APPENDIX I: WATER QUALTY

2020 SUPPLEMENT NO. 2 TO THE 2007 FINAL SUPPLEMENT NO. 1 TO THE 1982 YAZOO AREA PUMP PROJECT FINAL ENVIRONMENTAL IMPACT STATEMENT (FEIS)

Water Quality Appendix

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1.0 GENERAL

1.1 INTRODUCTION

1. Across the world as farmers have ramped up production to meet the increasing populations demand for food, water quality has suffered. Most of the major river basins focused on agricultural production, especially, those from the upper Midwest have suffered from degraded water quality conditions for many years due to agricultural runoff. To a lesser extent, the Mississippi Yazoo Basin has experienced a decline in water quality conditions over the last six decades. Many efforts have been made to describe these conditions through the use of numerical models and routine monitoring. These efforts have allowed practitioners to develop a better understanding of the root causes that plague riverine ecosystems. This report will provide insight into the numerical nutrient SPAtially Referenced Regression On Watershed (SPARROW) models created for the Mississippi River Valley by the U.S. Geological Survey (USGS) and the sub basins contained within. This report will also analyze the water quality data collected from the Yazoo River Basin over the last few decades. The analysis will pay close attention to the depressed levels of dissolved oxygen concentrations observed throughout the basin. The data will also show the trends and current conditions of nutrient concentrations observed in the main stems of the Steele Bayou and Big Sunflower basins. This report will describe the declining river stages observed over the last 90 years in the Yazoo Basin. These reduced stages show that healthy baseline water quality conditions will continue to be impaired without the availability of adequate year-round flow in the aquatic systems. Finally, this appendix will discuss the impacts to water quality resulting from the two structural features proposed for flood control and water quality in the Yazoo Area Basin. The first structural component consists of a 14,000-cubic-foot-per-second (cfs) pump with a year-round operational pump elevation of 87.0 feet, National Geodetic Vertical Datum (NGVD) in the lower Yazoo Area Basin (Deer Creek). The second feature includes the construction of 34 independent supplemental low flow groundwater wells along headwater streams of the Big Sunflower, Upper Deer Creek and Steele Bayou Basins. The proposed wells will help alleviate the negative environmental impacts resulting from the observed changes during minimum flow conditions within the three watersheds.

1.2 BACKGROUND

2. At the time of writing the Yazoo Backwater Area Reformulation Report of 2007 (YBARR-07), it was assumed that the Yazoo River Basin, like many of the agricultural basins of the Midwest, was a disproportionate contributor of nutrients to the Mississippi River and thus a major contributor to the hypoxic conditions in the Gulf of Mexico. This was primarily due to the close proximity of the Yazoo River to the Gulf of Mexico as well as the level of agricultural activity taking place in the Yazoo River Basin. Water Quality models (SPARROW) were created for the Major River Basins (MRB) (as defined by Goolsby et al. 1999) in the Mississippi and Atchafalaya River Basins (MARB) that lent support to this assessment. Subsequent nutrient data collected from the Yazoo River has shed new light on the false premise that the Basin is a major contributor to the nutrient loading in the Mississippi River and instead it shows that loading from the Yazoo Basin is similar to or below the National Median Concentrations (Coupe 1998).

3. The depleted dissolved oxygen concentrations (< 2 milligrams per liter (mg/L)) found in the Gulf of Mexico typically referred to as the Hypoxic Zone have long been attributed to the

nutrient loading of Nitrogen (N) and Phosphorus (P) from the MARB. Extensive efforts have been made over the last few decades to develop an understanding of where these nutrient loads originate as well as their fate and transport to the Gulf of Mexico.

4. Several numerical models have been created to help with this determination. Many of the early models utilized multiple-regression techniques related to N and P inputs (Goolsby et al. 1999; David et al. 2010; Jacobson et al. 2011) which pointed to the intensive agricultural regions of the Midwest typically referred to as the Corn Belt. The models showed that the Corn Belt region was responsible for contributing the highest loads and yields to the MARB (Gage 1996). These regression techniques fell short in accounting for downstream transport, long term storage (as found in reservoirs), and permanent removal of nutrients such as denitrification (Robertson et al. 2014).

5. A national-scale (SPARROW) model was developed to account for these under estimated variables of nutrient fate and transport in the MARB. SPARROW expounded on the simple regression modeling techniques by using a process-based mass-balanced approach with a spatially detailed digital network of streams and reservoirs. This approach allowed for the attenuation of nutrients to be tracked from their application origin to their downstream location (Robertson et al. 2014). Data collected from 425 stream monitoring stations representing relatively large areas from throughout the entire U.S. was used to estimate N and P yields in several of the national-scale models created by Alexander et al. (2008). Long term mean annual nutrient loads were estimated for each monitoring station by combining regularly measured total nutrient concentrations with daily flow measurements for the 1975-1995 time frame. These annual load estimations were used as input for the SPARROW models. The mean annual load for each station was standardized to the 1992 base year (Alexander et al. 2008). The study was able to generate rankings for nutrient flux (contribution) to the Gulf Hypoxic Zone from each state which contributes to the drainage area of the MARB (Alexander et al. 2008).

6. Regional SPARROW models were also developed for several of the sub basins in the MARB which utilized refined national geospatial datasets based on land-use conditions and N and P inputs similar to 2002. The regional models also utilized inputs from wastewater treatment plants instead of population based surrogates to mimic point sources which had been previously used by Alexander et al. (2008). These regional models also employed estimates from long term averages of N and P loads standardized to the 2002 base year from approximately 3,000 sites in the U.S. (Robertson et al. 2014). The collection of these refined regional models was collectively used to create the MARB SPARROW. The output from MARB SPARROW model shed more light on the origin of N and P and a better understanding of their fate and transport to the Gulf of Mexico. The study was able to generate rankings for nutrient flux (contribution) to the Gulf Hypoxic Zone based on the MRB and the contribution of each state to the MARB. The output from the MARB SPARROW was also utilized to generate rankings for nutrient flux to the Gulf of Mexico from each of the HUC8 watersheds incorporated in the models (Robertson et al. 2014).

7. The output from the national-scale SPARROW models utilized by Alexander et al. (2008) allowed for the ranking of the 30 states considered to be nutrient contributors to the MARB. The state of Mississippi ranked 9th and 8th for total flux of Total Nitrogen (TN) and Total Phosphorus (TP) to the Gulf of Mexico, respectively. This total flux equated to a delivered

yield (kg km^{-2} yr^{-1}) of 863.5 and 101.6 for TN and TP, respectively for the state. The state of Illinois was ranked as the highest contributor for total nutrient flux. This equated to a delivered yield (kg km^{-2} yr^{-1}) of 1,734.9 and 117.4 for TN and TP, respectively (Alexander et al. 2008).

8. The output from the MARB SPARROW model utilized by Robertson et al. (2014) allowed for the ranking of nutrient contribution to the Gulf of Mexico based on MRB regions as well as states in the MARB. Goolsby et al. (1999) classified the MARB into eight MRB to help delineate the origin of nutrient input into the Mississippi River Watershed. The Yazoo Basin was included in one of the southernmost MRB labeled as Lower Mississippi (186,000 km^2) which is largely contained within the states of Mississippi, Arkansas, and Louisiana (Robertson et al. 2014). This region has traditionally been centered on agricultural production due to the high productivity of the deltaic soils and the wet climate. The Lower Mississippi MRB was ranked 6th and 4th in descending order out of the 9 MRB's for delivered TN Load and TP Load (112,000 and 15,700, tons), respectively. When considering Total Delivered Yield of TN and TP, the Lower Mississippi MRB was ranked 4th and 2nd (603 and 84.6, kg/km^2), respectively. For comparison, the MRB labeled as Middle Mississippi which is comprised mostly of the Ohio Valley was ranked as the highest contributor for delivered TN Load and TP load (337,000 and 23,300 tons), respectively. The Middle Mississippi was also ranked as the highest contributor for Total Delivered Yield of TN and TP, (1,230 and 85.0, kg/km^2), respectively (Robertson et al. 2014).

9. The MARB SPARROW model output ranked the state of Mississippi as 13th and 11th in descending order of the 30 states considered for Delivered Load and Delivered Yield of TN (32,356,714 kg and 568 kg/km^2), respectively. The state of Iowa was the highest contributor for Delivered Load of TN at 203,348,552 kg. The state of Illinois was the highest contributor for Delivered Yield of TN at 1,804 kg/km^2 (Robertson et al. 2014, supplement).

10. When considering Delivered Load and Delivered Yield of TP, the state of Mississippi was ranked 11th and 2nd (5,244,570 kg and 92.1 kg/km^2), respectively. The state of Missouri was the highest contributor for Delivered Load of TP at 15,051,168 kg. The state of Illinois was the highest contributor for Delivered Yield of TP at 97.2 kg/km^2 (Robertson et al. 2014, Supplement).

11. The MARB SPARROW model output ranked the nutrient delivery from 822 HUC8 watersheds that contribute to the Mississippi River. The Steele Bayou HUC8 (08030209) ranked as number 241 and number 303 in descending order for delivered TN Load and TP load (1,910,808 and 145,091 kg), respectively. When considering delivered yield of TN and TP, the Steele Bayou HUC8 (08030209) was ranked #192 and #138 (67.53 and 889.3, kg km^{-2} yr^{-1}), respectively. The Big Sunflower HUC8 (08030207) was ranked as 42nd and 36th in descending order for delivered TN load and TP load (6,230,620 and 556,058 kg), respectively. When considering delivered yield of TN and TP, the Big Sunflower HUC8 (08030207) was ranked number 158 and number 173 (842.6 and 75.2, kg km^{-2} yr^{-1}), respectively. The Lower Yazoo HUC8 (08030208) was ranked as number 508 and number 535 in descending order for delivered TN load and TP load (355,658 and 34,652 kg), respectively. When considering delivered yield of TN and TP, the Lower Yazoo HUC8 (08030208) was ranked number 237 and number 225 (609.0 and 59.3, kg km^{-2} yr^{-1}), respectively. The Upper Yazoo HUC8 (08030208) was ranked as number 144 and 68th in descending order for delivered TN load and TP load (3,149,347 and

448,603 kg), respectively. When considering delivered yield of TN and TP, the Upper Yazoo HUC8 (08030206) was ranked number 201 and 91st (701.8 and 100.0, kg km^{-2} yr^{-1}), respectively (Robertson et al. 2014).

12. The MARB SPARROW model lends support to the general assertion that nutrients from the State of Mississippi specifically the agricultural regions of the Steele Bayou and Big Sunflower Basins are not the highest contributors to the overall loading of TN to the Gulf of Mexico (Hicks et al. 2017). The national water quality stream assessment published by USGS asserted that the lower concentrations of nitrogen in streams of the Southeast are partly due to the soil and hydrologic characteristics that support greater loss of nitrogen through biological uptake and denitrification before overland flow reaches the streams (Dubrovsky et al. 2010). The Big Sunflower HUC8 sub-basin did rank as 36th for delivered yield for TP which is based on the overall area of the drainage basin. The rankings for TN and TP loads coming from the Big Sunflower HUC8 watershed can be attributed to several factors. The relatively close proximity of the outlet of the Big Sunflower River to the Yazoo River, thence into the Mississippi River, and thence into the Gulf of Mexico, minimizes the available time for in-stream utilization. The slightly higher rankings associated with TP can be partially attributed to the properties associated with the highly erosive Loess soils of which readily bind with the phosphorus present. However the overall load to the Gulf of Mexico is far less than that contributed to the Mississippi River from the upper Midwest. It should be noted that a third MARB SPARROW model had been conducted during the time this report was written but has not been published. This most recent iteration is believed to corroborate the premise that the Yazoo Basin is not a disproportionate contributor to the nutrient loading of the Gulf Hypoxic Zone.

2.0 DISSOLVED OXYGEN AND SUSPENDED SOLIDS

2.1 GENERAL

13. Dissolved Oxygen (DO) has long served as one of the primary indicators of aquatic health in aquatic ecosystems. Adequate concentrations of DO are mandatory to sustain healthy populations of diverse fish species. The rivers and bayous have little chance of sustaining their fish and wildlife support classification without adequate concentrations of year around DO. Low DO conditions are impacted by warm climates as well as excessive concentrations of suspended solids which can negatively influence the overall population of aquatic communities.

14. A water quality monitoring program was initiated in 2004 in the Yazoo Backwater Area by the Vicksburg District which extended through 2015. The Steele Bayou Monitoring Program (SBMP) was initially focused on capturing the effectiveness of recently constructed erosion control structures situated along the edge of agricultural fields on top bank of the Steele Bayou Basin. After realizing the extensive value of the program, monitoring quickly grew to include tributaries in the Big Sunflower Basin. The similar nature of the Big Sunflower Basin allowed it to serve as a control for the work performed in the Steele Bayou Basin. In addition to monthly grab samples, water quality sondes were utilized to collect hourly, in-situ data for DO, pH, Turbidity, Conductivity, and Temperature. The sondes collected data at four locations in the Steele Bayou Basin: Steele Bayou at Low Water Bridge, Steele Bayou at Grace, Main Canal at Surveillance Station Road, and Black Bayou at Highway 12. This captured conditions in the upper, middle, and lower part of the Steele Bayou Basin. Additionally, one sonde was deployed

on the Big Sunflower River for hourly data collection at Anguilla. This site captured conditions in the middle of the Big Sunflower Basin. The sondes were deployed from the bridge decking in corrugated metal pipes or polyvinyl plastic tubes with open bottoms and slots in the side wall. The sondes were suspended into the water approximately two to five feet from the bottom so that the probes would remain inundated during low flow conditions. The grab samples were analyzed for Total Suspended Solids (TSS), Total Dissolved Solids, Total Organic Carbon, Dissolved Organic Carbon, Total Kjeldahl Nitrogen, Nitrate/Nitrite, TN, TP, Total Dissolved Phosphorus, Orthophosphate, Chlorophyll A (CHLOROA), Pheophytin A, and Biochemical Oxygen Demand. Laboratory analysis was conducted on all the samples according to Environmental Protection Agency (EPA) methods. In addition to the locations previously mentioned, the grab samples were collected from the Big Sunflower River at Holly Bluff, Little Sunflower River at Dummy Line Road, and Steele Bayou on Highway 465 downstream of the Steele Bayou Structure. Since its inception, the stations utilized in the SBMP have been able to capture the pooling effects of most of the backwater flood experienced in the Yazoo Delta. Figure 2-1 shows the locations of stations previously described.

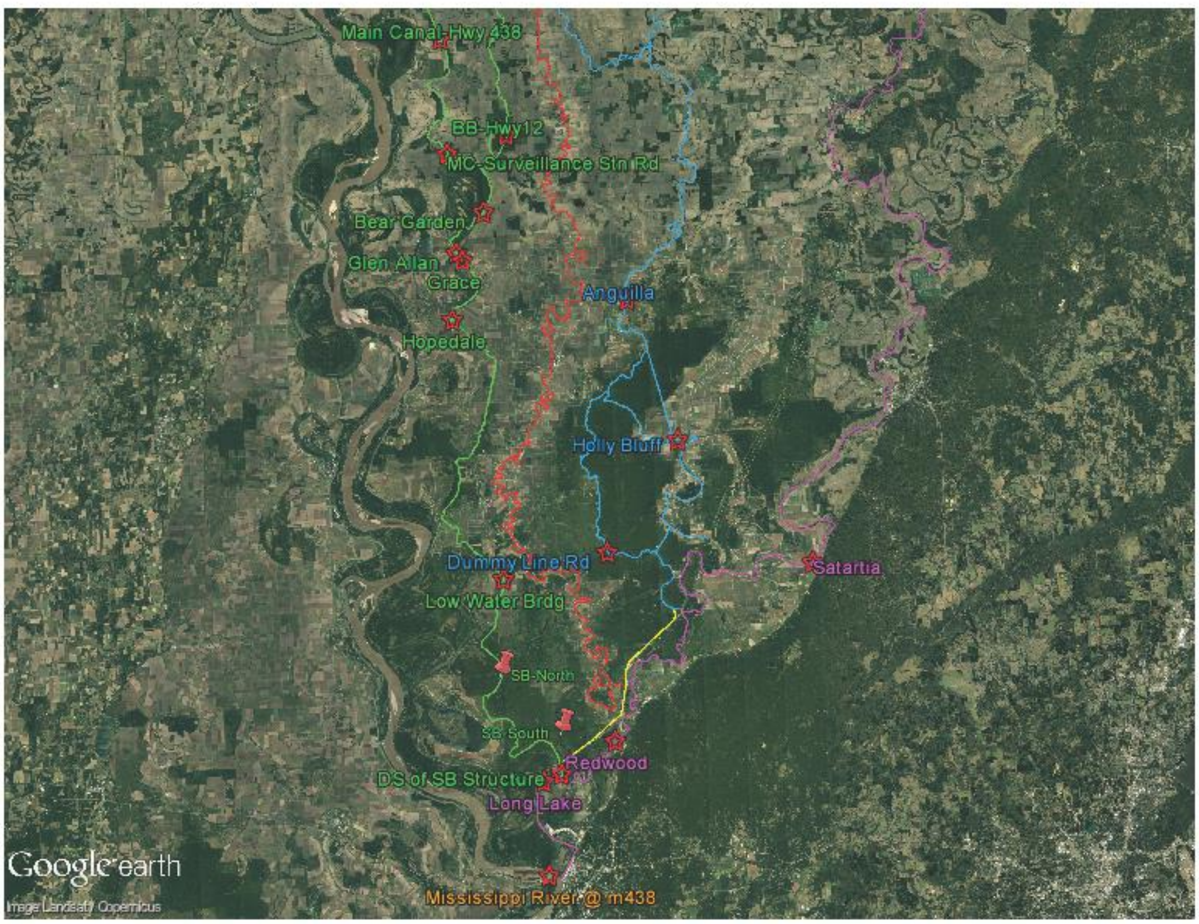

Figure 2-1. SBMP and NWIS stations utilized for deployment of water quality sondes and monthly grab samples.

15. A statistical analysis was generated from the data using SAS Univariate software. The software was used to calculate the daily mean values from the hourly data collected. Mean values were also calculated from the concentrations of Total Suspended Solids (TSS) measured from the grab samples. The mean values were grouped on an annual basis for each available year and subdivided on a monthly basis. This grouping allowed for a more direct comparison of the agricultural growing season and corresponding irrigation typically found in the Yazoo Backwater Area.

16. Additional water quality data has been collected by the USGS on many of the primary tributaries in the Yazoo Backwater Area stretching back to the 1970's. Information related to TSS concentrations was retrieved from surface water grab samples accessed through USGS's online National Water Information System (NWIS) website. Available data was sorted according to the HUC8 watersheds and analyzed through 2016. The watersheds of interest were the Big Sunflower, Steele Bayou, Upper Yazoo, and the Lower Yazoo which were labeled as BigSun, Steele, UppYaz, and LowYaz respectively. A statistical analysis was generated from the data using SAS Univariate software. The software was able to define values for mean, max, and minimum concentrations of DO and TSS. The statistical output was grouped by month, season, year, and decade. The addition of this data helped to supplement the SBMP data previously mentioned.

2.2 DISSOLVED OXYGEN (TEMPERATURE)

17. Many of the tributaries in the Yazoo Backwater Area have suffered from depressed DO which impose stressful conditions on the aquatic ecosystem. Lower DO observations start in the spring and extend through the fall months when average temperatures exceed 20 degrees Celsius. These conditions are exacerbated during extended backwater floods, when runoff is trapped in the basin due to the closure of the Little Sunflower and Steele Bayou Water Control Structures.

18. The 1986 EPA handbook – *Quality Criteria for Water* (EPA 440/5-86-001) sets the one day minimum for ambient DO concentration for warm water streams to be 5.0 mg/L for all early life stages of fish which include embryonic, larval, and early juvenile forms. The SBMP conducted by the Vicksburg District has documented how these streams have experienced reduced DO concentration in both the Steele Bayou and Big Sunflower Basins.

19. Mild winters and hot summers are not uncommon in the Yazoo Basin. The data analyzed from the SBMP shows that mean monthly water temperatures in the Yazoo Basin reach 20 degrees Celsius in April and remain at that temperature or greater until October. Furthermore, temperatures don't fall below 15 degrees Celsius until November (Figure 2-2).

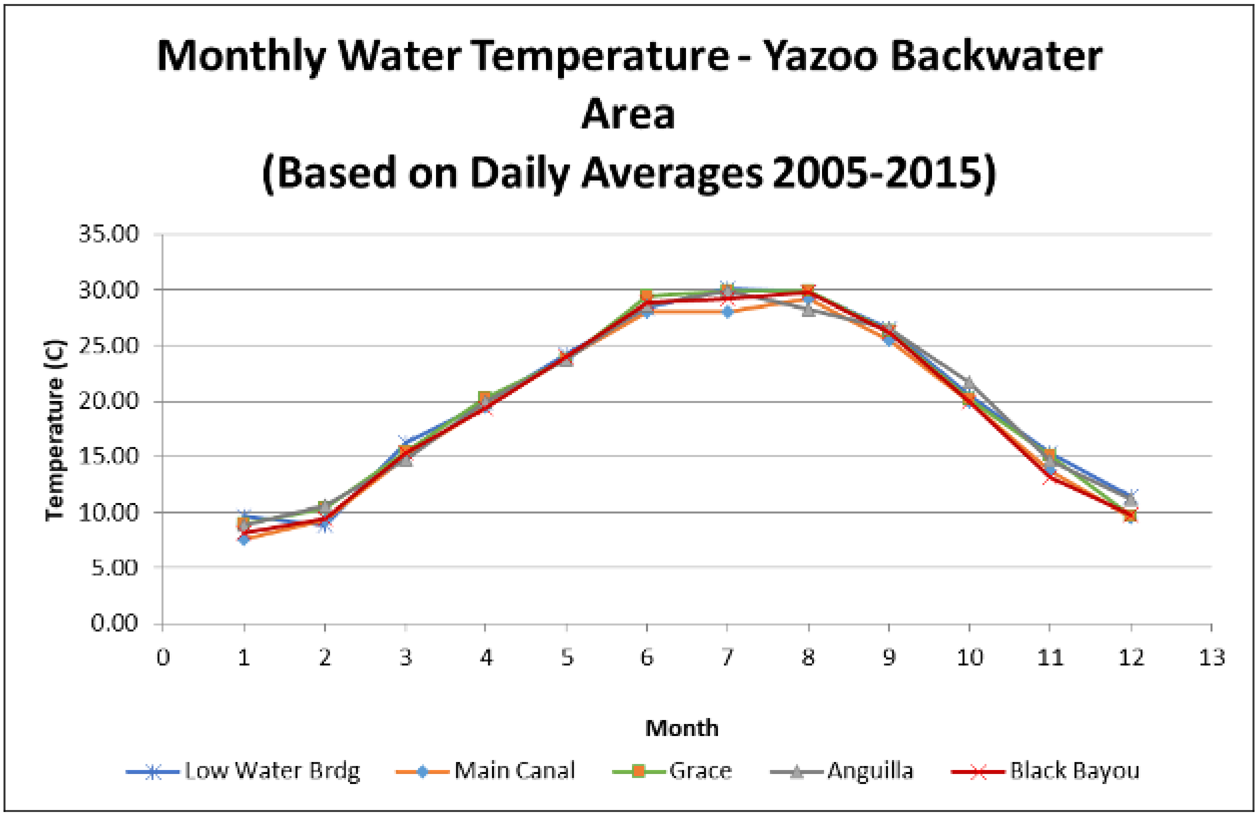

Figure 2-2. SBMP–Monthly Mean Water Temperatures Derived from Daily Means Compiled from Hourly Sonde Data (2–5 feet from bottom).

20. These warmer conditions have a significant impact on the maximum oxygen concentration that can be dissolved into a stream. Figure 2-3 shows that the DO saturation percentage from the sonde data for the streams monitored in the Steele Bayou Basin (Main Canal, Black Bayou, Grace, Low Water Bridge). The DO saturation rarely reaches 50% from April to November. The sonde data collected from the Big Sunflower River (Anguilla) shows the DO saturation percentage falling below 50% in April and slowly climbing to 60% and 75% in August and October, respectively. The slightly higher DO saturation measurements observed from July to October are likely due the irrigation return flows coming into the Big Sunflower River. This corresponds to the time of intense irrigation from in the Big Sunflower Basin which has a higher percentage of agriculture production than the Steele Bayou Basin.

