Total suspended sediment concentrations in Wolf Lake, Mississippi: An EPA 319 (h) landscape improvement project

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The Wolf – Broad Lake water body (13 km in length) was evaluated as impaired and included on the Mississippi 303(d) list of impaired water bodies. As such, the EPA 319 (h) program, through the Mississippi Department of Environmental Quality selected this water body and its associated watershed for landscape improvement, with the goal of moving towards improving the lakes water quality, meeting associated evaluated total maximum daily loads, and ultimately de-listing the water body for total suspended sediment (TSS) impairment. A study was undertaken for 2 years to evaluate and document appropriate changes to the total suspended sediment loads (mg/L) and overall lake turbidity. These two objectives were analyzed with monthly surface sampling events of turbidity using automated sampling technology (Eureka – Manta 2, Automated Data-son) as well as 20 random samples per sampling trip for TSS analysis. Results from a non-parametric Kruskal-Wallis analysis indicate a significant month-by-year effect on turbidity and TSS (Chi-square = 76.08, P = 0.001), but reach (Chi-square = 2.45, P = 0.784) and depth by reach (Chi-square = 2.44, P = 0.784) did not show significant effects on turbidity. There were no significant correlations between TSS and turbidity concentrations and two day, and seven day summed or mean rainfall. Spearman correlation analysis for TSS indicated significant correlations between TSS and mean two day (r^2= 0.62, P= 0.002) and seven day (r^2= 0.51, P= 0.014) wind speeds. All other variables used in the analysis did not show significant correlation with TSS (P> 0.05). This suggests that wind conditions, rather than rainfall predict the greatest variability in TSS and turbidity in Wolf Lake. These documented correlations between lake water column TSS and turbidity, and wind highlight the difficulties of demonstrating success in a short temporal period between project initiation and completion. Unmanageable environmental conditions (wind speed and direction), and limited temporal monitoring scales (1½ years post BMP implementation) limit the possibility of demonstrating success of water quality improvement within Wolf Lake a 303(d) listed water body.

Key words: Water Quality, Source Water, Geomorphological and Geochemical Processes, Ecology, Models

Introduction

The implementation of the Federal Water Pollution Control Amendments of 1972 and Clean Water Act in 1977 brought about an increased awareness of the status of our nation's water bodies and necessitated programs geared towards the improvement of aquatic systems health in the United States, and decreases in contaminant loads. Areas in which agriculture dominates a major portion of land usage are particularly susceptible to harmful effects of non-point source pollutants. In the Mississippi Delta, much of the focus on water quality improvement has been placed on the numerous oxbow lakes of the region which are seeing increases in recreational and development activities. A number of oxbows have been designated 303d impaired water bodies, with Wolf-Broad Lake considered impaired for sediments.

Wolf Lake and Broad Lake (here forth referred to as Wolf Lake) were once part of the Yazoo River. Their creation is mostly attributed to natural Oxbow formation, as Wolf Lake was formed by the Yazoo River in the most recent meander belt of the Mississippi River. Current hydrology and drainage of these lakes and its watershed are mostly attributed to modifications made for the purpose of flood control. Currently the watershed has one central outlet at the confluence of Wolf Lake and Broad Lake which drains through two channels into the landside ditch of the Wittington Canal, and then into the Yazoo River. Ironically, this connection leaves the watershed un-protected from high water events on the Mississippi River. Lake levels typically fluctuate around 88 ft, however floodwaters from the Mississippi River can push the lake level much higher, flooding farmland and residences in the watershed. Surface water levels in the watershed are maintained by rainwater, the Mississippi River alluvial aquifer, and the Yazoo River. Ground water withdrawals for agricultural use (primarily irrigation) are made from the alluvial aquifer and surface water, with a majority coming from the alluvial aquifer.

The Wolf Lake watershed has been evaluated as impaired (not based on water quality measurements) and is included on the Mississippi 303 (d) List (MDEQ 2004). Agriculture in the Mississippi Alluvial Valley has been an important economic driver and with more land being used for growing crops, there is a growing concern about the maintenance of water quality in the region (Locke 2004, McHenry et al. 1982). To improve sediment load within the lake a number of best management practices (BMPs) are being installed to control and trap sediments in runoff.

Best management practices can be used to help mitigate some of the harmful effects of erosion and sedimentation, and the goals of the Wolf Lake watershed plan can most likely be achieved through the implementation of agricultural BMPs. To reduce sediment loading, structural measures can be installed to allow sediment loads to "fall out" before reaching the lake. This can be done through the installation of sediment retention structures (grade stabilization structures, slotted board risers, slotted pipes, sediment basins) on the fields before they reach the drains. Sloughing and/or head cutting in main ditches can be addressed by stabilizing the ditch banks with alterations of slope, hydro-seeding, and installing low-grade weirs. Low-grade weirs are rip-rap structures that increase the hydraulic capacity of the drainage ditch and are an innovative technology that have great potential for sediment reduction (Kröger et al. 2008). All technologies employed and installed, increase hydraulic residence, decrease runoff velocity, and increase sedimentation.

This BMP implementation project was developed and undertaken by Delta F.A.R.M. (Farmers Advocating Resource Management) and Mississippi Department of Environmental Quality to implement solutions associated with decreasing sediment concentrations in Wolf Lake. The current study evaluated temporal changes in turbidity and total suspended sediments (TSS) within Wolf Lake to monitor whether BMP installation within the watershed showed a downstream improvement in sediment load within the water column, and thus a water quality improvement to the lake as a whole.

Materials and Methods

Study Site

The Wolf Lake watershed is approximately 27,113 acres and is extremely rural and predominately agricultural. The watershed is underlain by Mississippi River alluvium. The topography of the watershed is primarily flat, with some ridge and swale topography provided by river terraces (MDEQ 2000). Approximately 44% of the watershed is in production agriculture, with the remaining 66% percent of watershed area split among bottomland hardwood forest, non-cropland (pasture, afforested cropland, etc.), aquaculture, and residential development. The geology of the watershed comprises highly productive soil types that include the Dundee and Dubbs silty loam series of soils. The balance of the soils are found to have moderate to extreme clay contents and include the Alligator and Sharkey soil series. Wolf Lake is a 417 hectare oxbow located in the Lower Mississippi Alluvial Valley (MAV) near Yazoo City, Mississippi (32°54'38.76"N, 90°27'39.72"W) (Figure 1). The morphology of the lake is elongated with a varying length, depending on the water level, of approximately 13.8 km. Width similarly varies up to 0.3 km. Wolf Lake is known for its murky, turbid waters that are common throughout lakes in the region (McHenry et al. 1982). Similar to other lakes in the Mississippi Alluvial Valley, water conditions have been affected by past landscape modifications used to control flooding and support agriculture (Cooper and McHenry 1989, Cooper et al. 2003).

