 40 to 60 % of clay which has a higher phosphorus adsorption capacity than silt and sand.

Aluminum The RS2 concept and design were developed over the past years in field research at CSU. The primary design objectives of RS2 are to stabilize the stream bank, minimize bank erosion, and reduce phosphorus and nitrogen loads through the reactive barrier that contains aluminum to adsorb phosphorus and organic matter for accelerating denitrification. To reduce P and N loads, aluminum (as alum) and organic matter (as mulch) were added to the reactive barrier with the bank soils.

As shown in Figure 8, aluminum in the reactive barrier is three to five times greater than surrounding areas and is significantly greater than the control area ($p<0.05$). The mean concentration of alum in the reactive barrier is 2.1 mg/g (Coefficient of Variance=0.49) and the mean concentration of the field in the study area is 0.67 mg/g, 0.46 mg/g in the bank area, and 0.53 mg/g in the control zone.

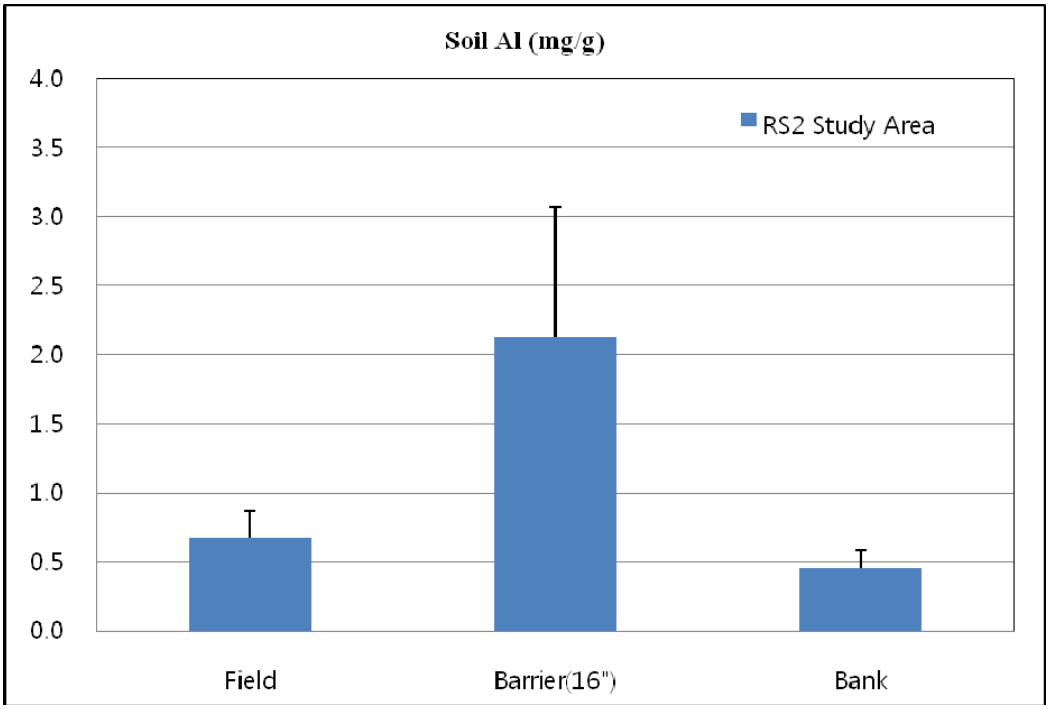

Figure 8 Concentration (mg/g) of total Aluminum in RS2 study area and control area (Error bars indicate 95% Confidence Intervals).

Phosphorus It can be expected that the concentration of phosphorus is decreasing with the bank elevation where the stream bank is stable. As shown in Figure 9, the amount of total soil P tends to be reduced from field to bank in the study area ($p<0.05$) but it is increased in the control area (Figure 10). This data indicates that the reactive barrier captured the soil TP when the field phosphorus went through the barrier.

Mehlich P is the loosely bound, biologically available phosphorus in the soil. Our analysis shows that Mehlich P constitutes only 10 to 20 percent of TP, however, it is the major form of

phosphorus needed to be reduced since it is bioavailable and causes eutrophication when it is present in excess. The mean of Mehlich P in soil from the field side was 0.05 mg P/g soil as shown in Figure 11. It is a lower value than expected, but is still within the recommended range of Mehlich P for crop growth; 45-50 mg P/kg soil (Sims, 2000). Mehlich P tends to be reduced through the RS2 barrier ($p<0.05$) as shown in Figure 11, a very encouraging result.

