RED BUG SLOUGH RESTORATION (W624)
FINAL PROJECT REPORT

PROJECT

The project was a multi-year, cooperative funding project with the Southwest Florida Water Management District (District). The project area is located within the Red Bug Slough Preserve (Preserve) in Sarasota County, Florida. Red Bug Slough (Slough), a tributary to Phillippi Creek, drains to North Roberts Bay and ultimately to Sarasota Bay, a District Surface Water Improvement and Management Program (SWIM) priority waterbody. It is consistent with the SWIM plan for Sarasota Bay, which outlines goals to restore habitat throughout the bay area and reduce pollutant loads entering Sarasota Bay. Project design and permitting began in May 2009 and was completed in March 2013. Construction began June 2013 and was completed in November 2014.

OBJECTIVE

The objective was to complete design, permitting, and construction of up to four restoration areas identified within the Preserve. The end result of the project was to restore and enhance historical wetlands, restore hydrologic connectivity to the slough, enhance native plant communities, and improve the quality of water entering Phillippi Creek and ultimately Sarasota Bay.

DESCRIPTION

The Preserve is a 72-acre natural preserve located on Beneva Road, north of Ashton Road and south of Proctor Road, within Sarasota County, Florida. It was acquired by the County for natural preservation and restoration in November 2000 and February 2001 with grant funding from the Florida Community Trust. The Preserve, which includes Red Bug Slough Lake (Lake) is included in the Red Bug Slough catchment, which also includes West Clark Lake, East Clark Lake, and Mirror Lake and drains an area approximately 600 acres in size.

PROJECT CONSULTANT

The County retained the services of Atkins, 4030 West Boy Scout Boulevard, Suite 700, Tampa, Florida 33607 for the design, permitting, and construction phases of the project.

CONSTRUCTION CONTRACTOR

The County retained the services of Ecosystem Technologies, Inc., 2221 McGregor Boulevard, Ft. Myers, Florida 33901 to construct the project.

RESTORATION SITES

Four restoration areas were initially identified within the Preserve, and the District Agreement required the restoration of all four areas if funding was available. Funding became available for the restoration of only the following three:

1) Restoration Area 1 (Segment C) includes a historical marsh/herbaceous wetland system located on the west and east sides of the Slough immediately south of Proctor Road.

   Goal: The restoration goal was to provide water quality treatment by enhancing and restoring the hydrology of a portion of the historical marsh system.

Result: Three wetlands on the west side, once separated, were inter-connected and reconstructed to receive water from the Slough during periods of high flow, and return treated water via an outfall pipe immediately south of Proctor Road. To preserve and enhance native habitat and improve wetland functions, invasive vegetation was removed and approximately 6060 native plants (pickerelweed, arrowhead, golden canna, button bush, spikerush, and marsh haygrass) were planted in a 10' buffer around each wetland. The total area restored was approximately 0.29 acres.

Invasive vegetation was removed from the wetland on the east side; the area was re-graded and contoured; and approximately 3,815 native plants (button bush and marsh hay cordgrass) and 145 native trees (sugarberry, swamp tupelo, and laurel oak) were planted within the project area and along the shoreline to restore and enhance wetland functions. The total area restored was approximately 0.35 acres.

2) Restoration Area 2 (Segment B) includes two areas: 1) a historical marsh/wetland located along the west side of the Slough just downstream of the main lake and 2) the western shoreline adjacent to the Slough and lake.

Goal: The restoration goal was to restore and enhance a historical wetland, increase aquatic habitat, and provide water quality treatment.

Result: Invasive vegetation was removed from the wetland; the area was re-graded and contoured; an outfall structure and pipe were constructed to re-connect the wetland to the Slough; and approximately 300 native wetland trees (Florida ash, pop ash, and swamp tupelo) were planted. The total area restored was approximately 0.98 acres.

Invasive vegetation was removed from the western shoreline; the bank was graded and contoured to decrease the slope; approximately 1,547 linear feet of littoral shelf was created; and the bank and littoral shelf were planted with 9,660 native plants (marsh hay cordgrass, muhly grass, pickerelweed, arrowhead, spikerush, and golden canna). The total area enhanced was approximately 0.88 acres.

3) Restoration Area 3 (Segment A) includes two areas: 1) the County-maintained open stormwater ditch, 10-187, flowing from the east and west between Beneva and Swift Roads and 2) the open water area located at the culvert connecting the stormwater ditch and West Clark Lake with Red Bug Slough Lake.

Goal: The restoration goal for the stormwater ditch was to enhance the shoreline to a more natural state by re-contouring the bank to create some sinuosity and create littoral shelves for habitat enhancement.

Result: Construction debris and invasive vegetation were removed along the bank of the ditch; it was graded and re-contoured to reduce the slope; approximately 791 linear feet of littoral shelf was created; and the bank and littoral shelf were planted with 3,245 native plants (marsh hay cordgrass, muhly grass, sand cordgrass, and spikerush). The total area restored was approximately 0.67 acres.

Goal: The goal for the open water area was to prevent floating, invasive vegetation from entering the Lake from the stormwater ditch from the east and west and West Clark Lake from the south in order to reduce nutrient loading and protect the downstream water quality of the Slough.

Result: Two vegetation collectors were constructed and installed in the flow-way of the ditch on the east and west sides of the culvert connecting the ditch and West Clark Lake to Red Bug Slough Lake.