Between June 2008 and September 2009 BMPs were put into place in pre-determined areas of the Wolf Lake Watershed based on accessibility, landowner cooperation and site placement. Eighty (80) slotted pipes and 12 low grade weirs (Figure 2) were installed in various agricultural ditches to decrease sediment/nutrient loads in run-off and slow down erosive processes in the watershed which in turn should lead to decreases in turbidity and TSS throughout Wolf Lake.

Data Collection

To determine variability and distribution of turbidity and TSS within the lake, water samples were collected once month from June 2008 to June 2010 using a Eureka Manta multi-probe (Eureka Environmental Engineering, Austin, TX). The multiprobe was attached to the boat, and a pumped, flow-through system, similar to the method used by Peterson (2007) was used to sample 0.3 m below the water surface of the lake. This system pumped small volumes of lake water from the lake, through a manufacturer supplied flow-cell which houses the sensors (from bottom to top), and back to the lake. Data were collected at 10 second intervals while traveling in a series of "zigzag" transects across the lake, similar to the methods used in Brydsten et al. (2004). The Eureka Manta system simultaneously collected GPS coordinates along with water quality data at each time interval which allowed for the mapping of turbidity distributions across the surface of Wolf Lake. Cleaning and decontamination of Eureka Manta multi-probes and in situ Eureka Manta sampler, proper maintenance, deployment, and operation procedures were run according to the Eureka Manta Manual. Total suspended solids (TSS) samples were collected at 20 randomly selected locations monthly in conjunction with the surface water turbidity measurements, including required replicate and blank sampling for quality control/assurance. Grab samples were collected in 3-L (>500 ml) polyethylene cubitainers at the surface at a depth < 0.5 m. The 20 collection sites were changed monthly to ensure appropriate representation of the conditions across the surface of the lake. Sampling locations were spatially stratified within Wolf Lake to ensure an adequate sampling of the entire lake. Samples were brought back and analyzed at the Mississippi State University (MSU) Department of Wildlife and Fisheries Water Quality Laboratory using Standard Method 2450D for total suspended sediment determination. Grab samples were shaken in the field for homogenization and, once back in the lab, re-suspended to ensure homogeneity within the sample prior to analysis. Samples were refrigerated at 4°C if not analyzed immediately upon return. Water samples collected for TSS analysis did not require acidification preservation and were analyzed within seven days. One duplicate sample was collected for every 10 random samples collected. Precision and accuracy of lab analyses were assessed through routine analysis of duplicates and laboratory control samples. Results that were determined to be outside acceptance criteria required repeated analysis and/or sampling.

Data Analysis

ArcMap (ESRI 2010) was used to build water quality distribution maps to visualize the spatial distribution of turbidity throughout Wolf Lake. Point data from each month during the study period (n = 19) collected with the Eureka multi-probe were plotted in ArcMap using GPS coordinates (latitude/longitude; ESRI 2010). For each month, turbidity values (NTU) were interpolated using Inverse Distance Weighting (IDW), using the lake edge as a barrier. Wolf Lake was divided into six reaches (five main channel sections and one outlet section). Zonal statistics (count, area, minimum, maximum, range, mean, standard deviation, and sum) were calculated for each reach using the ArcGIS Spatial Analyst geoprocessing toolbox.

For turbidity and TSS statistical analysis, normal probability plots and Shapiro-Wilk values generated from Proc univariate (SAS Institute Inc 2008) were used to test assumptions of normality. The turbidity and TSS data were found to be significantly non-normal and various transformations were unable to normalize the data. As a consequence of the inability to normalize the turbidity data, a non-parametric Spearman correlation analysis (Proc Corr) was developed to examine possible correlation between mean turbidity and reach, and mean reach depth. Mean and sum seven and two day precipitation measurements (inches), and mean seven and two day wind speeds prior to the monthly sampling date were also included in the correlation analysis. Precipitation and wind data were collected from the USDA SCAN site at Mayday, which is in Yazoo County east of Yazoo City (approximately 20 miles directly east). For visual trend analysis, graphs of mean turbidity and TSS versus the different environmental variables across months of the study were created. A graph of mean TSS and turbidity versus two day wind direction (from the Mayday site) was also created, with a vector direction chosen between the two day wind direction vectors if they did not come from the same direction for both days. Due to the sinusoidal shape of Wolf Lake, however, inferences made from that graph were limited.

A non-parametric Kruskal-Wallis analysis (Proc npar1way) (SAS Institute Inc 2008) was used to test for significant month-by-year effects on TSS and turbidity which could indicate the effectiveness of the BMPs in the Wolf Lake watershed. Models directly tested the effect of month-by-year on turbidity, as well as the effects of reach and mean reach depth on turbidity. Multiple Kruskal-Wallis analyses (Proc npar1way) were developed to test for significant differences in turbidity by corresponding months before and after BMP implementation. All statistical analyses for both TSS and turbidity were run at an alpha value of 0.05.

