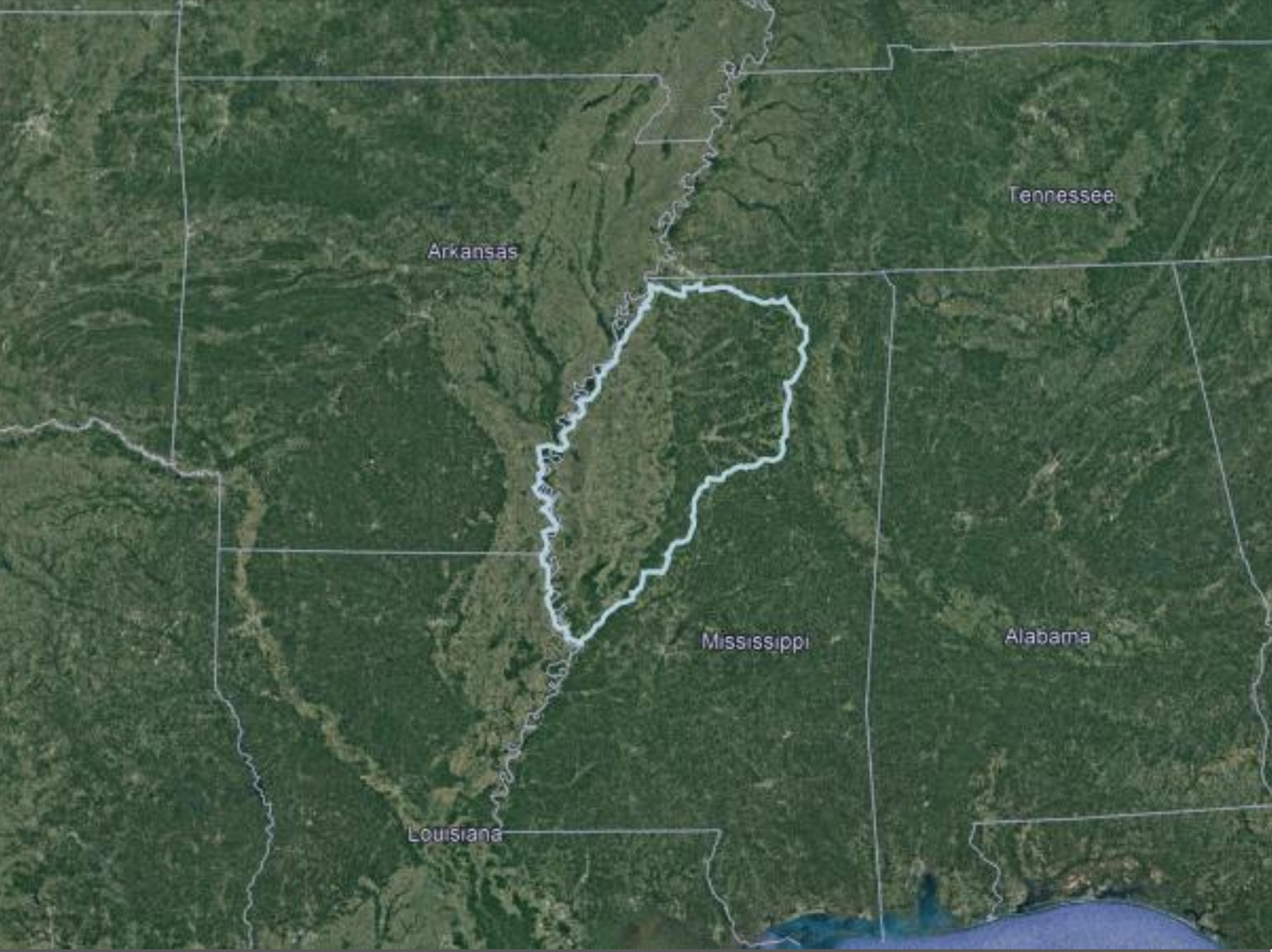

Yazoo River Basin Watershed Assessment

Eric White | RCSE-6840 | May 5, 2019

Executive Summary

The intent of this watershed assessment is to determine what data has been collected throughout the Yazoo River basin, and whether a holistic picture of the basin health can be built from this historic data. If so, what are the opportunities that can be taken to improve water quality throughout the Yazoo River basin. And if a holistic picture cannot be found from existing data, what additional data should be collected to help diagnose these issues?

The Yazoo River basin is a 13,510 square mile watershed located in the northwestern corner of Mississippi. The watershed outlet is at the Mississippi River at Vicksburg, MS and extends along the Mississippi valley north to the Tennessee state line just south of Memphis. The Yazoo River basin is predominantly agricultural land – particularly within the Delta Plain. The Delta Plain is the lower [approximately] half of the basin and is flat alluvial plain formed by historic floods of the Mississippi River. The upper half of the Yazoo basin is termed the Bluff Hills and consists of highly erodible loess soils. The Bluff Hills are predominantly pasture and forest lands. The entire basin is rural, not densely populated, and exposed to a variety of water quality concerns.

Four large flood control reservoirs are located within the Bluff Hills, and are actively managed by the US Army Corps of Engineeers. Between the upstream hydrologic alterations, downstream irrigation and hydraulic control structures, and intensive agricultural use the issues facing the Yazoo River basin are formidable.

This assessment aims to analyze historic data and parse it into various landuse and hydrologic alteration regions – to determine what are the most significant drivers of the Yazoo Basin hydrology and water quality. To achieve these aims, the Yazoo River basin was divided into four regions. First, the natural division of the basin along the ecoregion boundaries was conducted (Delta Plain versus Bluff Hills. Each of these two regions were then subdivided once more to account for whether or not the data collection site was impacted by upstream flood control reservoirs and dams.

Three gaging stations were identified that did not have any upstream flood control reservoirs; two in the Bluff Hills and one in the Delta Plain. Four gaging stations located on mainstem river channels downstream of at least one flood control reservoir were also identified. In order to compare these data across sites (which had various upstream drainage areas), the flow data was normalized by first calculating the daily anomaly from the long-term mean flowrate

The relative influence of upstream flood control reservoirs on baseflow in the Yazoo River was analyzed. The Grenada Lake outflows provide a relatively stable and consistent baseflow that is seen at the mouth of the Yazoo. The Tallahatchie River has substantial portions of uncontrolled runoff (as each of the three rivers draining the lakes travel to their confluence, they drain additional tributaries), and periods of rainfall can be seen in the hydrographic signal – resulting in stable baseflow but also “flashier” response to rainfall within the basin. The most distinct rainfall response throughout the Yazoo basin, however, is coming from the Delta Plain tributaries, which contribute almost no baseflow to the Lower Yazoo. In fact, during a few periods in spring and summer, there is actually more flow upstream in the Tallahatchie than is flowing out of the Lower Yazoo at the Mississippi River.

In addition to hydrologic data, historic suspended sediment and nutrient data (here total Kjeldahl nitrogen) were reviewed and compiled.

The complexities of land and water use management throughout the Yazoo basin, as well as the dire nature of the Yazoo basin waterways, anything short of a dedicated and directed interagency effort led by the federal government will likely result in more of the status quo in the Yazoo basin: periodic detailed monitoring campaigns, widespread discrete water quality sampling and very little in the way of actual improvement to waterbodies of the Yazoo River basin.

Contents

Study Area

Location

The Yazoo River basin is a 13,510 square mile (8.65 million acres) watershed located in the northwestern corner of Mississippi (Figure 1) (Parajuli and Kim, 2012). The watershed outlet is at the Mississippi River at Vicksburg, MS and extends along the Mississippi valley north to the Tennessee state line just south of Memphis.

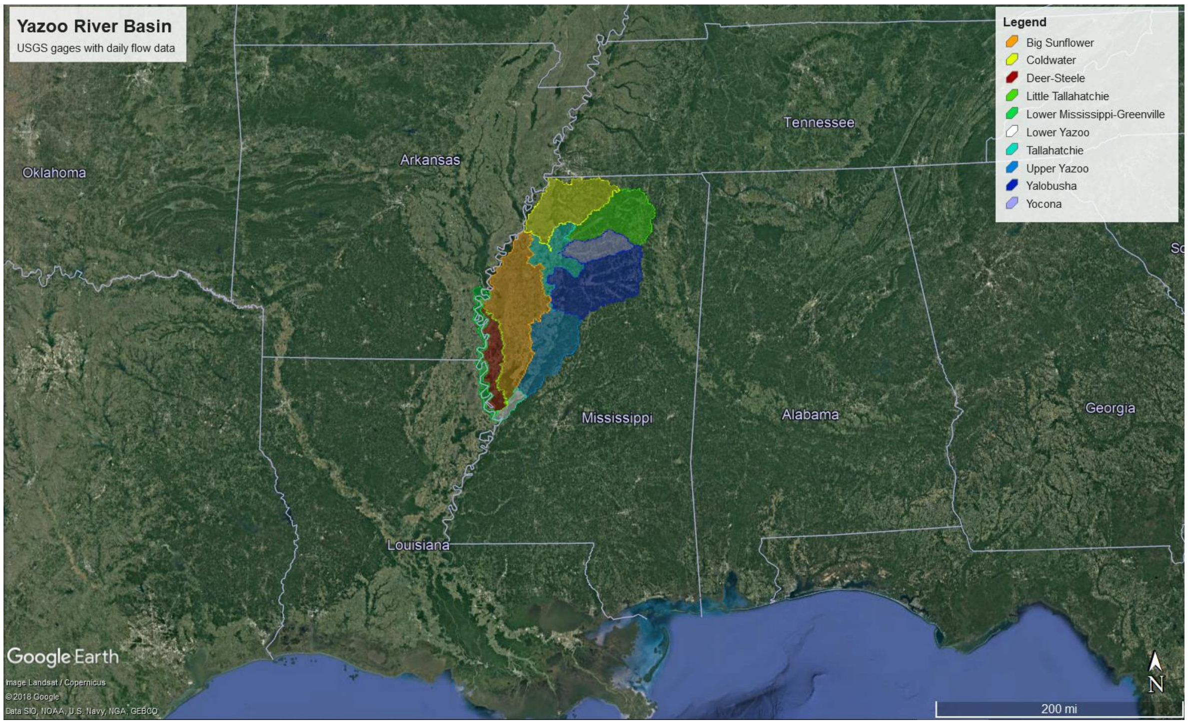

Figure 1. Location of the Yazoo River Basin in the Lower Mississippi River Valley.

The Yazoo River basin is split approximately in half by two distinct regions: the Delta Plain and the Bluff Hills. The Delta Plain is part of Mississippi Alluvial Plain ecoregion (73) and consists primarily of the Northern Holocene Meander Belts (73a), the Northern Pleistocene Valley Trains (73b), and the Northern Backswamps (73d). The Bluff Hills immediately adjacent to the Delta Plain are located within the Mississippi Valley Loess Plain (74) and are further categorized as Bluff Hills (74a) or Loess Plains (74b). Further upland, portions of the Yazoo basin are located in the Southeastern Plains ecoregion (65) which are predominately further classified as the Southern and Northern Hilly Gulf Coastal Prairie (65d and 65e, respectively). The ridge along the watershed divide is located within ecoregion 65b, Flatwoods/Blackland Prairie (Figure 2) (USEPA, 2013). The topography of the basin provides a clear distinction between these two regions; where the Delta Plain is low elevation with minimal slope changes, and the Bluff Hills increases substantially in elevation and have much greater topographic relief (Figure 3).

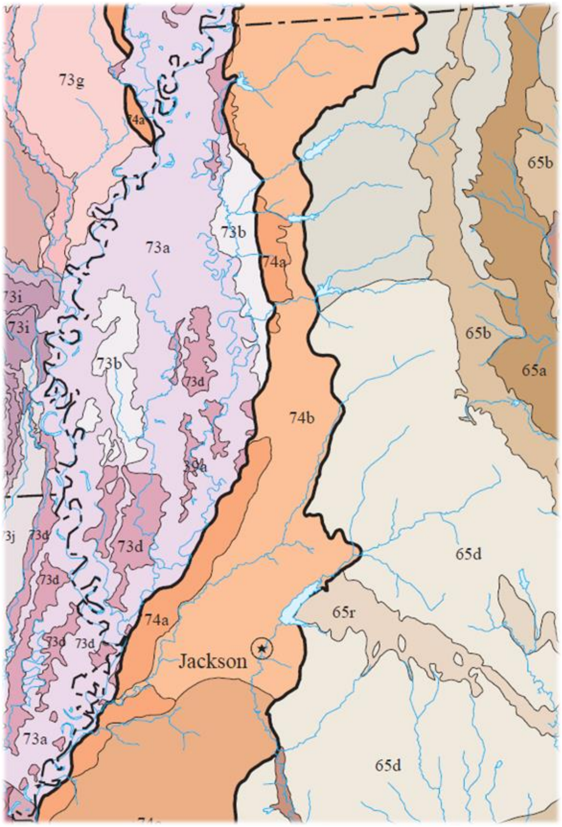

Figure 2. Ecoregions of the Yazoo River Basin. Figure from U.S. EPA (2013).