BEST MANAGEMENT PRACTICES EVALUATION

Atkins conducted hydrologic modeling of Segment C and water quality analyses of all three restoration areas in 2011 to quantify the nutrient removal potential of the restored systems (Appendix A). Based on

Table 1. Nitrogen Load Reduction – Pounds/Year

	TN Concentrations (mg/L)		TN Loading (kg/month)			
Month	Input from 30203	Output from Wetland	Input from 30203	Output from Wetland	% Reduction	Reduction kg/month
January	1.98	0.75	11.4	4.3	0.62	7.068
February	1.98	1.10	35.6	19.8	0.44	0.871
March	1.98	1.33	87.0	58.5	0.33	0.653
April	1.98	0.63	7.3	2.3	0.68	1.346
May	1.98	0.94	22.0	10.4	0.53	1.049
Jine	1.98	1.39	102.6	71.8	0.30	0.594
July	1.98	1.39	106.0	74.2	0.30	0.594
August	1.98	1.39	106.0	74.2	0.30	0.594
September	1.98	1.39	102.6	71.8	0.30	0.594
October	1.98	0.87	17.4	7.6	0.56	1.109
November	1.98	0.75	11.0	4.1	0.62	1.228
December	1.98	0.78	12.9	5.1	0.60	1.188
			Total Reduction Per Month (kg)			**16.8888**
			Total Reduction Per Year (kg)			**202.6656**
			Total Reduction Per Year (lbs)			**446.79658**

Table 2. Phosphorus Load Reduction – Pounds/Year

	TN Concentrations (mg/L)		TN Loading (kg/month)			
Month	Input from 30203	Output from Wetland	Input from 30203	Output from Wetland	% Reduction	Reduction kg/month
January	0.74	0.29	4.2	1.7	0.60	2.520
February	0.74	0.44	13.3	7.8	0.29	0.215
March	0.74	0.53	32.5	23.1	0.67	0.496
April	0.74	0.25	2.7	0.9	0.50	0.370
May	0.74	0.37	8.2	4.1	0.26	0.192
June	0.74	0.55	38.3	28.4	0.26	0.192
July	0.74	0.55	39.6	29.4	0.26	0.192
August	0.74	0.55	39.6	29.4	0.26	0.192
September	0.74	0.55	38.3	28.4	0.54	0.400
October	0.74	0.34	6.5	3.0	0.36	0.266
November	0.74	0.29	4.1	1.6	0.58	0.429
December	0.74	0.31	4.8	2.0	0.60	0.444
			Total Reduction Per Month (kg)			**5.909**
			Total Reduction Per Year (kg)			**70.910**
			Total Reduction Per Year (lbs)			**156.329**

estimated monthly concentrations, loads, and percent removal of total nitrogen (TN) and total phosphorus (TP), the restored systems have the potential to remove 446.8 pounds of TN and 156.3 pounds of TP per year (Tables 1 and 2).

PERFORMANCE EVALUATION

1. Restoration Area 1 (Segment C)

1.1 Wetland System (West)

   a. Inter-connecting the three historical wetlands and restoring the hydrologic connection to the Slough created a "treatment train" approach that improves the quality of water flowing out of the Preserve to Phillippi Creek.
   b. Invasive vegetation removal and re-establishment of wetland species improves wetland function, and provides water quality treatment and valuable native habitat for a wide variety of wetland dependent species.

1.2 Eastern Wetland

   a. The restored historical forested wetland retains runoff and protects the water quality of the Slough.
   b. Re-establishment of native trees and shrubs provides food and habitat to a variety of wildlife species.

2. Restoration Area 2 (Segment B)

2.1 Marsh/Wetland

   a. Restoring the historical marsh/wetland and its hydrologic connection to the Slough protects and improves the water quality of the Slough and Phillippi Creek. It captures runoff from surrounding neighborhoods and provides increased residence time for water quality treatment prior to its discharge to the Slough.
   b. Native plants in the littoral zone provide valuable habitat and food for many bird and wildlife species; uptake nutrients; absorb and break down contaminants; improve water clarity by stabilizing bottom sediments, and add oxygen to the water through photosynthesis.

2.2 Western Shoreline

   a. Grading the bank to decrease the slope, stabilizing the bank, and planting native vegetation eliminated previous stream bank undercutting and reduced excessive sediment transport by the Slough. This prevents bottom habitat smothering, a decrease in water clarity, and sediment transport to Phillippi creek.
   b. Creating a littoral zone and planting native, aquatic plants improves the quality of the water flowing through the Slough and provides valuable native habitat as well as all of the benefits listed Section 2.1.b.

3. Restoration Area 3 (Segment A)

3.1 Stormwater Ditch (10-187)

   a. Grading the ditch bank to decrease the slope, stabilizing the bank, and planting native vegetation eliminated previous stream bank erosion and reduced excessive sediment transport to the Slough and Lake. This prevents bottom habitat smothering, a decrease in water clarity, and sediment transport to Phillippi Creek.

b. Creating a littoral zone and planting native, aquatic plants improves the quality of the water entering the Slough and provides valuable native habitat as well as all of the benefits listed in Section 2.1.b.

3.2 Vegetation Collectors

a. The vegetation collectors trap floating, invasive vegetation (primarily water lettuce) to allow for more efficient removal, which protects water quality by reducing the need for chemical herbicide spraying. Spraying contributes to lower dissolved oxygen (DO) levels, since DO is rapidly consumed as microorganisms work to decompose the vegetation. It also contributes to the build-up of muck in bottom sediments because decaying vegetation sinks to the bottom where it further decomposes and creates a soft, mucky bottom that is an unhealthy habitat for bottom dwelling organisms. Decaying vegetation also releases nutrients back into the water column which can cause algae blooms and fish kills.
b. An added benefit is that litter is also trapped and removed from the system.

ADDITIONAL INVASIVE VEGETATION REMOVAL – SEGMENT C

The County Construction Contract 2013-298 allowed for invasive vegetation removal from within a 10' buffer around each of the three western wetlands in Segment C. The County determined that removal of invasive vegetation from within each wetland footprint would improve wetland function and provide added water quality benefits. The County contracted Rick Richards, Inc., separate to the cooperative funding agreement, to manually remove and/or cut and treat the following invasive vegetation species: Surinam Cherry, Primrose Willow (exotic), Brazilian Pepper, Cattail, Water Lettuce, Cesar Weed, Bishop Wood, Nightshade, Climbing Fern, Cogon Grass, Guinea Grass, Wild Taro, Wedelia, Para Grass, and Air Potato. The agreement provided for a 30-day follow-up treatment. The work was completed in June 2014, and added 0.90 acre of wetlands to the restoration area.

ADDITIONAL NATIVE VEGETATION PLANTING – SEGMENT B

The County Construction Contract 2013-298 allowed for the planting of wetland tree species along the bank of the wetland pond restored in Segment B. The County determined that planting native wetland plant species in the littoral zone around the pond would provide added water quality benefits to water flowing into the Slough. A volunteer planting event was held on Saturday, October 4, 2014. Six County staff and five volunteers planted 310 plants consisting of the following species: Pickerelweed, Golden Canna, Fire Flag, Lizard's Tail, Royal Fern, Cinnamon Fern, String Lily, Soft Rush, White-Topped Sedge, and Soft-Stemmed Bulrush.