Results

Results from the non-parametric Kruskal-Wallis analysis indicate a significant month-by-year effect on turbidity (Chi-square = 76.08, P = 0.001), but reach (Chi-square = 2.45, P = 0.784) and depth by reach (Chi-square = 2.44, P = 0.784) did not show significant effects on turbidity. Decreases in mean turbidity after the implication of BMPs were seen between November 2008 (mean turbidity= 72.27 NTU, SE = 31.14) and November 2009 (mean turbidity = 40.77 NTU, SE = 5.55), December 2008 (mean turbidity = 296.18 NTU, SE = 50.46) and December 2009 (mean turbidity = 290.70 NTU, SE = 77.11), and May 2009 (mean turbidity= 141.60 NTU, SE= 17.07) and May 2010 (mean turbidity = 93.70 NTU, SE = 8.43). Comparing median turbidity values (more appropriate indicators of central tendency for non-normal data), the November 2008 (median turbidity = 38.34 NTU) to November 2009 (median turbidity = 40.21 NTU) interval showed an increase in median turbidity level, while the December 2008 (median turbidity = 268.15 NTU) to December 2009 (median turbidity = 231.63 NTU) and May 2009 (median turbidity = 161.15 NTU) to May 2010 (median turbidity = 96.34) intervals showed decreases in median turbidity levels. The May 2009 to May 2010 period was the only interval of the three above that was found to have a statistically significant decrease in turbidity (Chi-square = 4.59, $P = 0.032$). Interestingly, rainfall over July – October in 2009 had the largest summed precipitation in the state of Mississippi for more than 73 years. There was no statistical difference between median turbidity values between October 2008 (median turbidity = 88 NTU) and October 2009 (median turbidity = 85 NTU), while there was a statistical difference (Chi-square = 8.34, $P = 0.001$) in daily summed rainfall (October 2008: 2.04"; October 2009: 11.04").

Mean seven and two day precipitation values were similar for months in each time interval, but mean seven and two day winds speeds differed between months within each time interval (Table 1). Though the variable reach did not significantly affect turbidity, Table 2 shows a large discrepancy in mean turbidity levels for Reach 1 as compared to all of the other reaches. Median turbidity levels, however, did not differ as greatly between reaches which may be an indication of large ranges of turbidity values and significantly non-normal turbidity data by reach.

Results from the Spearman correlation analysis indicate significant correlations between turbidity and mean two day (r^2= 0.53, P< 0.05) and seven day (r^2= 0.38, P< 0.05) wind speeds (Figures 3 and 4). All other variables considered in the analysis showed no significant correlation with turbidity (P> 0.05), including mean two day and summed seven day precipitation. Figure 5 highlights how a northerly wind may lead to larger turbidity levels on Wolf Lake. Due to small sample sizes of turbidity measurements by direction, no statistical comparisons could be performed and results should be interpreted only for possible trends and further analysis in the future.

For TSS, the Kruskal-Wallis non-parametric analysis indicated a significant month-by-year affect on mean TSS (Chi-square= 362.15, P< 0.05). Decreases in mean TSS after the implication of BMPs were seen between July 2008 (mean TSS= 15.38 mg/L, SE= 2.95) and July 2009 (mean TSS= 14.45 mg/L, SE= 4.40), November 2008 (mean TSS= 31.50 mg/L, SE= 1.96) and November 2009 (mean TSS= 18.08 mg/L, SE= 0.81), December 2008 (mean TSS= 175.80 mg/L, SE= 17.85) and December 2009 (mean TSS= 172.44 mg/L, SE= 24.24), April 2009 (mean TSS= 103.20, SE= 10.36) and April 2010 (mean TSS= 57.54, SE= 8.29), and May 2009 (mean TSS= 98.49 mg/L, SE= 5.65) and May 2010 (mean TSS= 37.34 mg/L, SE= 7.47) (Figure 6). Median TSS levels for all intervals above also decreased during the given time periods. Pairwise Kruskal-Wallis analysis of the above intervals showing decreases in mean TSS found that only the November 2008 to November 2009 (Chi-square= 23.89, P< 0.05), April 2009 to April 2010 (Chi-square= 8.22, P= 0.004), and May 2009 to May 2010 (Chi-square= 22.71, P< 0.05) intervals showed statistically significant decreases in mean TSS after BMP implementation.

Spearman correlation analysis for TSS indicated significant correlations between TSS and mean two day (r^2= 0.62, P= 0.002) and seven day (r^2= 0.51, P= 0.014) wind speeds. All other variables used in the analysis did not show significant correlation with TSS (P > 0.05). Similar to Figure 5, it appears that a northerly wind may lead to larger TSS levels on Wolf Lake which is similar to what was found for turbidity. Like the turbidity analysis, small sample sizes of TSS measurements by direction made statistical comparisons of TSS by wind direction inappropriate and results should be interpreted only for possible trends and further analysis in the future.

Discussion

In several watersheds nonpoint source pollutants, typically from agriculture, are major contributors to water quality problems (Moore et al. 2001, Park et al. 1994, Sharpley et al. 2000). The implementation of best management practices (BMPs) in landscapes that avoid, control or trap nonpoint source pollutants before runoff reaches downstream ecosystems is a viable management strategy to improve downstream water quality (Watson et al. 1994). Demonstrating this success of implementation on downstream water quality is vital for understanding how management translates to environmental integrity improvement. This management for water quality is no more vitally important than in the Mississippi River Basin where runoff and degraded water conditions result in hypoxic conditions in the Gulf of Mexico, resulting in severe economic and environmental consequences.

The EPA 319 (h) program office has provided funds that are used for improving watersheds landscape management to decrease and create attainable water quality conditions in 303(d) impaired waters. Wolf Lake is a listed 303(d) impaired water body in the Delta region of Mississippi (FTN 1991, MDEQ 2003, MDEQ 2004), and this current projects objective was to demonstrate significant improvements in TSS and turbidity within Wolf Lake through BMP implementation. The majority of BMPs installed advocated increasing hydraulic residence time on the landscape (Cooper and Lipe 1992) by installing slotted pipe and drop pipe structures on the edge of field, creating improved drainage channels with herbaceous vegetation, and installing low-grade weirs within the drainage channels (Kröger et al. 2008). Environmental circumstances, however, can reduce the ability to detect water quality improvements and thus success of BMP implementation and 319(h) fund appropriation. Though there were several instances where distinct improvements of water quality occurred, significant correlations to unmanageable environmental variables suggests that external factors could bias data collection and ultimate success determination, and TMDL attainment within Wolf Lake.