Geology

Hydrography & Hydrology

The furthest upstream areas of the Yazoo River Basin are controlled by four flood control reservoirs. Arkabutla Lake captures runoff from 640,000 upstream acres (USACE, 2019a), and is drained by Coldwater River (HUC-08030204), a watershed that is a total of 1,200,000 acres. Nearly 990,000 acres drain into Sardis Lake, which outflows into Little Tallahatchie River (HUC-08030201), which has a total watershed size of 1,055,000 acres. The Little Tallahatchie and Coldwater Rivers meet near Lambert, MS and form the Tallahatchie River (HUC-08030202). Historically, the Yocono River also converged with the Tallahatchie at this point, however due to various channelization projects the Yocono converges with the Tallahatchie further downstream. The Yocono basin (HUC-08030203) is only 476,000 acres, 75% of which is located upstream of Enid Lake which is the third of the four flood control reservoirs in the Yazoo basin. The final reservoir is Grenada Lake, which drains 845,000 acres and is located within the 1,462,000 acre Yalobusha watershed (HUC-08030205). The Yalobusha and Tallahatchie Rivers combine to form the Yazoo River near Greenwood, MS. At this point, the Yazoo River meanders at the base of the Bluff Hills through the Delta. The Big Sunflower River (HUC-08030207) basin drains 2,029,000 acres of the of the Delta Plain and has a confluence with the Yazoo River near Sataria. The combined Sunflower and Yazoo Rivers are then referred to as the Lower Yazoo (HUC-08030208). Deer Creek and Steele Bayou (HUC-08030209), which drain the remaining 524,000 acres of the Delta Plain join the Lower Yazoo, which then has a confluence with the Mississippi River approximately 15 miles downstream at Vicksburg.

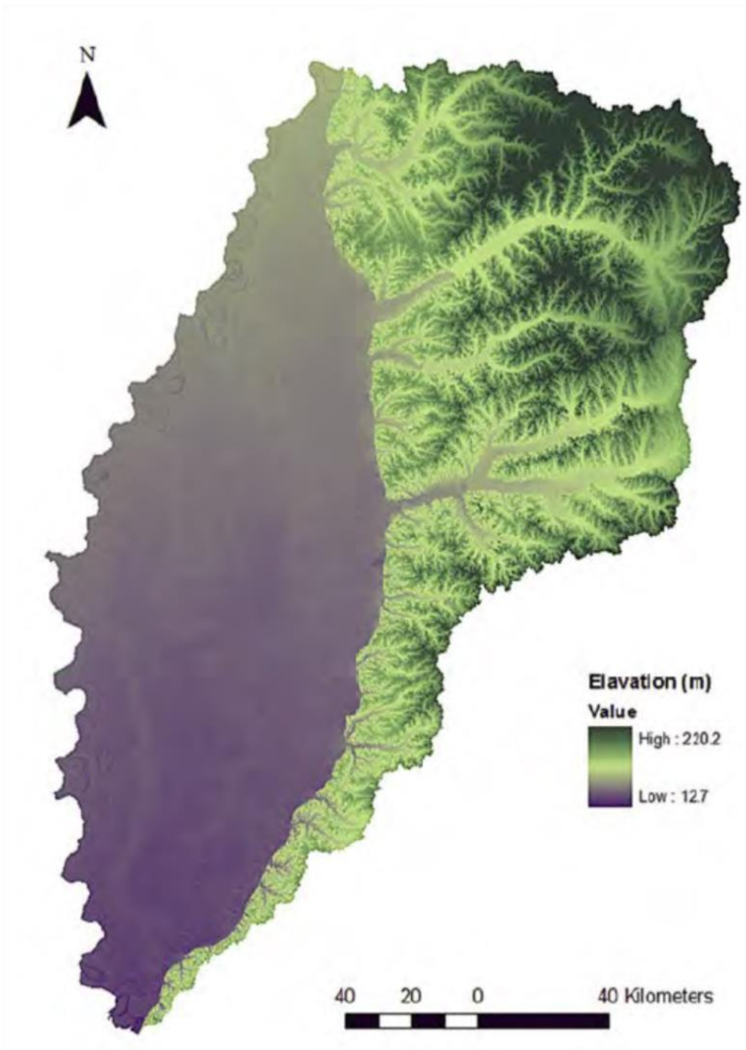

Figure 3. Elevation of the Yazoo River Basin. Figure from Parajuli and Kim (2012).

The flow conditions of the Lower Yazoo can be controlled by downstream boundary conditions, depending on flows within the Mississippi River. When the Mississippi River is under high-flow, bi-directional and even reverse-flow conditions can occur in the Yazoo below the confluence with Steele Bayou. During normal low through high flows in the Mississippi River, backwater conditions impact the lower reaches of the Yazoo – with free flow occurring in the lower reaches of the Yazoo only during extremely low conditions in the Mississippi River (Runner et al., 2002).

Embedded within the nine HUC-8 basins describe above, there are a total of 153 named streams covering over 24,500 stream miles throughout the Yazoo River Basin. In addition to the four flood control reservoirs, the Delta Plain is pockmarked with abandoned oxbow lakes and forested wetland areas, including the primary named waterbodies of: Lake Bolivar, Lake Washington, Lower Lake, Staten Brake and Swan Lake (USGS, 2019; Parajuli and Kim, 2012).

Land Use and Land Cover

Historically, the Yazoo delta plain was heavily forested in riparian areas. Tree growth and frequent flooding from the Mississippi River resulted in uneven micro-topographic features. These natural levees were often the site of extensive canebrakes, prior to European settlement. It has been hypothesized that the canebrakes established due to agricultural disturbances (e.g. clearing of trees) by pre-European inhabitants of the area. In addition to the extensive riparian forests, log-jams within the Yazoo basin waterways were a frequent occurrence – evidence of these jams data back to the 1541 explorations by Hernando DeSoto. By the late 1800s, most of the log-jams had been removed for lumber and large-scale logging and deforestation of the basin occurred (Bryant, 2010).

Today, 41% of the Yazoo basin is cropland, while 30% remains forested. Wetlands cover 12% of the basin, 10% is pasture, 4% is urban/developed land and 3% is water (Parajuli and Kim, 2012). The cropland is located almost exclusively in the fertile alluvial soils of the Delta Plain, whereas the forest and pasture land is largely located in the Bluff Hills region (Figure 4).

Demography

The Yazoo River basin cover 30% of Mississippi's land area and contains 30 of the state's 82 counties. Over 800,000 Mississippi citizens (20% of the state's total population) live within the predominantly rural watershed, which contains 183 cities/towns. (USGS, 2019; Parajuli and Kim, 2012)

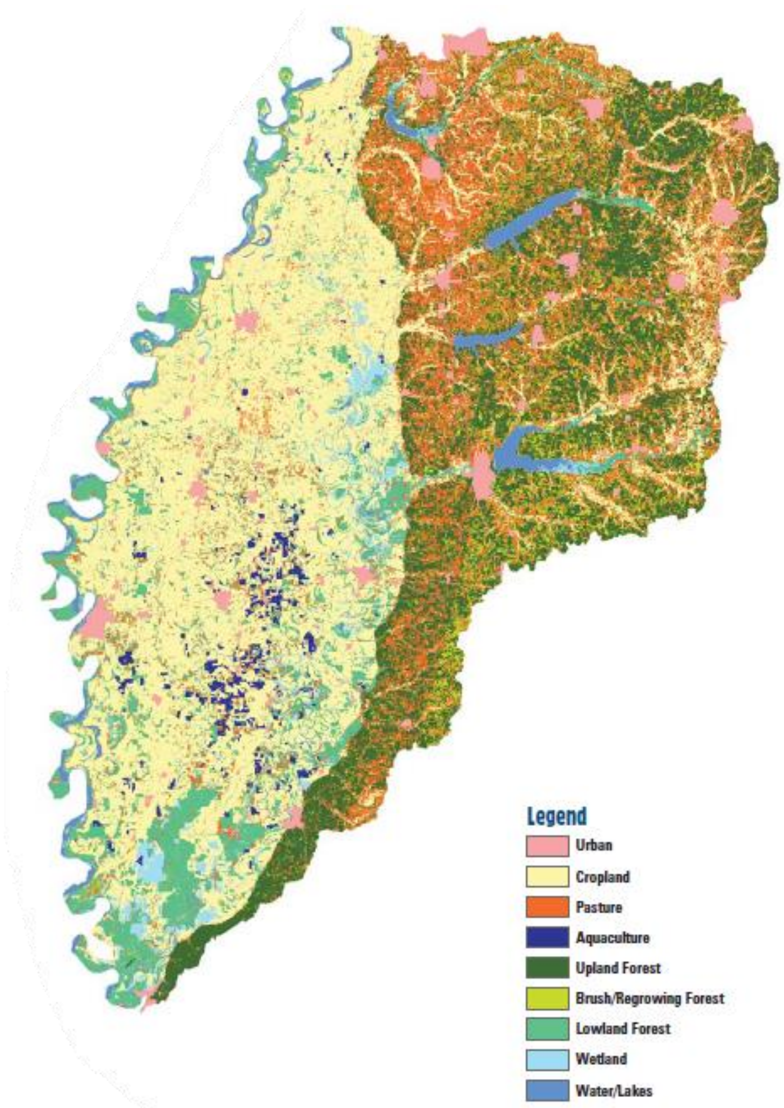

Figure 4. Land use and land cover of the Yazoo River Basin. Figure from MDEQ (2006).

There is a long history of biological data collection and assessment for the Yazoo River basin, and the importance of both geologic/geomorphologic and anthropogenic factors on species present in the Yazoo basin (Bryant, 2010). An inventory of available biological data from the USGS NWIS database indicates that the bulk of the data was collected in the main stem of the Yazoo and Sunflower Rivers, with a heavier concentration nearest the confluence with the Mississippi River. The MDEQ, on the other hand, in their dedicated benthic/biological data monitoring program did not collect any samples from the Delta Plain but did sample locations in samples in the Bluff Hills (MDEQ, 2018).

Water Quality

In addition to the fish and toxicity sampling described above, there are numerous other water quality concerns throughout the Yazoo basin, in both the Delta Plain and the Bluff Hills. Previous efforts went in to determining Total Maximum Daily Load (TMDL) values for a large number of streams within the Yazoo basin (MDEQ, 2006). However, not many have been implemented; MDEQ has developed a list of priority watersheds throughout the state, and many of the channel reaches throughout the Yazoo basin have yet to have an official TMDL be developed. Of the 26,379 miles of streams classified for Aquatic Life Use within the state of Mississippi (most streams in the Yazoo basin are classified as such), only 11% have been assessed to determine whether they are attaining the ability to provide support for aquatic life. Of these 2,978 assessed streams, 1,311 (44%) are not attaining – and of the non-attaining streams, only 493 (38%) either have a TMDL or the TMDL approach is not applicable (MDEQ, 2019). There are currently no TMDLs for sediment or nutrients available from the MDEQ TMDL library for any of the streams within the Yazoo Basin (MDEQ, 2018), which is not surprising given the TMDL coverage statistics provided above. Figure 5, below shows the classified conditions of streams located in the Bluff Hills.