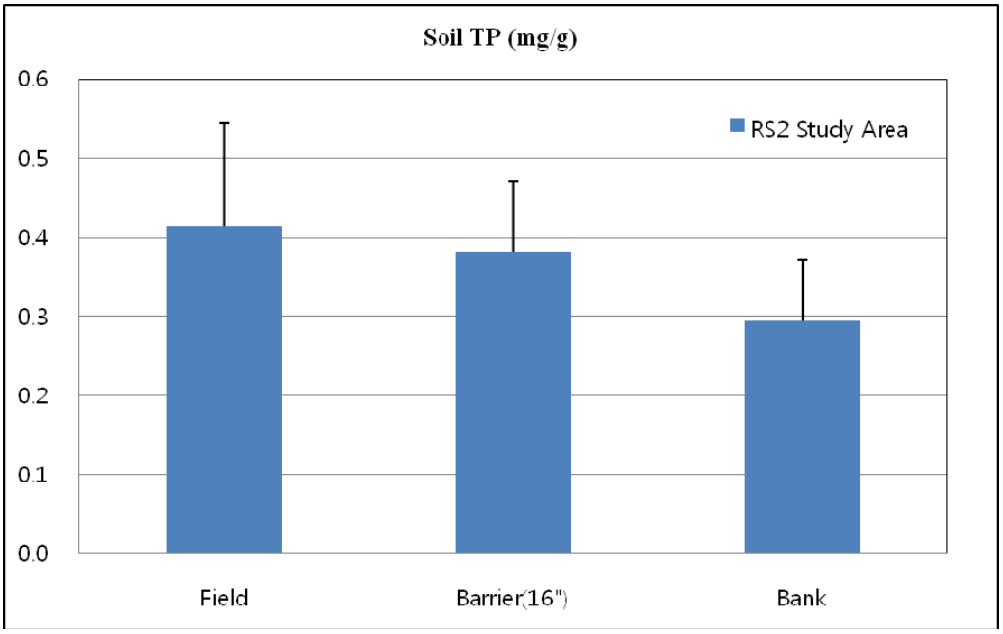

Figure 9 Concentration (mg/g) of soil total phosphorus (TP) in RS2 study area and (Error bars indicate 95% confidence intervals)

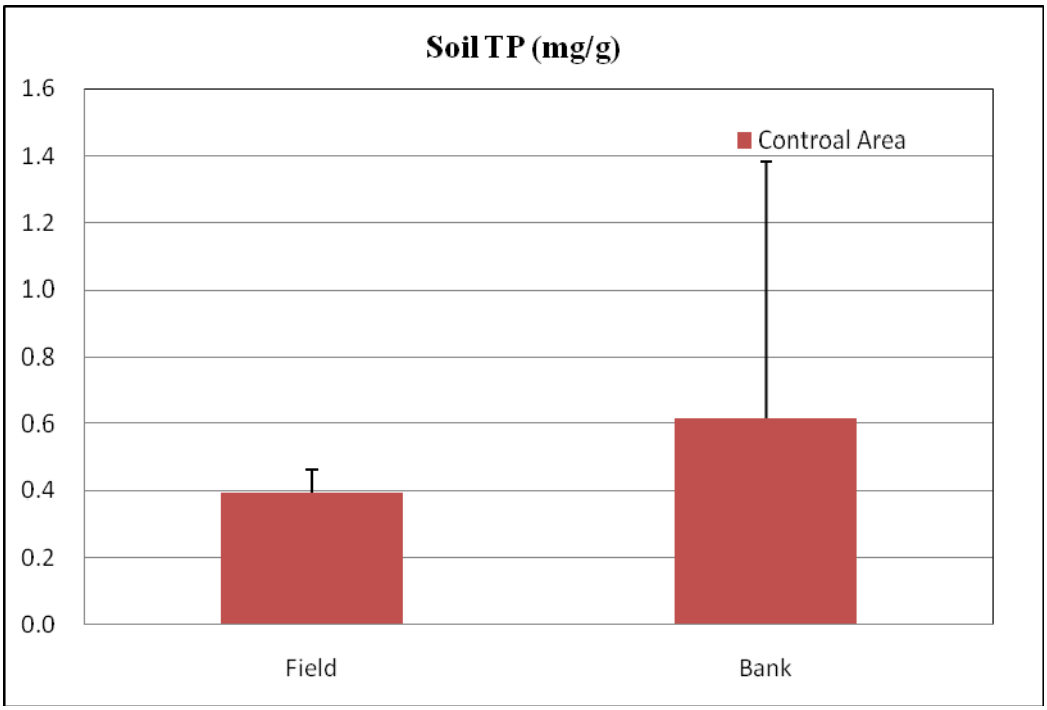

Figure 10 Soil TP concentrations in the field side and the lower bank in the control area.