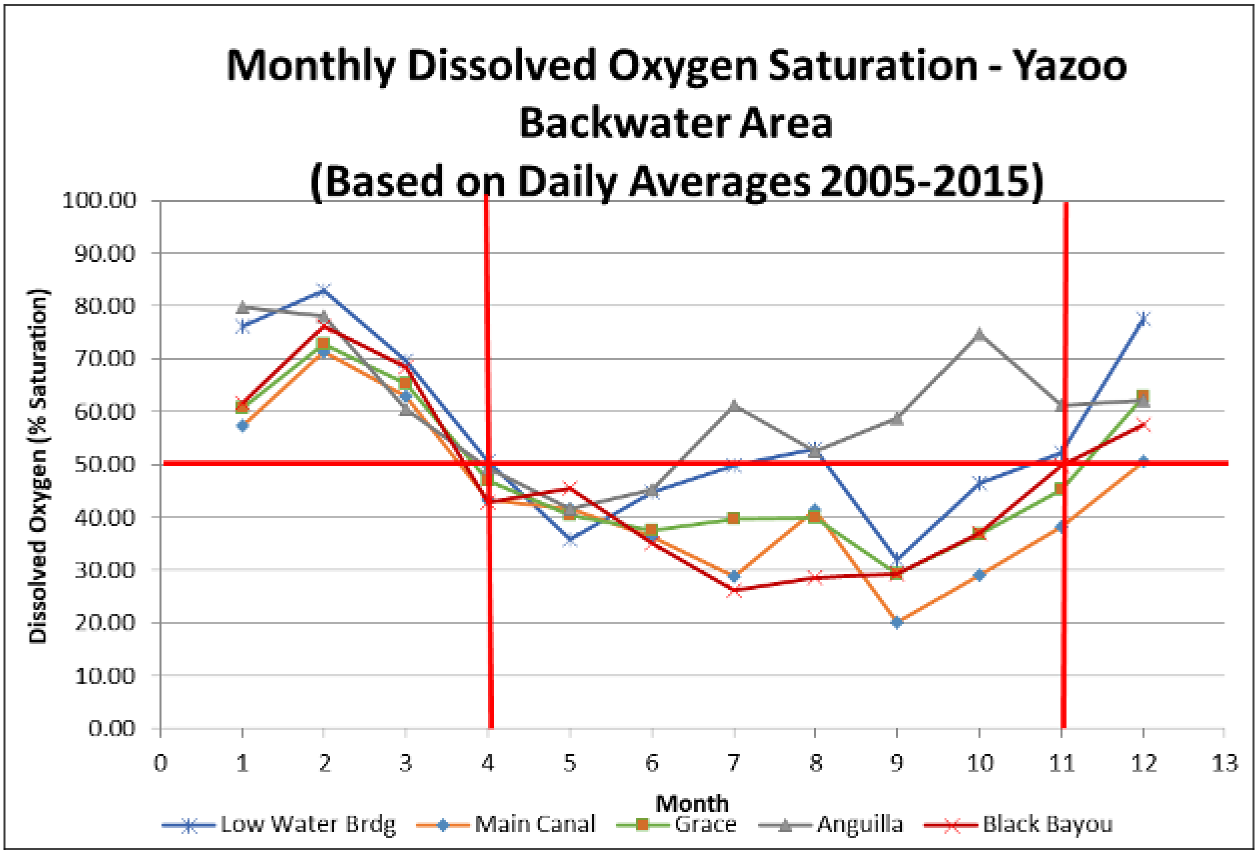

Figure 2-3. SBMP–Monthly Mean of DO Saturation Percentage Derived from Daily Means Compiled from Hourly Sonde Data (2–5 feet from bottom).

21. The values displayed in Table 2-1. Dissolved Oxygen Saturation Table for Yazoo Backwater Area show saturation potential for DO concentration for freshwater typically found in the Yazoo Basin as temperature increases. When water temperatures reach 20 degrees Celsius, the 50% DO saturation potential falls below 5.00 mg/L.

Table 2-1. Dissolved Oxygen Saturation Table for Yazoo Backwater Area

Temperature (C)	**Dissolved Oxygen Concentration (mg/L)**	
	100%	50%
15	10.13	5.07
20	9.14	4.57
25	8.30	4.15
30	7.60	3.80

22. When warm weather is combined with conditions of minimal DO saturation, aquatic life typically suffers from long periods of low DO. Figure 2-4 plots the mean monthly DO concentration (mg/L) observed in the Yazoo Backwater Area. The published EPA requirement

for minimal DO concentration of 5.0 mg/L for early life stages of fish was not met in most years beginning in April and extending through November for the Streams in the Steele Bayou Basin. The minimal DO concentration for streams in the Big Sunflower Basin again started in April and extended through October. These depleted DO conditions for over half of the year in the Yazoo Backwater Area impose a severe impact on the overall health of the aquatic ecosystem.

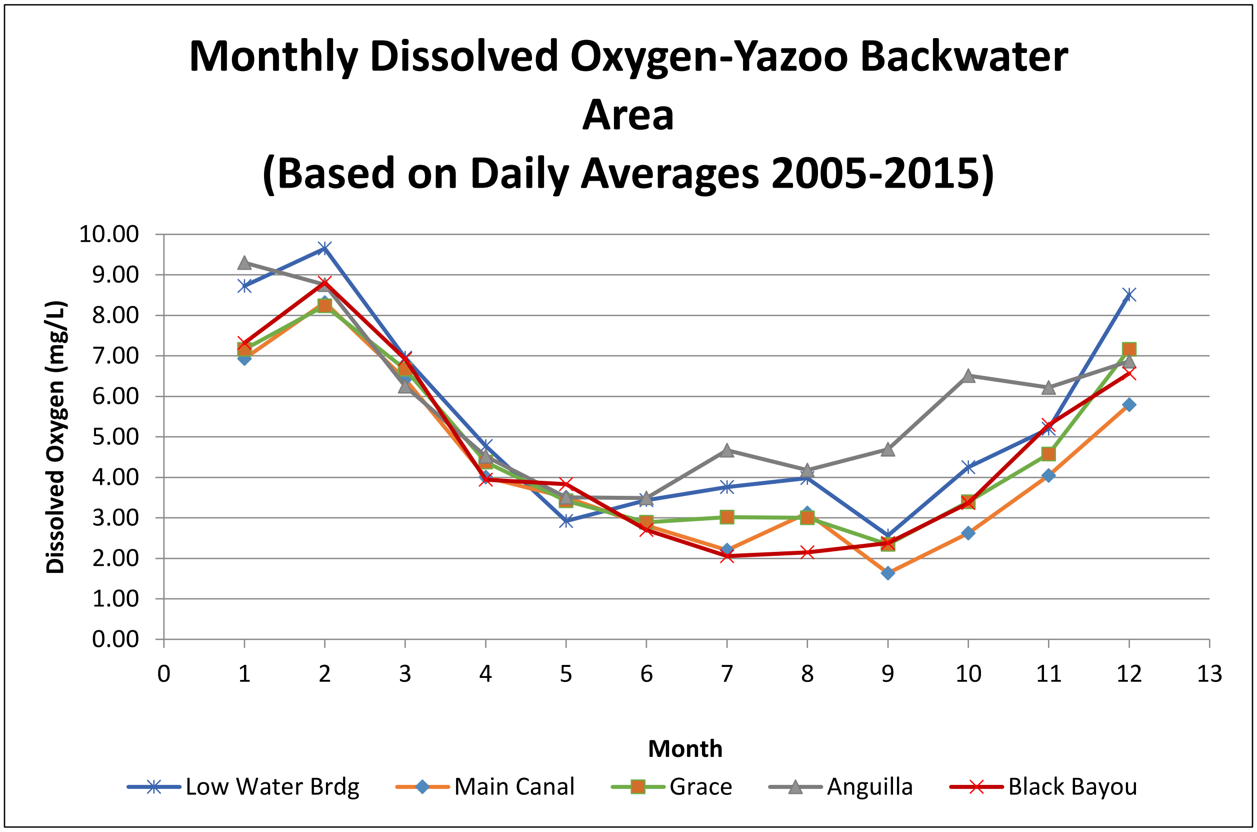

Figure 2-4. SBMP–Monthly Mean DO Concentrations Values Derived from Daily Means Compiled from Hourly Sonde Data (2-5 feet from bottom).

2.3 DISSOLVED OXYGEN (FLOODS)

23. The SBMP in situ data was used to compile the monthly averages for DO. The hourly in situ data has been displayed in Figure 2-5 using the daily averages. The data has been plotted with the mean daily elevation (NGVD) for Steele Bayou at Grace Gage. The two areas shaded in red highlight the decrease in DO as water levels reach higher stages. These two events coincide with the Yazoo Backwater Area Floods of 2008 and 2009. The two area shaded in green also highlight the decrease in DO as water levels reach higher stages during a Yazoo headwater flood. The inverse effect can be seen for higher DO concentrations when lower river stages are observed. It should be noted that the weir at the Grace Gage has a crest elevation of 86.0 feet (NGVD) which is also one foot below the elevation the Yazoo Backwater Pumps will turn on. Figure 2-5 shows the DO found in the channel is already low before it becomes trapped behind the Steele Bayou water control structure.

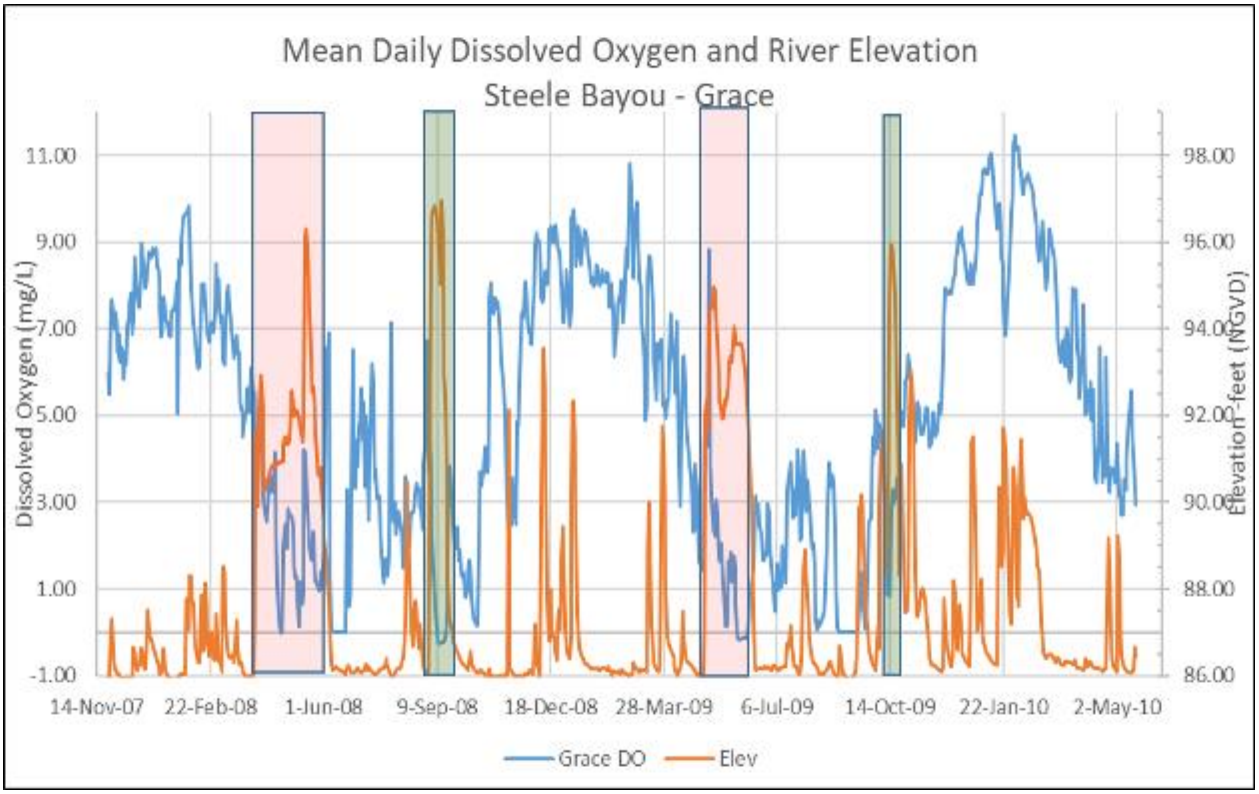

Figure 2-5. SBMP–Daily Mean DO Concentrations (2-5 feet from bottom) and Elevations for Steele Bayou at Grace Gage.

24. A similar trend as seen in Figure 2-5 can be observed in Figure 2-6 where daily DO concentrations decrease on the Big Sunflower River at Anguilla Gage as river stages increase. The two areas shaded in red highlight the decrease in DO as water levels increase coinciding with the Yazoo Backwater Area Floods of 2008 and 2009. The area shaded in green also corresponds to a decrease in DO as water levels reach higher stages which depicts a headwater event. Likewise, the higher DO concentrations are observed when river stages are low.

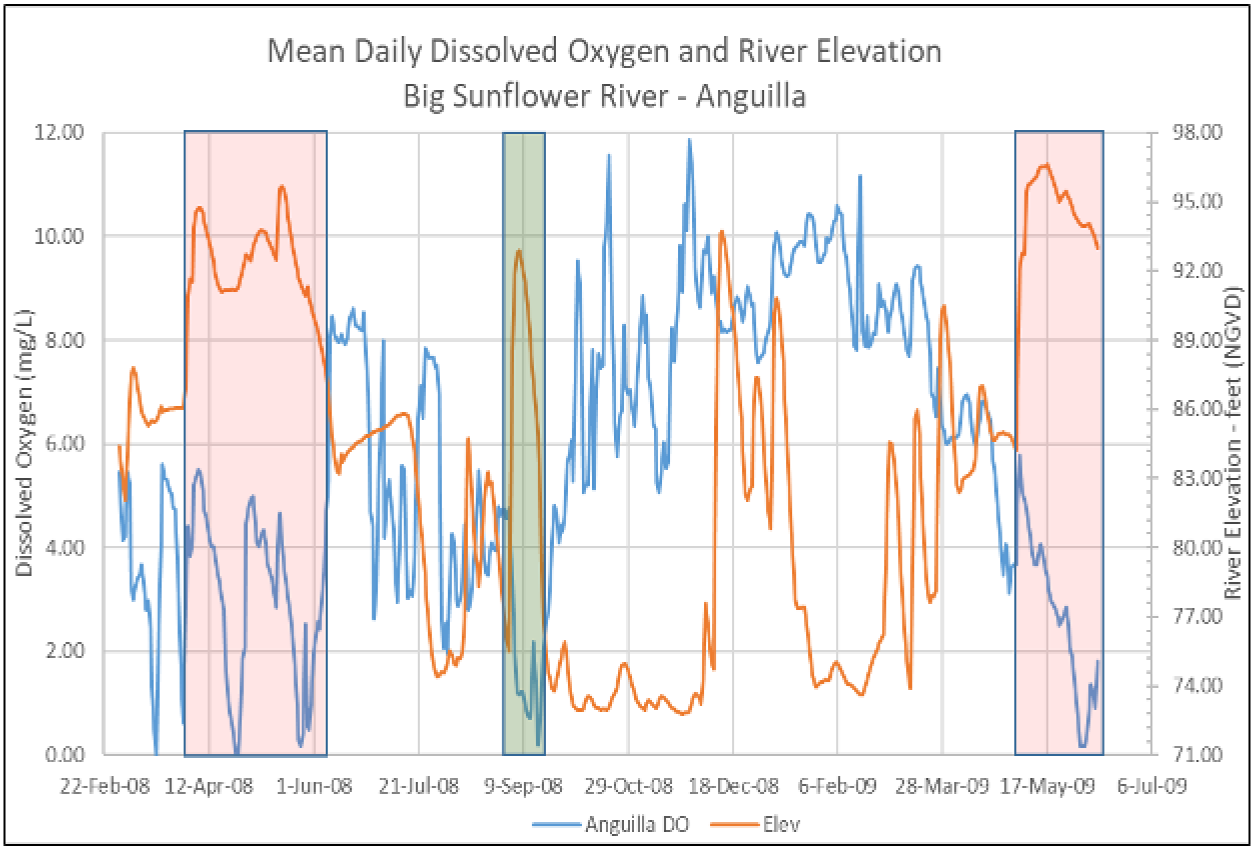

Figure 2-6. SBMP–Daily Mean DO Concentrations (2-5 feet from bottom) and Elevations for the Big Sunflower River at Anguilla Gage.

25. Data collected from subsequent floods since the YBARR-07 show that long duration floods impose a detrimental impact on the DO levels found in the water column. During the Yazoo Backwater floods of 2011, 2015, and 2019 the Vicksburg District collected water profile data for Dissolved Oxygen and Turbidity throughout the Yazoo Backwater Area.

26. Figure 2-7 shows how the DO concentration decreases below 5.0 mg/L with depths below 7 and 10 feet at the upper, middle, and lower portions of the Steele Bayou and Big Sunflower Basins. This data was collected during the latter half of the Yazoo Backwater Flood event. Most of the stream locations would have been experiencing low flow or stagnant water conditions minimizing the potential for agitation and re-aeration.

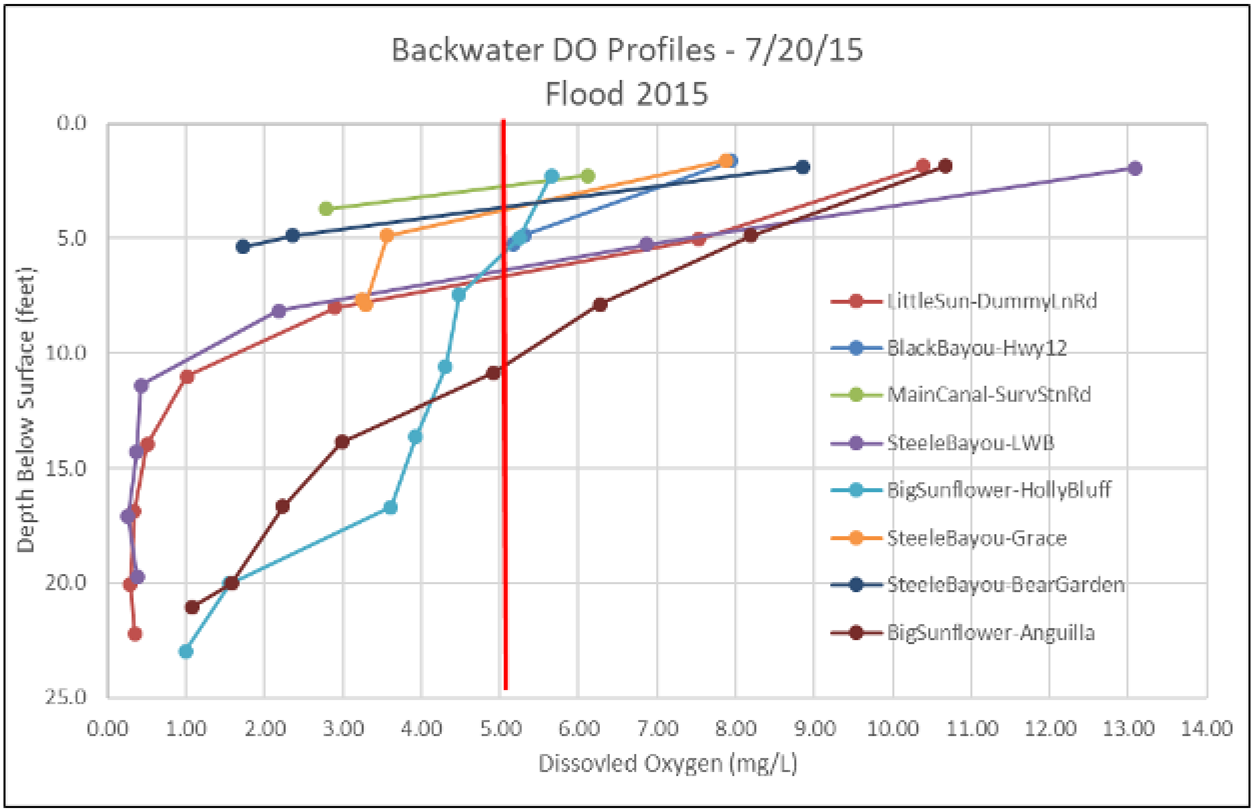

Figure 2-7. DO Water Column Profiles of Streams in the Yazoo Basin taken on July 20, 2015. This data was collected during the peak of the flood which lasted from 6 June to 8 August.

27. The DO profile displayed in Figure 2-8 shows two successive measurements (one week apart) on the Little Sunflower River at Dummy Line Road during the same Backwater Flood event of 2015. A slight reduction of DO concentration can be seen within the top five feet of the water column for the latter measurement. The layer of water at the surface containing a DO concentration above 5.0 mg/L reduces slightly from 7 to 5 feet thick.

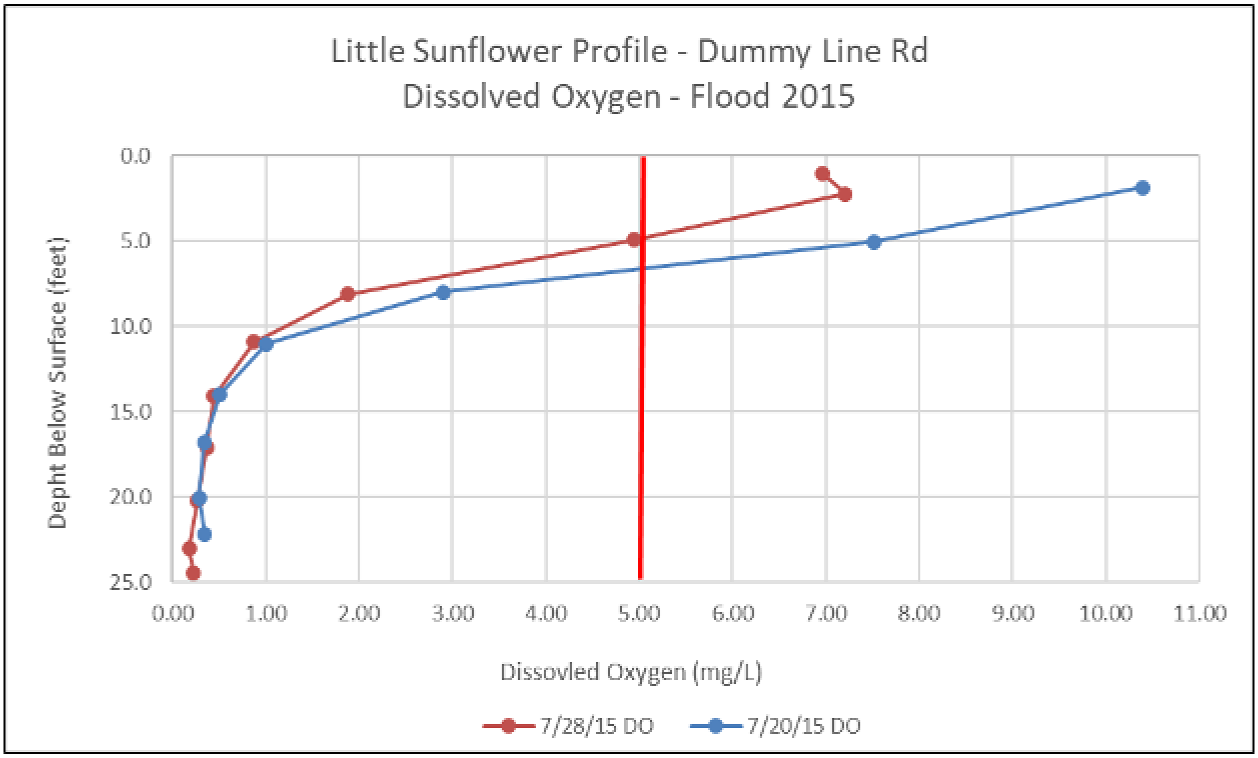

Figure 2-8. DO Water Column Profiles of the Little Sunflower River at Dummy Line Road taken during the Flood of 2015. This data was collected during the middle of the flood which lasted from 6 June to 8 August.

28. Similar DO water column profiles were collected immediately upstream of the Steele Bayou Structure during the Yazoo Backwater Flood of 2019. Figure 2-9 shows reduced concentrations of less than 5.0 mg/L below the upper seven feet of the water column. This is again likely due to the stagnant flow conditions found in the bottom of the Steele Bayou Basin. The slight increase in DO concentration over the two-week time frame is likely due to the effects of primary productivity which will be discussed later in the document.

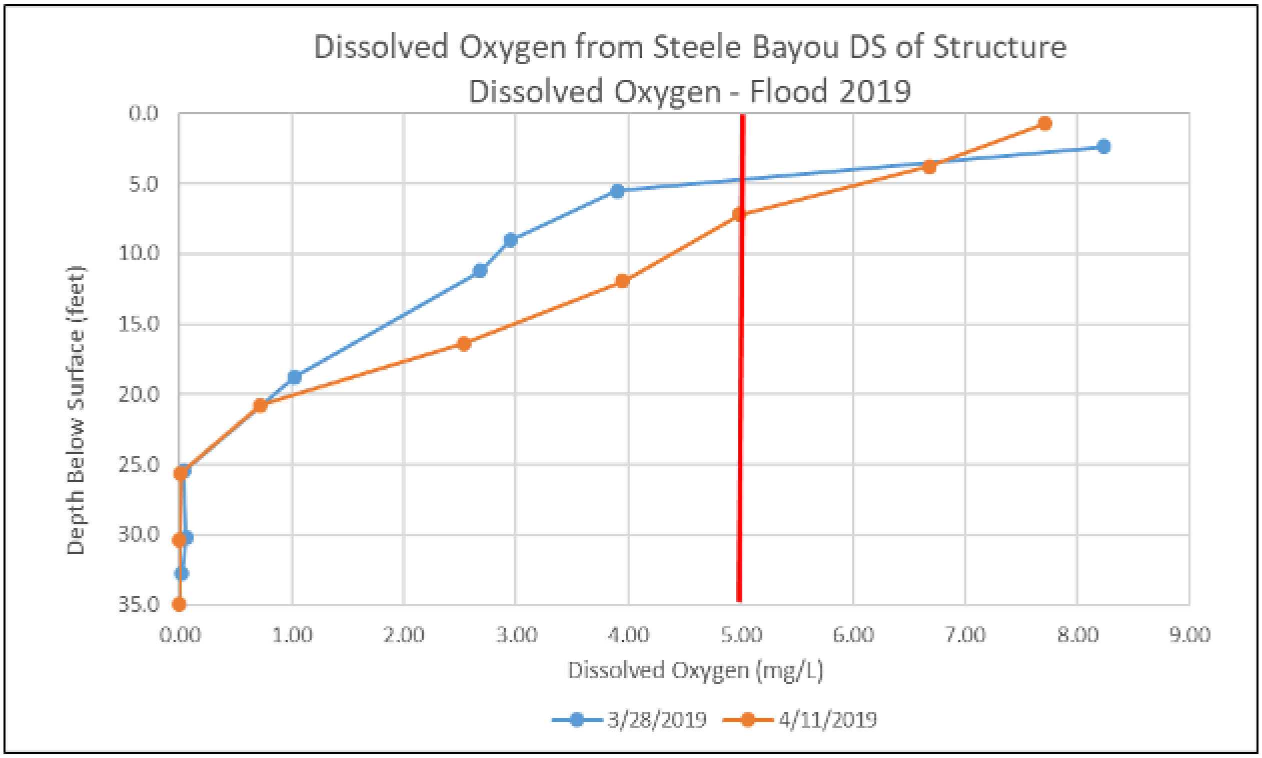

Figure 2-9. DO Water Column Profiles from Steele Bayou Downstream of the Steele Bayou water control structure at Highway 465. This data was collected during the middle of the flood which lasted from 6 June to 8 August.