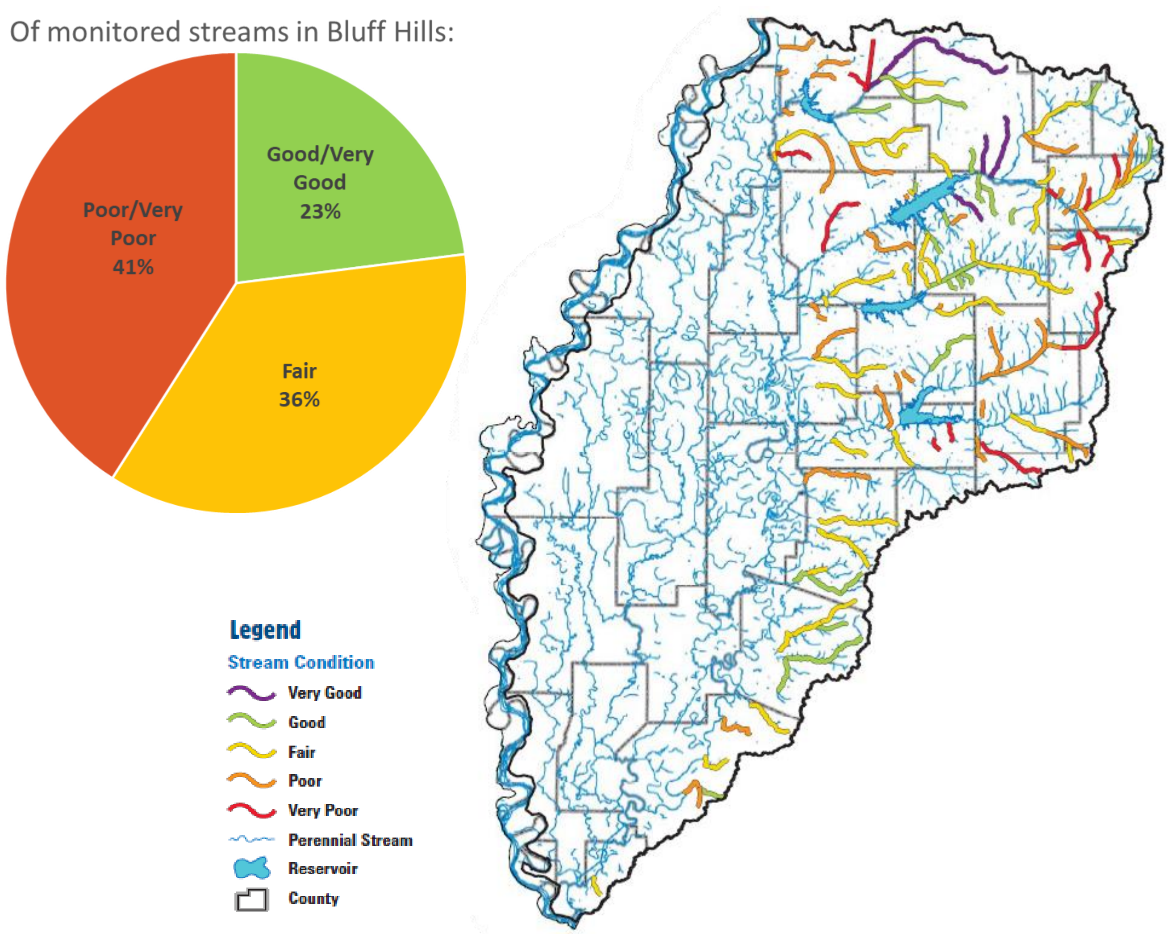

Figure 5. Water quality stream condition of streams in the Bluff Hills. Figure from MDEQ (2006).

Data Collection and Assessment

The nine HUC8 watersheds of the Yazoo River Basin contain 73 stream gages maintained and operated by the U.S. Geological Survey (USGS) and partners (USGS, 2019). The continuous data collected at these gaging stations varies both in temporal coverage and by what observational data is collected; with daily flowrate data having been collected within some basins as far back as the early 1900s (Figure S-21 and Figure S-22). The U.S. Army Corps of Engineers (USACE) also maintains a network of 51 water level gages throughout the basin

(USACE, 2019a); however, flow data is not maintained (or at least published) by the USACE – although several of the USGS gages are cooperative sites between the USGS and the USACE.

In addition to monitoring flowrate and water level, several of the gage locations are also used to collect continuous water quality data such for a variety of constituents such as temperature, suspended sediment (concentration and total daily load), turbidity and specific conductance. In addition to the continuous monitoring, there are several thousands of locations throughout the Yazoo basin where discrete water quality and biological data have been collected over the past several decades.

For this assessment, not all available data were analyzed; rather, three specific data types (flow, suspended sediment and total Kjeldahl nitrogen) were chosen with the intent to focus on impacts of both agricultural/land use practices throughout the basin as well as the impact that the upstream flood control reservoirs may have on water quantity and quality of the Yazoo River basin.

In order to collect and analyze these data, the *dataRetrieval* library for the statistical software program, *R*, was utilized. This R library is developed and maintained by the USGS and provides a single portal to access USGS data stored within the National Water Information System (NWIS) as well all available discrete water quality and biological data that is housed in various national databases; including the UGSS's NWIS, the USEPA's STORET database, and the USDA's STEWARDS database (De Cicco and Hirsch, 2014).

Assessment objective

The intent of this watershed assessment is to determine whether there are trends visible within the available data that indicate differences in water quantity and quality throughout the Yazoo River basin that may vary as functions (either independent or in combination) of predominant land use/land cover, regional geology, and hydrologic alterations. By attempting to examine the relative impact of these various drivers, resource and regulatory agencies will be able to gain a holistic view of the Yazoo Basin and the issues that it faces. From this, the most sensitive issues can be identified, examined, and targeted in a concerted manner.

To achieve these aims, the Yazoo River basin was divided into four regions. First, the natural division of the basin along the ecoregion boundaries was conducted. The Mississippi Alluvial Plain ecoregion is located in the flatter Delta Plain of the Yazoo Basin – and all data collected from locations within these ecoregions are referred to simply as the Delta Plain Region. Conversely, data collected in the hillier Mississippi Valley Loess Plains or Southeastern Plains ecoregions will be referred to here as the Bluff Hills region. Each of these two regions were then subdivided once more to account for whether or not the data collection site was impacted by upstream flood control reservoirs and dams. Sites were only classified as being impacted by upstream reservoirs/dams if they were located on a main river channel that was downstream of one of the four USACE flood control reservoirs (Arkabutla, Sardis, Enid and Grenada Lakes)

The division between the Delta Plain and Bluff Hills regions is evident not just in the underlying geology and topography (Figure 3), but also in the predominant land use and land cover (Figure 4). Therefore, by splitting the data analysis by this regional divide, trends informed by geologic as well as anthropogenic processes will be able to be examined. While trends and correlations may be evident based upon these regional divides, causation may be difficult to determine if a specific characteristic could be impacted by both geologic and/or anthropogenic forcings. For example, extreme values of suspended sediment in streams may be a function of intensive deforestation and agricultural management, or it may be a function of the highly erodible alluvial soils of the Delta Plain and loess of the Bluff Hills. Perhaps most likely it is a combination of these factors.

Flow

Three gaging stations were identified that did not have any upstream flood control reservoirs; two in the Bluff Hills and one in the Delta Plain (Figure 6). In order to compare these data across sites (which had various upstream drainage areas), the flow data was normalized by first calculating the daily anomaly from the long-term mean flowrate. This flow anomaly was then normalized by the peak flow-rate during the same period. If the flowrate for any given day was equal to the long-term mean, the normalized flow would be equal to zero; if it were less than the mean, it would be negative, and if it were the peak flowrate for the period of record, than the normalized flow would be equal to one.

The normalized flow timeseries indicates that the two sites within the Bluff Hills, with no reservoirs upstream, are quite flashy – meaning the baseflow values are near zero and there is a near-immediate response to rainfall with a very short recession limb. This is generally consistent with a topographically diverse watershed with little upstream drainage area. The site on the Delta Plain, had a noticeably different pattern, with much more prolonged recession limbs post-rainfall. This is likely due to the low gradient nature of the Delta Plain (Figure 3) with possible impacts of downstream boundary conditions/backwater on the Lower Yazoo. One other difference between the Bluff Hills and the Delta Plain sites are that the Delta Plain site has baseflow conditions much lower than the long-term mean flowrates, with minimum flow anomaly values near -0.15, where the Bluff Hills minimum flow anomaly was just slightly less than zero). This could potentially be due to the longer recession limb of the Delta Plain hydrographs – which would serve to increase the mean flowrate used for calculating the flow anomaly. Another possible explanation could be related to the known issues with abnormally low baseflows within the Delta Plain due to high irrigation rates and depletion of the alluvial aquifer (MDEQ, 2006)

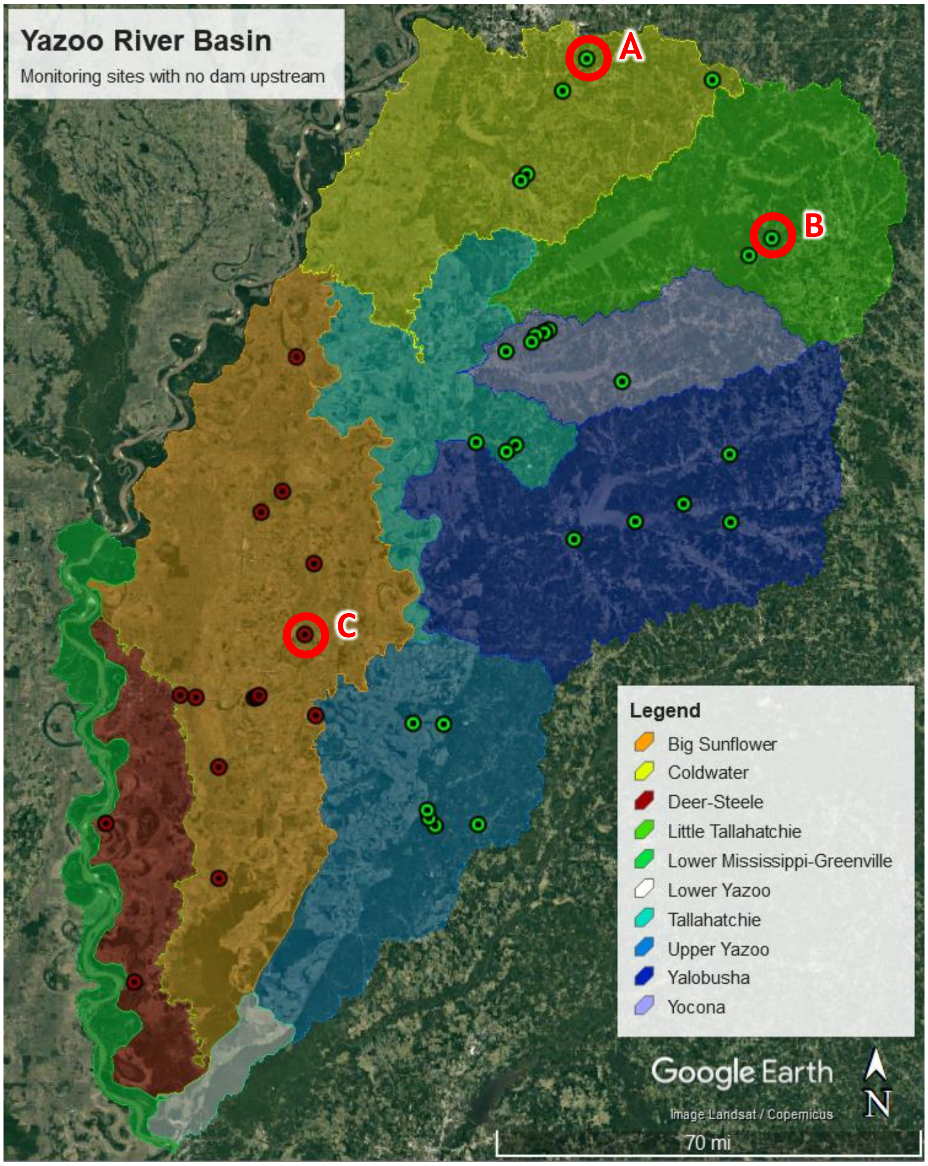

Figure 6. Map of USGS gage locations with at least 90% daily data coverage and that do not have any flood-control reservoirs/dams located upstream. Green dots are sites in the Bluff Hills, brown dots are sites in the Delta Plain. Refer to Table S-2 for a description of the three sites highlighted (A, B and C).