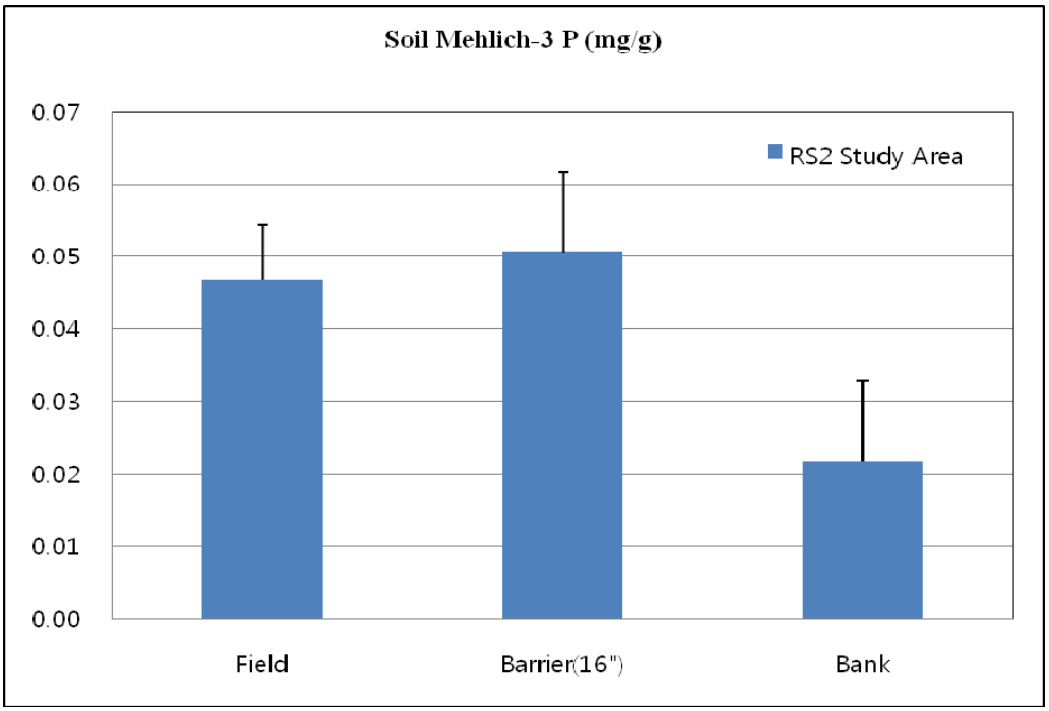

Figure 11 Concentration (mg/g) of Mehlich-3 Phosphorus in RS2 study area.

The soil P results relating to the RS2 structure are summarized in Table 2. Through the RS2 barrier, soil TP was reduced by 44% of the mean value from the field to the bank. In contrast, the soil TP concentration was increased by 58% of the mean value from the field to the bank in the control area where the RS2 barrier was not present. Concentrations of Mehlich P were decreased by 55% from the field to the bank in the RS2 study area and 20% in the control area. The sample size of the control area was not enough to confidently represent mean concentration of phosphorus since the range of 95% C.I. is too high. Additional samples in the control area are needed in future research.

Table 2 Soil total phosphorus (TP) and Mehlich phosphorus reductions in Reactive Stream Stabilization (RS2) structure (mean ± 95% C.I.).

	TP (mg/g)		Mehlich-3 P (mg/g)	
	RS2	Control	RS2	Control
Field	0.41±0.13	0.39±0.07	0.05±0.01	0.05±0.05
Bank	0.23±0.08	0.62±0.78	0.02±0.02	0.04±0.01
Delta (%)	- 44	+ 58	- 55	- 20