PROJECT COSTS

The total acres restored in each Segment are show in Table. 3.

Table 3.

Segment	Acres Restored
A	0.67
B	1.86
C	1.55
Total	4.08

The total project costs and cost per acre are shown in Table 4.

Table 4.

Red Bug Slough Restoration (W624)	
Project Costs	
Phase I	$104,877.54
Phase II	$103,690.00
EOR Services	$42,700.00
Construction	$464,552.64
Total	$715,820.18
Acres Restored	4.08
Cost Per Acre	$175,446.12

WATER QUALITY MONITORING

Twenty months of baseline water quality data for Red Bug Slough were collected from October 2005 through August 2008 from nine stations by the Environmental Stormwater Division of Sarasota County Public Utilities for the following parameters: total kjeldahl nitrogen (TKN), nitrite+nitrate (NOX), total nitrogen (TN), ammonia nitrogen (NH_4), orthophosphate (PO_4), total phosphate (TP), chlorophyll a, turbidity, total suspended solids (TSS), biochemical oxygen demand (BOD), and color. Physical conditions such as water temperature (°C); dissolved oxygen saturation (%); dissolved oxygen (mg/l); specific conductance (µmhos/cm); salinity (ppt); meter depth (ft); water depth (ft); and pH (ppt) were also recorded. Six stations were located upstream and three stations were located downstream of the Preserve. While water quality monitoring is not a requirement of the Agreement, one sampling station (RBS-J) just downstream of the Preserve was added back into the Phillippi Creek monitoring program in May 2014 to collect monthly post-restoration water quality data for the same parameters and physical conditions (Appendix B).

RECOMMENDATIONS

As constructed, the restoration project will improve the quality of water entering Phillippi Creek and Roberts Bay primarily through off-line detention and uptake through the wetland planted areas. Additional sedimentation will be reduced by bank stabilization.

Initially, four restoration areas were identified for this project. As funding was available for only three of the sites, securing funding to implement the improvements at Restoration Area 4 (Segment D) could further improve the quality of water entering Roberts Bay. Restoration Area 4 includes an historical wetland north of the Lake along the eastern shoreline of the Slough. The site has been filled and currently contains a monoculture of Brazilian pepper with some pine and palm trees. Restoration would include clearing and re-grading the site to lower the elevation to create a wetland/marsh system, and planting native wetland vegetation. This would re-establish wetland vegetation, enhance native habitat, and protect and improve the water quality of Red Bug Slough, Phillippi Creek, and, ultimately, North Roberts Bay. A rough estimate of the cost of the project in 2009 was $200,000 - $350,000.

APPENDIX A

Hydrologic Modeling Report for Red Bug Slough Preserve Restoration Project

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Hydrologic Modeling Report for Red Bug Slough Preserve Restoration Project

Prepared For:

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February 2011
Revised March 2011

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1.0 Introduction

Red Bug Slough Preserve (Preserve) is a 72 acre natural preserve located on Beneva Road, north of Ashton Road and south of Proctor Road, in Section 9, Township 37 S, Range 18 E within Sarasota County, Florida. The Preserve was acquired for natural preservation and restoration in November 2000 and February 2001 by Sarasota County with grant funding from the Florida Community Trust.

The Preserve, which includes most of Red Bug Slough Lake (Lake), is located in the Red Bug Slough (RBS) catchment, which includes West Clark Lake, East Clark Lake, and Mirror Lake. RBS is a tributary to Phillippi Creek, which in turn is a tributary to Roberts Bay. RBS is approximately 600 acres in size.

The purpose of this report is to present the results of hydrologic modeling of Restoration Area 1 and water quality analysis of all restoration areas. In order to quantify the nitrogen removal potential of both systems it was first important to calculate the amount of water entering and leaving the system and the retention time. The objective of the modeling and analysis was to optimize these values by altering the hydraulic connections between the wetlands and the slough via a combination of open ditches, culverts and/or structures while maintaining the habitat value of the system. Model simulations were run for the pre and post conditions using ICPR v 3.10 for various design alternatives and storm events. Once the most beneficial hydrological/hydraulic design was identified the pollutant reduction numbers were calculated based on reduction rates established in the peer reviewed literature.

2.0 Hydrologic Modeling

2.1. Red Bug Slough Model Description

A submodel was cut from the larger Phillipi Creek ICPR model to evaluate alternatives. The full model domain is shown in Figure 1. The local scale model is shown in Figure 2. Inflow boundary conditions were extracted from the larger regional model and applied to the local scale model.