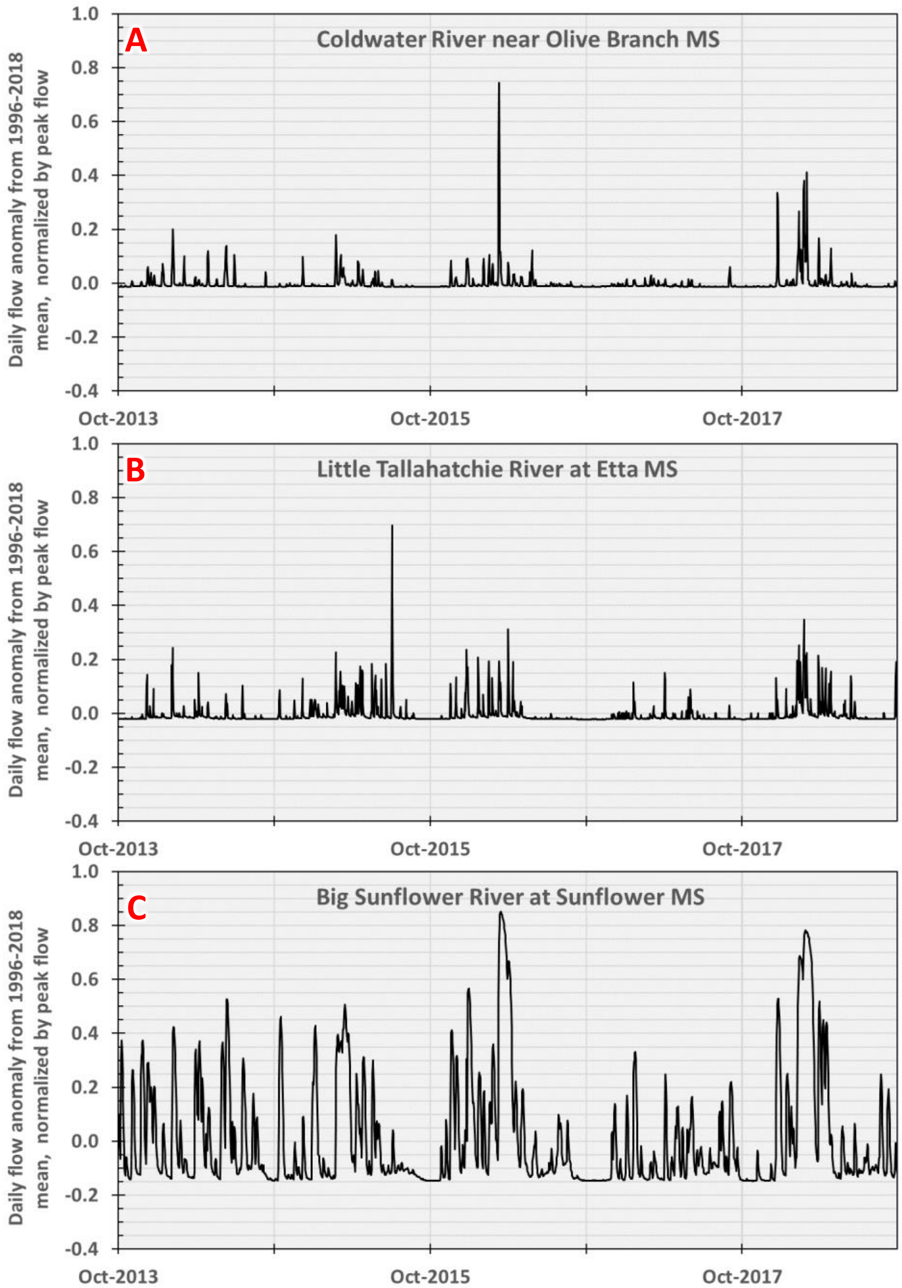

Figure 7. Five years (2013 – 2018) of daily flow anomaly from the long-term mean, normalized by peak flow, for three gages that do not have any flood-control reservoirs/dams located upstream; two sites (A – Coldwater River and B – Little Tallahatchie) are located in the Bluff Hills, one site (C – Big Sunflower River) is located in the Delta Plain.

Four gaging stations located on mainstem river channels downstream of at least one flood control reservoir were identified for this study (Figure 8). Site D, the Yalobusha River at Grenada, MS has one reservoir (Grenada Lake) upstream; Site E, the Tallahatchie River at Money, MS has three reservoirs (Arkabutla, Enid and Sardis Lakes) upstream, and Site F and G (Yazoo River below Steele Bayou and Yazoo River at Greenwood, respectively) are both located downstream of all four reservoirs.

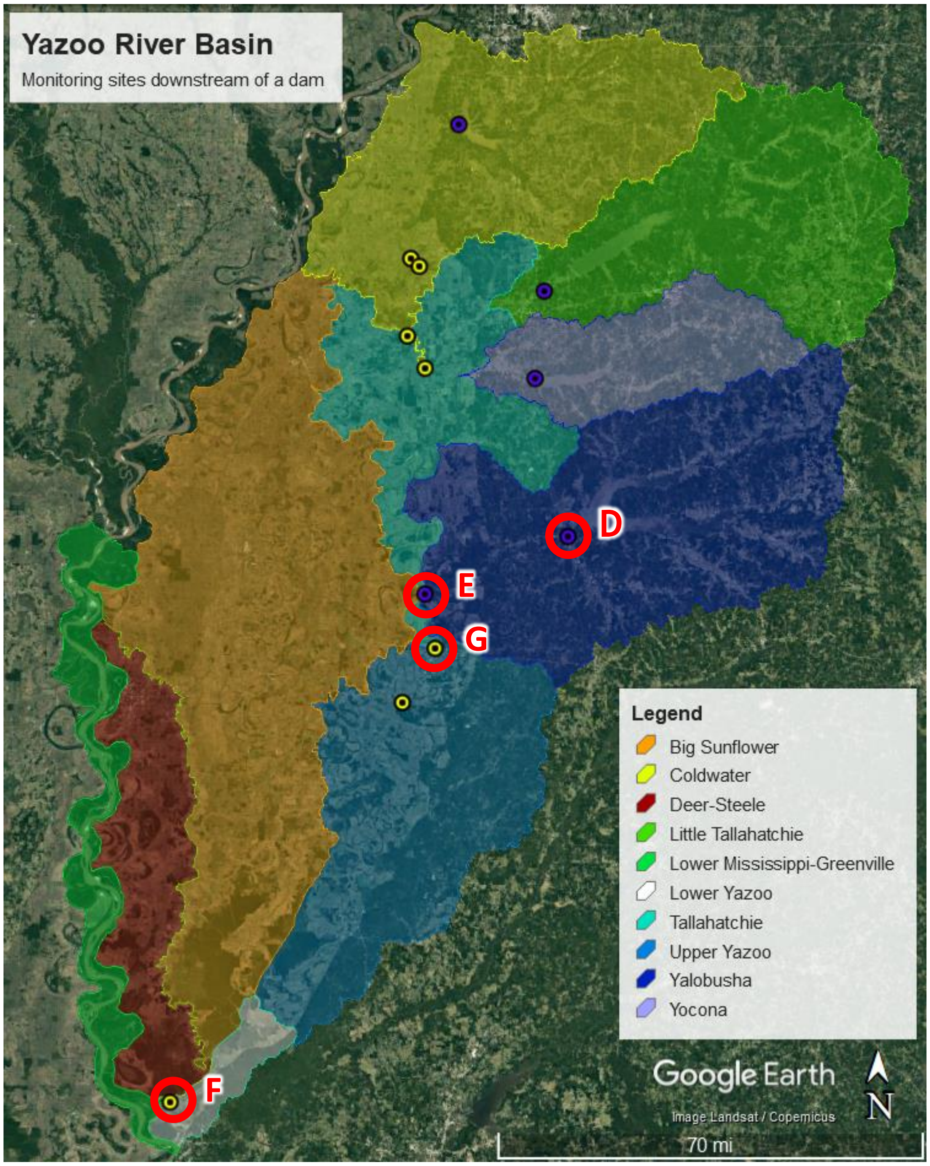

Figure 8. Map of USGS gage locations with at least 90% daily data coverage and that are downstream of a flood-control dam/reservoir. Blue dots are sites in the Bluff Hills, yellow dots are sites in the Delta Plain. Refer to Table S-2 for a description of the four sites highlighted (D, E, Fand G).

The sites located downstream of the flood control reservoirs (Figure S-24) have a markedly different hydrograph shape than those sites located upstream of any reservoirs. The rivers that are receiving outflows from the flood control reservoirs have a much more regulated and less flashy hydrograph than those of the uncontrolled upstream rivers, as seen in Figure 9 for the Yalobusha River just downstream of Grenada Lake. While still subjected to some flashy peak flows, the long-term behavior indicates that the flowrate oscillates around a mean value. Additionally, distinct patterns of operational behavior can be seen in the flow anomaly signal. There are long periods of nearly constant flow during late summer months, which is likely due to minimum discharge requirements for ecological flow conditions in the streams.

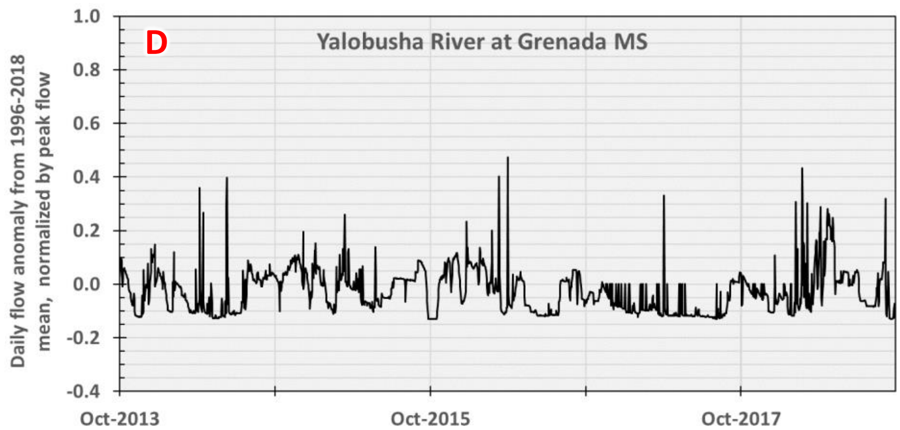

Figure 9. Five years (2013 – 2018) of flow anomaly from long-term mean, normalized by peak flow for Yalobusha River at Grenada (F) – upstream of any flood control reservoir.

The Yazoo River at Greenwood, MS (site F), does not have current flow data being collected, however there is a lengthy record of historic data. Five years of daily flow anomaly data (normalized by peak flow) from 1968 through 1973 are shown in Figure 10 (non-normalized flowrate data is shown in Figure S-25) - as well as data for the same time period for a station upstream of any flood control reservoir. Note that for the historic Yazoo River flow at Greenwood, MS, the 1973 water year has a distinct higher flow regime than the previous four years. According to the USACE, flows entering three of the four flood control reservoirs (Grenada, Sardis and Enid Lakes) exceeded storage capacity and triggered spillway overflow. This 1973 flood was the first time that the overflow spillways were active; Grenada Lake has experienced four overflow floods; in 1973, 1980, 1983 and 1991 (USACE, 2019b). Enid Lake has experienced flood spillway overflows in 1973, 1983, 1991, and 2002 (USACE, 2019c) and Sardis Lake had overflows in 1973, 1983, and 1991 (USACE, 2019d). While the Little Tallahatchie station located upstream of Sardis Lake also was experiencing extremely high flows, the hydrograph was still quite flashy – with frequent recessions back to near the long-term mean flowrate. The Yazoo River site quite a bit further downstream, remained elevated nearly for the entire year. While there is a clear signal difference between these two sites, the difference cannot be solely pinpointed to the presence of the upstream dams; comparison between watershed pourpoint and an upstream subbasin in the headwaters will quite frequently return a similar difference in hydrograph shapes. However, the fact that the downstream signal is elevated over an entire year is not likely commensurate with the size of the Yazoo River basin; the lag-time in this hydrograph is on the order of magnitude as the much-much larger Mississippi River basin, which displays similar annual flood cycles.