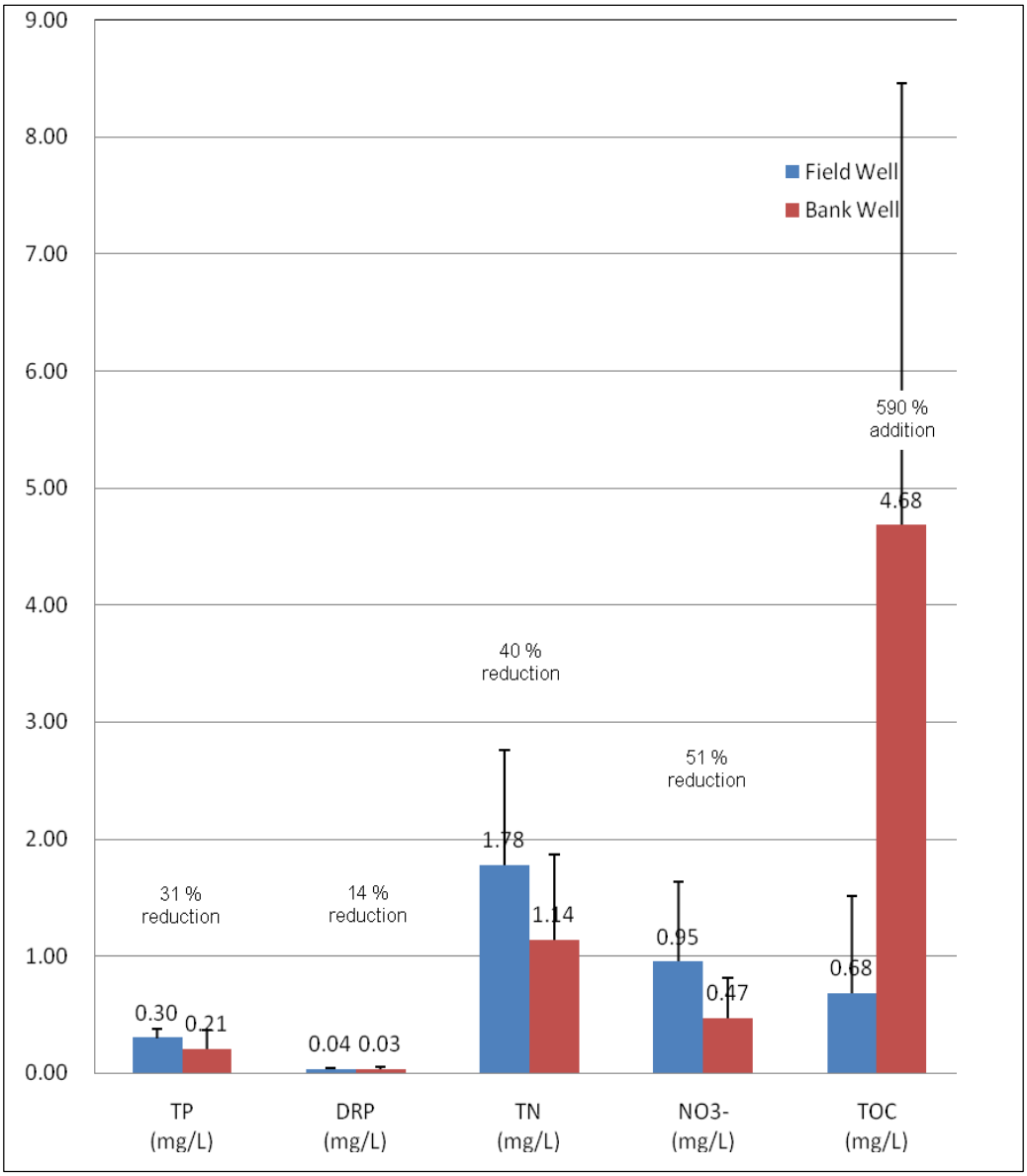

Figure 12 Concentrations (mg/L) of total phosphorus (TP), dissolved reactive phosphorus (DRP), total nitrogen (TN) and nitrate (NO_3^-) and total organic carbon (TOC) in groundwater from the monitoring wells on the field and bank sides of the reactive barrier.

Water Concentrations Groundwater samples collected from the monitoring wells adjacent to the RS2 reactive barrier were analyzed and the results are shown in Figure 12. The concentration of TOC in the bank well is 590 percent higher than the TOC in the field well, most likely due to the mulch amendment added to the barrier. This is a positive result since one of the design objectives of the RS2 system was to accelerate denitrification by increasing the bioavailable organic matter. The analyses also indicated that TN and nitrate (NO_3^-) concentrations are reduced by 40 and 51 percent, respectively, through the reactive barrier, further evidence that we are meeting one of our design objectives. Continued monitoring will help verify these trends. Aqueous phase TP and DRP reductions were measured to be 31 percent and 14 percent, respectively, as shown in Figure 12. These reductions are lower than

that measured in soil samples (50 percent TP and 55 percent Mehlich P) across the barrier. Again, continued monitoring is needed to fully understand the P removal benefits of the RS2 system.

CONCLUSIONS

The initial results from the Little Bogue Creek Reactive Stream Stabilization project are very encouraging. The design objectives of installing a reactive barrier with significantly elevated concentrations of aluminum for P adsorption and bioavailable organic matter for enhanced nitrogen removal appear to have been achieved. Based on sampling data from 5 and 7 months after construction, the RS2 structure appears to be removing significant amounts of N and P from agricultural runoff that would normally enter the creek. Additional monitoring is scheduled in next few months and these results will be presented at the conference. The ongoing monitoring is needed to verify the trends identified thus far. In addition, we are proposing installing RS2 systems on additional sites to expand the application and provide more data on efficacy.

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