Demonstration of success suggests measurable and statistical decreases in TSS and turbidity levels through time as a direct result of BMP implementation. From May 2009 (during BMP implementation) to May 2010 (6-10 months post implementation) there were statistically significant declines in TSS and turbidity. There was no statistical difference between median turbidity values between October 2008 (median turbidity = 88 NTU) and October 2009 (median turbidity = 85 NTU); however, there was a statistical difference (Chi-square = 8.34, P = 0.001) in daily summed rainfall between months (October 2008: 2.04"; October 2009: 11.04"). This suggests that even though rainfall and runoff had increased fivefold, there was no commensurate increase in TSS or turbidity. This lack of increase in sediments can only be explained by structures on the landscape, retaining water, slowing water, and increasing sedimentation. Other months showed no statistical differences in TSS and turbidity concentrations pre and post BMP implementation. Difficulty arises when temporal periods of BMP success have not been adequately defined in the scientific community. Questions arise to how long post BMP installation would be adequate for statistically significant differences to be documented? Interestingly a study by Cooper et al. (2003) and Knight et al. (in press) on Beasley lake, in the Mississippi Delta, has showed statistically significant declines in lake TSS levels as a result of BMP implementation in the watershed. These results, if documented and published within three years of project initiation, would have shown negligible effects of BMP implementation on TSS levels in Beasley Lake. Only 15 years of data collection on the site has shown a significant declining trend of TSS with time. This lag period has been classified as a transitional-period condition (Walker 1994, Walker and Graczyk 1993). This transitional period recognizes that BMP implementation and effectiveness are not mutually exclusive. There is a certain time period required for the system with BMPs implemented, to mature, stabilize and begin to provide effective non-point source pollutant mitigation. Early success in demonstrating statistical differences within the transitional period documents the benefit of BMP implementation; however, longer monitoring will provide a greater understanding of the effectiveness of BMP implementation.

BMP implementation / pre – post demonstration of success

Often it is difficult to demonstrate success in improvements to water quality with BMP implementation within limited temporal periods. This study has documented that external environmental conditions play significant roles in demonstrating BMP success. The current study highlighted no significant relationship between TSS or turbidity and mean or summed two day or seven day rainfall. There were, however, statistically significant correlations between lake TSS and turbidity levels and mean two day and seven day wind speeds (Turbidity: r^2= 0.62, P= 0.002; r^2= 0.51, P= 0.014; TSS: (r^2= 0.53, P< 0.05; r^2= 0.38, P< 0.05). This suggests that though BMP implementation advocated a reduction in sediment load being delivered to Wolf Lake, monitoring efforts towards documenting this decline were thwarted by wind conditions increasing lake turbidity and TSS. The fetch and sinuosity of Wolf Lake, as well as shallow reaches (Figure 7) provided perfect conditions for wind to create turbulent, agitated conditions. Wolf Lake has a maximum depth of 20 ft, creating a median lake depth of 8 ft. The long fetch reaches of Wolf Lake, and the increased edge to surface area ratio due to sinuosity suggests that monitoring declines in TSS and turbidity would be difficult.

Furthermore, an added human dimension also limits the success of monitoring changes to sediment characteristics within Wolf Lake. Wolf Lake is a popular destination for recreational water sports such as waterskiing and wakeboarding. The longitudinal nature of Wolf Lake lends itself to ideal water skiing and wakeboarding conditions during the spring and summer months. Through personal observation, a busy weekend of recreational activities over the summer could elevate TSS and turbidity values. Increased turbulence from props, boat and skier wakes stirring shallow littoral zone sediments and general overall mixing of the water column in three dimensions (lateral, vertical and longitudinal) will increase TSS and turbidity levels within Wolf lake, and could artificially elevate and thus bias or skew interpretations of BMP success.

Conclusion

When determining and demonstrating success of BMP implementation with downstream improvements of water quality, it is important to holistically interpret environmental circumstances within each watershed. Important components of the environment (i.e. wind conditions), recreation (water skiers) and time are three major factors that contribute a significant amount of variation to overall TSS and turbidity loads within an aquatic system, specifically Wolf Lake. Best Management practices that increase hydraulic residence time on the agricultural landscape, slow runoff velocities and increase sedimentation are beneficial to decreasing downstream effects of suspended sediment loads. Probability of demonstrating this success will improve with increased temporal monitoring of the Lake system, as well as being cognizant at the outset of potential bias from environmental stochasticity.

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Table 1. Environmental parameter averages and associated standard errors used for Spearman correlation analyses with turbidity and TSS. Precipitation and wind data were collected from the USDA SCAN site at Mayday, which is in Yazoo County, east of Yazoo City.

Sample Date	Mean 7-Day Pre-cipitation (Inches)	Standard Error	Mean 2-Day Pre-cipitation (Inches)	Standard Error	Mean 7-Day Wind Speed (MPH)	Standard Error	Mean 2-Day Wind Speed (MPH)	Standard Error
05/29/08	0.16	0.14	0.07	0.06	5.94	0.64	6.70	0.40
07/22/08	0.00	0.00	0.00	0.00	2.61	0.18	2.10	0.10
08/08/08	0.18	0.11	0.00	0.00	3.80	0.44	3.00	0.50
09/07/08	0.54	0.30	0.06	0.06	7.23	1.48	5.25	0.95
10/30/08	0.26	0.25	0.00	0.00	5.60	0.98	7.05	2.85
11/21/08	0.05	0.05	0.00	0.00	5.37	1.07	5.55	1.05
12/13/08	0.77	0.45	1.28	0.75	9.61	1.94	15.00	0.40
01/29/09	0.04	0.04	0.00	0.00	7.36	1.01	6.30	2.10
02/20/09	0.06	0.05	0.05	0.05	7.47	1.43	11.40	3.40
03/05/09	0.04	0.03	0.00	0.00	10.54	1.37	7.00	1.40
04/17/09	0.07	0.07	0.00	0.00	9.64	1.36	6.25	0.95
05/10/09	0.62	0.33	0.01	0.00	6.59	0.68	7.10	1.70
06/28/09	0.00	0.00	0.00	0.00	3.27	0.32	2.10	0.40
07/08/09	0.01	0.00	0.01	0.01	4.10	0.53	5.45	1.15
10/30/09	0.16	0.09	0.29	0.28	4.96	1.09	4.95	0.15
11/18/09	0.05	0.05	0.18	0.18	3.91	1.29	3.20	1.90
12/10/09	0.29	0.21	0.92	0.58	5.80	1.08	8.05	2.95
01/27/10	0.15	0.07	0.02	0.02	7.66	0.83	7.40	1.20
02/17/10	0.08	0.05	0.11	0.11	5.54	1.28	7.15	2.35
03/10/10	0.00	0.00	0.00	0.00	4.77	1.22	3.70	0.99
04/21/10	0.00	0.00	0.01	0.01	5.00	0.72	6.30	1.90
05/25/10	0.23	0.15	0.00	0.00	4.70	0.68	3.40	0.60
06/11/10	0.04	0.03	0.02	0.02	4.64	0.51	4.25	0.25

Table 2. Mean and median turbidity values with associated standard errors for the six reaches of Wolf Lake, near Yazoo City, Mississippi. Sampling took place from June 2008 thru June 2010.