Figure 1. Phillippi Creek ICPR Model Area

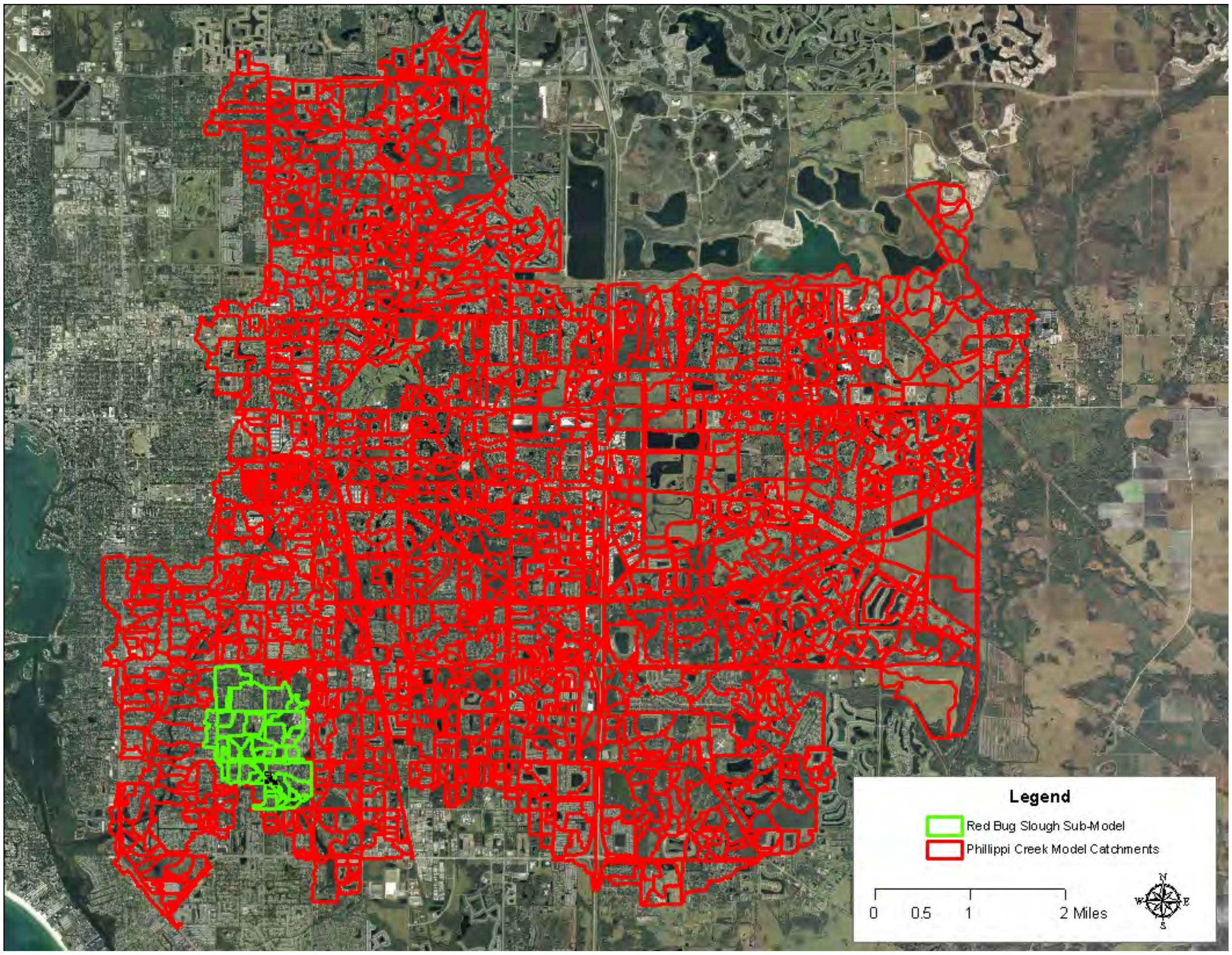


Figure 2. Red Bug Slough Sub-Model Area

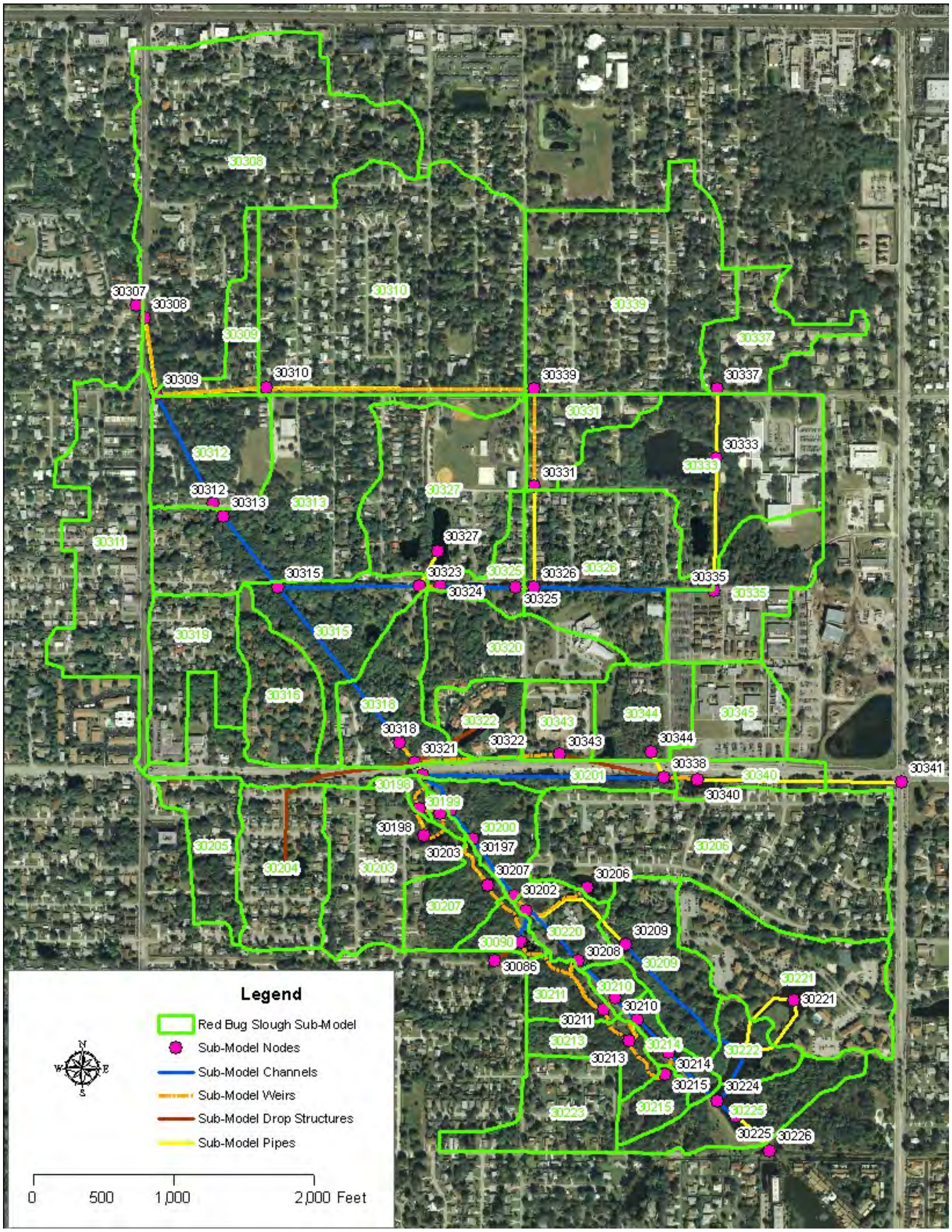


Table 1 describes the type of boundary node and associated boundary condition applied. Boundary time series were extracted from the larger Phillippi Creek model and applied at the boundary locations described in Table 1.