29. Low DO concentrations were also observed outside of the Yazoo Backwater Area in the channels of the Big Black River and the Yazoo River as a result of the backwater effects resulting from the high stages of the Mississippi River. Water column profiles were collected on the Big Black River at Highway 61 (approximately 11 miles upstream of confluence with the Mississippi River) and the Yazoo River at Satartia (approximately 53 miles upstream of confluence with the Mississippi River) during the Flood of 2011.

30. The profiles collected from the Big Black River, which flows directly into the Mississippi River south of Vicksburg, show the effects of the colder water from the Mississippi River moving upstream on the Big Black River as the flood progresses. The minimal DO concentration at the surface on the 13 May 2011 is representative of the warmer water flowing downstream from the Big Black River as the cooler water from the Mississippi River moves upstream along the bottom (Figure 2-10 and Figure 2-11). This phenomenon is depicted by the wedge shape from the surface to a depth of approximately 10 feet. A similar change in conductivity can be seen on 13 May 2011 where the measurements quickly change from less than 0.10 to greater than 0.25 µS/cm at depths from 5 to 10 feet (Figure 2-12). A similar effect can be seen on 19 May 2011 with the "wedge" moving down deeper in the water column. The last two days of observation show a decrease in the conductivity observed which indicates that mixing of the surface water from the Big Black River, the older Mississippi River water which had previously migrated upstream, and the new Mississippi River water continuing to push its way up the channel.

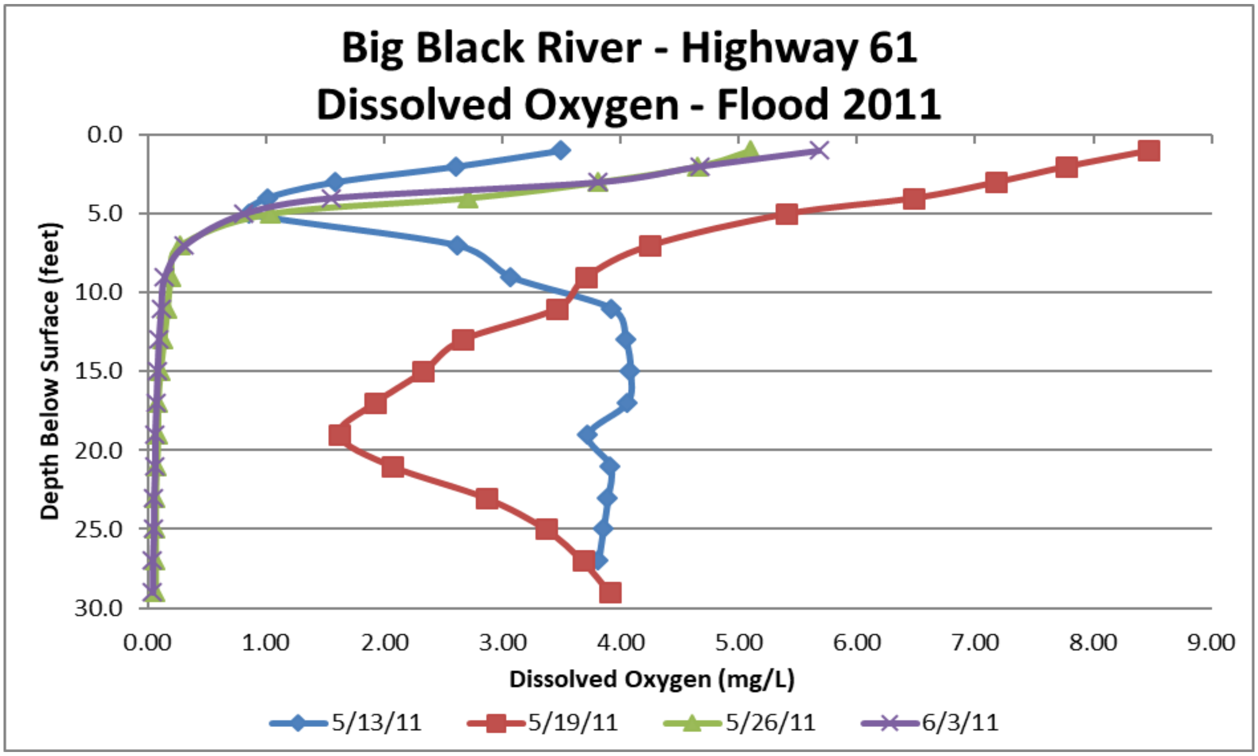

Figure 2-10. Depleted DO Concentrations from the Big Black River at Highway 61 throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

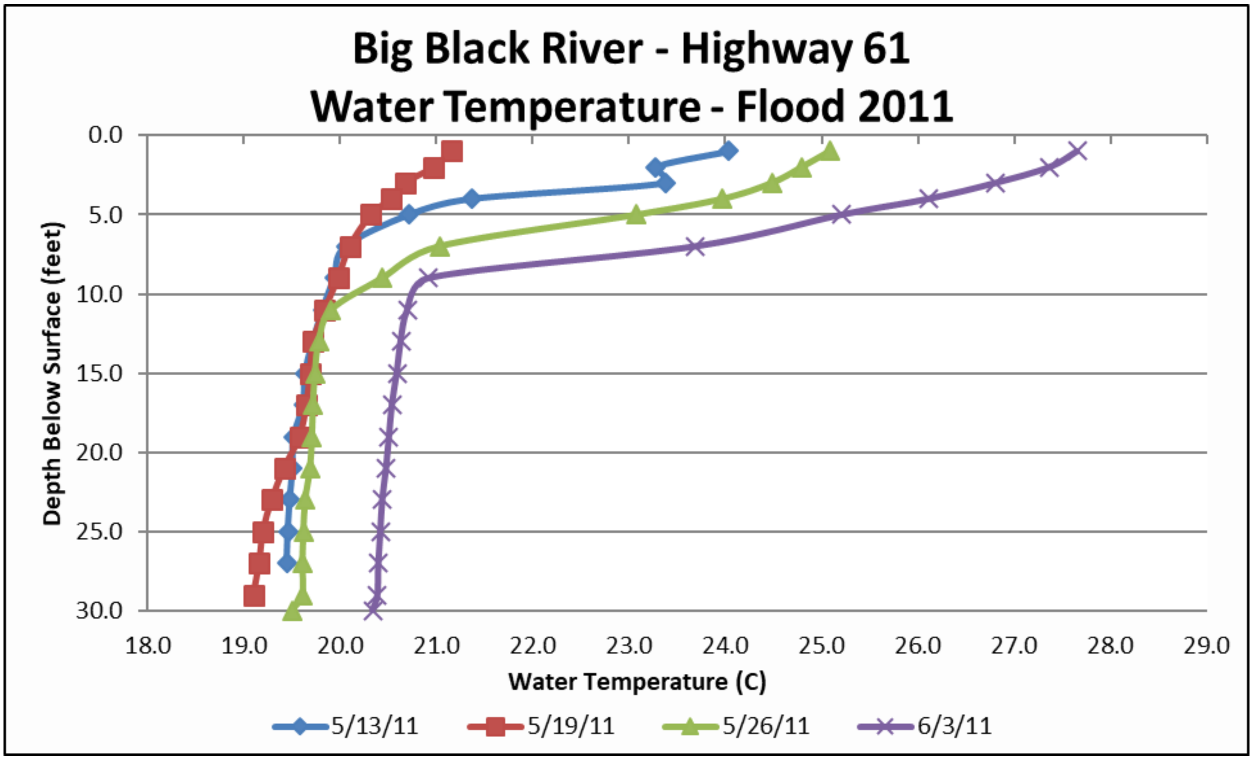

Figure 2-11. Water temperature from the Big Black River at Highway 61 throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

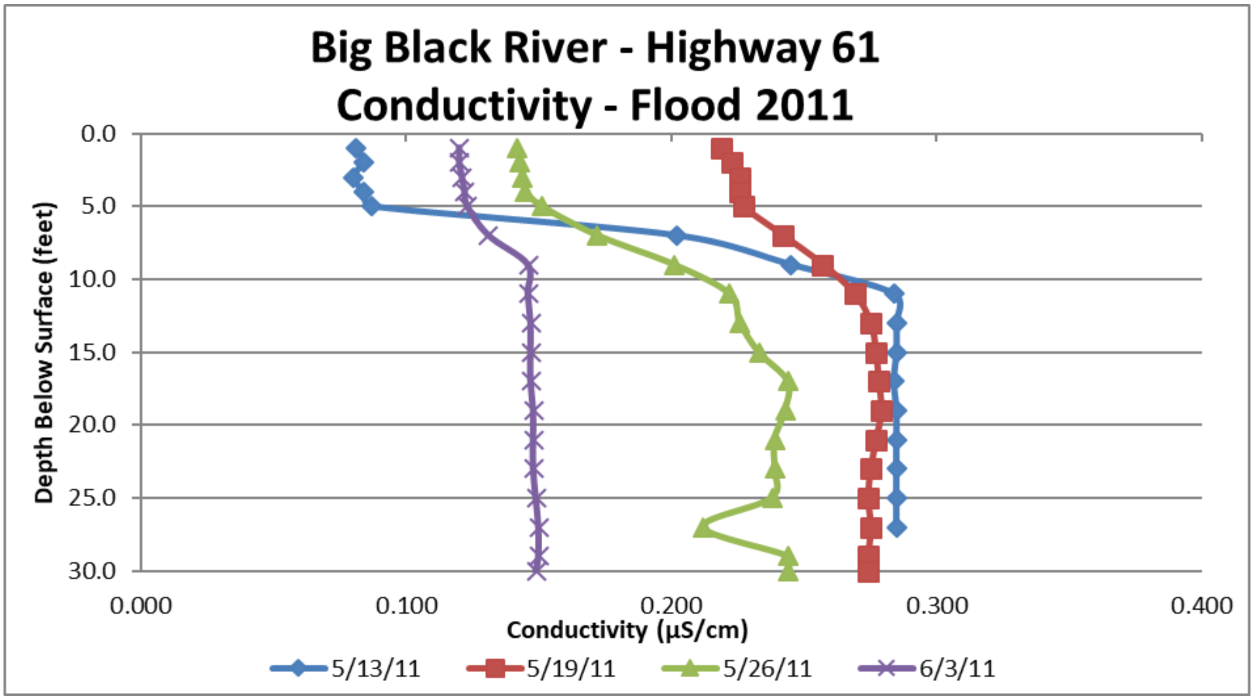

Figure 2-12. Conductivity measurements from the Big Black River at Highway 61 throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

31. The profile collected from the Yazoo River at Satartia which flows directly into the Mississippi River at Vicksburg shows a pattern similar to the one previously described, which has a slight rise and fall of DO concentration throughout the flood event. A small increase in DO concentration in the surface layer of water (approximately 5 feet) can be seen during the early part of May when the Mississippi River was rising (Figure 2-13). The DO concentration quickly falls out for the latter portion of May and into June as water exchange with the Mississippi River becomes negligible and the flows are held to a minimum.

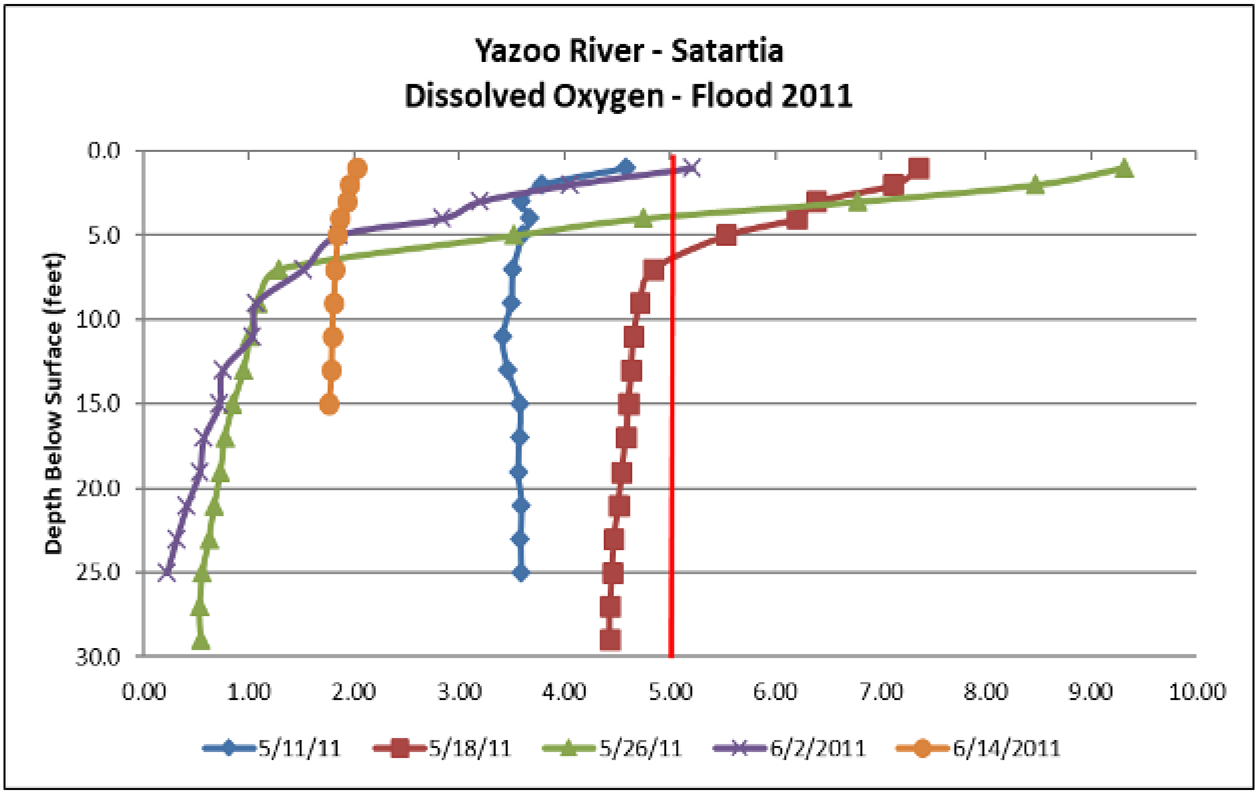

Figure 2-13. Depleted DO Concentrations from the Yazoo River at Satartia throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

32. During the Flood of 2015, a DO profile was collected on Steele Bayou at Highway 465 downstream of the Steele Bayou water control structure. This location is outside of the bathtub created by the Yazoo Backwater levee and is within 1,500 feet of the confluence with the Yazoo River and approximately nine miles from the Mississippi River. The graph in Figure 2-14 demonstrates the effects of stagnant conditions on DO when the high stages of the Mississippi River backs upstream into its tributaries minimizing flow. Theses profiles were collected towards the latter half of the flood event and show low DO conditions throughout the entire water column.

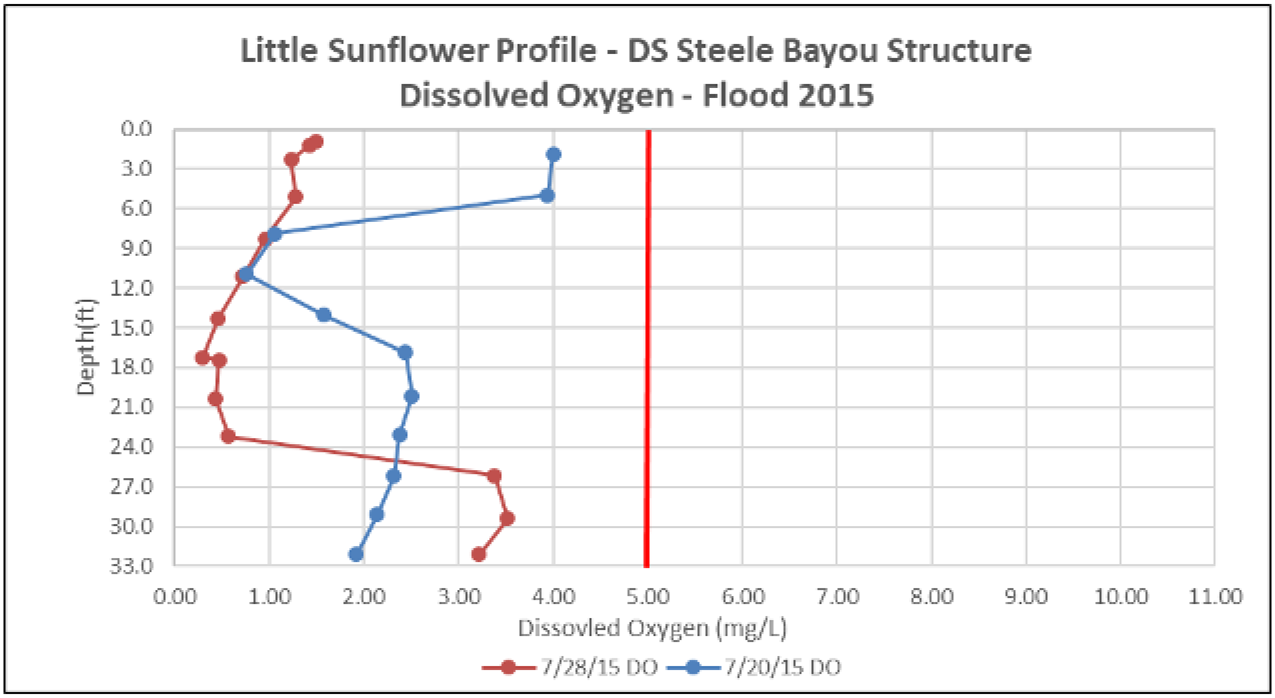

Figure 2-14. DO water column profiles of Steele Bayou at Highway 465 taken during the Flood of 2015. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

33. During the Yazoo Backwater flood of 2019, hourly measurements were collected by water quality sondes in the flooded timber at two locations adjacent to Steele Bayou. The first and northern most site was placed approximately 600 feet west of the Steele Bayou Channel and 14.7 miles upstream of the Steele Bayou water control structure. The second and southern most site was placed approximately 750 feet north of Cypress Bayou, on the eastern side of the Steele Bayou Channel, and at a distance of 3.1 miles upstream of the Steele Bayou water control structure (Figure 2-15). The sondes were suspended from tree limbs to a depth of 3 feet from the bottom. The daily means for DO and depth, plotted in Figure 2-15 shows how the minimal DO concentrations fluctuated during the later weeks of April, and the depth fluctuated during the second Steele Bayou water control structure opening for the 2019 flood (shaded area). It should be noted that the initial water control structure opening is not represented in the time frame in Figure 2-15. During the first week of May, the DO concentrations completely fall to 0.00 mg/L and remain below 0.20 mg/L for the duration of the deployment period until they are retrieved at the end of June. This data further reiterates the depletion of DO in the Yazoo Backwater Area during extended flood events.

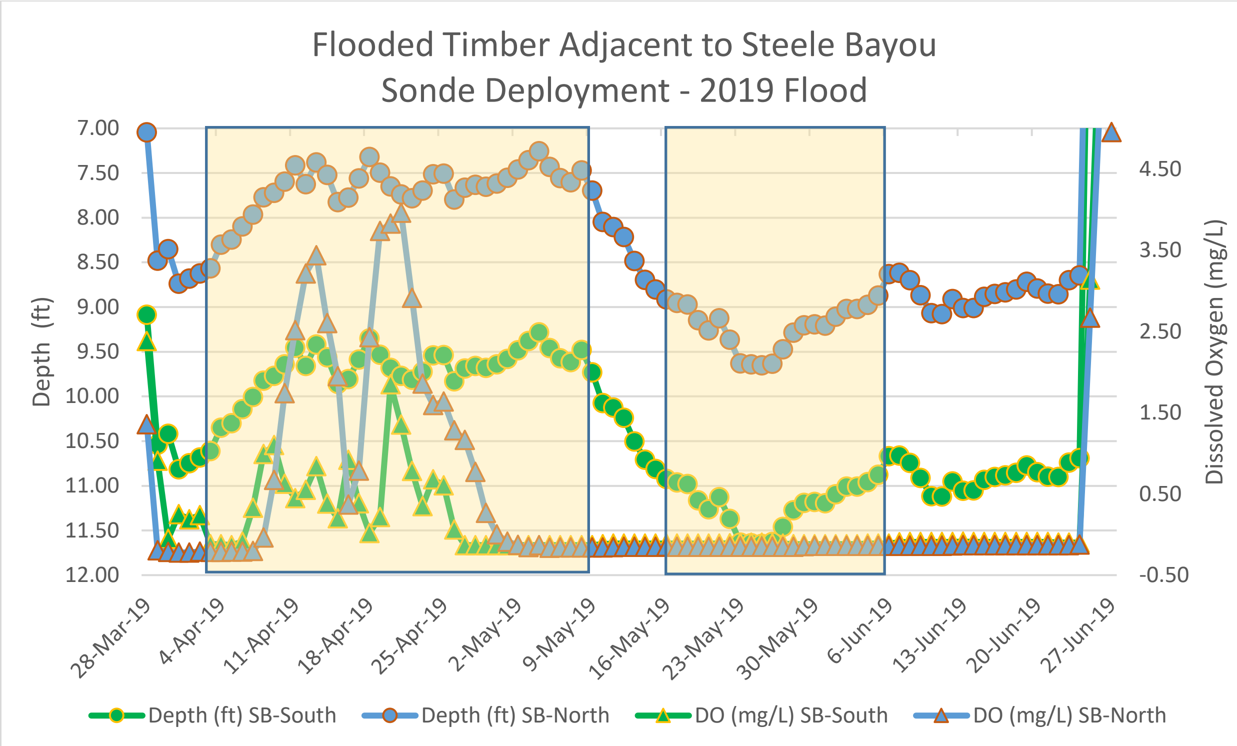

Figure 2-15. Daily mean DO concentrations (3 feet from the bottom) and depth below the surface from sondes deployed in flooded timber adjacent to Steele Bayou during the 2019 flood event: SB-North (above Muddy Bayou water control structure), SB-South (above Steele Bayou water control structure).

34. During the Yazoo Backwater flood of 2020, multiple measurements were collected by water quality sondes throughout the day from the Steele Bayou and Little Sunflower Channels. The location of the Steele Bayou sonde was located 2.85 miles upstream of the Steele Bayou water control structure labeled Cypress Bayou. This channel location was in close proximity to the sonde deployment utilized during the 2019 Flood. The location of the Little Sunflower sonde was located 6.5 miles upstream of the Little Sunflower water control structure labeled South Greentree. Two sondes were suspended at each location beneath the surface from a floating platform and tethered to a firm location in the channel. The fixed depths of the units were approximately 3.0 feet and 8.0 feet. The daily means for DO observed in the Steele Bayou Channel, plotted in Figure 2-16, show how the minimal DO concentrations fell to below 3.0 mg/L for the first water control structure closure in the month of January and then started to climb again when the Steele Bayou water control structure was opened (yellow shaded area) at the beginning of February. The increase in DO continued through the first week in March where water control structure operations were open but a limited head differential between the stages on Steele Bayou and the Mississippi River were minimal thus minimizing flow out of the basin. The DO concentrations again continued to fall below 5.0 mg/L at the beginning of April when the water control structure was closed again. While the DO concentration at the surface remained at or below 5.0 mg/L, the concentrations measured at the eight foot depth ranged from 0.5 to 3.6 mg/L for the rest of the flood event.

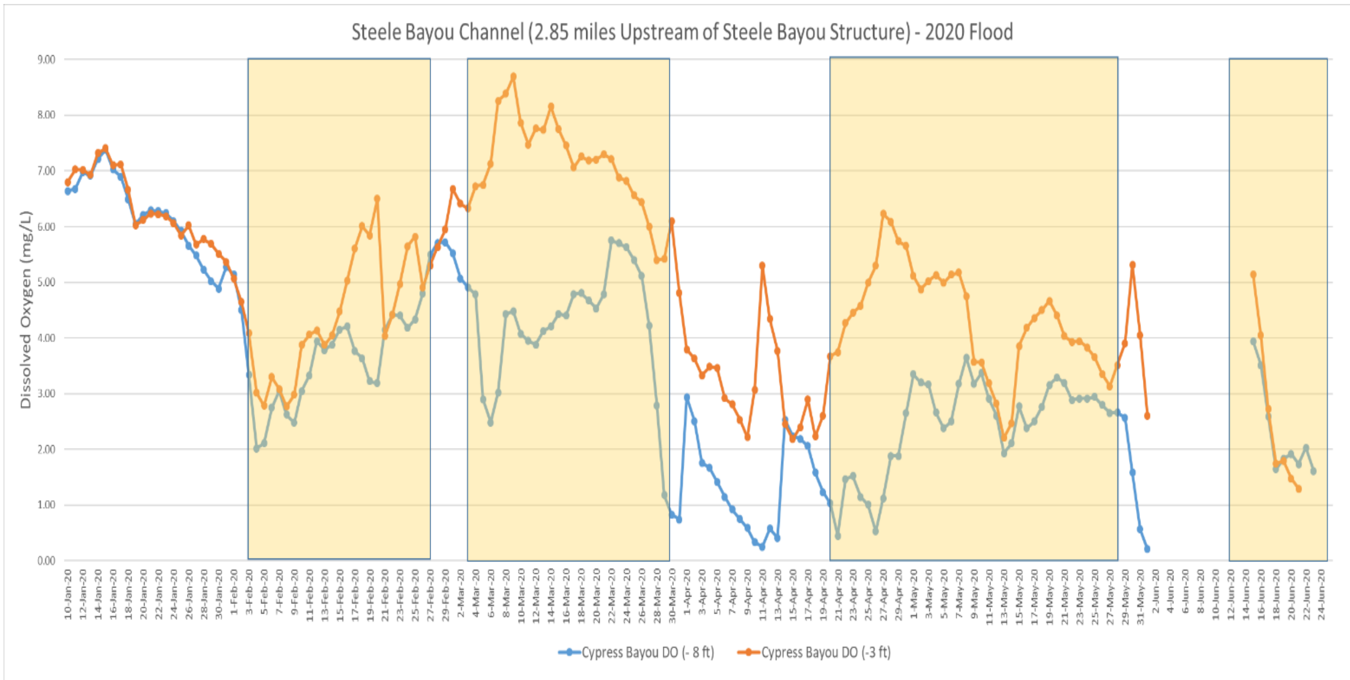

Figure 2-16. Daily mean DO concentrations (3 feet and 8 feet below the surface) from sondes deployed in Steele Bayou Channel during the 2020 flood event (labeled Cypress Bayou, yellow shading – water control strucutre open)

35. The daily means for DO observed in the Little Sunflower Channel, plotted in Figure 2-17, show how the minimal DO concentrations fell to below 5.0 mg/L for the first water control structure closure in the month of January and then started to climb again when the Steele Bayou water control structure were opened (yellow shaded area) at the beginning of February. The increase in DO continued through the first week in March where water control structure operations were open but a limited head differential between the stages on Steele Bayou and the Mississippi River were minimal thus minimizing flow out of the basin. The DO concentrations on the Little Sunflower River again continued to fall below 4.0 mg/L at the beginning of April when gate operations were closed again. While the DO concentration at the surface remained at or below 4.0 mg/L, the concentrations measured at the 8 foot depth ranged from 0.25 to 3.8 mg/L for the rest of the flood event. The gates at the Little Sunflower water control structure were closed and remained closed for the flood event restricting water release from the Yazoo Basin to the Steele Bayou water control structure. Due to the distance between the Little Sunflower water control structure and the Steele Bayou water control structure, flow was further restricted in the upper basin along with the potential for intermittent re-aeration as can be seen with the second graph. This data further illustrates the condition of low DO in the Yazoo Backwater Area during extended flood events.