Reach	**Mean Turbidity (NTU)**	**Median Turbidity (NTU)**	**Standard Error**
1	233.49	152.16	54.65
2	143.47	176.49	20.42
3	144.48	159.25	22.79
4	144.96	128.18	29.03
5	129.17	107.63	23.59
Outlet	138.46	177.21	29.15

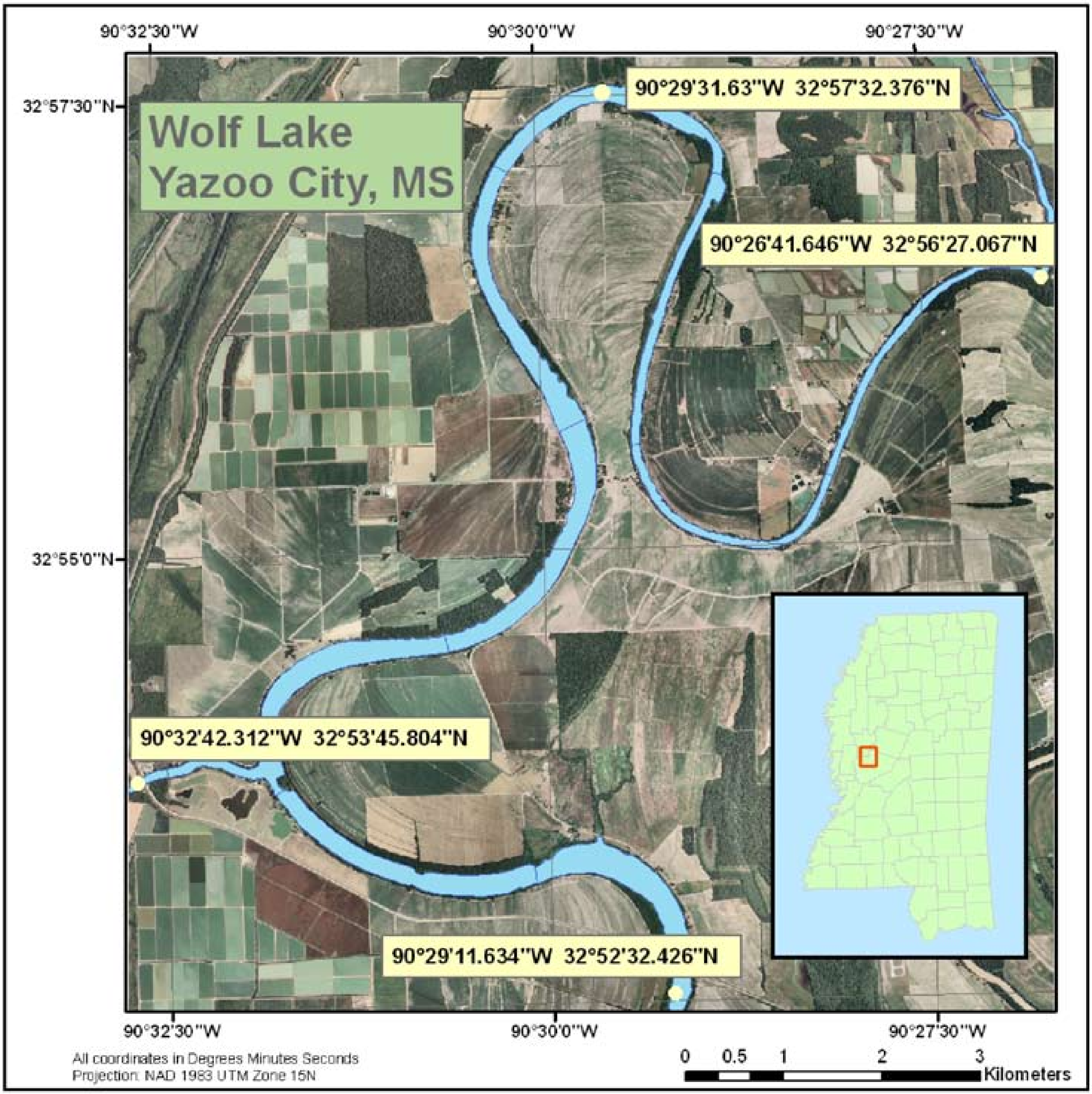

Figure 1. A GIS image of Wolf – Broad Lake complex illustrating position within Mississippi, and GPS co-ordinates within the lake.