Table 1. Red Bug Slough Boundary Conditions

Node ID	Boundary Location	Boundary Type
30226	Upstream Boundary	Time/Flow
30341	Upstream Boundary	Time/Flow
30086	Downstream Boundary	Time/Stage
30307	Downstream Boundary	Time/Stage

2.2. Description of Modeled Improvements

Improvements to RBS are considered in the areas shown in Figure 3 and in the plan sheets from the 30% Plan set located in the Appendix. The objectives of the proposed modifications to the system are to:

- Improve habitat by adding littoral shelves to Red Bug Slough.
- Provide additional water quality treatment by increasing retention time is existing wetland areas.

Figure 3. Area of Modeled Proposed Improvements (Restoration Area 1)

The following changes were made to the model to evaluate the benefits of these proposed modifications.

1. The cross-section of RBS between Stations 13+00 and 46+30 will be modified to include a littoral shelf. The shelf will be at an elevation of 15 feet NGVD and will be approximately 10 feet wide.
2. Re-grade the western bank of the RBS near Station 42+00. There is a natural depression in the bank that allows the adjacent wetland to drain quickly after a storm event. The natural depression has a low point at elevation 15.25 NGVD that connects basin 30199 to the channel. This will be re-graded to a consistent elevation of 16.1 feet NGVD. The model assumes that a 50 foot long weir is installed in the re-graded berm at elevation 16.1 ft NGVD.
3. Build flow ways to connect basins 30199 and 30203. The model assumes a 50-foot wide flow way at an invert elevation of 14.1 NGVD.
4. Build a flow way to connect basins 30203 and 30198. The model assumes a 25-foot wide flow way at invert elevation 14.1 NGVD.
5. Water is allowed to leave the wetland systems adjacent to RBS via an 8-inch diameter pipe with upstream invert of 15.6 feet and a downstream invert of 15.0 ft NGVD.

2.3. Model Comparison

The following section will provide a comparison of model results between the existing and proposed conditions in RBS. All runs were made using the Mean Annual Storm of four (4) inches over 24 hours. Figures 4 – 7 show comparisons of stage for the existing and proposed conditions at nodes 30198, 30199, 30200, and 30203; respectively. Nodes 30198, 30199, and 30203 are located within the wetlands adjacent to RBS. The graphs indicate that more water is stored in the system and will provide additional water quality treatment. The normal pool elevation will be at 15.6 feet NGVD in all wetlands which is equal to the seasonal high water elevation in Node 30198.

The graph for node 30200, located in RBS, shows that the peak water surface elevation is unchanged between the existing and proposed conditions. However, the stage in RBS does decrease more rapidly in the proposed condition. This can be attributed to the water being released from the wetlands at a slower rate than in the existing conditions.