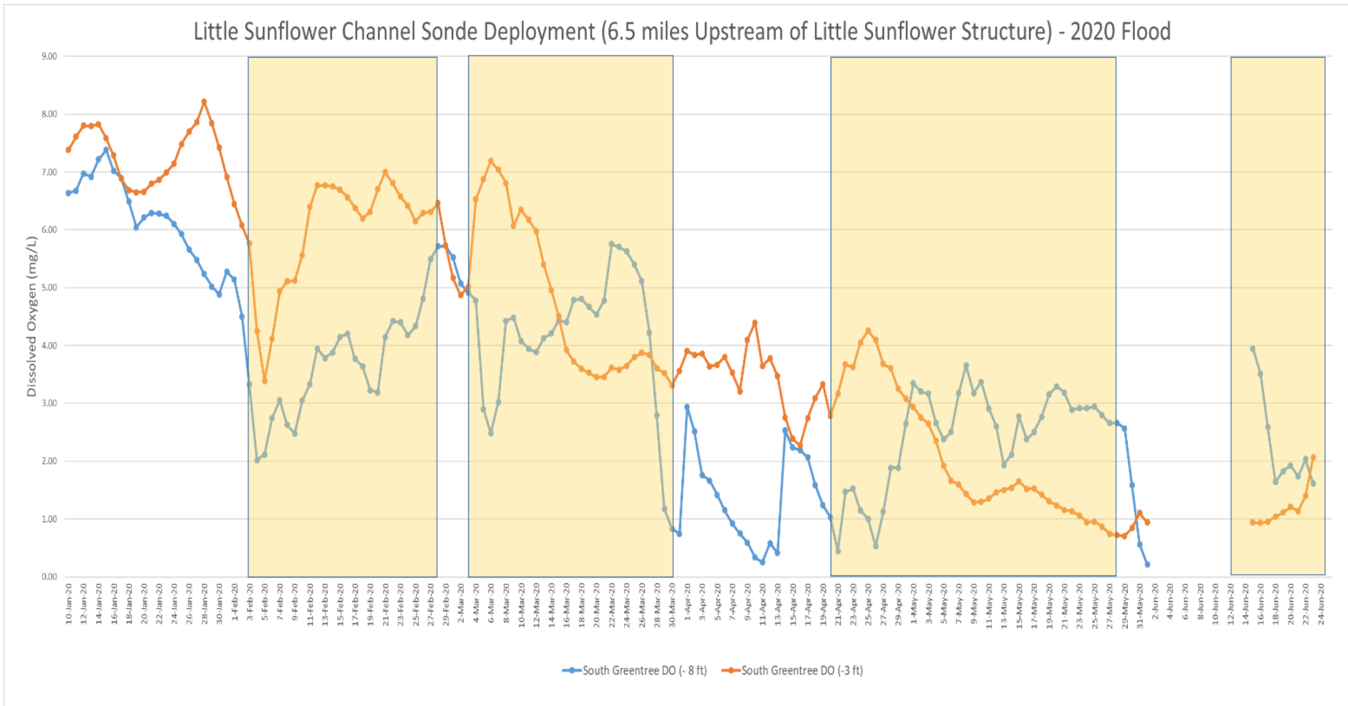

Figure 2-17. Daily mean DO concentrations (3 feet and 8 feet below the surface) from sondes deployed in Little Sunflower Channel during the 2020 flood event (Labeled South Greentree, yellow shading – water control strucutre open)

36. In 2005 and 2006 the Vicksburg District performed a study on the Little Sunflower River to show the effects of primary productivity on DO in the water column. Water quality profile measurements were collected one day per month from June to October, in the morning and after mid-day. The graph in Figure 2-18 shows how DO concentration increased from 3.0 to 7.0 mg/L from morning to afternoon. The increase in DO is likely due to photosynthesis. Figure 2-19 shows a similar diurnal increase in DO as the day progresses. Both graphs in Figure 2-18 and Figure 2-19 represent the overall higher DO concentrations found in the Little Sunflower during non-flood conditions. These higher concentrations are in stark contrast to the DO conditions found during a flood event.

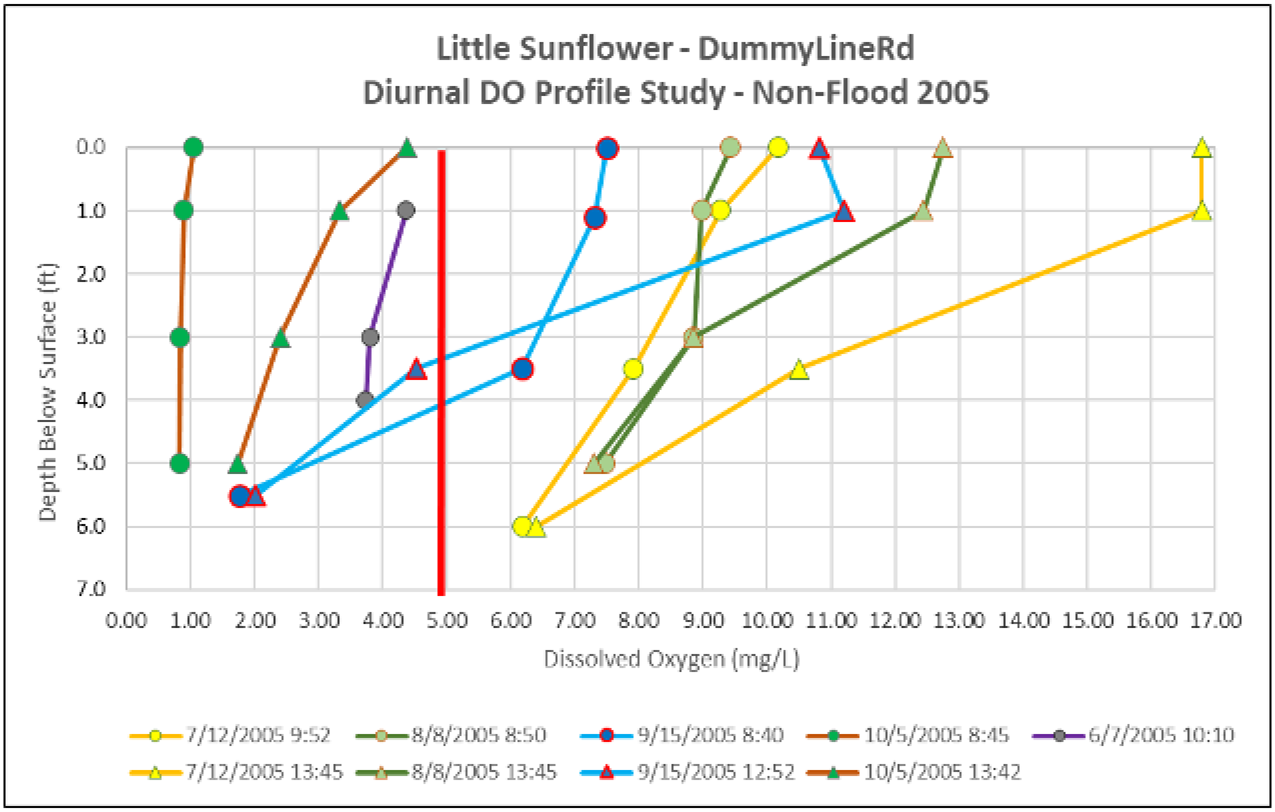

Figure 2-18. Diurnal Patterns for DO observed over a four-month period on the Little Sunflower River.

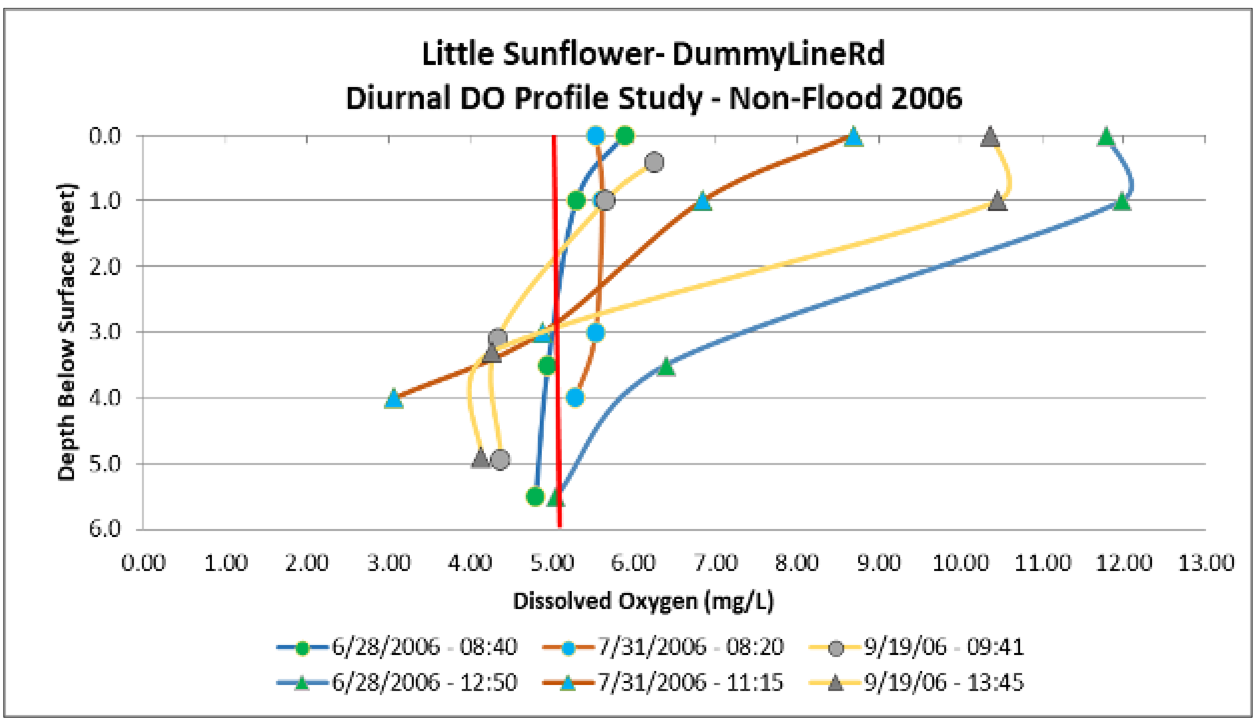

Figure 2-19. Diurnal Patterns for DO observed over a four-month period on the Little Sunflower River.

37. The low DO concentrations found in the Yazoo Basin have been associated with many corresponding factors. Warm water temperatures in excess of 20 degrees Celsius observed from the months of April to the fall months of October and November show a reduced concentration of DO. Low DO concentrations have also been observed during periods when the Steele Bayou and Little Sunflower water control structures are closed. One of the eight HGM functions, used to evaluate wetlands, is the export of nutrients and carbon. This function is simply a euphemism for non-point source pollution. This "export of nutrients and carbon," can generally be assimilated in a flowing stream, but it becomes a burden during extended flood events. During these periods, backwater pools are created with higher than normal depths for extended periods. These extended periods of stagnant water limit the ability for re-aeration through agitation. For the first few weeks of a typical backwater flood, water depth and temperature stratification slow the process of diffusion limiting the principal mechanism for oxygen transfer into the water column from the surface. This condition compounded with the increase Biochemical Oxygen Demand (BOD) exerted by the organic matter (leaf litter) on the unmixed water closer to the forest floor allows for severe DO depletion (Delaune, R.D. et al. 1993).

38. Construction of the supplemental low flow groundwater wells located at the headwaters of the Steele Bayou and Big Sunflower basins will provide a positive benefit to the overall low DO and minimal base flow conditions observed during the critical months. These warmer months typically coincide with the low flow periods in the primary tributaries of the two basins. The supplemental water provided to increase base flow should stimulate re-aeration through agitation minimizing the presence of stagnant intermittent pools along the channels.

39. The paired groundwater - surface water gage at Anguilla shows that the alluvial aquifer is fully charged thus there is no volume available for recharge during flood events. Groundwater recharge does not account for high losses to the overall flood volume. The Yazoo Area Backwater Plan calls for the construction of a 14,000 cfs pump at Deer Creek to reduce the flood impacts on the area by moving water over the backwater levee into the Yazoo River. Construction of the 14,000 cfs Yazoo Backwater Pump will help increase DO in the water column by minimizing the overall depth of a flood event and improving diffusion from the surface water. Activation of the pumps will also draw water primarily from the bottom of the flood pool taking with it water most depleted of DO and highest in SOD concentration. The combination of these effects should have an overall benefit to DO in the Yazoo Backwater Area during extended flood events. Sediment disturbance during construction of the Yazoo Backwater Pump may cause temporary increases in turbidity and nutrient levels. Temporary decreases in light penetration from localized increases in turbidity could cause reductions in photosynthesis. This could result in temporary, localized decreases in DO concentrations. Such increases would be of short duration. The DO and nutrient levels should return to preconstruction concentrations once the turbidity clears and photosynthesis rates return to normal.

2.4 SUSPENDED SOLIDS

40. Suspended solids have been observed to preclude the transmission of light through the water column in the Yazoo Backwater Area. This limited light can significantly restrict the growth of phytoplankton in the water column thus inhibiting the primary productivity. The Vicksburg District collected turbidity and DO profile measurements from the water column during the Backwater Flood of 2011 over a five week period from 11 May to 14 June. The

following graphs will show a correlation between the decrease in turbidity and the increase in DO as time passes. The data will also show how DO concentrations decreased with depth as described in the previous section.

41. The Low Water Bridge station is situated in the lower portion of the Yazoo Backwater Area. The graph in Figure 2-20 for the Steele Bayou Channel at Low Water Bridge shows a distinct decline in DO concentration as the depth increases during the Yazoo Backwater Flood of 2011. During the 2011 Flood Event, this location experienced the effects of “Backwater” flooding as a result of the closure of the Steele Bayou water control structure. This backwater flooding created pooling which restricts re-aeration due to increased depth. The highest DO levels are just below the surface and are at or below 5 mg/L for the first four weeks of the flood event. Surface DO concentrations eventually increased as the flood event progressed.

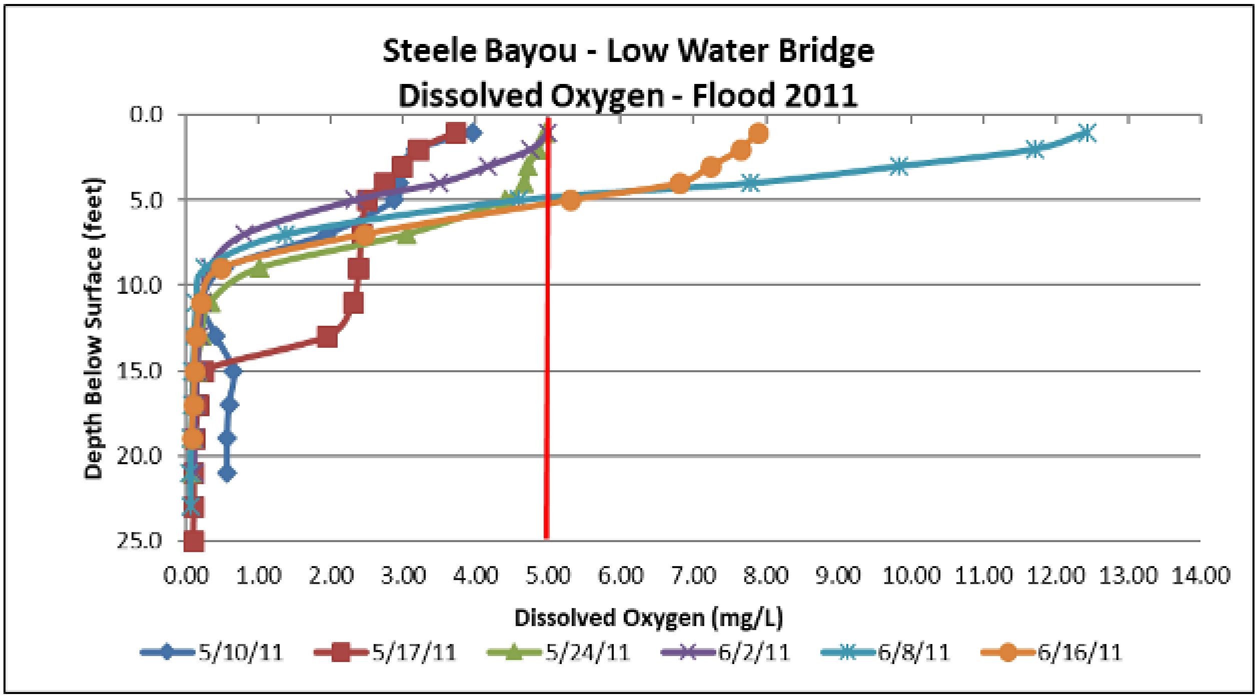

Figure 2-20. Depleted DO concentrations from the Steele Bayou Channel at Low Water Bridge throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

42. The graph shown in Figure 2-21 shows the reduction of turbidity concentrations from over 150 to less than 10 nephelometric turbidity units (NTU) as the flood event progressed. The backwater pooling effect provides optimal conditions for settling. This settling of solids from the water column over the first few weeks of the flood allowed for better light transmission and consequently increased primary productivity. The production of oxygen from an increase in phytoplankton activity, along with the diffusion of oxygen from the surface, increased DO concentrations in the surface layer during the latter weeks of the flood event. ChloroA concentrations are considered a direct indicator of primary productivity. Laboratory analysis from the grab samples collected on 10 May and 8 June from Steele Bayou at Low Water Bridge

during the flood event revealed ChloroA concentrations to be less than 5.0 and 23.9 mg/m^3. The increase in ChloroA agrees well with the decrease in turbidity.

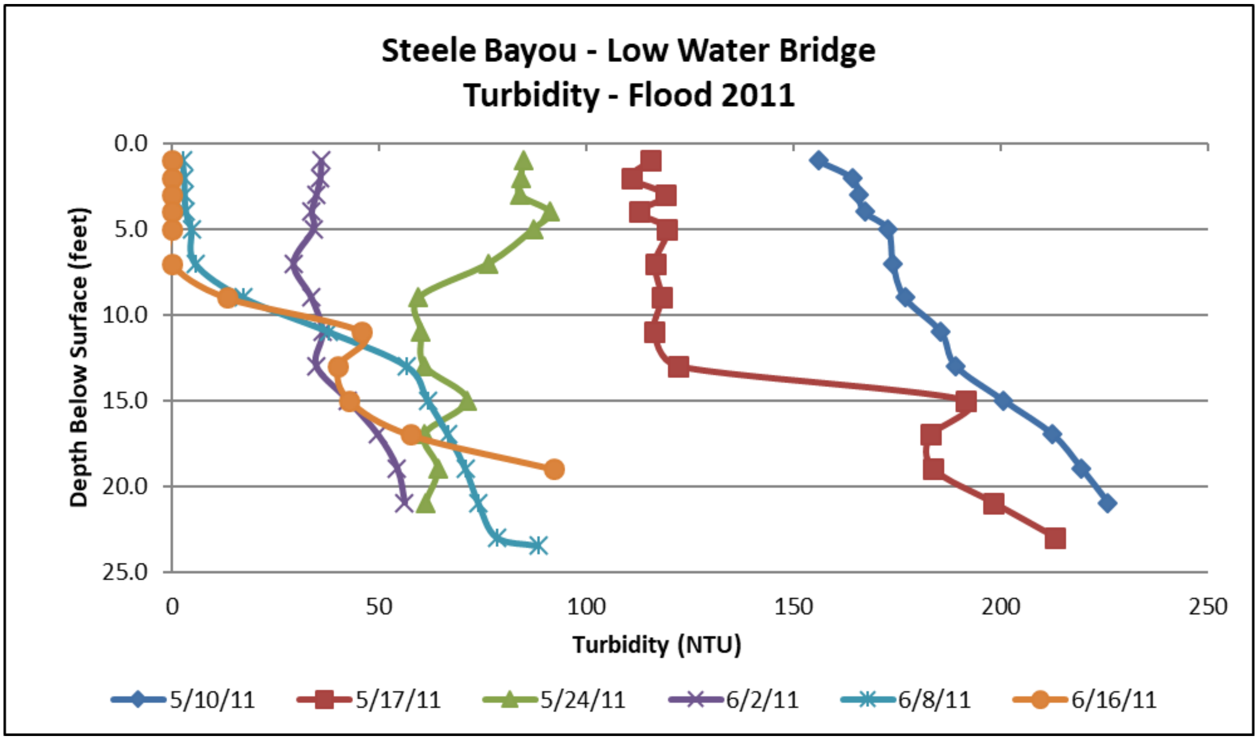

Figure 2-21. Turbidity concentrations from the Steele Bayou Channel at Low Water Bridge throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

43. The data shows a similar trend for depressed DO conditions at the Steele Bayou at Grace and Black Bayou at Highway 12 stations. Both of these locations were inundated with backwater during the May to June time frame. After the turbidity concentrations decreased to less than 50 NTU's, DO concentrations responded accordingly in the surface layer.

44. The Little Sunflower Channel at Dummy Line Road is situated in the lower portion of the Yazoo Backwater Area. The Dummy Line Road Bridge is located adjacent to the Delta National Forest and approximately seven miles from the Big Sunflower River. Most of the drainage to this site is forested. Similar to the conditions found at Low Water Bridge, turbidity decreased in the water column as the event progressed (Figure 2-22). However, only minimal increases in DO were observed at the Dummy Line Road Station throughout the entire monitoring period (Figure 2-23). The concentrations for ChloroA collected on 10 May and 8 June at this station were both found to be less than 5.0 mg/m^3. Turbidity values at this location did not decline as rapidly as the other stations. As such, increased levels of photosynthetic activity were not measured in the second grab sample.