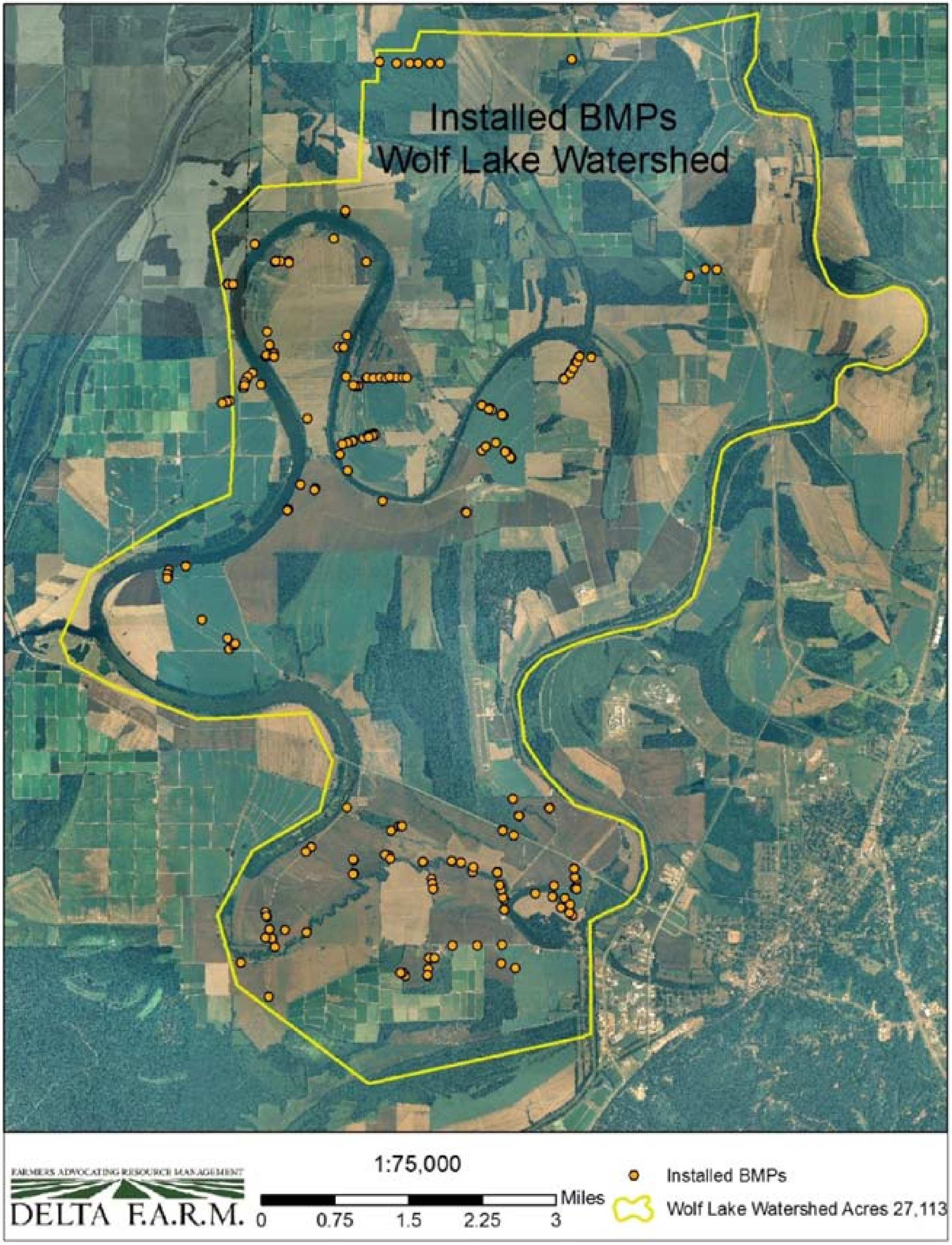

Figure 2. The Wolf Lake Watershed highlighting the installed BMPs from Delta F.A.R.M throughout the project. Site location, and BMP location were based on landowner cooperation as well as site accessibility.

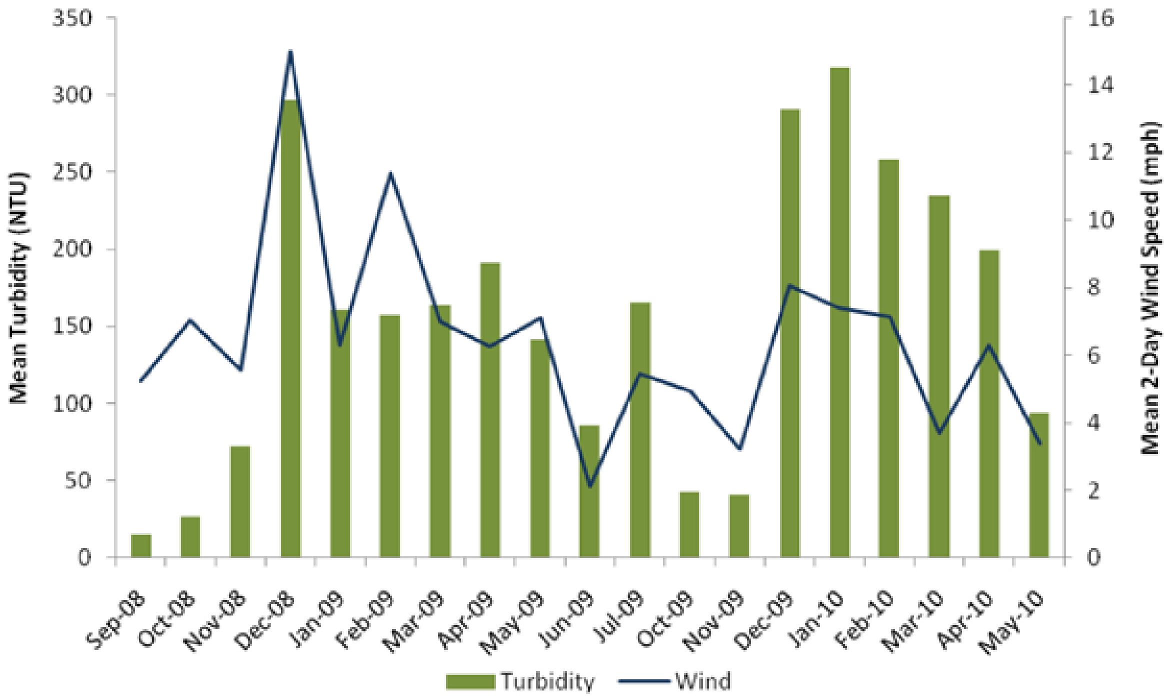

Figure 3. Mean turbidity levels (NTU) for Wolf Lake by month with mean two day wind speeds (mph) prior to sampling dates. Wind data were collected from the USDA SCAN site at Mayday, which is in Yazoo County, east of Yazoo City.