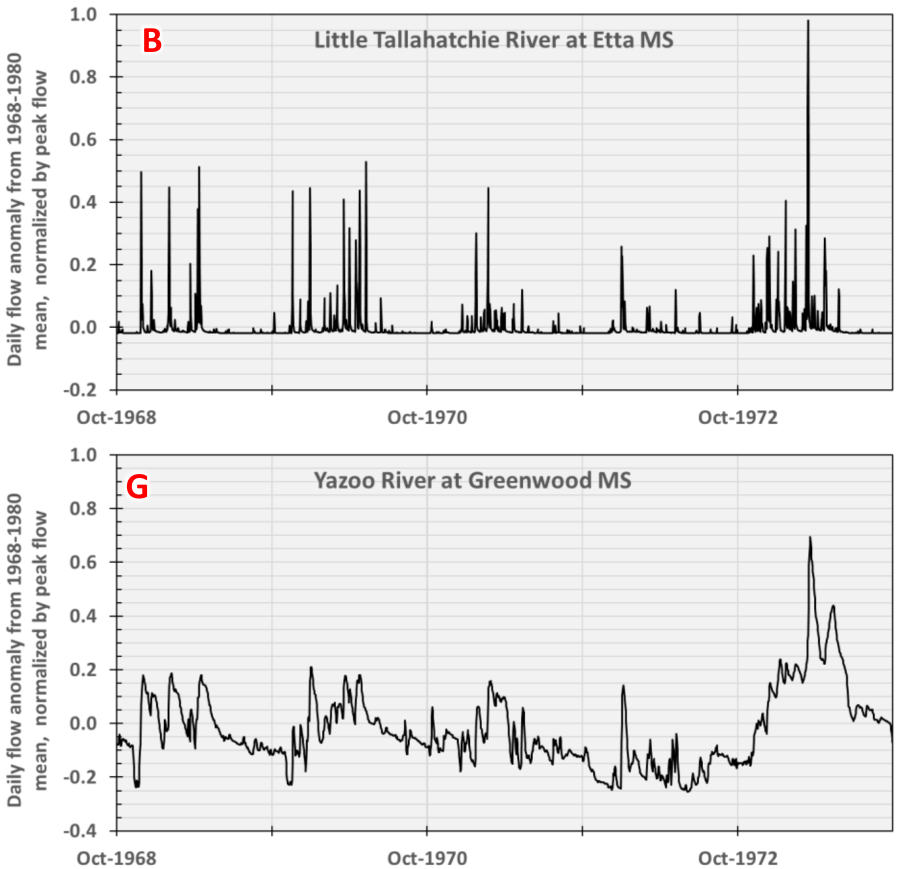

Figure 10. Five years (1968 – 1973) of flow anomaly from long-term mean, normalized by peak flow for Little Tallahatchie River at Etta, MS (B) – upstream of any flood control reservoir and in the Yazoo River at Greenwood, MS (G), which is downstream of the four flood control reservoirs. Note that in 1973, the reservoirs overflowed via flood control spillways for the first time since completion of the dams.

In addition to the gage-to-gage comparison of normalized flows, as discussed above, the four gages that were selected with reservoirs upstream can be used to assess what portion of flow at the Yazoo River's furthest downstream location is coming from each region of the basin. Figure 11, below, shows the relative influence of the Grenada Lake reservoir on Yazoo River baseflow (light gray), as well as the additional baseflow contributions from the other three flood control reservoirs (dark gray). The Grenada Lake signal is immediately downstream of the dam, and therefore there is very little uncontrolled runoff in that hydrographic signal. The Tallahatchie River signal (dark gray), however, has substantial portions of uncontrolled runoff (as each of the three rivers draining the lakes travel to their confluence, they drain additional tributaries), and a periods of rainfall can be seen in the hydrographic signal at this gage. The most distinct rainfall response, however, is coming from the Delta Plain tributaries, with almost no contribution to the baseflow of the Lower Yazoo. In fact, during a few periods in spring and summer, there is actually more flow upstream in the Tallahatchie than is flowing out of the Lower Yazoo (denoted by the dashed line in late April, June, July and September). This is likely from a variety of factors – it could be a high-flow period in the Mississippi River resulting in backwater conditions. There are also a lot of flood controls and diverted flowpaths throughout the Delta Plain, and water management operations could have been utilized.

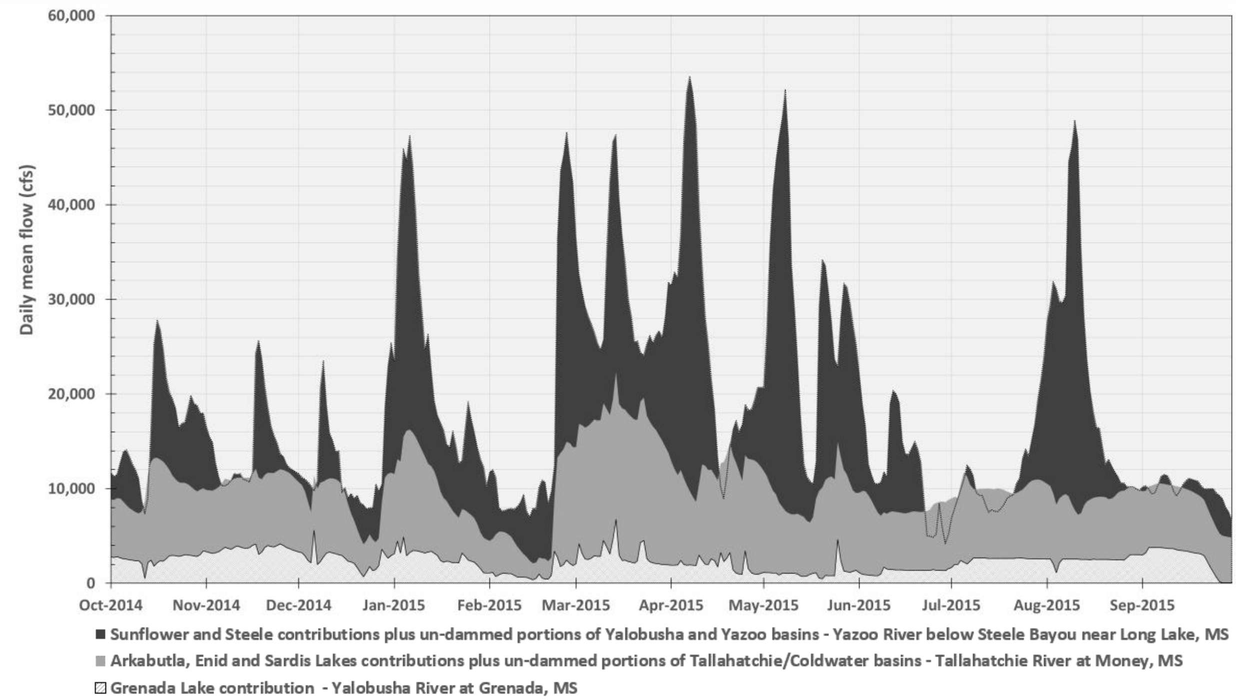

Figure 11. Flow at the furthest downstream Yazoo River gage showing flow contributions from the Grenada Lake reservoir (light gray), the three other reservoirs (dark grey) and the non-dammed basins of the Delta Plain, primarily the Sunflower River. Note the dashed line where the downstream flow is less than the upstream flow for four short periods of time during the 2015 water year.

Total Kjeldahl Nitrogen

Within the NWIS database, there are no sites within the Yazoo basin with continuous water quality monitoring for nutrients. However, there are over 11,600 discrete samples for Total Kjeldahl Nitrogen (TKN) that were available from the NWIS and STORET databases. The location at which these discrete samples were taken are shown in Figure 12. These data included groundwater samples, which were excluded from this analysis. Once filtered, over 7,800 discrete samples from surface waters for TKN collected from 1977 through 2018 were analyzed for this assessment.

Over the four-decade period in which this TKN data has been collected, neither a trend of increasing nor decreasing TKN concentrations is visible (Figure 13). Due to the discrete sampling and scores of sampling locations, a full temporal trends analysis was not conducted for this assessment. However, regardless of the sample's position in the Yazoo basin (Delta Plain or Bluff Hills, with or without a reservoir upstream), the range of TKN concentration values remained relatively consistent over time. The Delta Plain locations without any reservoirs upstream (e.g. the Sunflower, Deer and Steele river basins) experienced noticeably higher TKN concentrations than any of the other three basin zones with median TKN values above 1.0 mg/L for all four seasons (Table 1 and Figure 14). The sites in the Delta Plain that were influenced by upstream reservoirs had lower median concentrations of TKN, yet in both winter and spring they were still in excess of the Level of Concern concentration of 0.69 mg/L for the Mississippi Alluvial and Loess Valley Plains ecoregions, in which the Delta Plain is located (USEPA, 2001).

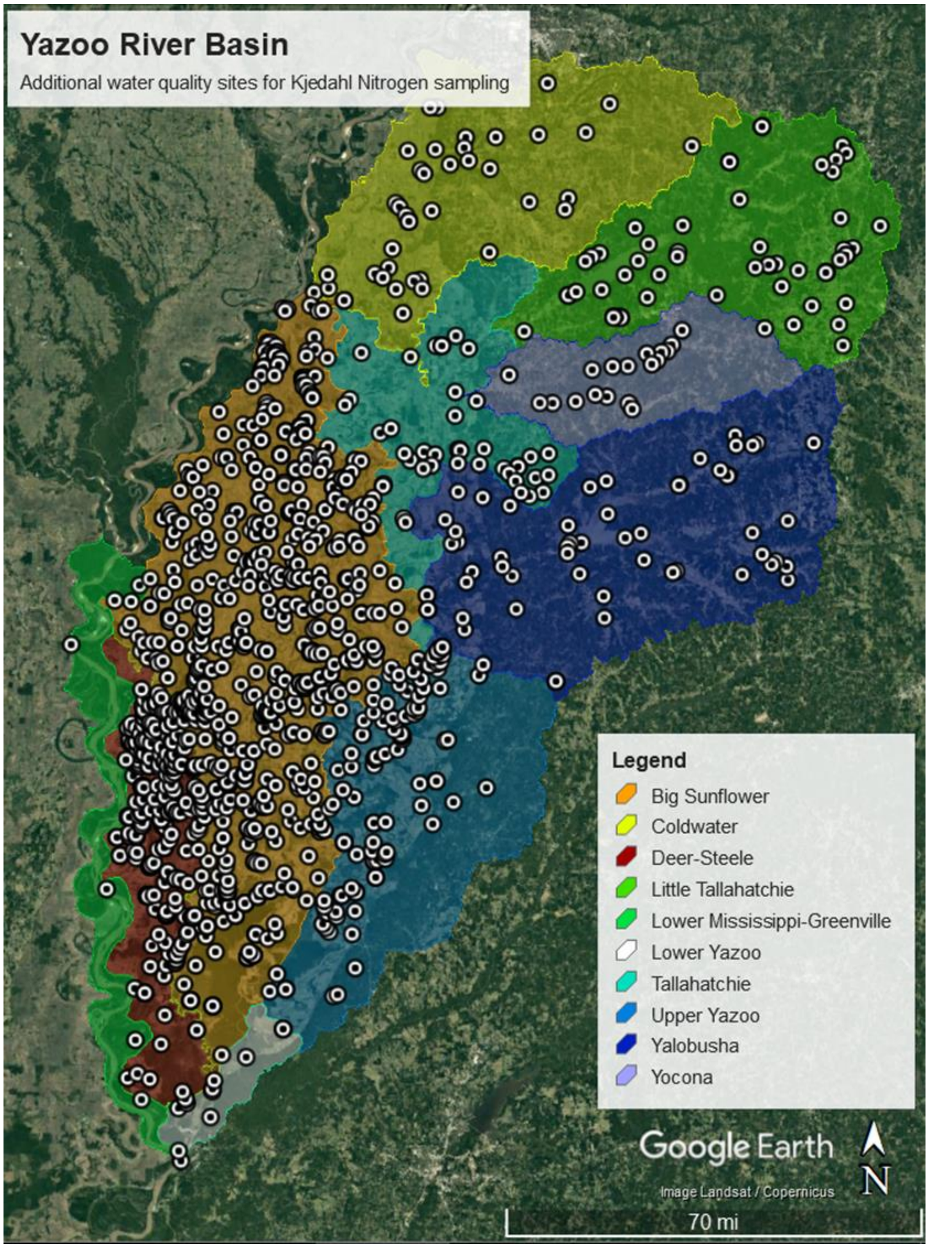

Figure 12. Map of Total Kjeldahl Nitrogen observations - all sites are shown, however only data from surface water samples were analyzed.

The two Bluff Hills zones experienced lower TKN concentrations than sites in the Delta Plain, however these sites are located in the Southeastern Plains ecoregion, and are subjected to a lower TKN Level of Concern concentration, 0.3 mg/L. Therefore, while these sites were noticeably lower in TKN concentration than the Delta Plain, they are still experiencing median concentrations at an elevated level.

An additional difference between the Delta Plain and Bluff Hills sites is the variability within the TKN concentrations. Concentration of TKN in the Delta Plains, both with and without any upstream reservoirs, was highly right-skewed (Figure S-26 and Figure S-27) with large standard deviations and mean values well above the median (in some cases the data was so skewed that the mean value was classified as an outlier). The sites within the Bluff Hills were much less variable with median and mean values that were much more aligned (although still slightly right-skewed). Therefore, it appears that the presence of reservoirs does not have a large impact on the TKN signal within the Yazoo basin; in the Bluff Hills there is consistency in TKN measurements at sites both upstream and downstream of reservoirs. The very large TKN concentrations and subsequent increase in variability appears to be a function of the Delta Plain. This trend is consistent with the land use practices throughout the Yazoo basin (Figure 4); the Bluff Hills are predominantly forest and pasture – whereas the Delta Plain is intensive cropland (with a substantial amount of aquaculture as well). Shields et al. (2009) estimate that more than 75% of all nitrogen input to the Yazoo basin is applied as fertilizer to farms, whereas only 10% comes from livestock manure.