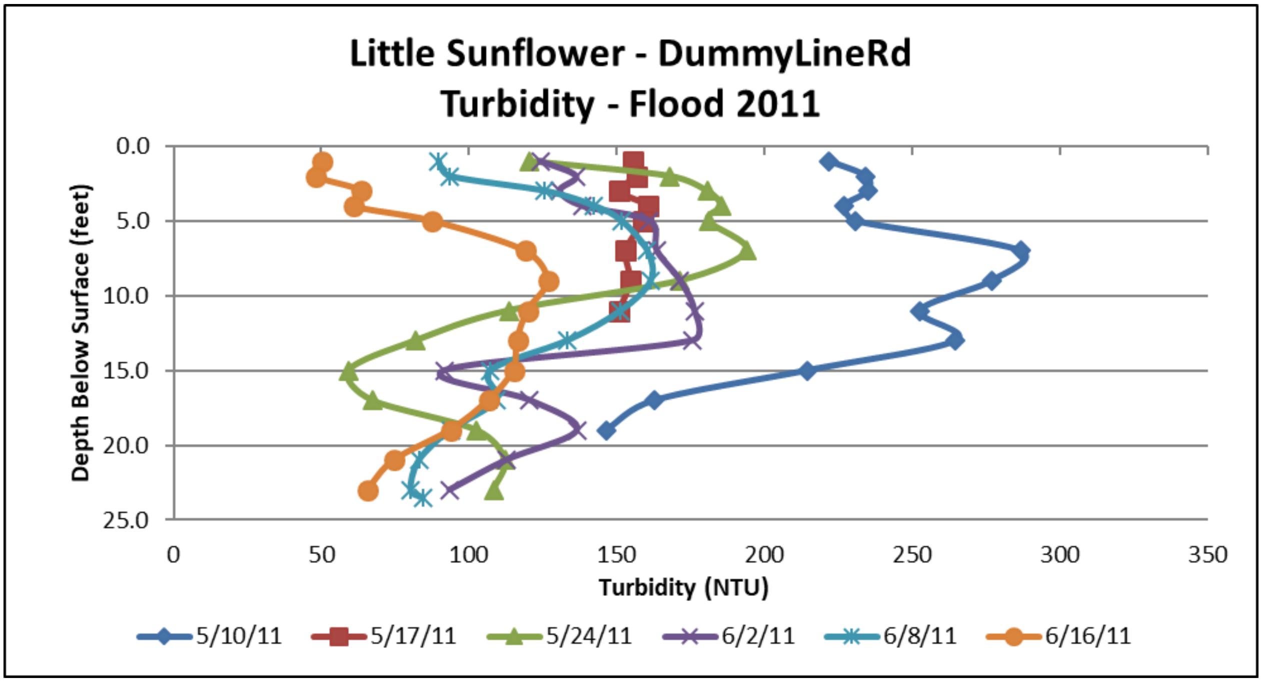

Figure 2-22. Turbidity concentrations from the Little Sunflower Channel at Dummy Line Road within Delta National Forest throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

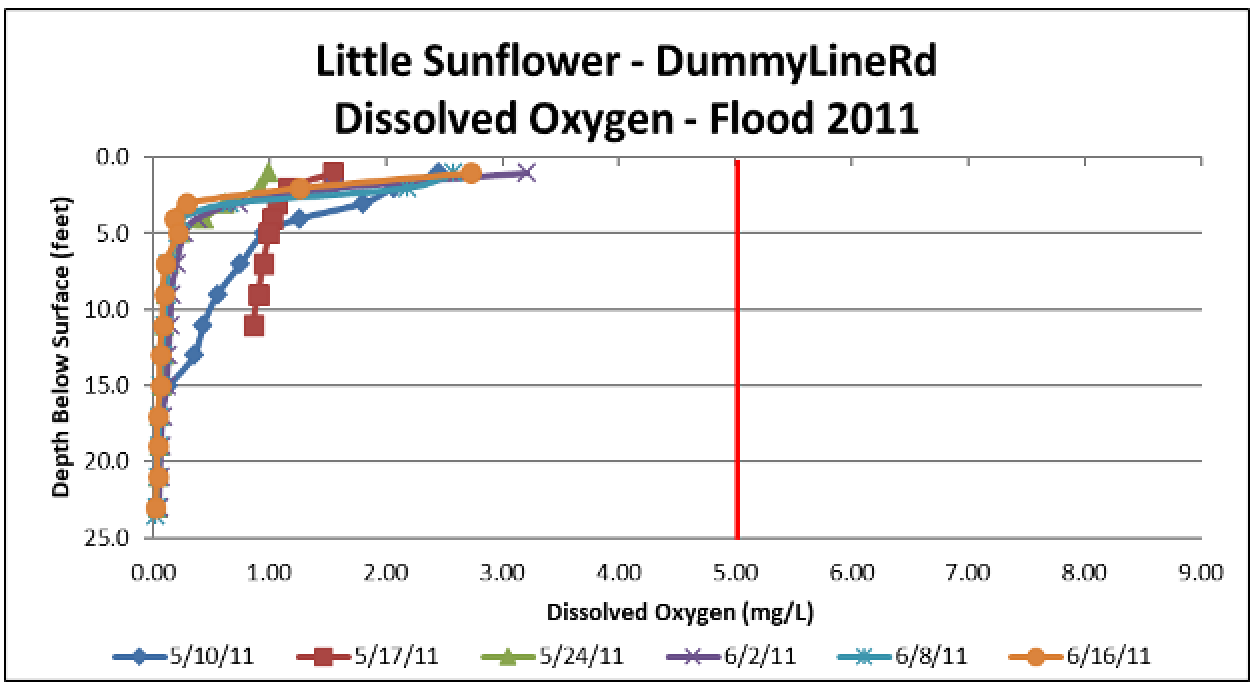

Figure 2-23. Depleted DO concentrations from the Little Sunflower Channel at Dummy Line Road within Delta National Forest throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

45. The Big Sunflower River experienced the same effects of depressed DO for the first few weeks of the monitoring period. The DO concentration at the Anguilla Station was less than 5.0 mg/L at the surface and decreased rapidly for the month of May (Figure 2-24). Turbidity decreased from 300 to less than 50 NTU's over the same time frame (Figure 2-25). Dissolved oxygen conditions responded accordingly in the surface layer for the month of June.

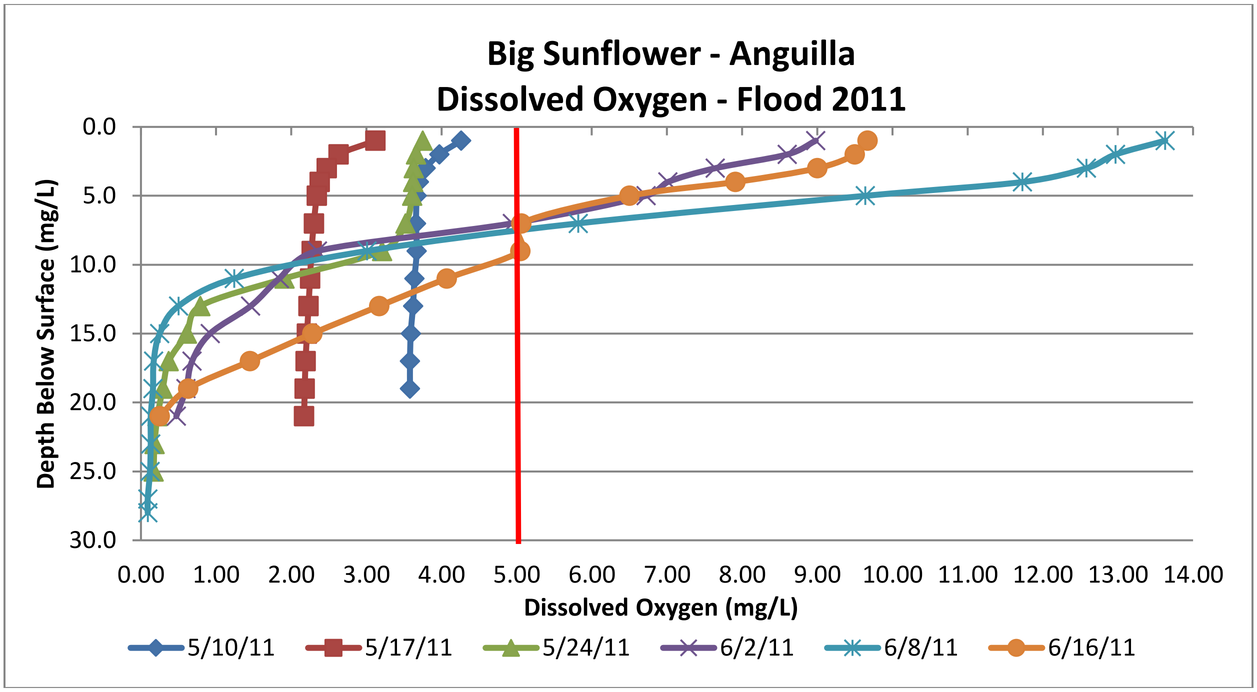

Figure 2-24. Depleted DO concentrations from the Big Sunflower River at Anguilla throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

46. The grab samples collected on 10 May and 8 June from the Big Sunflower River at Anguilla showed a similar response of ChloroA to turbidity. ChloroA was measured to be less than 5.0 and 22.7 mg/m^3, respectively. These measurements indicate an inverse relationship between turbidity and photosynthetic activity.

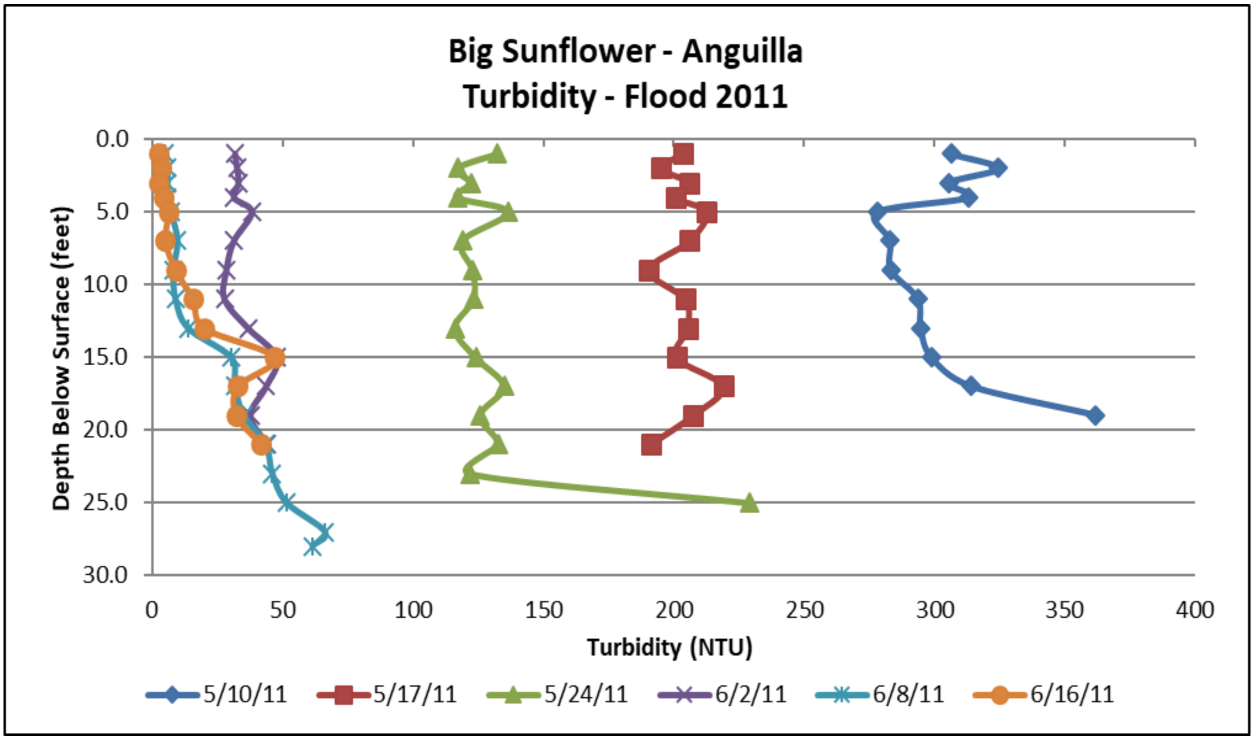

Figure 2-25. Turbidity concentrations from the Big Sunflower River at Anguilla throughout the 2011 Flood. This data was collected during the peak of the flood which lasted from 8 March to 20 July.

47. The Turbidity graphs from the Flood of 2011 displayed in Figure 2-21, Figure 2-22, and Figure 2-25 show the concentration decreasing at an average rate of 50 NTU's per week for the first three weeks of monitoring. This appears to slow down at a minimal concentration of 50 NTU. This corresponds to the initial period of a typical flood before the pumps would initiate pumping. The operation of the Yazoo Backwater Pumps would slightly reduce the overall settling time for suspended solids in the basin, but not before the majority of the settling had taken place. This is due to the typical time frame of three to four weeks that pass after the Steele Bayou water control structure and Little Sunflower water control structure close and the interior elevation reaches 87.0 feet (NGVD). This three to four week period of settling time would precede activation of the pumps.

48. In the 1990s, high suspended solids were observed throughout the Steele Bayou Basin. The same problems were noted in the Big Sunflower Basin. The high sediment loading was coupled with the intense agricultural production of the two basins as well as the high erosive potential of the deltaic soils. During post-harvest when farmers plow and re-dress their fields in preparation for the next spring, intense runoff or "first flush" rainfall events (typical of the tropical storm season) can contribute episodic erosion events to the watershed. These events have been observed to be a major contributor of the overall suspended solids problem in the Yazoo Basin.

49. The bar graph displayed in Figure 2-26 shows the average annual TSS concentrations found in the Steele Bayou Basin. The data collected from the SBMP shows how the

concentrations were reduced by approximately 50% from the early 1990's to the early 2000's from concentrations in excess of 200 mg/L to average concentrations of 100 mg/L. The concentrations were observed to increase the first few years of the 2010 decade, peaking in 2013 (likely due to the heavy precipitation associated with the Backwater Flood Event of 2013). A slight decrease was observed from 2013 to 2015. This most recent downward trend of TSS was likely the response from the installation of the last 50 Steele Bayou erosion control structures. The 1998 Section 305 (b) Report produced by the Mississippi Department of Environmental Quality (MDEQ) listed target levels for water quality criteria for use support decisions of Rivers, Stream, Lakes, and Estuaries. The report quantified the target level of TSS to be less than 80 mg/L. The average annual concentration for TSS observed in 2013 (highest for the 2010 decade) exceeded the target concentration for the Steele Bayou Basin by approximately 70 mg/L-TSS.

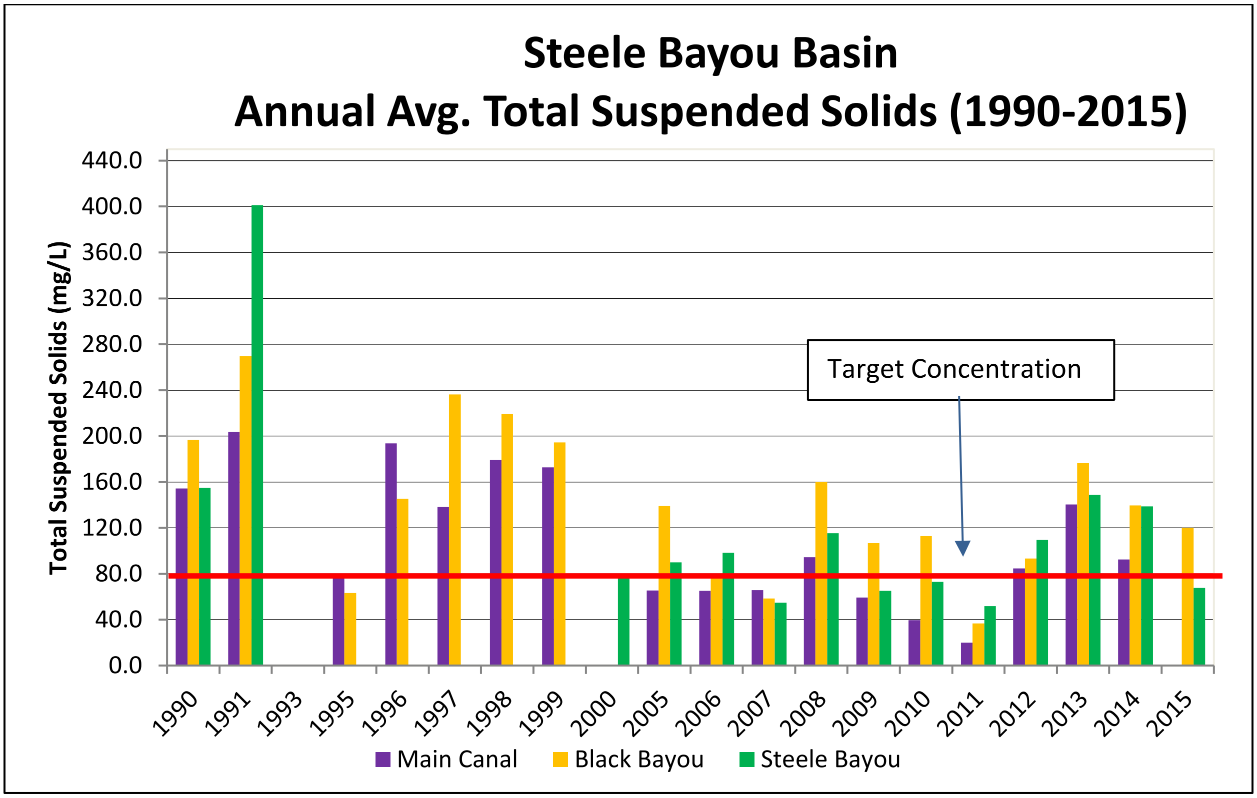

Figure 2-26. Average Annual TSS Concentration for the Steele Bayou Basin from SBMP.

50. The bar graph displayed in Figure 2-27 shows a similar increase in TSS concentration in the Big Sunflower Basin from the first few years of the decade starting in 2011 and peaking in 2014. The target concentration appears to be approximately 140 mg/L-TSS below the most recent average annual peak observed for the Big Sunflower Basin in 2014. It should be noted that the construction for the first Big Sunflower Erosion Control Structures began in 2016. The effectiveness of these structures is not reflected in the graph. A reduction in suspended sediment concentrations in the Big Sunflower Basin is expected in the subsequent years.

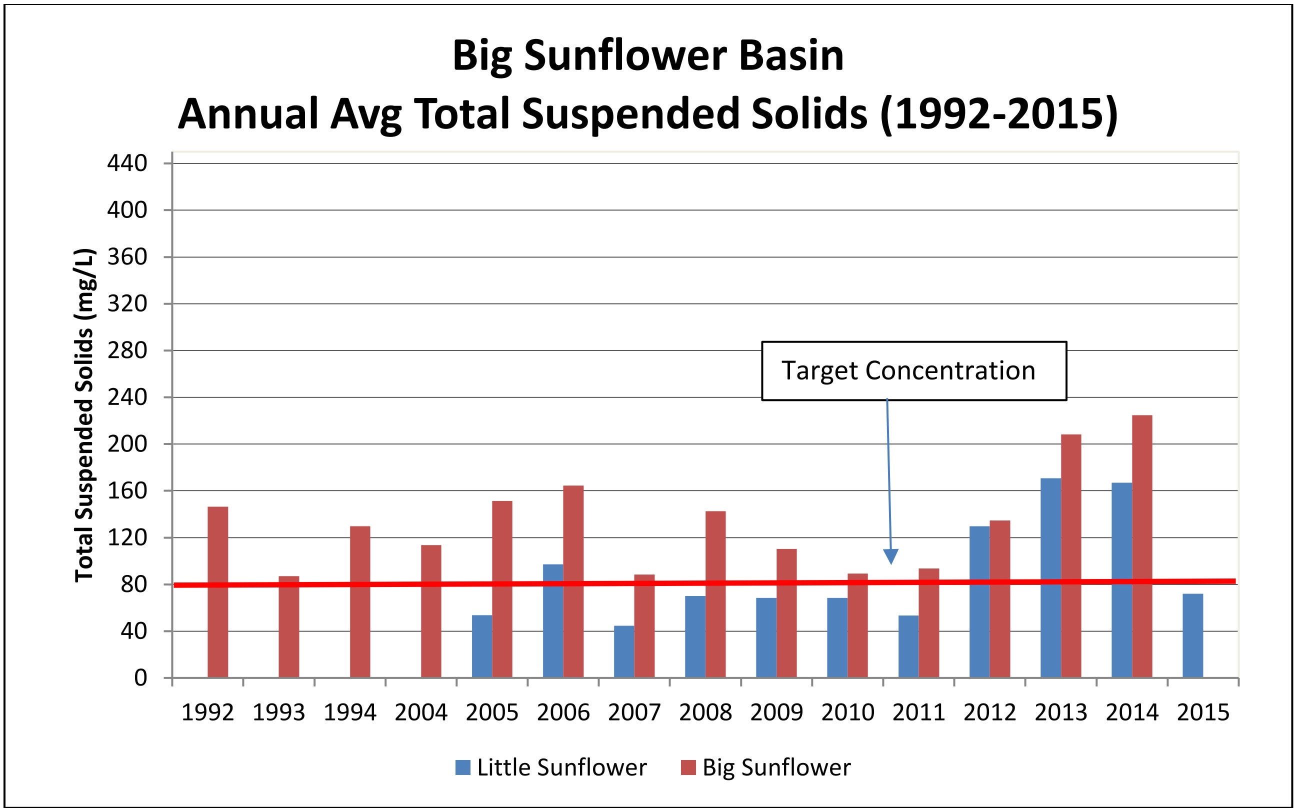

Figure 2-27. Average Annual TSS Concentration for the Big Sunflower Basin from SBMP.

51. The minimal DO concentrations observed in the main stems of the Steele Bayou, Upper Deer Creek and Big Sunflower Basin have been observed during the warmer months of the last ten years. These depressed conditions which have been defined by the EPA to be less than 5.0 mg/L in warm water streams have been shown to extend for over six months. The pools created in the lower portion of the basins during backwater flood events minimize the capacity for re-aeration of the water. This can further exacerbate a minimal DO problem especially in the deeper pools that last for multiple months. The data does support the re-emergence of DO in the surface layers of the flood pools by virtue of primary productivity. However, these conditions typically develop during a backwater flood after weeks of stagnant conditions when suspended solids have had a chance to fall out of the water column. The algae present is allowed to flourish from greater transmission of sunlight due to increased water clarity. This phenomenon can provide little influence on the health of the system since it comes after such an extended period of depressed DO or hypoxic conditions when fish and other aquatic species have either left the system or died.

52. The Vicksburg District initiated a program in 2004 to mitigate the impacts of increased sediment loading that had resulted in part from the increased agricultural land use within the Steele Bayou Basin. The Vicksburg District partnered with Delta Wildlife, Mississippi Levee Board, Natural Resources Conservation Service, Ducks Unlimited, and MDEQ to implement a program that would employ drop pipe inlet structures to help reduce the erosive effects of run-off from agricultural fields. The runoff was found to be associated with increased levels of sediment

/siltation and nutrients in the watershed. The aim of this program was to install approximately 100 drop pipe structures at the edge-of-field in order to reduce sediment loading into the watershed. This program was implemented alongside additional conservation farming practices and monitored to track effectiveness.

53. In the early part of the 2000 decade, the U.S. Department of Agriculture (USDA) started promoting the Educational Quality through Innovative Partnerships (EQUIP) Program to the agricultural community in the Yazoo Delta which educated farmers about the overall benefits of best management practices (BMP's) for row-crop production. These practices included the resurfacing of agricultural fields through land leveling to slopes typically less than 0.5% and the construction of pads/pipes around the perimeter of agricultural fields. The EQUIP Program also promoted the use of surge valves, deficit irrigation techniques, vegetative buffer strips, and moisture meters to optimize use of water applied through irrigation.

54. The water management BMP's act to slow the rate of runoff reducing siltation. The goal of the BMP's is to reduce the overall volume of irrigation water needed for efficient agricultural production and has had a favorable impact on the water quality in the Yazoo Basin. This was documented by the USGS - Steele Bayou 319 success story for sediment reduction from edge of field structures (Hickes et al. 2011). In this program, researchers demonstrate how these sediment reduction structures located in stream inlets at edge-of-field minimize the movement of valuable topsoil from the field into adjacent water bodies. These sediment reduction structures consequently reduce the amount of bound phosphorus that can enter the system and eventually the Mississippi River. The combination of these practices has been instrumental to slowing the rate of runoff and helping control the loading of sediment and nutrients into the Yazoo Watershed.

55. The data also shows that an overall decrease in TSS has been observed in the Steele Bayou Basin. The concentrations were reduced by approximately by 50% from the early 1990's to the early 2000's from concentrations in excess of 200 mg/L to average concentrations of 100 mg/L. These reductions are a result of the structures built by the Steele Bayou Erosion Control Program as well as the BMP's implemented by the farming community through the EQUIP Program. Similar reductions in TSS concentrations are expected from the construction of future erosion control structures built in the Big Sunflower Basin.

56. In summary, the data shows that turbidity is greatest during the first few weeks of a Yazoo Backwater Flood. As the backwater pools grow deeper and sustain prolonged periods of stagnation, the suspended solids have an opportunity to settle out of the water column. This process makes way for increased light transmission through the surface layer and the increased production of phytoplankton. As a result, DO concentrations begin to recover within the first 5 to 10 feet from the surface. This turnaround typically comes too late to provide habitat for aquatic species because they have either left the region or died from the extended period of low DO.

3.0 NUTRIENTS

3.1 GENERAL

57. As previously described in Sections 1 and 2 extensive efforts have been made by the Vicksburg District through the SBMP to collect water quality nutrient data throughout the Yazoo Backwater Area since the writing of the YBARR-07. A statistical analysis was generated from both of the data sets using SAS Univariate software. The software was used to calculate mean values from the concentrations generated from the monthly surface water grab samples. The mean values for TN and TP were grouped on an annual basis for each available year and subdivided on a monthly basis. This grouping allowed for a better comparison of the agricultural growing season and corresponding irrigation period typically found in the Yazoo Basin. The subsequent data collection efforts conducted over the last decade lends new insight to the overall trends for nutrient found throughout the Steele Bayou and Big Sunflower Basins.

58. Additional water quality data has been collected by the USGS on many of the primary tributaries in the Yazoo Backwater Area stretching back to the 1970's. Information related to TN and TP concentrations was retrieved from surface water grab samples accessed through USGS's online NWIS website. Available data was sorted according to the HUC8 watersheds and analyzed through 2016. The watersheds of interest were the Big Sunflower, Steele Bayou, Upper Yazoo, and the Lower Yazoo which were labeled as BigSun, Steele, UppYaz, and LowYaz respectively. A statistical analysis was generated from the data using SAS Univariate software. The software was able to define values for mean, max, and minimum for the following nutrient concentrations: TN and TP. The statistical data generated for the nutrient parameters was grouped into decade time frames starting with 1970 and continuing through 2010. The combination of these two data sets help to supplement the SBM Data used to describe the overall water quality health of the Yazoo Backwater Area.

3.2 PHOSPHORUS

59. Phosphorus is an essential plant nutrient and it has long been amended to soils to increase crop productivity. Residual phosphorus that is not utilized in the uptake for plant growth is typically bound to the soil particles. Runoff during precipitation events, brings these soil particles and their attached phosphorus molecules to the stream where the heavier soil particles settle out and the lighter clay particles slowly migrate downstream. The graph in Figure 3-1 shows a distinct relationship between the monthly averages of suspended solids and phosphorus concentrations found in the Steele Bayou Basin. The concentration for the two constituents appears to decrease from an approximate average peak of 0.33 and 150.00 mg/L for TP and TSS, respectively in the winter when conditions are wet. The concentrations reach an approximate low during the dry summer months of 0.17 and 40.0 for TP and TSS, respectively. Many of the acres utilized for agricultural production in the Steele Bayou Basin in the 1980's and 1990's have since been reforested through the Wetland Reserve Program and Conservation Reserve Program administered by the USDA.