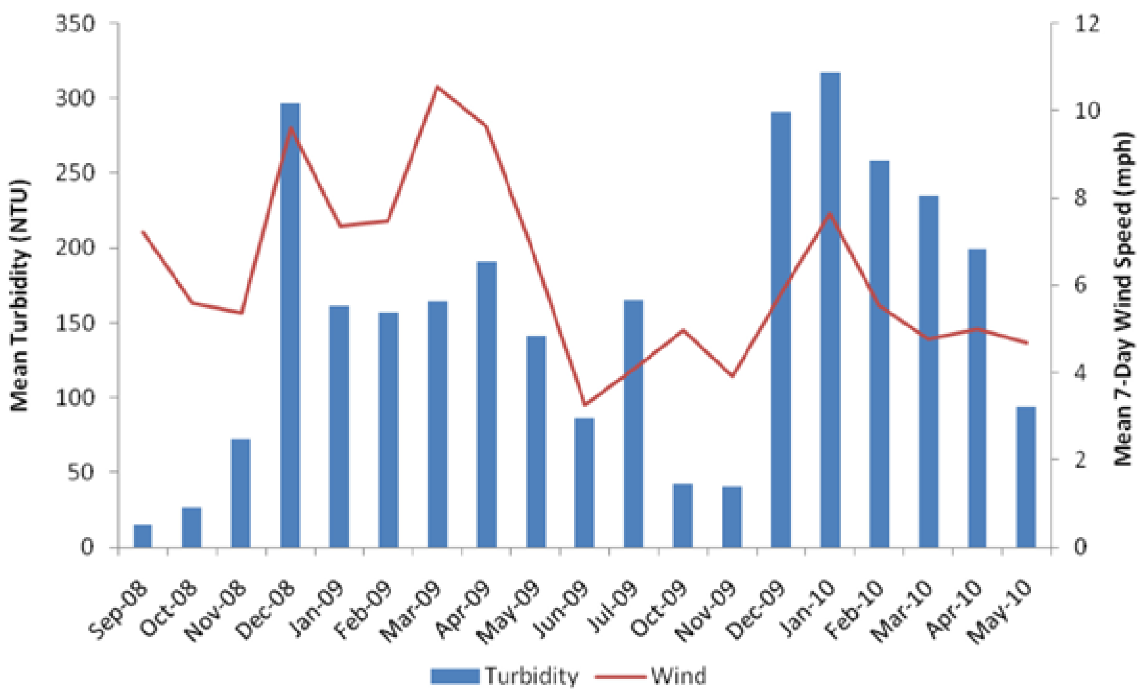

Figure 4. Mean turbidity levels (NTU) for Wolf Lake by month with mean seven day wind speed (mph) prior to sampling dates. Wind data were collected from the USDA SCAN site at Mayday, which is in Yazoo County, east of Yazoo City.

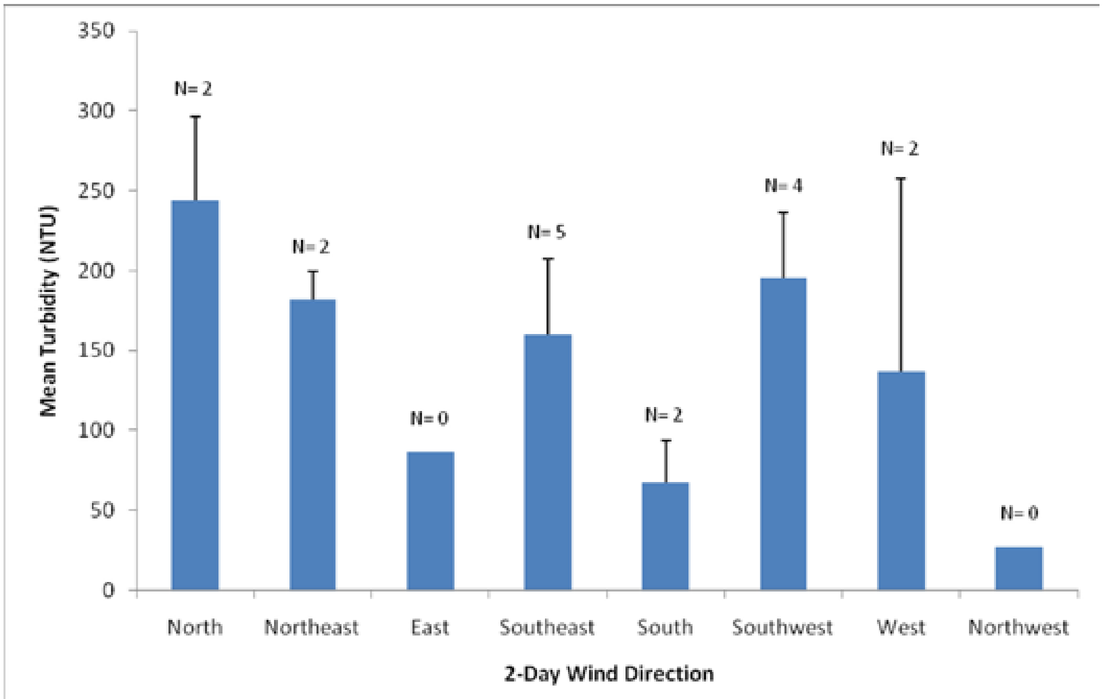

Figure 5. Mean turbidity levels (NTU) for Wolf Lake by mean two day wind direction. Wind data were collected from the USDA SCAN site at Mayday, which is in Yazoo County, east of Yazoo City.