It should be noted that due to the lack of continuous TKN monitoring at fixed gage locations coupled with flow rate monitoring, the above discussion is focused solely on concentrations and not total nitrogen loadings within the Yazoo basin. Concentrations of agricultural runoff water quality constituents (total nitrogen and phosphorus) have been shown to be inversely proportional to upstream drainage area – so while the concentrations within the Delta Plain are high (and substantially greater than the USEPA Level of Concern), the lower TKN waters flowing through the Delta Plain from the Bluff Hills serves as a partial dilution. This dilution effect (in addition to other intra-basin processes such as sedimentation, denitrification, biological uptake, etc.) the Yazoo basin contributed approximately 2.8% of the Mississippi River flow from 1996-2000, yet only delivered 1.4% of the total nitrogen load (Shields, et al., 2009; Runner et al., 2002).

Table 1. Total Kjeldahl Nitrogen statistics (mg/L).

Delta Plain with No Dams Upstream				***Delta Plain with Dams Upstream***			
	Mean	***Median***	***St Dev***		***Mean***	***Median***	***St Dev***
Winter	*1.5*	*1.1*	*1.4*	***Winter***	*15.3*	*0.70*	*193.0*
Spring	*5.5*	*1.4*	*77.1*	***Spring***	*1.5*	*0.76*	*7.2*
Summer	*4.4*	*1.0*	*62.9*	***Summer***	*1.0*	*0.62*	*3.9*
Fall	*1.7*	*1.3*	*1.3*	***Fall***	*19.6*	*0.51*	*195.3*
Bluff Hills with No Dams Upstream				***Bluff Hills with Dams Upstream***			
	Mean	***Median***	***St Dev***		***Mean***	***Median***	***St Dev***
Winter	*0.37*	*0.29*	*0.26*	***Winter***	*0.51*	*0.44*	*0.31*
Spring	*0.52*	*0.40*	*0.32*	***Spring***	*0.54*	*0.51*	*0.23*
Summer	*0.59*	*0.44*	*0.53*	***Summer***	*0.58*	*0.53*	*0.26*
Fall	*0.54*	*0.44*	*0.29*	***Fall***	*0.51*	*0.49*	*0.22*

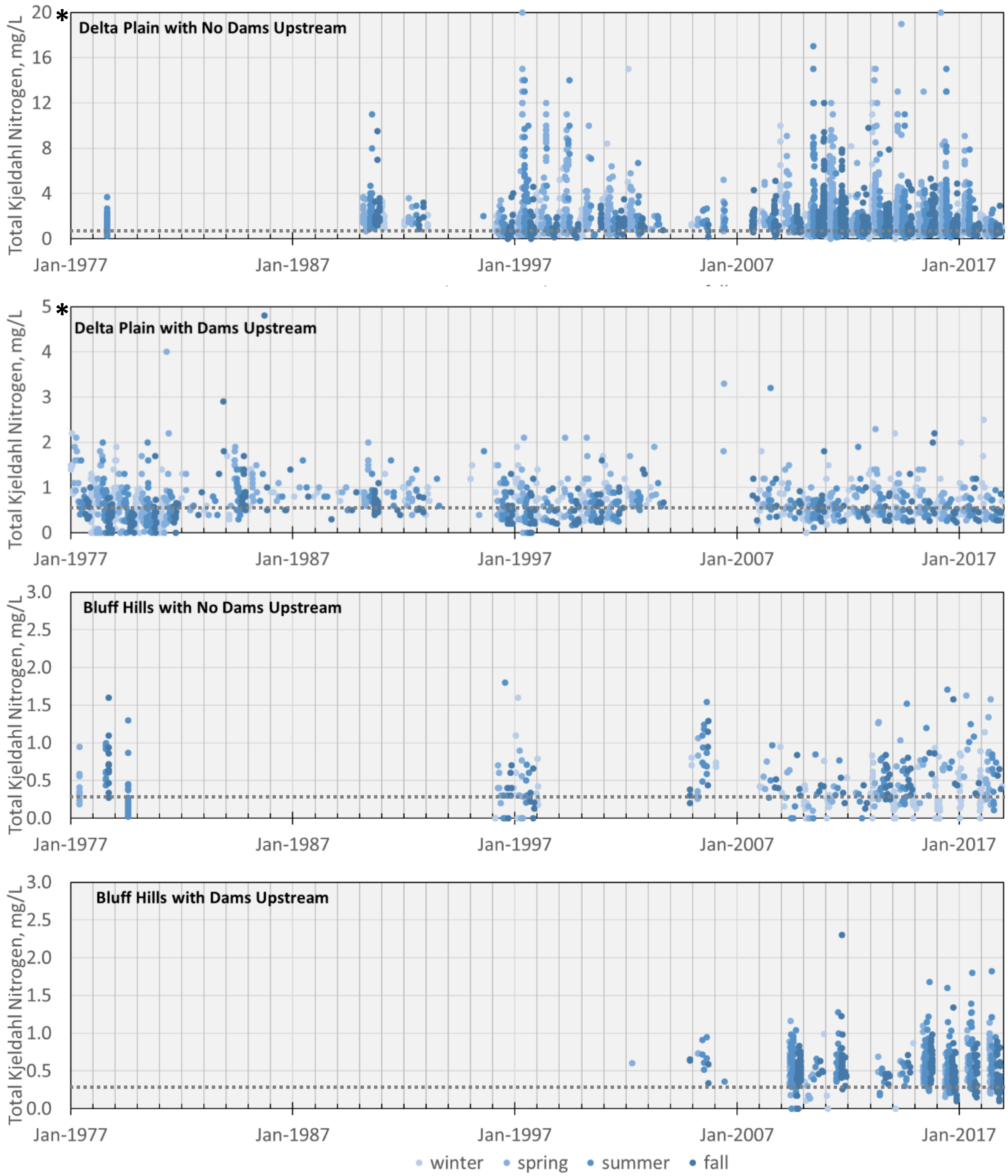

*Figure 13. Total Kjeldahl Nitrogen (TKN) timeseries for each of the four regions analyzed. *Note that extreme-high values for TKN in the Delta Plain are excluded from these plots in order to better visualize the data; 18 points were measured with concentrations greater than 5 mg/L in the Delta Plain with Dams Upstream and 22 points were measured with concentrations greater than 20 mg/L in the Delta Plain with No Dams Upstream. Outlier thresholds vary by region/season and are shown in Figure 14. Dashed horizontal lines indicate the level-of-concern concentration for TKN of 0.69 mg/L and 0.3 mg/L for the Delta Plain and Bluff Hills, respectively (USEPA, 2001; USEPA, 2000).*

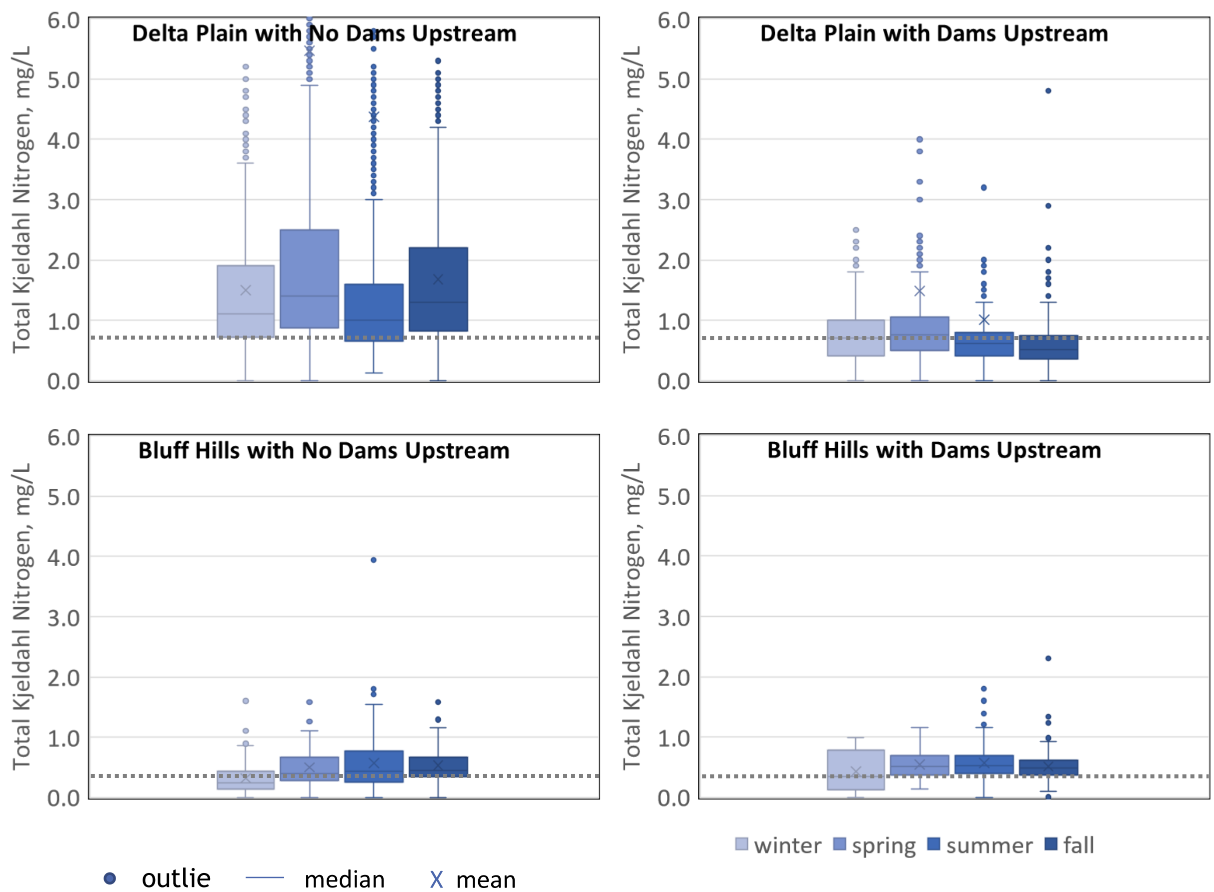

Figure 14. Seasonal Total Kjeldahl Nitrogen (TKN) box-and-whisker plots for Delta Plain (top) and Bluff Hills (bottom) both with no reservoirs/dams located upstream (left) and with upstream reservoirs/dams (right). Dashed horiztonal lines indicate the level-of-concern concentration for TKN of 0.69 mg/L and 0.3 mg/L for the Delta Plain and Bluff Hills, respectively (USEPA, 2001; USEPA, 2000).

Continuous Sediment Monitoring

Sediment concentrations for the Yazoo basin have been collected for at least the past 50 years, in both discrete sampling locations, as well as at several fixed gages with continuous daily monitoring of sediment suspended in streams and waterbodies. A dedicated sediment monitoring program (the Demonstration Erosion Control Project) was established in the 1980s, resulting in a decade of daily suspended sediment concentrations for eight gages at various locations upstream of the flood control reservoirs in the Bluff Hills (Rebich, 1993). In addition to the initial data collection, a follow-up deployment at select sites continued to collect daily sediment concentration data from the mid-1990s through 2003. The location of these continuous sediment monitoring sites are depicted by the brown markers in Figure 15, and a timeseries of data coverage showing the two separate sediment monitoring "campaigns" is shown for the Yalobusha basin in Figure 16.