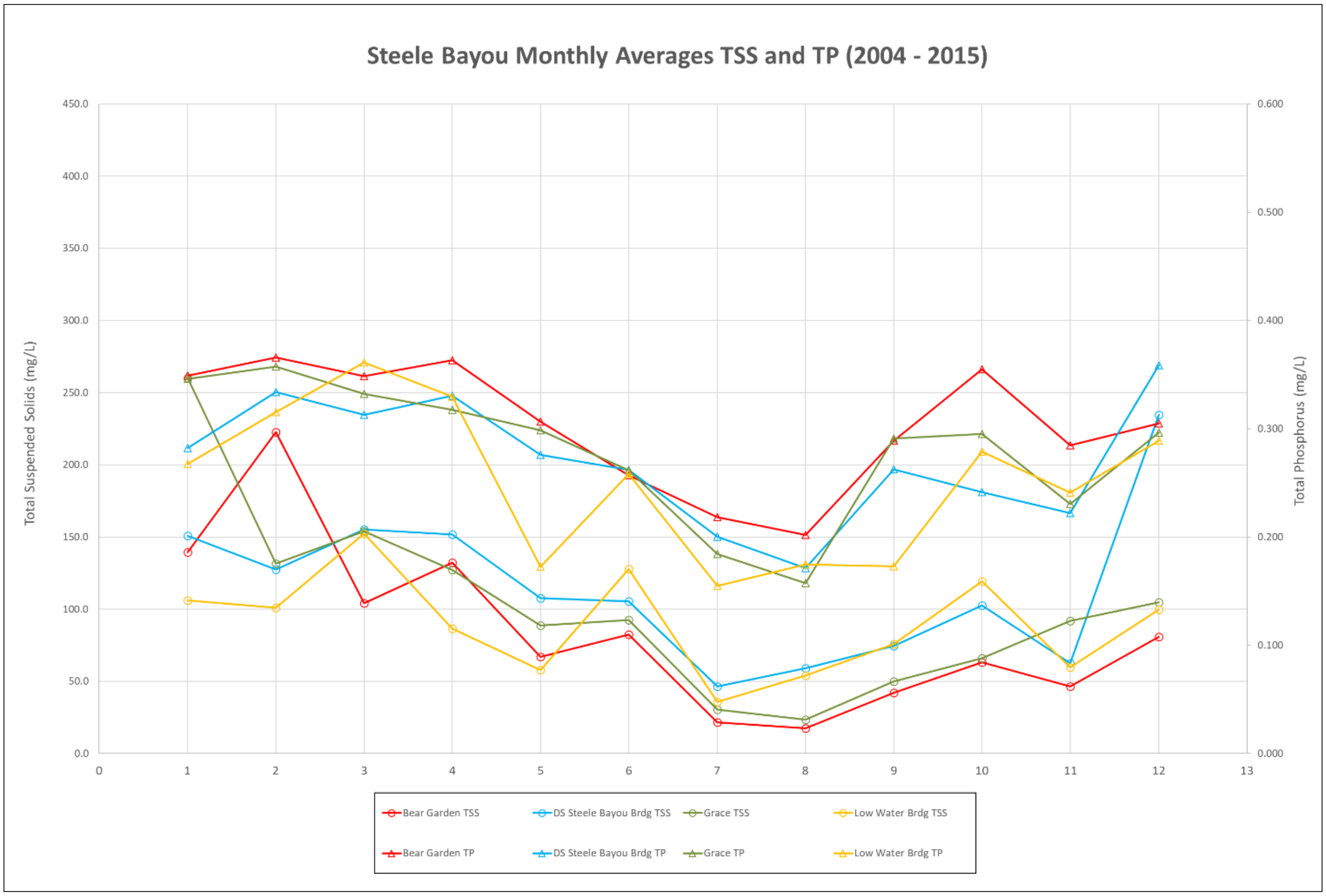

Figure 3-1. Average Concentrations for TSS and TP found in the Steele Bayou Basin grouped by month from data collected by the SBMP.

60. The link between TP and TSS was more pronounced in the Big Sunflower Basin where agricultural activity is more prevalent. The graph in Figure 3-2 shows the concentrations for the two constituents on the Big Sunflower River appear to decrease at a greater rate from an approximate average peak of 0.47 and 400.00 mg/L for TP and TSS, respectively in the winter when conditions are wet. The concentrations reach an approximate low during the dry summer months of 0.17 and 50.0 for TP and TSS, respectively. The link between the two constituents are not quite as clear for the data collected on the Little Sunflower River. This is likely due to the reduction in farm acres found in the Little Sunflower drainage basin as opposed to the Big Sunflower drainage basin.

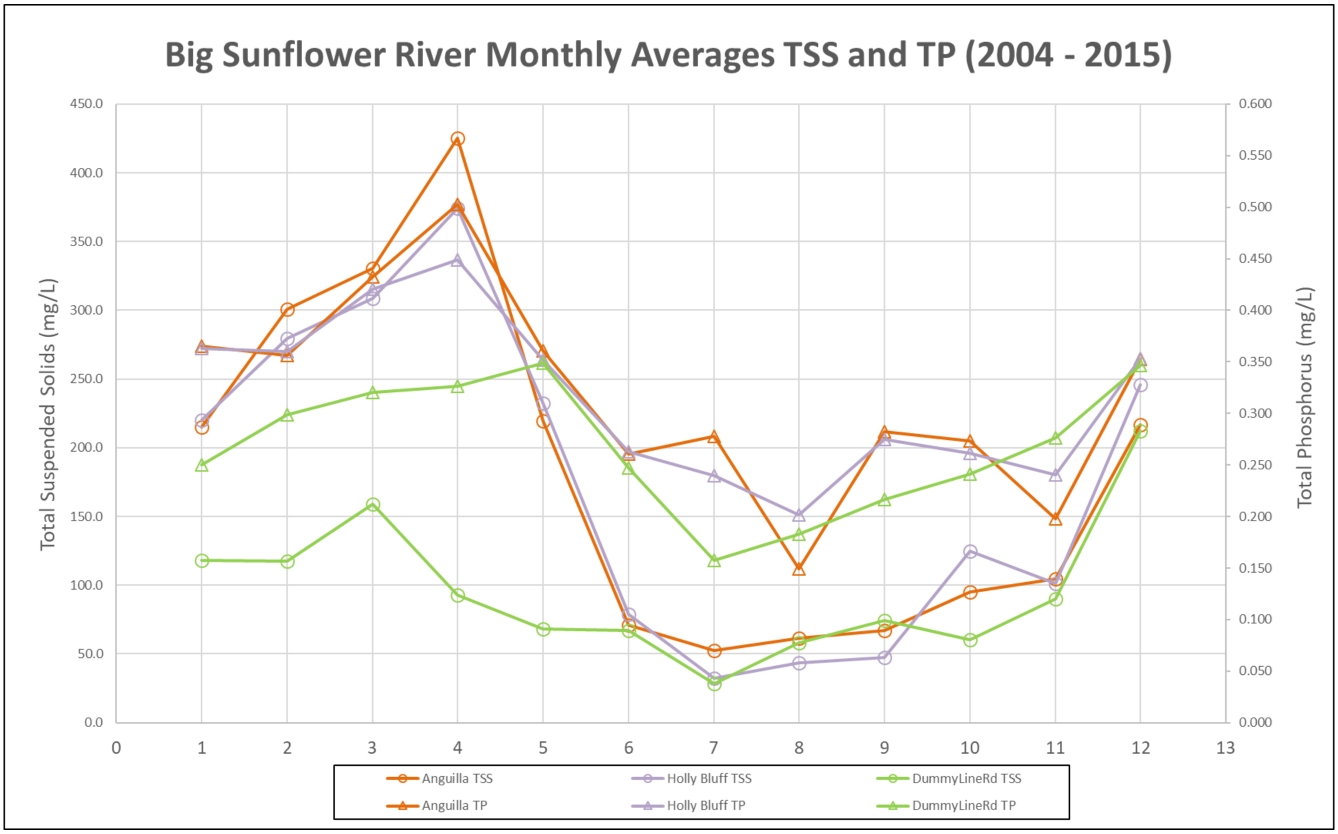

Figure 3-2. Average Concentrations for TSS and TP found in the Big Sunflower Basin grouped by month from data collected by the SBMP

61. The annual mean TP concentrations in the Steele Bayou Basin showed a decrease from the early 1990's of a concentration of 0.50 mg/L to the end of the decade of around 0.25 mg/L (Figure 3-3). The concentrations peaked again to 0.40 mg/L in the first decade following 2000 until falling back down to around 0.16 mg/L. Concentrations climbed again slightly to a value of 0.25 mg/L in 2015. This concentration agrees with the median stream TP concentration of 0.25 mg/L which was published by USGS from multiple streams situated in agricultural areas from the U.S. Median values were given for TP and TN in the Circular 1350, Nutrients in the Nation's Streams and Groundwater, 1992 – 2004.

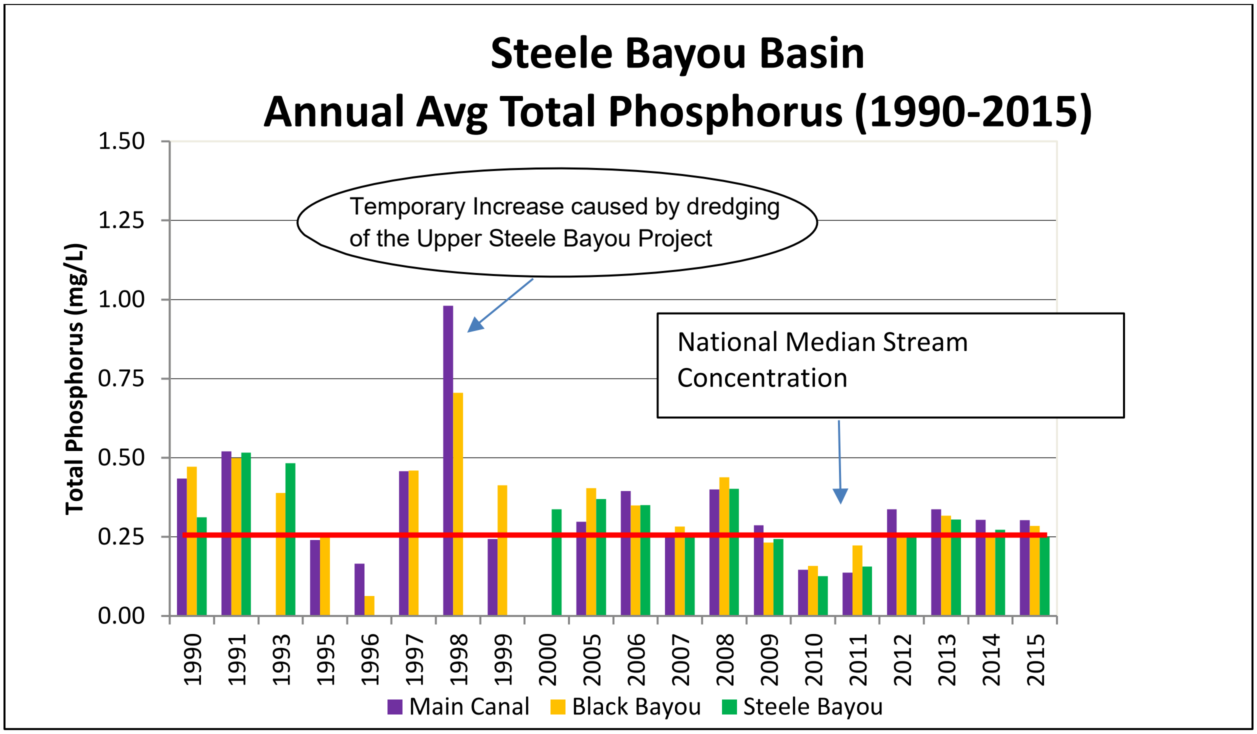

Figure 3-3. Average Annual TP Concentration for the Steele Bayou Basin from SBMP.

62. A similar pattern was observed in the Big Sunflower Basin for annual mean concentrations of TP as was described for the Steele Bayou Basin with lower peak values for the last two decades (Figure 3-4). The concentration in 1992 climbed from 0.18 to 0.445 mg/L in 2006. In 2010 the mean fell to 0.17 mg/L and then climbed back to 0.30 in 2014. Overall the TP concentrations for both basins are in close agreement with the median value of 0.25 mg/L-TP published by USGS.

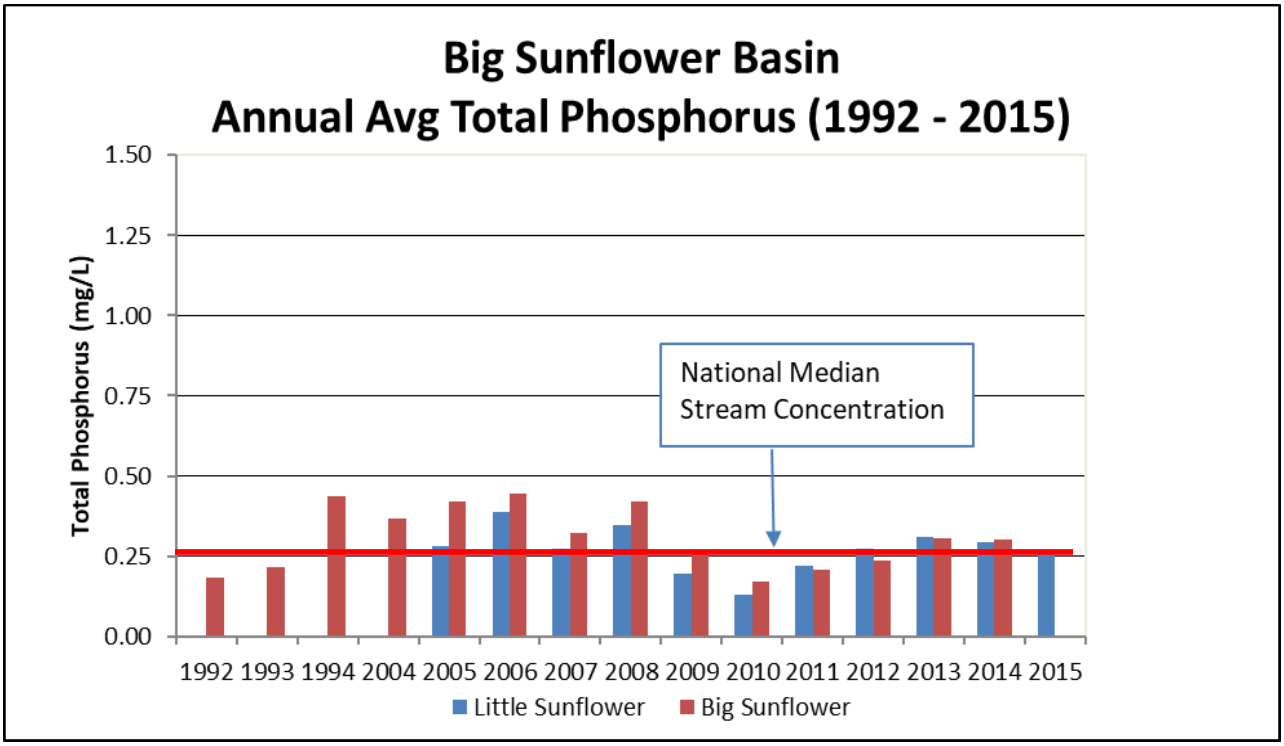

Figure 3-4. Average Annual TP Concentration for the Big Sunflower Basin from SBMP.

63. The bar graph displayed in Figure 3-5 shows the trends for long term TP monitoring in the Yazoo Basin. The graph presents the data from the NWIS and SBMP data sets for comparison of mean TP concentration by decade. A rise and fall of approximately 0.10 mg/L-TP can be seen from the SBMP data in the Big Sunflower Basin from the decades of 1990 to 2010. During the same time frame, TP fell approximately 0.20 mg/L-TP in the Steele Bayou Basin. Extreme discrepancies were noted between the NWIS and the SBMP data for the 2010 decade. Further study revealed that many of the measurements recorded for the NWIS data set in the Yazoo Basin appeared to show bias to hourly measurements from in-stream and edge-of-field storm water runoff studies. These collection efforts appeared to skew the mean values when compared to the monthly sampling efforts conducted in the SBMP. The phosphorus concentration for the 2010 decade appears to remain at approximately 0.25 mg/L-TP as it traveled from the Big Sunflower and Steele Bayou Watersheds to the Lower Yazoo Watershed. This analysis takes advantage of data collected from both programs.

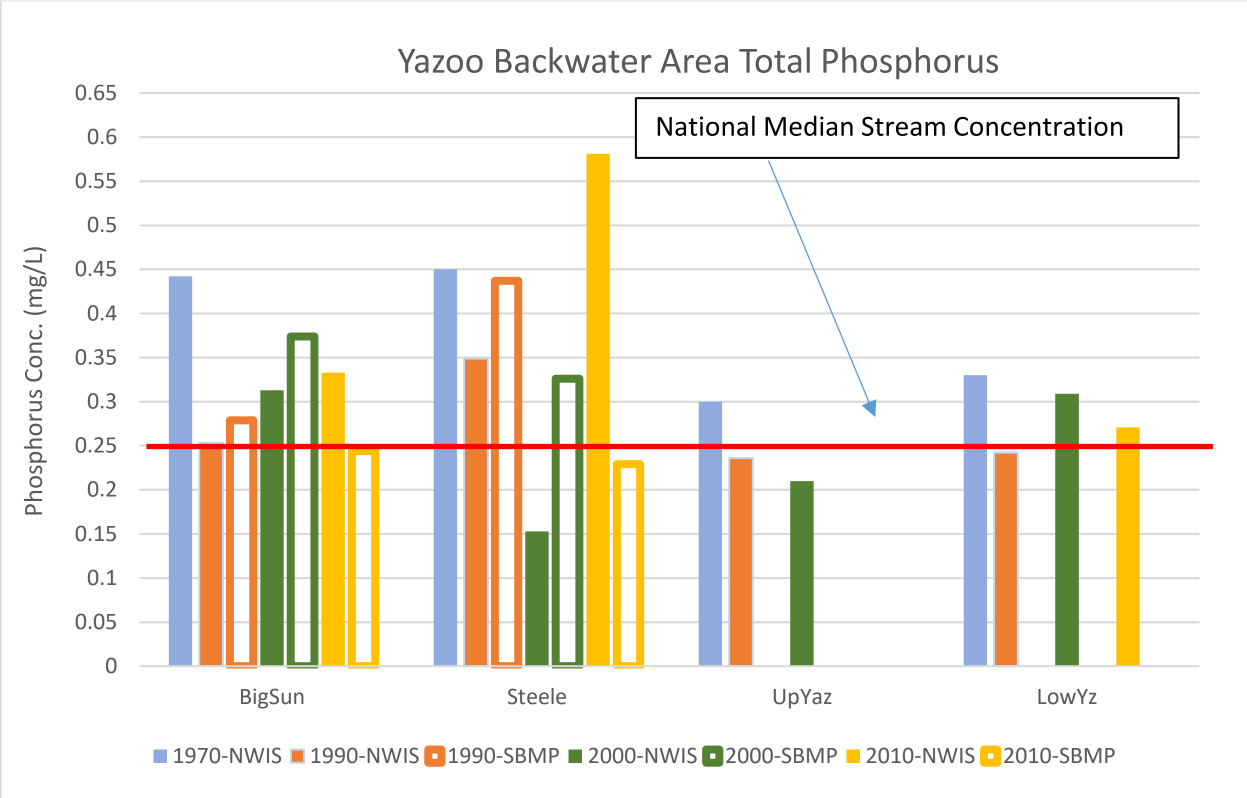

Figure 3-5. Mean Concentrations for TP found within the Big Sunflower, Steele Bayou, Upper Yazoo and Lower Yazoo HUC 8 Watersheds from NWIS and SBMP databases.

64. The concentrations for TP observed in both the Steele Bayou and Little Sunflower Basins increased from the decade starting in 2000 to the following 2010 decade. However, the TP concentrations observed in the Lower Yazoo Basin at Long Lake were observed to be lower. The Long Lake location represents the most downstream point in the Yazoo River before it enters the Mississippi River. From this, one can assume that higher concentrations of TP observed in the upper Steele Bayou and Big Sunflower Basins were either reduced through in stream utilization, bound to sediment particles and removed from the system by virtue of deposition, or diluted by downstream inflow.

65. The graphs from Figure 3-6 shows the relatively small increase of TP Load from the Yazoo Backwater Area to the Mississippi River during the 2008, 2009, 2011, and 2013 flood events. The figure compares the percentage increase of the overall TP load computed from monthly average data collected from the Mississippi River at Mile 438 (near Vicksburg, MS) and TP concentration data collected from 3 downstream locations in the Steele Bayou and Big Sunflower Basins (Dummy Line Road, Holly Bluff and Low Water Bridge). Average monthly TP Loads were calculated based on a discharge of 14,000 cfs times the proportional average of the YBA TP concentration. The proportional concentration was based on overall drainage area upstream of the three sample stations.

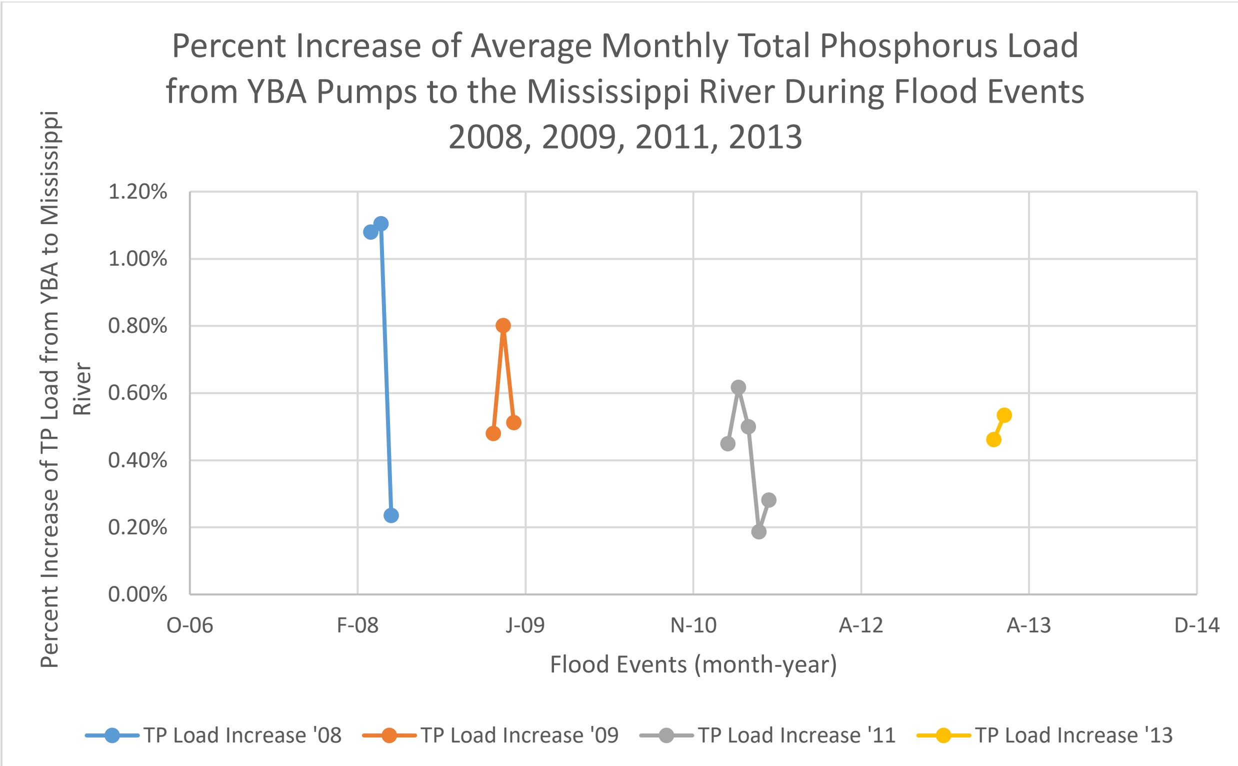

Figure 3-6. Theoretical Percent Increase of TP Load from the YBA to the Mississippi River during Previous Flood Events: 2008, 2009, 2011, 2013.

3.3 NITROGEN

66. The increased use of nitrogen amendments for enhanced agricultural yields has been fully utilized in the Yazoo Basin over the past few decades. This practice has become more prevalent over the last 20 years when the dominant crop shifted from cotton to corn and soybeans. This shift marked a drastic increase in the amount of nitrogen needed to optimize production. The demand for nitrogen fertilizers has almost doubled.

67. The TN concentrations in the Steele Bayou Basin follow a cyclical pattern similar to that observed for TP. The peak was observed to come during the spring months at a value of approximately 2.25 mg/L and then recede in the early fall to a value of approximately 1.00 mg/L (Figure 3-7). The National Median concentration given for TN concentrations categorized for agricultural regions was 3.8 mg/L (Dubrovsky et al. 2010). The monthly average mean concentrations for TN in the Steele Bayou Basin were approximately 2.0 mg/L-TN below the national median value (Figure 3-7).

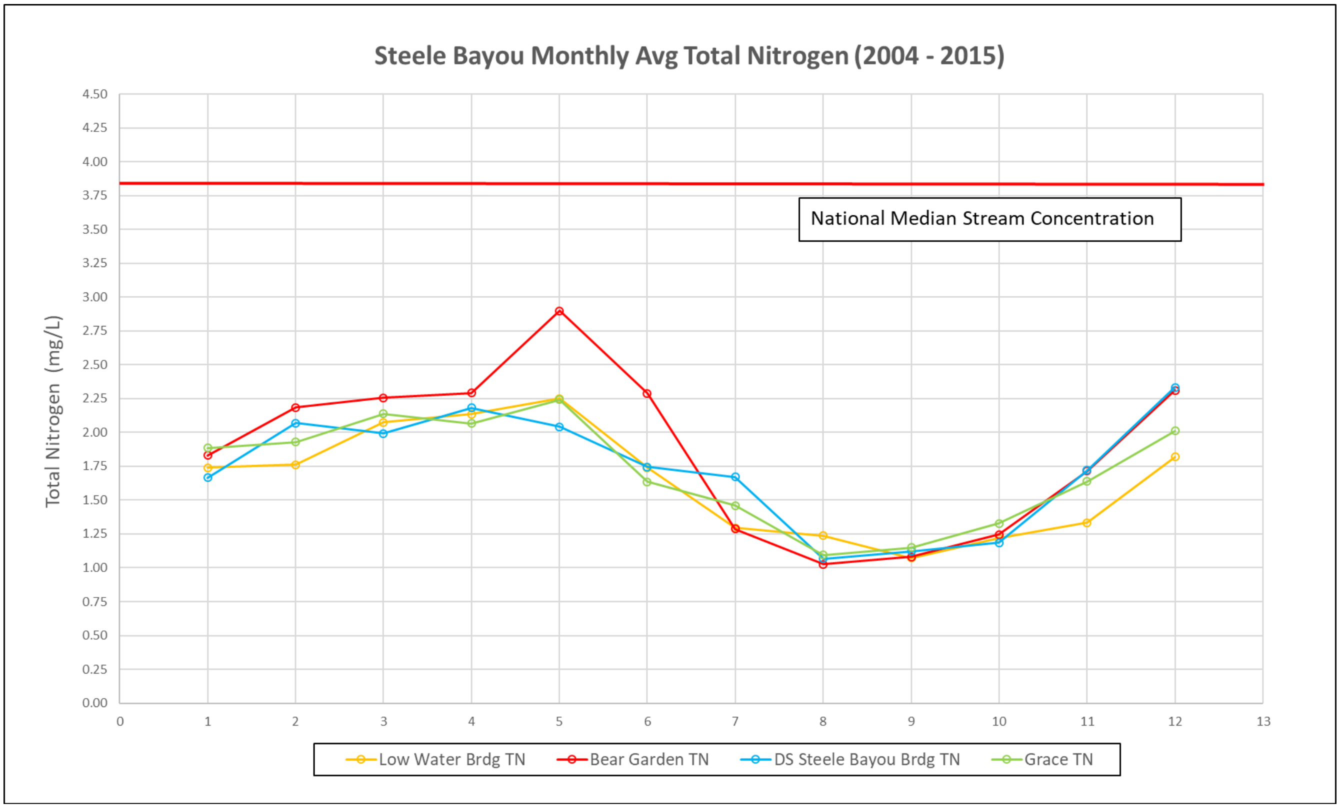

Figure 3-7. Average Concentrations for TN found in the Steele Bayou Basin grouped by month–SBMP Data.