Figure 4. Stage Comparison at Node 30198

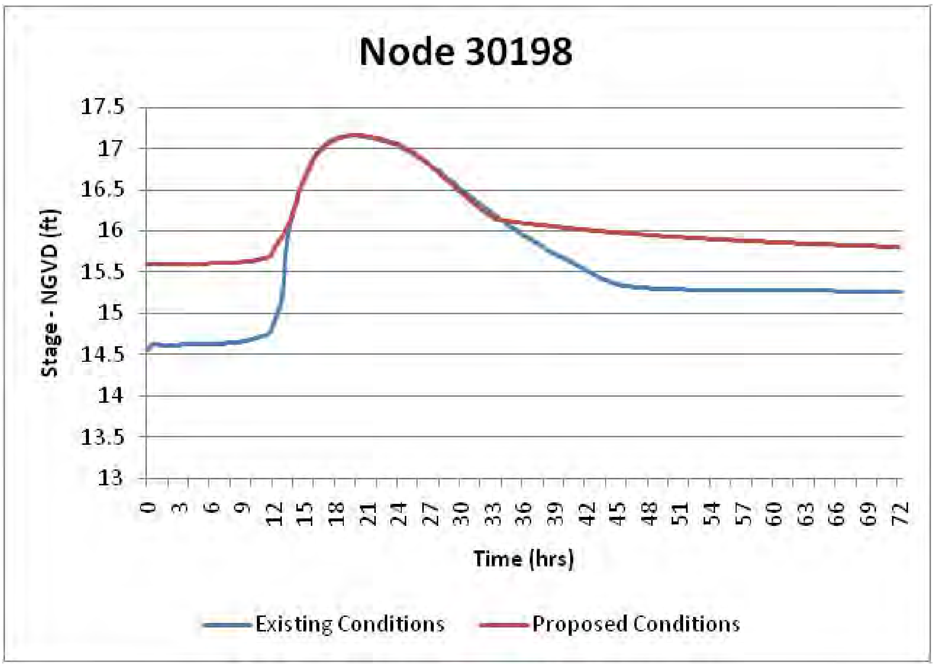


Figure 5. Stage Comparison at Node 30199

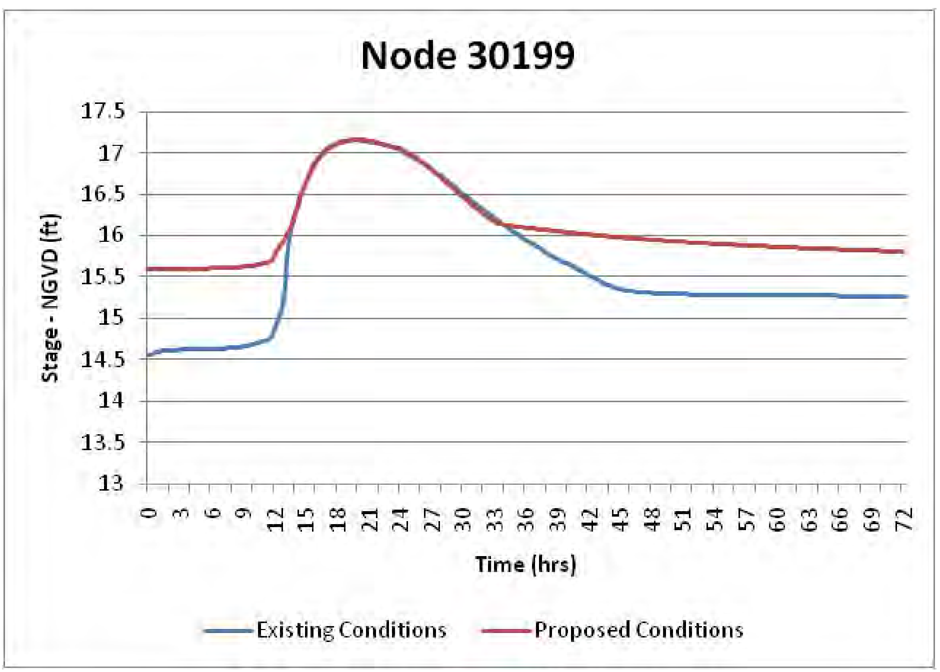


Figure 6. Stage Comparison at Node 30200

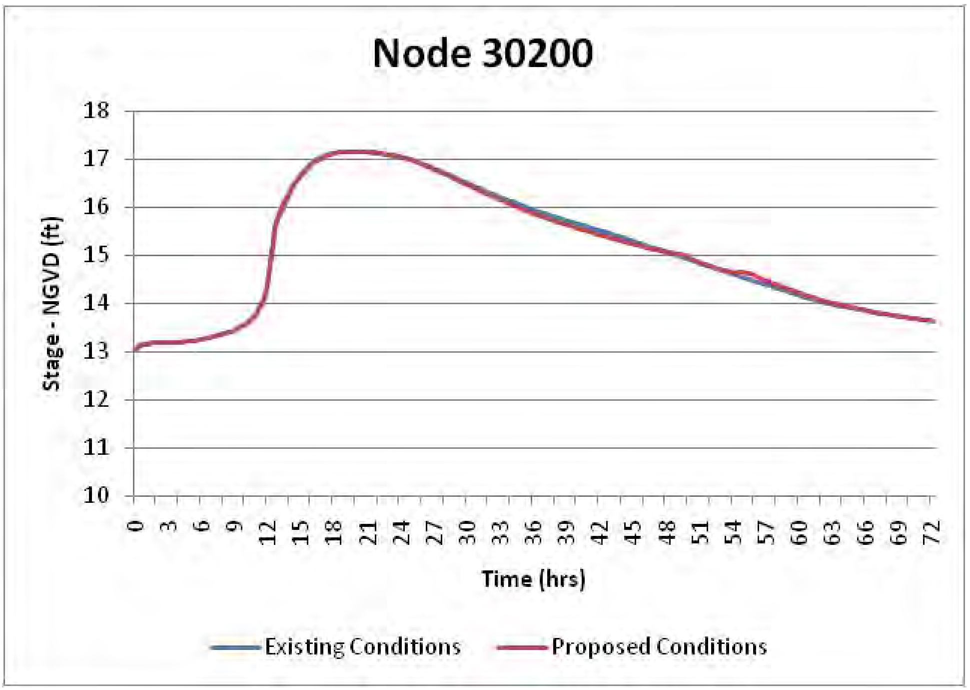
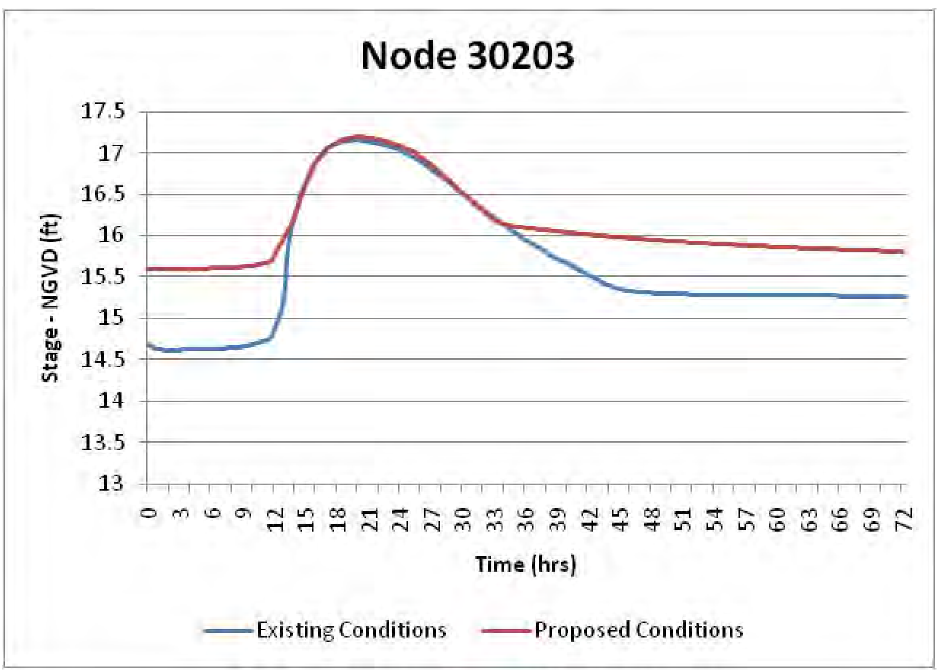


Figure 7. Stage Comparison at Node 30203



3.0 Water Quality

The method for predicting water quality responses of RBS was done by computing the probable loads of various constituents from the surrounding landscape. These probable loads were then attenuated as a function of travel time through wetland features south of Proctor Road. The wetland area in Restoration Area 1 involved in attenuation is approximately 2.17 acres in size, and is mostly comprised of marsh (herbaceous wetlands). These wetlands are currently hydrologically altered due to numerous man-made activities, and therefore the wetlands offer limited nutrient reduction due to the short residence time. Under the proposed restoration scenario, residence time would increase to 36 hours, allowing for some level of assimilation of nitrogen, phosphorus, and total suspended solids through multiple pathways (i.e., burial, plant uptake by both emergent and potential submergent vegetation, denitrification, etc. as outlined in Mitsch et al. 2001, Richardson and Nichols 1995).

The quantity and quality of stormwater water to be captured, by month, was used to calculate a constituent load for total nitrogen (TN) and total phosphorus (TP). TN and TP are the primary constituents used to categorize the eutrophication status of most U.S. estuaries (Bricker et al. 2007). Estimates of potential changes in water quality are based on a series of assumptions of presumed rates and efficiencies, and end-point values should be considered a reasonable estimate of the assimilative capacity of the improved wetland features. An adaptive management framework that includes ongoing water quality monitoring, regular reporting and analysis, and careful consideration of expected versus observed responses should be incorporated into future work efforts.