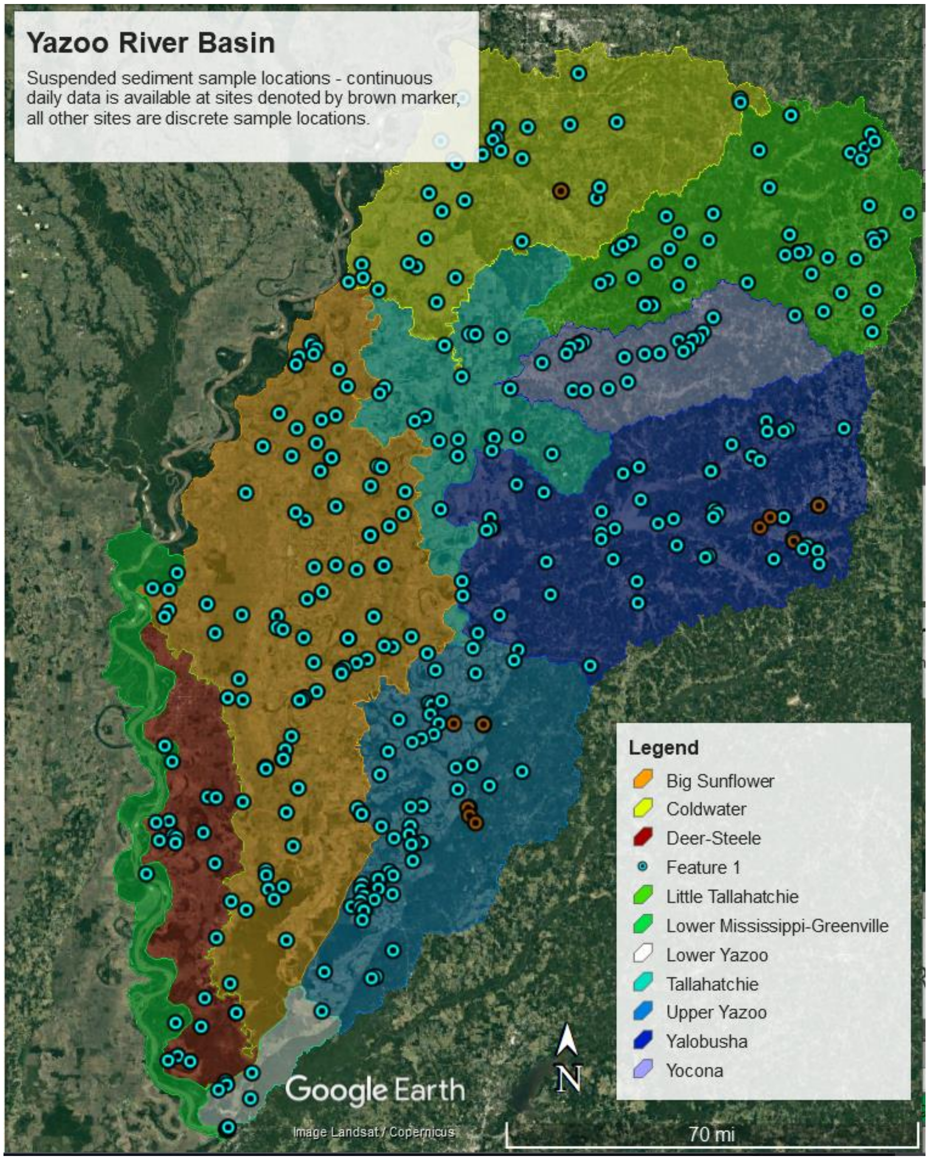

Figure 15. Map of stations with suspended sediment data. Brown markers indicate gaging stations that had collected continuous daily suspended sediment data; teal markers are locations of discrete suspended sediment samples.

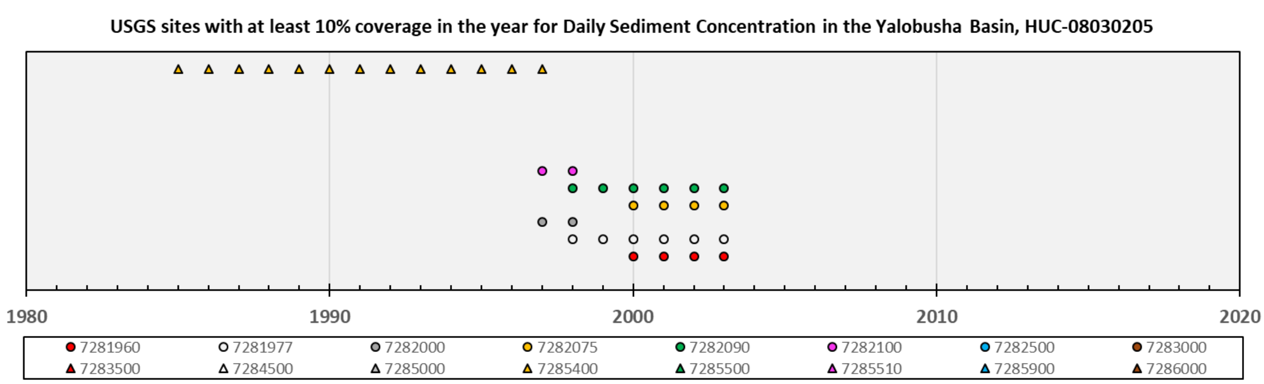

Figure 16. Daily suspended sediment concentration observations for the Yalobusha River basin, located in the bluff Hills. These data coverages show the two periods of dedicated daily sediment monitoring

in the Yazoo basin, the effort started in the 1980s (Rebich, 1993) and a later deployment which has no continuous data collected after 2003.

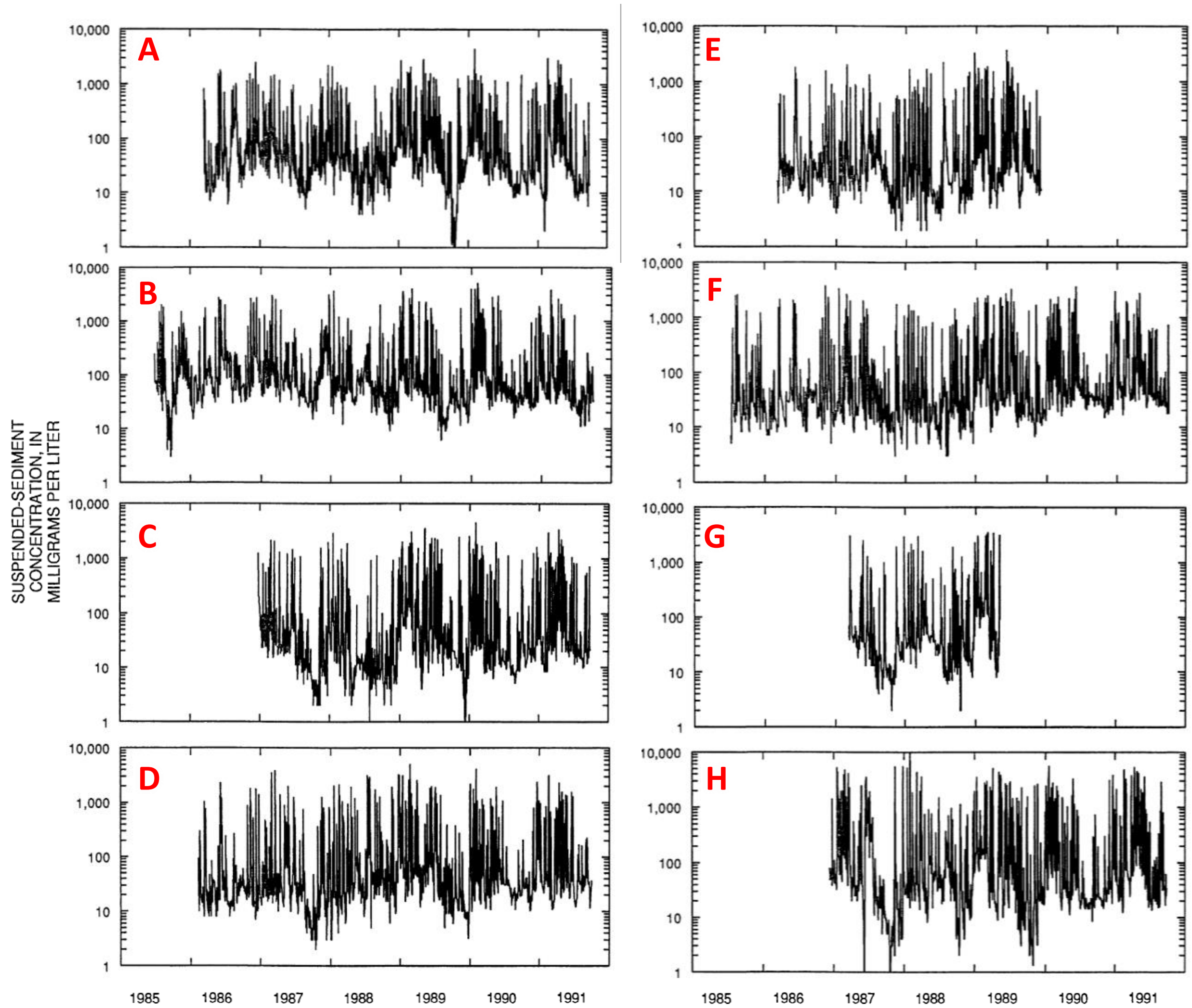

Figure 17. Daily mean suspended sediment concentration for eight locations in the Bluff Hills with no reservoirs/dams located upstream: (A) Hotopha Creek, (B) Otoucalofa Creek Canal, (C) Peters (Long) Creek, (D) Hickahala Creek, (E) Senatobia Creek, (F) Batupan Bogue, (G) Fannegusha Creek and (H) Harland Creek. Figures adapted from Rebich (1993).

In addition to the timeseries analysis of daily mean streamflow and suspended sediment concentrations, statistical techniques were used to determine any trendlines that may have been present in the data collected from 1985 through 1994 at two of the eight monitoring locations. This was undertaken to examine what, if any, impact erosion control and best management practices put in place during the Demonstration Erosion Control Project may have had on sediment discharge in the Bluff Hills. This follow-up analysis was conducted on instantaneous sediment load/discharge paired data points – and therefore was able to examine event-specific characteristics that may have been dampened when analyzing trends using daily mean values. The results of this statistical exercise indicated a 10 % annual reduction in flow-adjusted sediment discharge for the Hotopha Creek and an 11% annual reduction at the Otoucalofa Creek Canal site (Rebich, 1995).

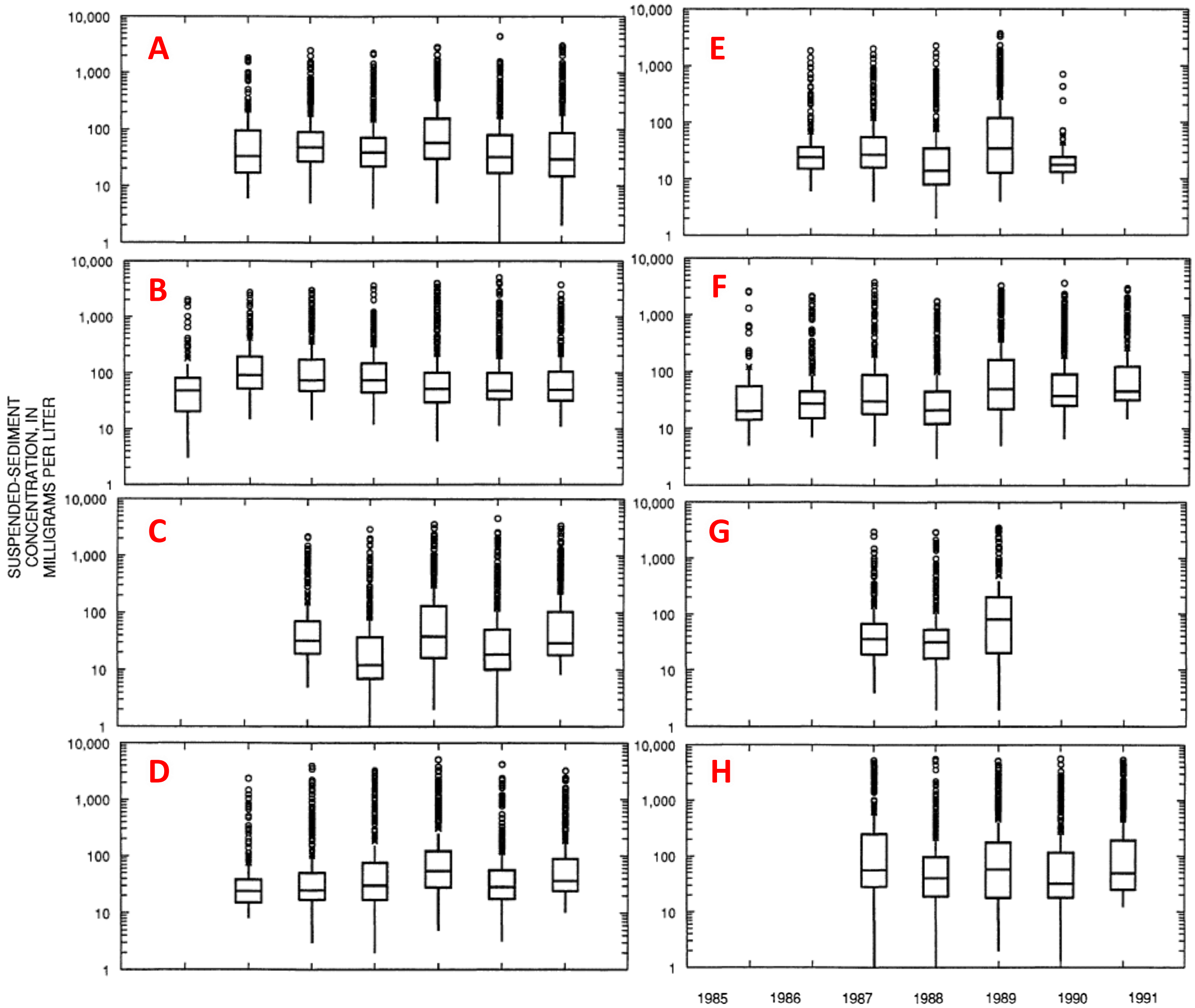

Figure 18. Annual Suspended Sediment Concentration box-and-whisker plots for eight locations in the Bluff Hills with no reservoirs/dams located upstream: (A) Hotopha Creek, (B) Otoucalofa Creek Canal, (C) Peters (Long) Creek, (D) Hickahala Creek, (E) Senatobia Creek, (F) Batupan Bogue, (G) Fannegusha Creek and (H) Harland Creek. Figures adapted from Rebich (1993).