68. The annual trend over the last two decades of record for the Steele Bayou Basin shows an approximate high and low of 2.00 and 1.00 mg/L, respectively (Figure 3-8).

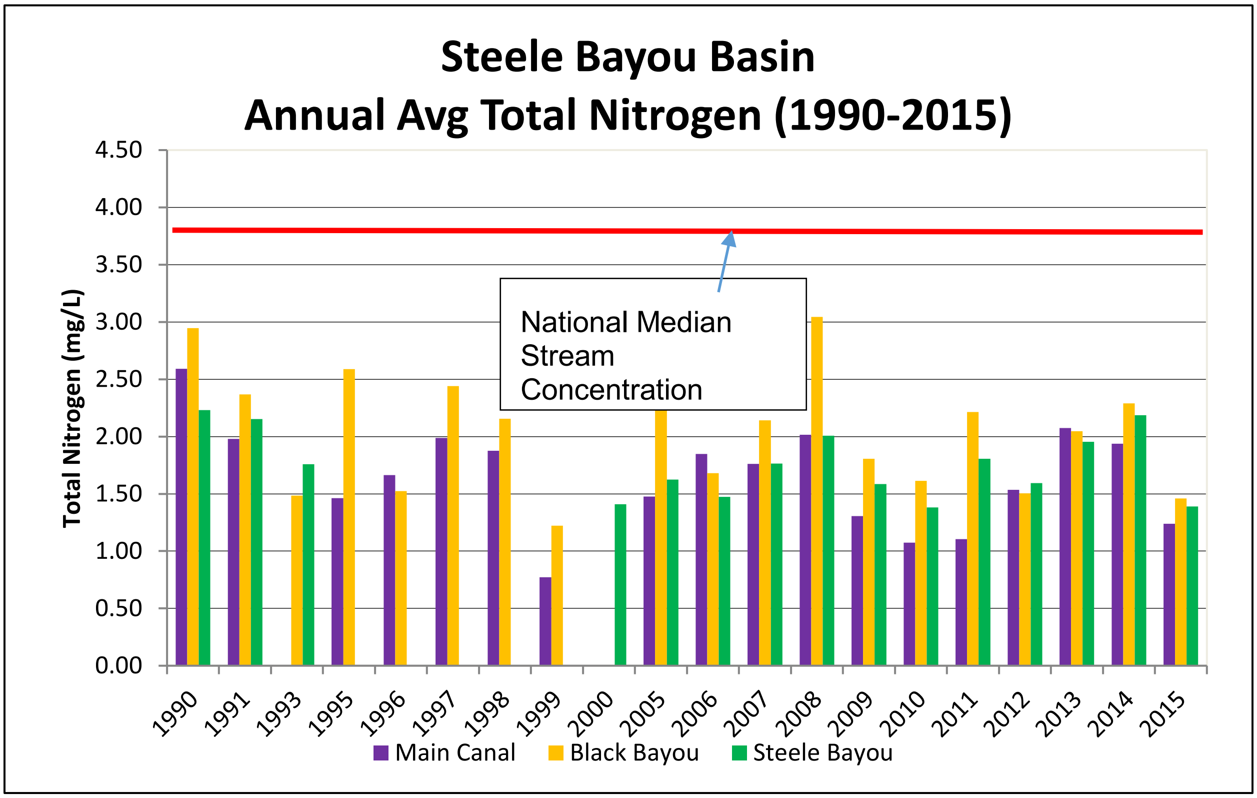

Figure 3-8. Average Annual TN Concentration for the Steele Bayou Basin from SBMP.

69. The TN concentrations in the Big Sunflower Basin follow the same annual cyclical pattern as previously mentioned with greater amplitudes of the high and low with approximate values of 4.00 and 1.25 mg/L, respectively (Figure 3-9). These larger peaks observed in April and May approach the national median concentration for TN published by the USGS (Dubrovsky et al. 2010). These high values can be attributed to the increase agricultural production found in the Big Sunflower Basin. The lower peak and valley value associated with the Dummy Line Road input are attributed to values from the Little Sunflower River which receives runoff from a disproportionately smaller area invested in agriculture.

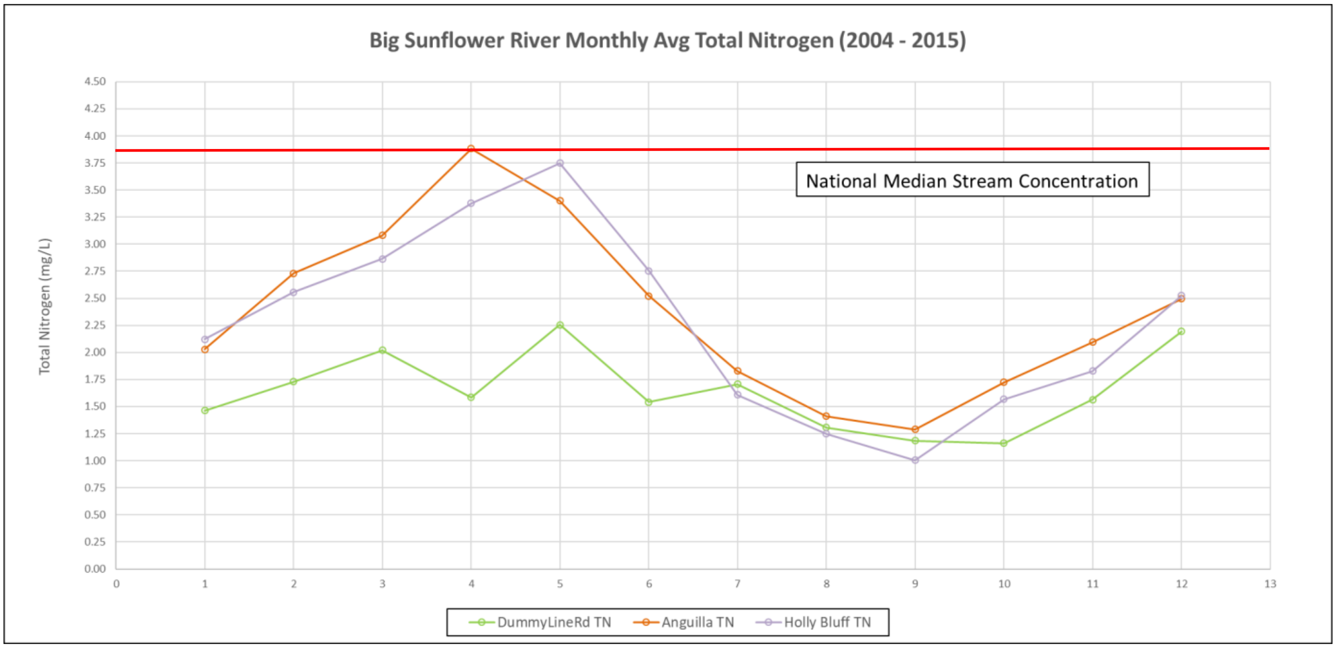

Figure 3-9. Average Concentrations for TN found in the Big Sunflower Basin grouped by month–SBMP Data.

70. The annual trend over the last two decades of record for the Big Sunflower Basin shows an approximate high and low of 2.50 and 2.00 mg/L, respectively (Figure 3-10). These values register far below the national median concentration published by USGS (Dubrovsky et al. 2010).

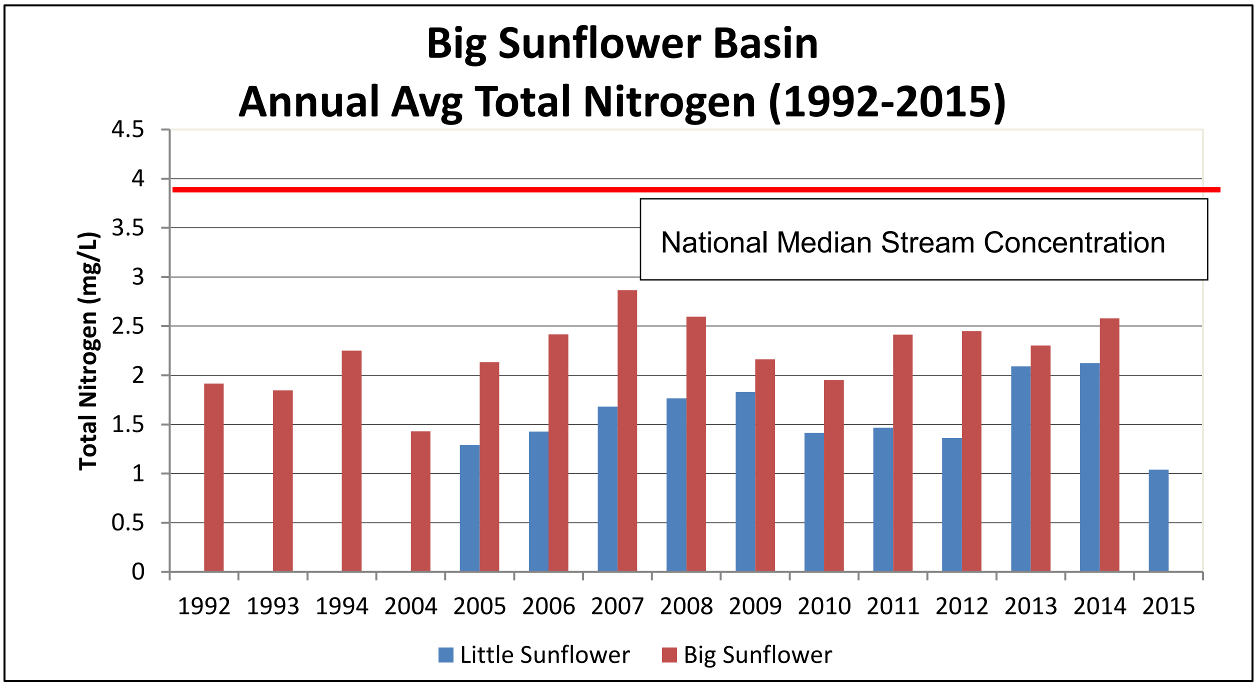

Figure 3-10. Average Annual TN Concentration for the Big Sunflower Basin from SBMP.

71. The bar graph displayed in Figure 3-11 shows the trends for long term TN monitoring in the Yazoo Basin. The graph presents the data from the NWIS and SBMP data sets for comparison of mean TN concentrations by decade. A slight increase of TN can be seen from the SBMP data in the Big Sunflower Basin from the decades of 1990 to 2010 while concentrations fell in the Steele Bayou Basin over the same time frame. In the 2010 decade, concentrations for TN from the Big Sunflower Basin were approximately 1.0 mg/L higher in the SBMP data. The inverse was observed for the Steele Bayou Basin where the average TN from the SBMP data set was approximately 1.5 mg/L lower than the NWIS data. It should be noted that measurements recorded for the NWIS data set in the Yazoo Basin appeared to show bias to hourly measurements from in-stream and edge-of-field storm water runoff studies. The nitrogen concentration for the extended time frame was reduced as it traveled from the Big Sunflower, Steele Bayou, and Upper Yazoo Watersheds to the Lower Yazoo Watershed. The overall trend for all the sub basins in the Yazoo Backwater Area appears to be far less than the national median concentration for TN published by the USGS (Dubrovsky et al., 2010).

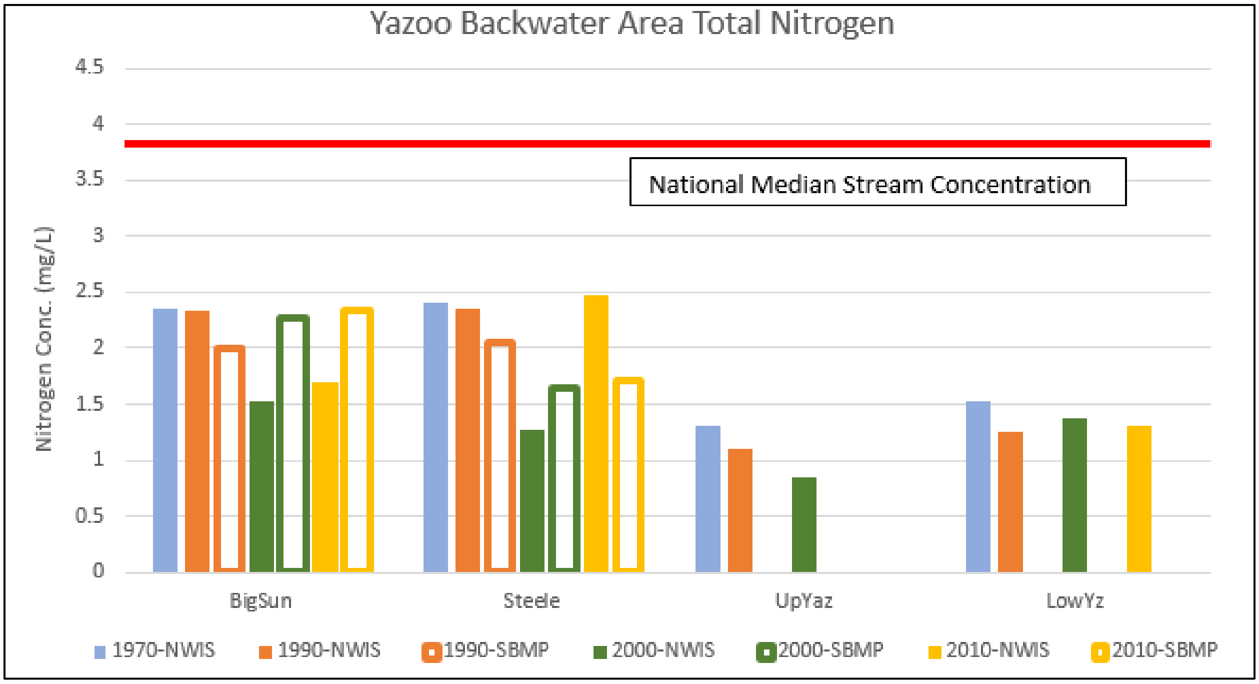

Figure 3-11. Mean Concentrations for TN found within the Big Sunflower, Steele Bayou, Upper Yazoo and Lower Yazoo HUC 8 Watersheds from data collected from NWIS and SBMP databases.

72. The graph from Figure 3-12 shows the relatively small increase of TN Load from the Yazoo Backwater Area to the Mississippi River during the 2008, 2009, 2011, and 2013 Flood Events. The figure compares the percentage of the overall TN load computed from monthly average data collected from the Mississippi River at Mile 438 (near Vicksburg, MS) and TN concentration data collected from three downstream locations in the Steele Bayou and Big Sunflower Basins (Dummy Line Road, Holly Bluff and Low Water Bridge). Average monthly TN Loads were calculated based on a discharge of 14,000 cfs times the proportional average of the YBA TN concentration previously described for TP Load.

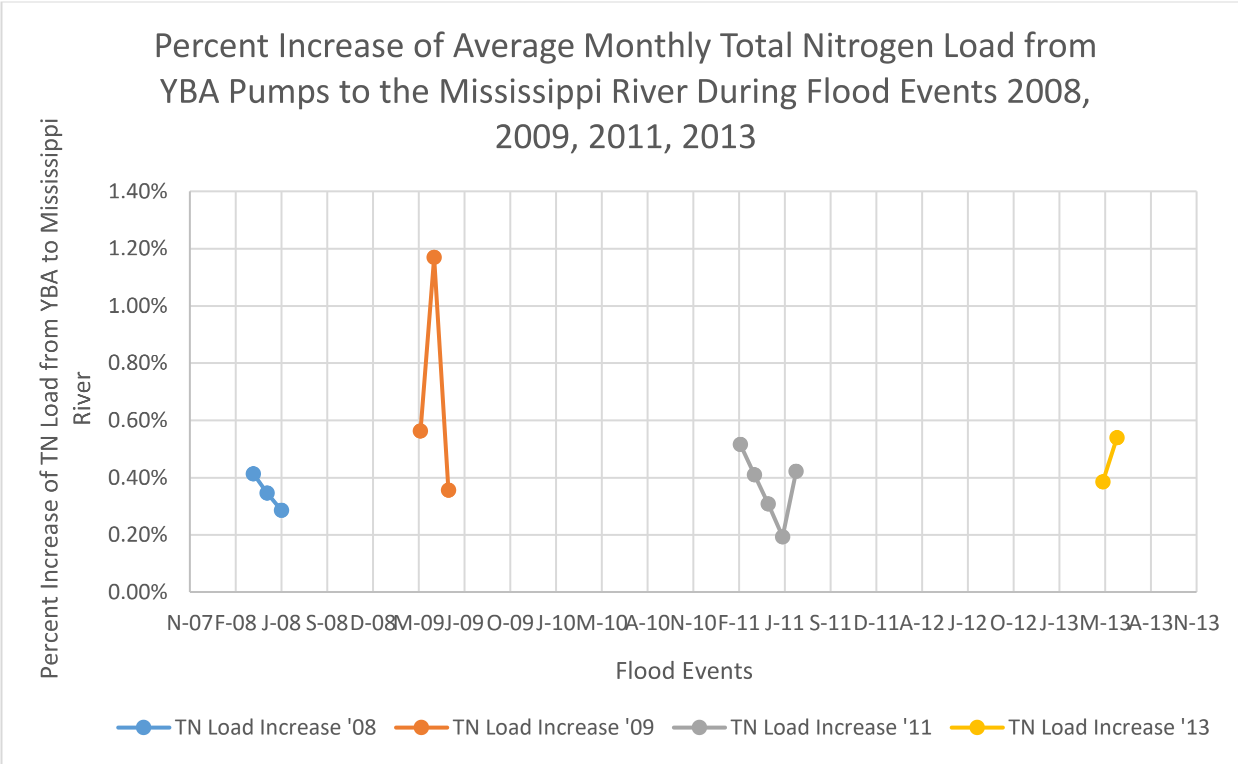

FIGURE 3-12. Theoretical Percent Increase of TN Load from the YBA to the Mississippi River during Previous Flood Events: 2008, 2009, 2011, and 2013.

It should be noted that the Yazoo Backwater Pumps will not increase the total loading of TP and TN to the Mississippi River. The timing of the nutrient loading to the Mississippi River will be increased by a few weeks however the overall mass should remain the same. Without the pumps the backwater collected during the flood events eventually escapes when flood conditions recede and the control structures are opened, releasing the water to the same destination. The overall mass loading to the Mississippi River under both conditions should remain the same.

4.0 LOW FLOW

4.1 GENERAL

73. In the early part of the twentieth century, flow in the rivers and streams of the Yazoo Basin remained in contact with the surficial aquifer. This connection allowed for water movement from the stream to the aquifer during periods of heavy rainfall and water movement from the aquifer to the stream during the dry periods of the year. The later condition describes what is traditionally referred to as environmental flow or base flow. Environmental flows or base flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems, and the human livelihoods and well being that depend on these ecosystems. Environmental flow in a stream can significantly influence the overall

potential for aquatic health since the availability of adequate water supply is necessary for aquatic habitat. These flows help to maintain the channel geometry allowing for suspension of sediments along the thalweg as well as providing an adequate wetted perimeter for bottom dwelling species like mussels which are prevalent in the two basins. Adequate environmental flow also helps to mitigate the oxygen dynamics in a stream by providing an adequate supply of DO to support both the needs of aquatic organisms as well as the demands imposed by sediment (SOD). However, when the surficial aquifer is heavily utilized for irrigation or some other consumptive use, the water level in the aquifer can fall below the stream bed, and the stream will no longer receive environmental or base flow from the aquifer.

4.2 HISTORICAL LOW FLOW

74. The main tributaries of the Steele Bayou and Big Sunflower Basins have suffered from decreasing annual minimum flows over the last 50 years. The station located on the Big Sunflower River at Sunflower, Mississippi represents a key position in one of the Yazoo Basin's major rivers to describe the historical decline in minimal flows over most of the last century. The graph in Figure 4-1 below shows that the minimum flow was around 200 cubic feet per second (cfs) in the 1930s through the 1940s, but that minimum flow diminished to just under 100 cfs during the next three decades. By the 1980s and 1990s the minimum flow (1% duration) had diminished by 90% to around 20 cfs, from the initial flow measurements taken in the mid 1930's.

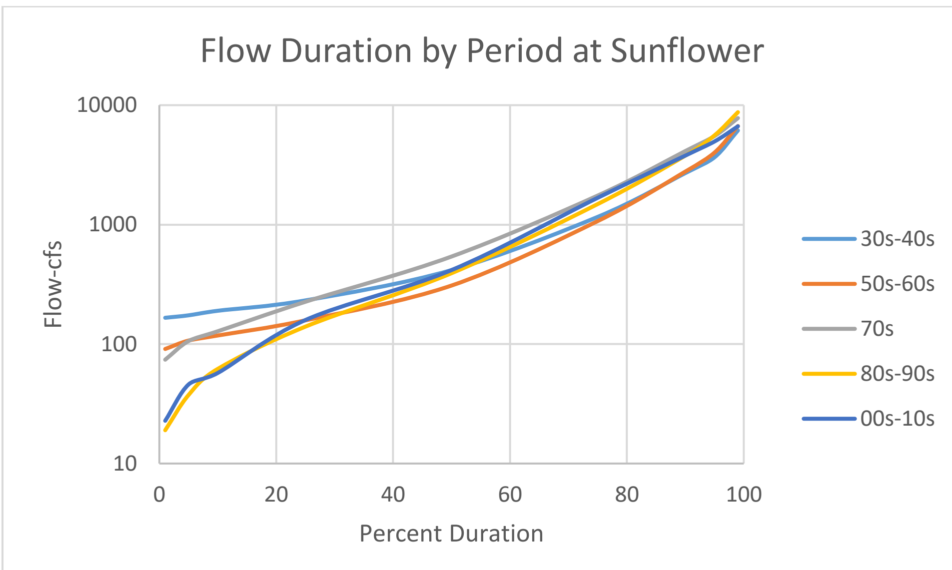

Figure 4-1. Flow Duration by Period in the Big Sunflower River at Sunflower, Mississippi

75. The historical flow depletion observed for each of the four seasons is explained in more detail in the Engineering Appendix, Section 2.0 (Low Flow in Delta Streams) of this report. The analysis from this section explains how the fall months have been observed to experience the most restrictive flows of which coincide with the season which receives the least precipitation. The median flow representing the fall months in the periods from 1980 to 1999 and the period from 2000 to 2019 were observed to be 102 and 106 cfs, respectively. These median flow values were substantially less than the median flow values observed in the fall

months from the 1930's to the 1970's which ranged from 153 to 225 cfs. These minimal stream conditions for the fall months are further reiterated by reporting the 1% flow of only 10 cfs for the 1980's and 1990's which had declined from 160 cfs for the 1930's and 1940's, 90 cfs for the 1950' and 1960's, and 71 cfs for the 1970's. The most recent period of 2000 to 2019 saw a slight increase for the 1% flow for the fall months to 18 cfs but still falls far below the historical base flows observed in the early part of the 19th century.

76. During the summer months, the more recent decades show a slight increase in observed flow. This increase is due to irrigation return flow. The median flows were 287 cfs for the 1930' and 1940's, 202 cfs for the 1950's and 1960's, 458 cfs for the 1970's, 440 cfs for the 1980' and 1990's, and 370 cfs for the 2000's and 2010's. The increase in minimal flows in the summer months for the recent periods can be attributed to the increasing use of irrigation in the Yazoo Basin largely starting in the 1970's. The widespread use of this fundamental agricultural practice has added to cumulative stream flows by virtue of irrigation runoff.

77. Recent attempts have been made to supplement base flow conditions in the Yazoo Basin. The flow representing the 5% duration for the 2000's was increased to approximately 50 cfs as a result of the flow augmentation implemented by Yazoo Mississippi Delta Join Water Management District in 1998 (Figure 4-2). The operation of these augmentation efforts has been hampered since their inception due to flow path restrictions from the wells to the channel of the Big Sunflouwer River minimizing the full potential of the project on the basin.