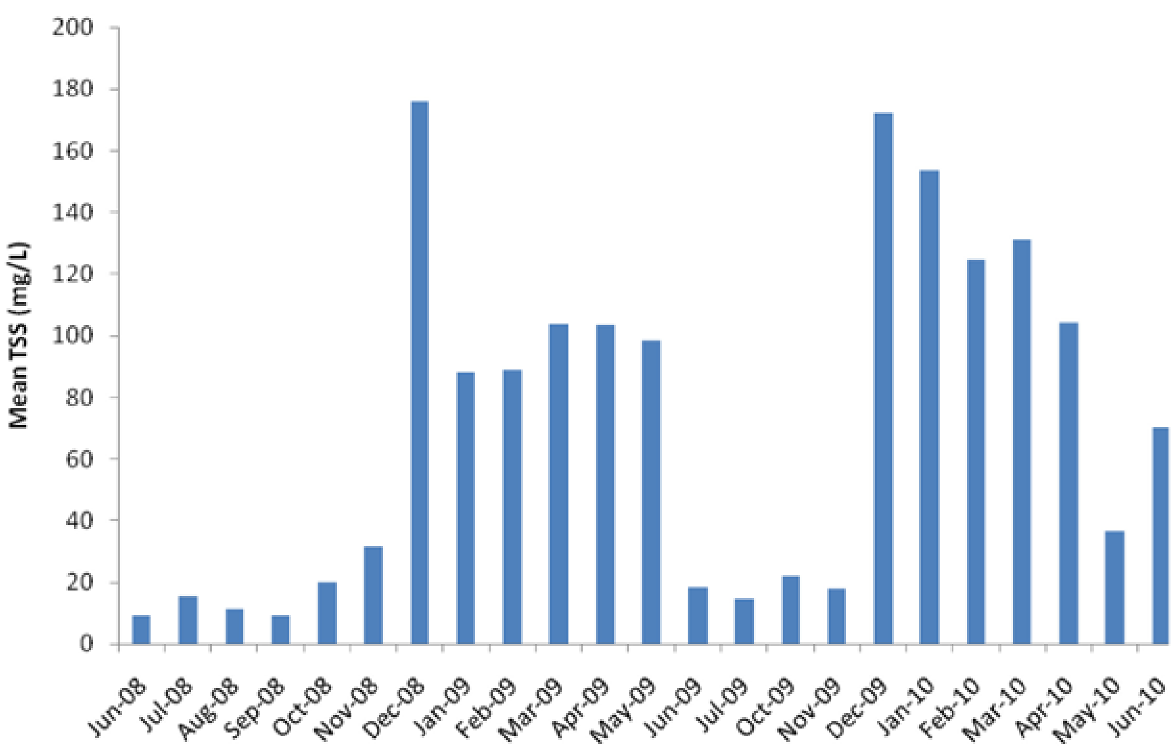

Figure 6. Mean TSS levels (mg/L) for Wolf Lake by month. Best management practices (BMPs) were implemented in the Wolf Lake watershed from August 2008 thru June 2009.

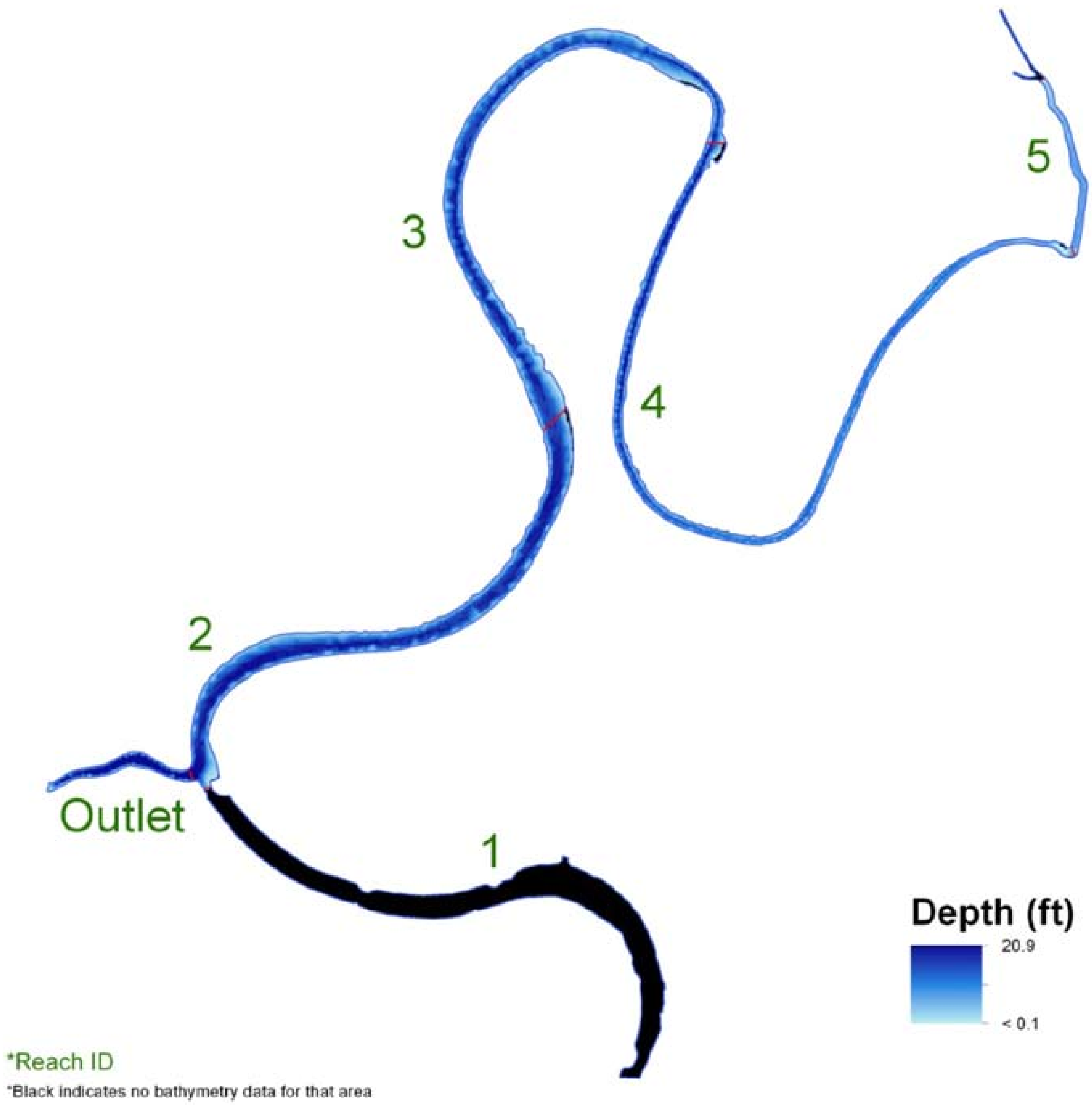

Figure 7. Bathymetry map of Wolf and Broad Lake split by reach. The sinusoidal shape shows longitudinal variations in depth as well as lateral gradient along the old river channel. Reach 1 has no depth data associated with it.