3.1. Data Sources

The treatment runoff volumes used in assessing the water quality benefits of retaining stormwater runoff in the adjacent wetlands of Red Bug Slough were provided from the hydrodynamic model for Red Bug Slough for sub-basin 30203 (Table 2). The pollutant concentrations were acquired from the Sarasota County specific pollutant load project completed in 2010 by PBS&J (PBSJ&J 2010; Table 3). These data were used to develop monthly constituent loads into the RBS, and loads were attenuated based on the approach outlined below.

Table 2. Estimated runoff volumes for Basin 30203

Month	Average Rainfall (in)	Estimated Runoff (acre-feet)	Estimated Treated Runoff Volume (acre-feet)
January	2.5	0.15	0.15
February	3.0	0.52	0.52
March	3.3	1.15	1.15
April	1.3	0.10	0.10
May	2.8	0.29	0.29
June	7.8	7.18	1.4
July	8.9	8.19	1.4
August	9.5	8.75	1.4
September	8.0	7.37	1.4
October	2.6	0.23	0.23
November	2.1	0.15	0.15
December	2.3	0.17	0.17

Table 3. Average pollutant concentrations for "Swale" stormwater samples collected in Sarasota County

Parameter	Value
Total Nitrogen (mg/L)	1.98
Total Phosphorus (mg/L)	0.74

Loading rates of TN, and TP were calculated for each month using average stormwater runoff values collected from Swale samples (Table 3) and the monthly treatment volume (Table 2). The percent removal of TN and TP by the wetlands was estimated based on published constituent removal rates, which vary as a function of the inverse of loading rates (Richardson and Nichols, 1985). The high removal rates, discussed in the next section, are related to the finding that much of the TN and TP in runoff in Swale locations in Sarasota County are in organic forms that can be efficiently removed via settling and burial.

3.2. Results and Discussion

Estimated monthly concentrations, loads, and percent removal of TN and TP are shown in Tables 4 and 5. TN percent reduction ranged between 30 and 68 percent from the watershed examined (Table 4). TP percent reduction ranged from 26 to 67 percent (Table 5). The proposed stormwater treatment provided by reconfiguring wetland treatment in the RBS watershed thus provides important reductions in pollutant loads to downstream waters, which would ultimately benefit both Philippi Creek and Roberts Bay. Reduced removal efficiencies in June through September reflect the finding that much of the runoff during these months is of such a greater volume that a high percentage is passed through with little time for any significant treatment. Discrepancies between modeled load reductions and the amount of flow attenuated can be ascribed to variability in model parameters, as well as differences in the amount of load reduction with attenuation of velocities insufficient to be termed "treatment". That is, particulate forms of nutrients, especially phosphorus, can be removed from runoff even under conditions that would normally be modeled as conveyance, rather than treatment. Based on literature, such high rates of nutrient reduction are much greater in flowing marsh systems, such as the anticipated wetland treatment area, rather than the more familiar nutrient removal efficiencies of ponds such as wet detention systems.

Table 4. Estimated monthly TN concentrations, loads and reduction for the input and output to RBS under proposed restoration scenario

Month	TN Concentration (mg/L)		TN loading (kg/month)		% Reduction associated with wetland
	Input from 30203	Output from wetland	Input from 30203	Output from wetland	
January	1.98	0.75	11.4	4.3	62
February	1.98	1.10	35.6	19.8	44
March	1.98	1.33	87.0	58.5	33
April	1.98	0.63	7.3	2.3	68
May	1.98	0.94	22.0	10.4	53
June	1.98	1.39	102.6	71.8	30
July	1.98	1.39	106.0	74.2	30
August	1.98	1.39	106.0	74.2	30
September	1.98	1.39	102.6	71.8	30
October	1.98	0.87	17.4	7.6	56
November	1.98	0.75	11.0	4.1	62
December	1.98	0.78	12.9	5.1	60

Table 5. Estimated monthly TP concentrations, loads and reduction for the input and output to RBS under proposed restoration scenario

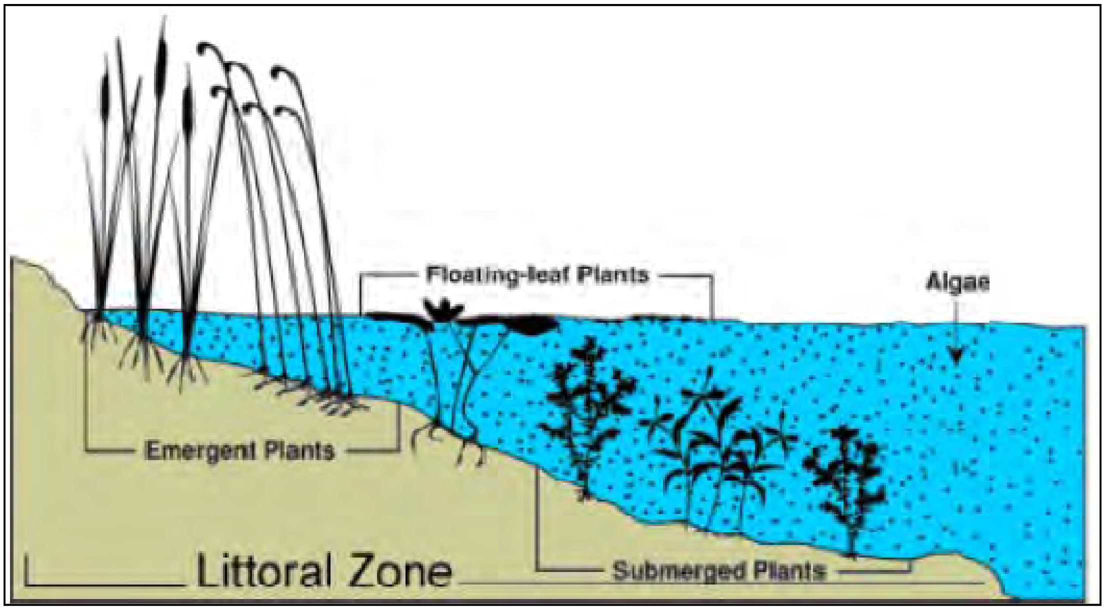
Month	TP Concentration (mg/L)		TP loading (kg/month)		% Reduction associated with wetland
	Input from 30203	Output from wetland	Input from 30203	Output from wetland	
January	0.74	0.29	4.2	1.7	60
February	0.74	0.44	13.3	7.8	41
March	0.74	0.53	32.5	23.1	29
April	0.74	0.25	2.7	0.9	67
May	0.74	0.37	8.2	4.1	50
June	0.74	0.55	38.3	28.4	26
July	0.74	0.55	39.6	29.4	26
August	0.74	0.55	39.6	29.4	26
September	0.74	0.55	38.3	28.4	26
October	0.74	0.34	6.5	3.0	54
November	0.74	0.29	4.1	1.6	60
December	0.74	0.31	4.8	2.0	58