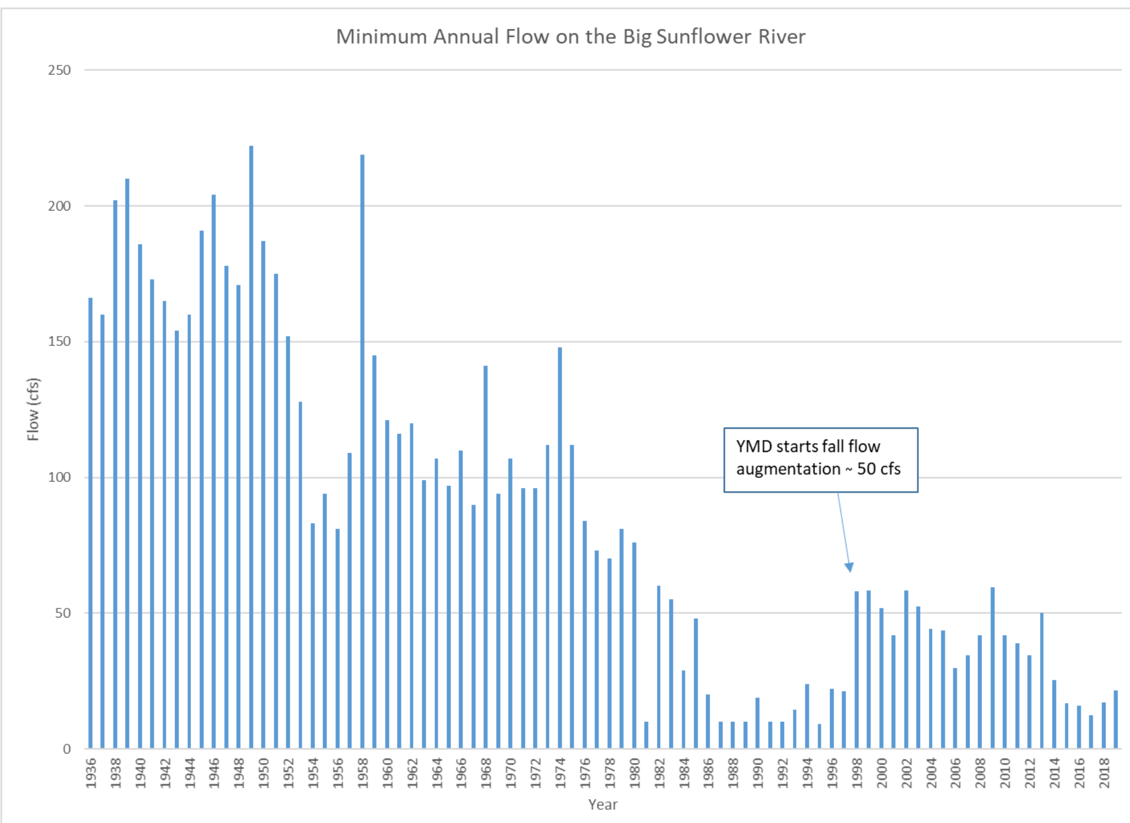

Figure 4-2. Annual Minimum Flow of the Big Sunflower River at Sunflower, Mississippi from 1936 to 2008.

4.3 SUPPLEMENTAL LOW FLOW GROUNDWATER WELL SITES

78. In addition to building a 14,000 cfs pump station in the lower Yazoo Basin, the YABP project intends to construct 34 supplemental low flow groundwater well sites in the headwaters of the Big Sunflower, the Upper Deer Creek, and the Steele Bayou basins. Early uses of flow augmentation were to improve water quality or to improve water quantity to ensure the water quality was maintained. The Federal Water Pollution Control Agency, in Atlanta, GA contracted with the University of Florida (Final Report to Southeast Region, FWPCA, Sep 1969, A Model For Quantifying Flow Augmentation Benefits; Pyatt et al. 1969) to examine the cost benefit of augmenting flow compared to the increased costs of waste water treatment. One of the EPA first reports dealt with flow augmentation, "Water Quality Control Though Flow Augmentation" (Heidelberg College, Biology Department 1971). Again, the emphasis of the study was improving water quality. The use of flow augmentation to improve water quality and aquatic health is explained in greater detail in the Engineering Appendix – Flow Augmentation.

79. The objective of the supplemental low flow groundwater well component of the project is to establish environmental flow or base flows for the region which will mimic flows observed in the mid 20th century found in the Yazoo Basin. The implementation of the supplement low flow groundwater well sites will ideally supplement existing flows to a rate of 0.1 to 0.2 cfs per square mile for the applicable watersheds. This projected per square mile flow rate will support year-round channel geomorphology conditions, provide the necessary water quality conditions for aquatic life, and maintain adequate inundation for mussel beds.

80. The proposed locations of the 34 supplemental low flow groundwater well sites were based on two criteria: the wells were within 30,000 feet of the Mississippi River channel and the wells reside on the landside of the Yazoo Backwater levee. The first condition was set to insure adequate groundwater supply from annual recharge from the Mississippi River. The potential for annual recharge of the alluvial aquifer from the Mississippi River is proportionally greater for water bearing strata closer to the channel. Significant drawdown of the alluvial aquifer has been primarily concentrated in the Sunflower and LeFlore counties. The supplemental low flow gourndwater wells have been located in areas that have not demonstrated long term decline in the water table. This natural phnomenon is explained in greater detail in the Engineering Appendix: Well Field Augmentation. The second condition was set to insure supplemental flows were going to areas with strong mussel bed populations that have been plagued with inadequate minimum flows. Each well site will mimic a common design capable of delivering a maximum of 5.0 cfs during low flow periods. The pump for each well site will be situated on the top bank of headwater stream with a pipe discharging water onto a splash pad which will then flow down a constructed re-aeration trough to the channel. The cooler temperature regime typically associated with groundwater will also have a positive effect on the DO saturation when mixed with warmer surface waters.

81. The water extracted from the MRVA is known to have higher levels of iron concentrations. Currently there are more than 20,000 wells in use for agricultural irrigation in the Yazoo Backwater Area. While the operation of these irrigation wells has had a significant contribution to Yazoo Basin via irrigation return flow, the surface water quality has not experienced a noticeable change. The ferrous iron pumped by each supplemental low flow groundwater well will likely precipitate in the reaeration trough adjacent to the channel and

should not have an adverse effect on stream water quality (may improve by removal of phosphorus). The clean groundwater taken from the MRVA has been found to be free of harmful contaminates and should have a positive impact on the overall water quality in the Yazoo Basin.

82. The period for critical flows in the YBA and corresponding use of the supplemental low flow wells comes after the agricultural growing season and notable decline in stream stages resulting from diminished irrigation return flow. The supplemental flow delivered to the streams should not be viewed as a water source for irrigation (via surface water) to nearby farming operations which could hamper the overall benefits to the project. The operational plan for the supplemental low flow groundwater wells will be structured based on adaptive management strategies tailored for low flow conditions when irrigation return flows have ceased. Depth transducers will be installed in each sub-basin, and pumping will be initiated or halted based on observed water surface elevations. Minimum flow targets will be established for downstream locations, and the number of wells operated will vary so target flows are achieved. The wells will not be operated during major flood events.

83. The three primary basins that will be supplemented by these well sites are: The Steele Bayou Basin, the Upper Deer Creek Basin, and the Big Sunflower Basin. The Big Sunflower includes the Harris Bayou, Hushpuckena River, and Bogue Phalia sub-basins. The number of well sites and cumulative additional flow each basin is set to receive is as follows: Steele Bayou - 8 well sites (40 cfs), Upper Deer Creek - 5 well sites (25 cfs), and Big Sunflower - 21 well sites (105 cfs). A map depicting the locations of the proposed well locations along with the tributaries they will support is shown in Figure 4-3, Figure 4-4, and Figure 4-5. Coordinates for each of the proposed wells is given in Table 4-1. It should be noted that each well site may move up to 1,000 feet up or down stream and/or to the opposing bank from the proposed locations. These relocations could result from unforeseen limitations with HTRW, cultural artifacts, power availability, or unwilling land owners.

Figure 4-3. Map of the proposed 21 well sites for the Big Sunflower Basin along with the tributaries that will be supplemented.

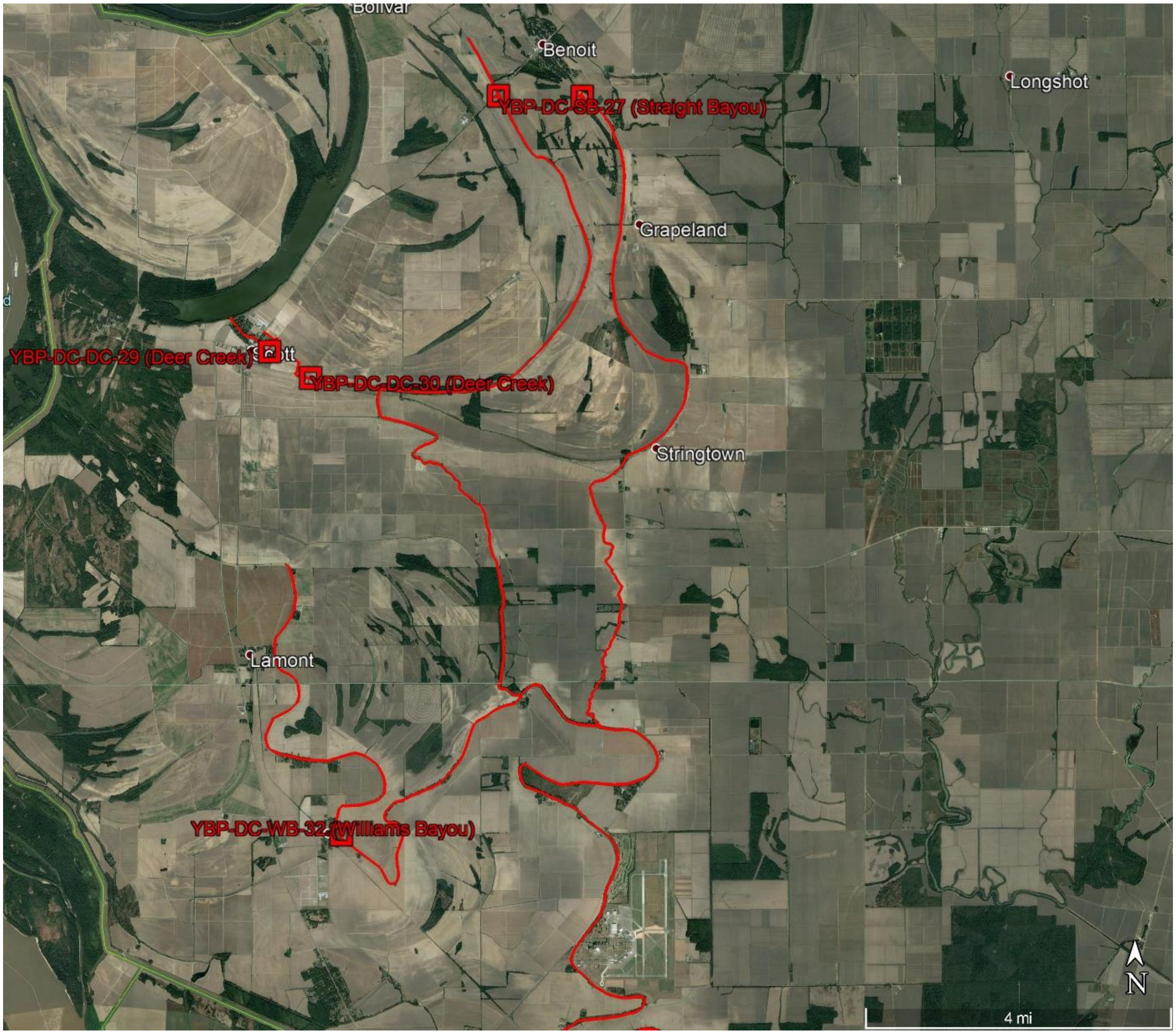

Figure 4-4. Map of the proposed 5 well sites for the Upper Deer Creek Basin along with the tributaries that will be supplemented.

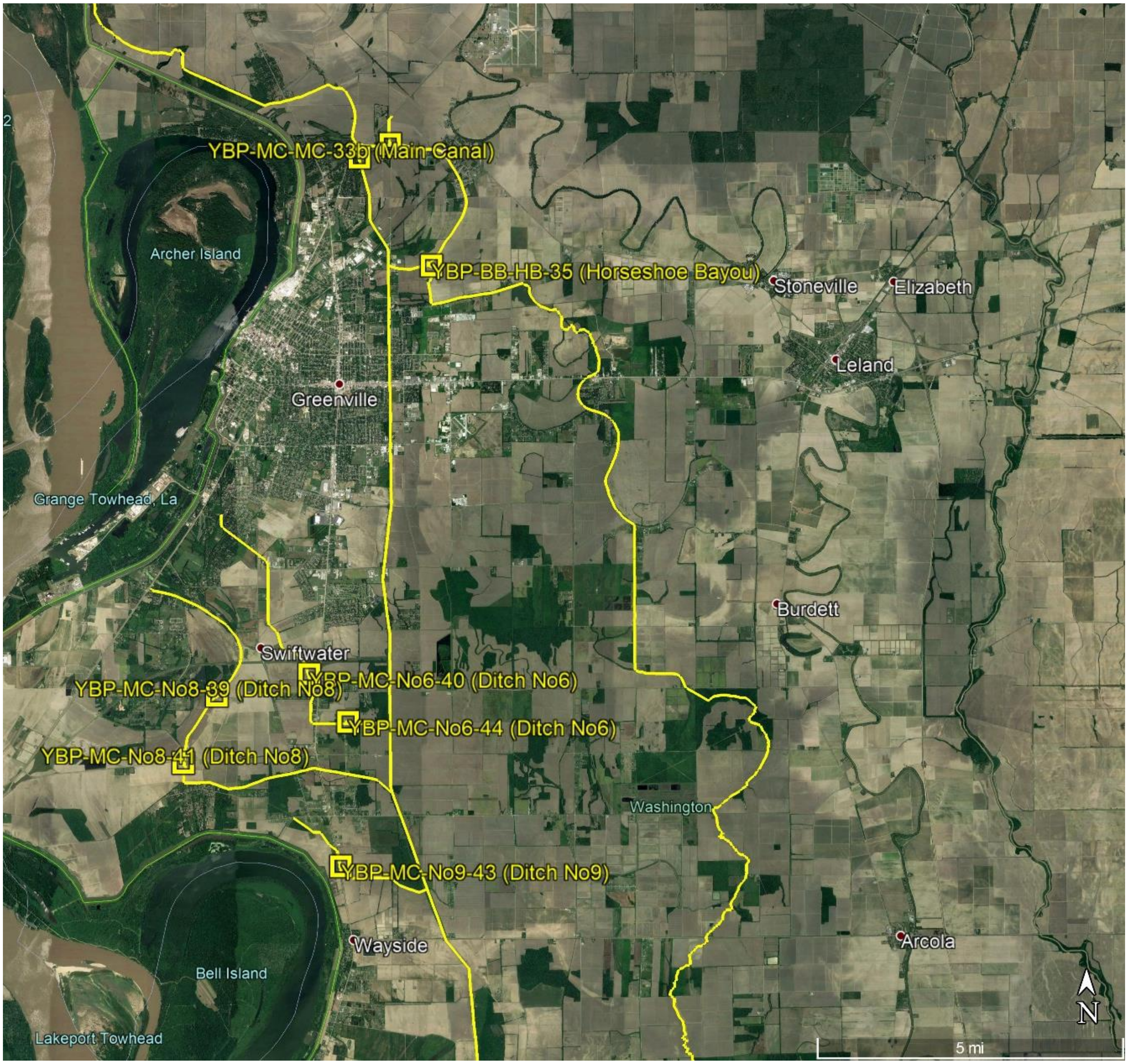

Figure 4-5. Map of the proposed 8 well sites for the Steele Bayou Basin along with the tributaries that will be supplemented.

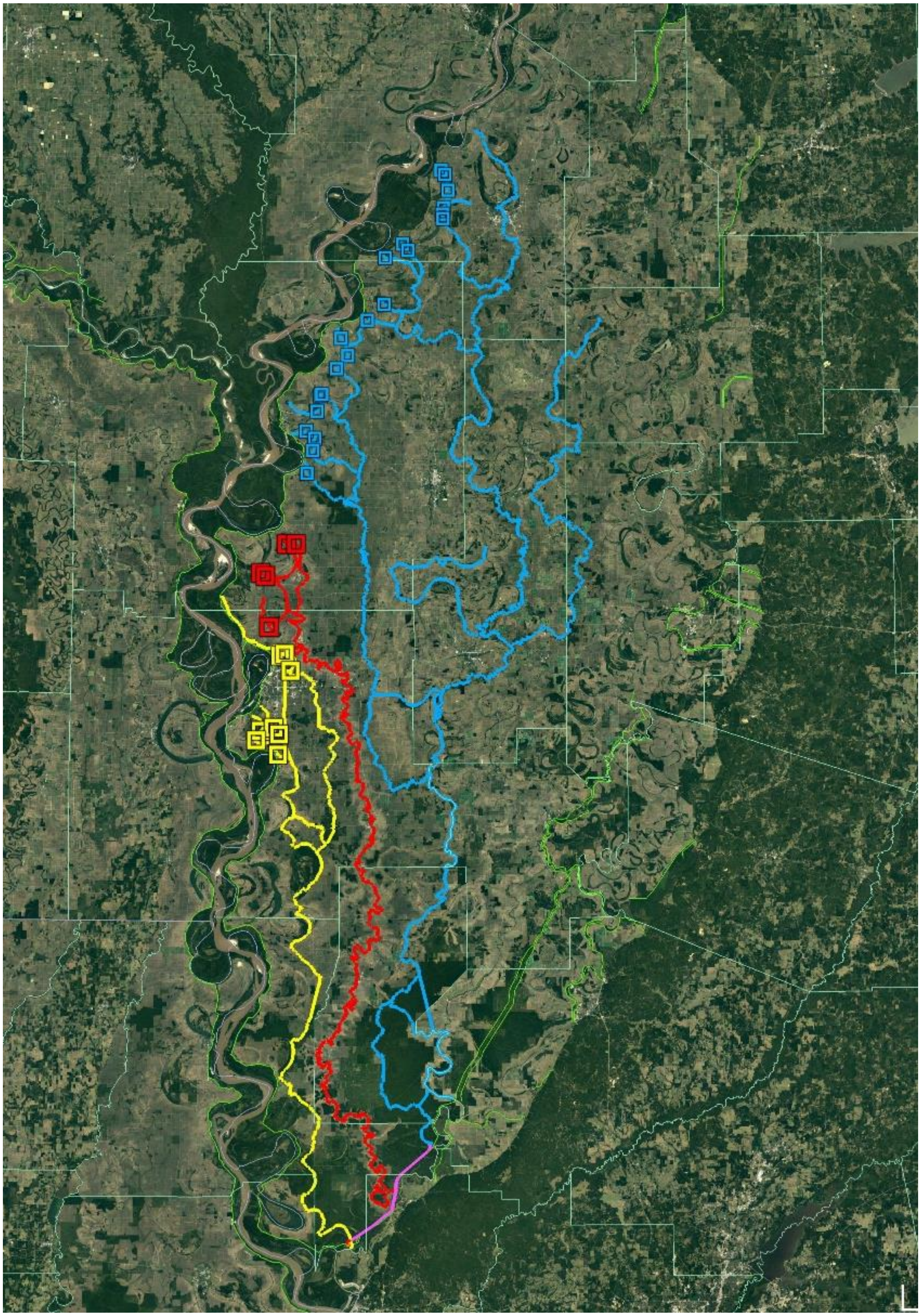

Figure 4-6. Location of the Well Sites for the Yazoo Area Pump Project.

YBW FEATURES						
County	**Site Name**	**Water Body**	**Latitude**	**Longitude**	**Area (Acres)**	**Access Road acres**
Coahoma	YBP-HB-RB-1	Ritchies Bayou	34 16 23.97	90 42 12.22	1.25	0.01
Coahoma	YBP-HB-RB-2	Ritchies Bayou	34 15 58.58	90 41 43.83	1.25	0.47
Coahoma	YBP-HB-RB-3	Ritchies Bayou	34 14 22.73	90 41 21.95	0.75	0.52
Coahoma	YBP-HB-HB-4	Harris Bayou	34 12 36	90 41 58.13	1.00	0.40
Coahoma	YBP-HB-HB-5	Harris Bayou	34 11 56.5	90 42 03.88	0.75	0.38
Coahoma	YBP-HB-HB-6	Harris Bayou	34 11 29.5	90 41 59.22	0.50	
Coahoma	YBP-HP-HP-7	Hushpuckena River	34 08 54.31	90 46 55.7	0.75	0.05
Coahoma	YBP-HP-HP-8	Hushpuckena River	34 08 15.62	90 46 18.67	1.00	0.21
Coahoma	YBP-HP-MS-10	McNeil Slough	34 07 31.98	90 49 05.41	1.00	
Bolivar	YBP-HP-SB-12	Upper Stokes Bayou	34 02 46.25	90 49 14.8	1.25	0.13
Bolivar	YBP-HP-EB-13	Edwards Bayou	34 01 10.4	90 51 17.92	0.75	
Bolivar	YBP-BP-BP-14	Bogue Phalia	33 59 21.2	90 54 30.41	0.50	0.03
Bolivar	YBP-BP-BP-15	Bogue Phalia	33 57 35.52	90 53 42.1	1.25	0.95
Bolivar	YBP-BP-BP-16	Bogue Phalia	33 56 15.99	90 55 05	1.00	0.03
Bolivar	YBP-BP-LB-18	Lane Bayou	33 53 31.9	90 57 04.02	1.25	0.14
Bolivar	YBP-BP-LB-19	Lane Bayou	33 51 56.91	90 57 27.04	0.75	0.42
Bolivar	YBP-BP-LB-20	Lane Bayou	33 53 40.58	90 56 52.45	1.25	0.32
Bolivar	YBP-BP-LB-22	Laban Bayou	33 49 56.2	90 58 47.65	1.00	0.15
Bolivar	YBP-BP-LB-23	Laban Bayou	33 49 12.94	90 57 44.89	0.75	0.09
Bolivar	YBP-BP-LB-24	Laban Bayou	33 47 57	90 57 57.95	1.25	0.12
Bolivar	YBP-BP-SB-26	Lower Stokes Bayou	33 45 40.48	90 58 42.05	0.50	2.02
Bolivar	YBP-DC-SB-27	Straight Bayou	33 38 29.69	91 01 11.03	1.00	0.23
Bolivar	YBP-DC-BB-28	Browns Bayou	33 38 29.25	91 00 01.99	0.75	0.25
Bolivar	YBP-DC-DC-29	Deer Creek	33 35 34.08	91 04 18.96	0.75	1.69
Bolivar	YBP-DC-DC-30	Deer Creek	33 35 15.99	91 03 45.3	0.75	0.04
Washington	YBP-DC-WB-32	Williams Bayou	33 30 05.44	91 03 19.84	0.75	0.06
Washington	YBP-MC-MC-33b	Main Canal	33 27 10.9	91 01 55.46	1.00	0.05
Washington	YBP-BB-HB-34	Horshoe Bayou	33 27 22.32	91 01 23.97	0.75	1.72
Washington	YBP-BB-HB-35	Horshoe Bayou	33 25 39.19	91 00 42.18	1.00	0.29
Washington	YBP-MC-No8-39	Ditch No8	33 19 34.82	91 04 19.98	0.75	0.03
Washington	YBP-MC-No6-40	Ditch No6	33 19 52.99	91 02 46.29	0.75	0.61
Washington	YBP-MC-No8-41	Ditch No8	33 18 37.89	91 04 53.86	0.75	0.45
Washington	YBP-MC-No9-43	Ditch No9	33 17 10.54	91 02 14.22	0.75	0.22
Washington	YBP-MC-No6-44	Ditch No6	33 19 12.66	91 02 06.97	1.25	0.11

Table 4-1. Overall acres associated with Well Sites described for the Yazoo Area Backwater Project

5.0 CONCLUSION

84. The mean concentrations observed for nitrogen and phosphorus coming from the Yazoo Backwater Area fall far below the concentrations estimated out of the Midwest Tributaries as detailed in MARB SPARROW model. The Yazoo Backwater Area does not contribute a disproportionate load of nitrogen to the Gulf of Mexico and is generally in line with its proportionate contribution of phosphorus to the Gulf hypoxic zone. The extensive erosion control measures employed by the Vicksburg District and its Federal, State and local sponsors have made significant strides to control the nutrient contributions from the Yazoo Basin to the Gulf Hypoxic Zone. The Yazoo Backwater Pumps will not increase the total loading of TP and TN to the Mississippi River. The timing of the nutrient loading to the Mississippi River will be increased by a few weeks however the overall mass should remain the same.

85. Implementation of the Yazoo Backwater Pump Project can significantly enhance the overall water quality in the Yazoo Backwater Area. Construction of the 14,000 cfs Backwater Pumps will help increase DO in the water column by minimizing the overall depth of a flood event thus improving diffusion from the surface water. Activation of the pumps will also draw water primarily from the bottom of the flood pool taking with it the most depleted DO concentrations. As the backwater pools grow deeper and sustain prolonged periods of stagnation, the suspended solids have an opportunity to settle out of the water column. This process makes way for increased light transmission through the surface layer and the increased production of algal productivity. As a result, DO concentrations begin to recover within the first 5 to 10 feet of surface. This turnaround typically comes too late to provide habitat for aquatic species because they have either left the region or died from the extended period of poor conditions. The construction of the Yazoo Backwater Pumps would slightly reduce the overall settling time for suspended solids in the basin but not before most of the settling has taken place. The reduced time frame should have a minimal impact on DO contributions from primary productivity. The construction of the Yazoo Backwater Pumps would reduce this extended period of poor DO conditions lessening the impacts of aquatic species evacuation or death. The combination of these effects should have an overall benefit to DO in the Yazoo Backwater Area during extended flood events.

86. The construction of supplemental low flow groundwater well sites built in the headwaters of the two basins will help to supplement needed base flow in the major arteries of the systems allowing for year-round in-channel habitat during critical low flow periods. These well sites will provide a positive benefit to the overall low DO conditions observed during the warmer months. These warmer months typically coincide with the low flow periods in the primary tributaries of the two basins. The supplemental water provided should stimulate re-aeration through agitation minimizing the presence of stagnant intermittent pools in the channels. Water from the well sites will likely decrease the ambient temperature of the streams and have a positive effect on DO saturation which would be beneficial to aquatic life.

6.0 LITERATURE CITED

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