3.3. Littoral Zone

The conceptual plan for Red Bug Slough restoration includes the creation of two littoral shelves. The first is approximately 0.7 acres in size and extends east/west north of Lake Arrowhead Trail. The second littoral shelf is approximately 1.2 acres in size positioned north/south along the western bank of Red Bug Slough. Both features are proposed to be modified to create a 1:4 slope. Littoral zones are typically less than three meters in depth, thereby allowing sunlight penetration adequate for plant growth. The littoral zone includes emergent (EAV) and submerged (SAV) aquatic vegetation at different depths, but typically overlapping (Figure 8). EAV includes aquatic plants that are rooted in the lake bottom but protrude above the water surface, e.g. floating water lilies (*Nuphar spp.* and *Nymphaea spp.*), bulrushes (*Scirpus validus*), wild rice (*Zizaniopsis miliaceae*), duck potato (*Sagittaria spp.*), and cattails (*Typha latifolia*).

SAV and EAV establishment in Red Bug Slough along the proposed littoral shelves is expected to improve water quality. Removal of nutrients from the water column by SAV and EAV is well documented (Kadlec and Wallace 2009, Kadlec and Knight 1996, Knight et al. 2003, Blindow et al. 2002, Canfield et al. 1984, Havens 2003, Shireman et al. 1985). The average TN and TP load removal efficiency for 80 wetland treatment systems included in the North American Wetland Treatment System Database indicate 55 and 34 percent TN and TP reduction, respectively, for surface flow systems (Kadlec and Knight 1996). The probable pathways for nutrient removal are briefly described below for phosphorus and nitrogen.

Figure 8. EAV and SAV distribution in the lake littoral zone (after MDNR 2010).



Phosphorus

The accretion and permanent burial of phosphorus into the sediments via EAV and SAV is the only sustainable removal mechanism for phosphorus in aquatic systems. Organic, adsorbed, and mineral phosphorus are unavailable to plants and adsorption and precipitation are major mechanisms of phosphorus retention. Sediment characteristics affecting phosphorus availability include:

- Adsorption/desorption. Adsorption is the chemical binding of plant available phosphorus to soil particles, making the phosphorus unavailable to plants. Desorption is the release of adsorbed phosphorus from its bound state into the soil solution. Higher iron and/or aluminum content of the sediment increases adsorption.
- Precipitation/dissolution. Phosphorus can become unavailable via precipitation of plant available inorganic phosphorus with dissolved iron, aluminum, manganese (in acid soils), or calcium (in alkaline soils) to form phosphate minerals. Precipitation is more permanent when compared with adsorption. High concentrations of calcium, aluminum, or iron can also precipitate phosphorus into water column. The presence of redox-insensitive phosphorus binding systems such as Al(OH)3 and unreducible Fe(III) minerals can enhance the phosphorus retention and completely prevent phosphorus release even in case of anoxic conditions (Hupfer and Lewandowski 2008).
- Immobilization/mineralization. Mineralization is the microbial conversion of organic phosphorus to plant available orthophosphates. Immobilization occurs when the plant available phosphorus is consumed by microbes and thereby converted unavailable organic phosphorus.

Nitrogen

Denitrification and assimilation are the major pathways which result in permanent nitrogen removal in aquatic systems.

- Denitrification. Denitrification is a process that occurs in anaerobic aquatic and soil conditions. In the absence of free oxygen, denitrifying bacteria use molecules other than oxygen as final electron acceptors while obtaining energy from fixed carbon. Upon using nitrate or nitrite molecules, the intermediate product is nitrous-oxide, and the final end product is di-nitrogen gas, a biologically inert form of nitrogen.
- Assimilation. Assimilation is the conversion of inorganic nitrogen (i.e., nitrate, ammonia) into organic compounds (i.e., plant biomass).

A good example of the effectiveness of vegetated wetland buffers (compared with no EAV or SAV) is illustrated in a comparison of a control site with a seven meter wide switchgrass (*Panicum virgatum*) wetland buffer, and the same buffer with an additional 13 meter wide forested buffer (Zaimes et al. 2004). The switchgrass buffer alone removed more than 90 percent of sediments and 80 percent of TP over the 18 month study period. The combined buffer zone reduced TP from 200 g/hectare to 19 g/hectare and sediments from 587 g/kg to 16 kg/hectare (Lee et al. 2003). Wider vegetated zones promote more water infiltration and nutrient retention (Schmitt et al. 1999). Wetland species other than switchgrass would also be effective buffers.

4.0 Conclusion

For smaller storms, downstream waters will benefit from the nutrient removal process occurring in the restoration areas for the runoff volumes from basins contributing to those wetlands.

For larger storms approximately 3” of rainfall to the relevant basins as illustrated in Figure 2, there will be an additional exchange of water between the slough and the wetland system. During both, small or large storm events an improvement to downstream water quality should occur as a result of the proposed improvements.

Creation of two littoral areas is expected to improve water quality by removal of nutrients from the water column.

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Appendix: Selected 30 % Plan Sheets

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PROJECT:
RED BUG SLOUGH

SHEET TITLE
PLAN VIEW CONTOUR MAP
ELEVATIONS IN FEET (NGVD 29)

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RED BUG SLOUGH RESTORATION (W624)
FINAL PROJECT REPORT

APPENDIX B

Water Quality Monitoring Station RBS-J

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RBS-J
PROCTOR RD
SWIFT RD
BENEVA RD
Segment C
Segment B
Segment A
Legend
RBS-J
Red Bug Slough Preserve
Red Bug Slough Subasin