Discrete Sediment Monitoring

While the Demonstration Erosion Control Project yielded important data used to assess efficacy of best management and various land use practices examined by agencies (Rebich, 1995), the location of these continuous data monitoring sites were all located on tributaries to the Yazoo River – no continuous sediment monitoring was conducted on the main stem of the Yazoo or in any of the Delta Plain basins. Also, of the sites in the Bluff Hills that did have continuous data, most sites were discontinued by 1997, with a small additional deployment which ended in 2003. It appears that there are no continuous sediment monitoring locations anywhere within the Yazoo basin (at least within NWIS) since 2003.

However, there are over 9,700 discrete samples for Total Suspended Sediment (TSS) that were available from the NWIS, STEWARDS and STORET databases. The location at which these discrete samples were taken are shown as teal markers in Figure 15. These data included samples within lakes throughout the Yazoo basin, which were excluded from this analysis. Once filtered, approximately 8,000 discrete samples from surface waters for TSS collected from 1969 through 2018 were analyzed for this assessment.

Whereas the continuous suspended sediment monitoring was all on smaller tributaries, the wide expanse of discrete sampling locations indicates strong differences between regions of the Yazoo basin. From both timeseries (Figure 19) and descriptive statistics (Figure 20) perspectives, the Delta Plain locations that are not impacted by upstream reservoirs have substantially higher suspended sediment concentrations than the other three regions assessed. Additionally, the springtime concentrations within the Delta Plain with no upstream reservoirs are much higher than other seasons, with wintertime concentrations also noticeably higher in magnitude than summer and fall sediment concentrations. There are not clear seasonal patterns for the Delta Plain locations that do have upstream reservoirs; the suspended sediment concentration at these sites are relatively constant across seasons. The Bluff Hills sites that are located upstream of any dams also do not appear to have a very strong seasonal pattern; with the exception that spring and fall samples appear to have fewer sites with low concentrations (Figure 20 and Figure S-30).

The most striking pattern from the Bluff Hill sites is the large increase in suspended sediment concentrations downstream of reservoirs during the winter months (Figure 20). This is likely due to the fact that the flood control reservoirs are typically drained during the winter to their lower regulated levels to increase storage capacity in preparation for any impending spring and summer rainstorms (USACE, 2019c), releasing sediment-laden water from the reservoirs into the receiving waters downstream. This signal appears to be muted once the flow reaches the locations within the Delta Plain that are impacted by upstream reservoirs; no large increase in wintertime sediment concentrations are clearly seen at these locations downstream compared to other seasons. This is likely caused by a variety of factors, including "dilution" of sediment concentrations as additional drainage areas come online within the mainstem of the Yazoo River, as well as the complexities of sediment and water transport through a highly altered hydraulic network. One final, yet very important, point is that the number of data points for suspended sediment concentration in the Bluff Hills at locations impacted by upstream reservoirs is very small for winter sampling events (bottom plot in Figure 19). These samples were taken across a variety of years, so they are not all taken from one anomalous event; however, a more rigorous data collection and analysis should be conducted before making strong conclusions on this potential seasonal impact on suspended sediments due to operations of upstream reservoirs

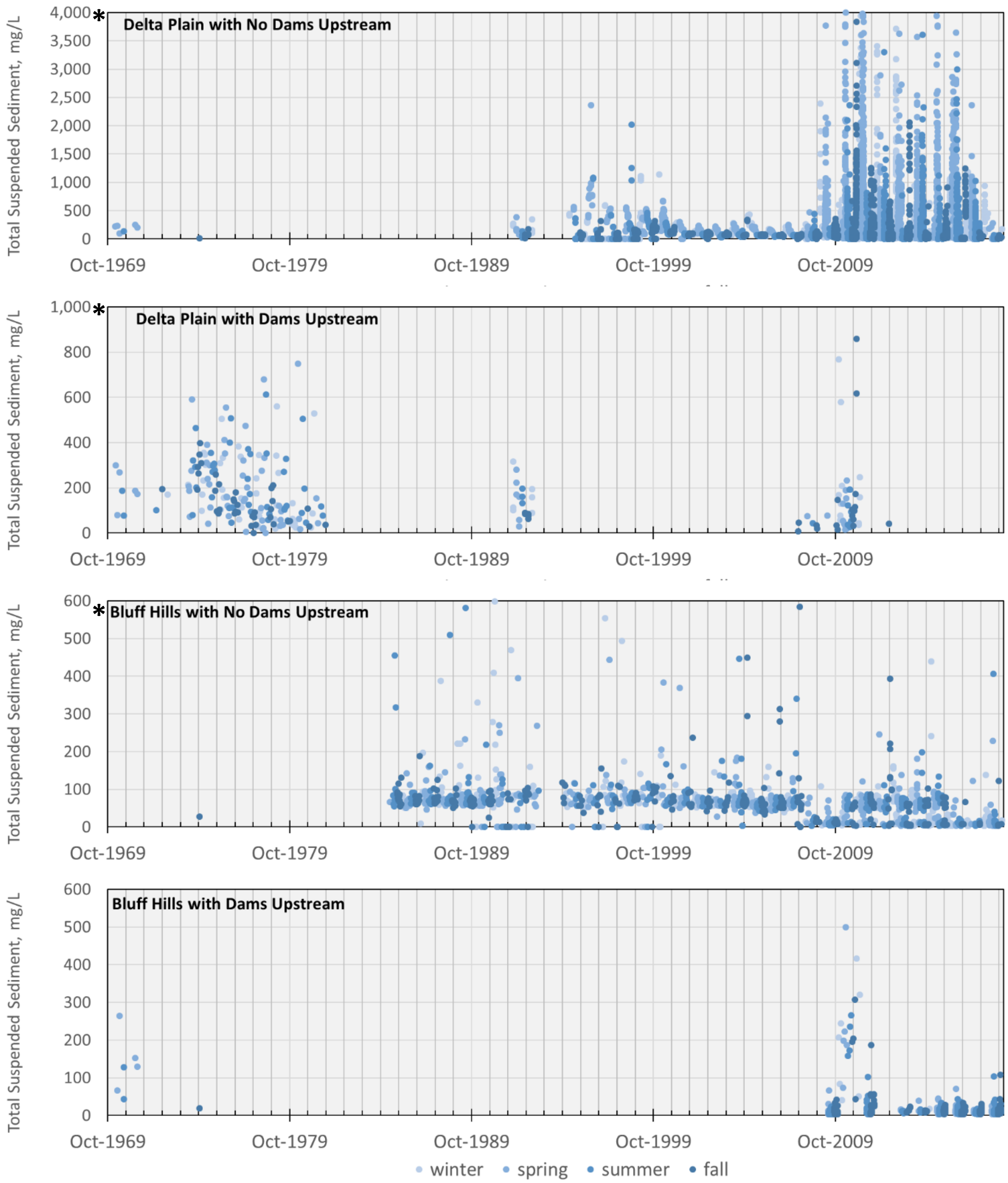

*Figure 19. Total Suspended Sediment (TSS) timeseries for each of the four regions analyzed. *Note that extreme-high values for TSS are excluded from these plots in order to better visualize the data; 38 points were measured with concentrations greater than 4000 mg/L in the Delta Plain with No Dams Upstream, 2 points were measured with concentrations greater than 1000 mg/L in the Delta Plain with Dams Upstream and 9 points were measured with concentrations greater than 600 mg/L in the Bluff Hills with No Dams Upstream. Outlier thresholds vary by region/season and are shown in Figure 20.*

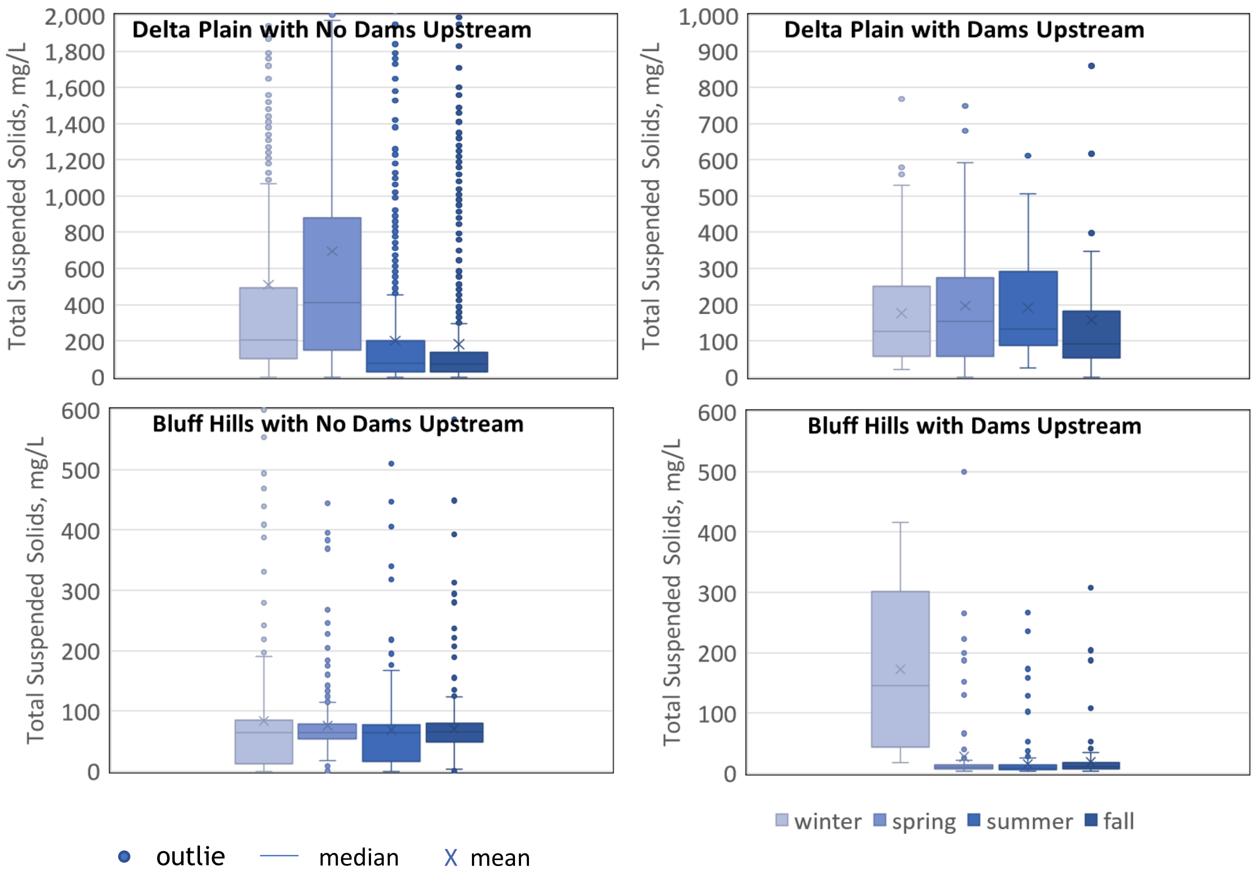

Figure 20. Seasonal Total Suspended Solids (TSS) box-and-whisker plots for Delta Plain (top) and Bluff Hills (bottom) both with no reservoirs/dams located upstream (left) and with upstream reservoirs/dams (right).

Future Opportunities within the Yazoo River Basin

Data mining and analysis of existing data

Historic data collection throughout the Yazoo River Basin has resulted in a wealth of discrete sampling data for multiple types of water quality data. Previous efforts have been taken to examine the available datasets and identify which data could be used to help examine a variety of priority issues facing the Yazoo River Basin (MDEQ, 2001). Unfortunately, since this data compilation/collection plan was developed, a large set of continuous water quality monitoring stations have been discontinued and are no longer providing daily suspended sediment data that had been in place, in various locations throughout the upper basins of the Yazoo, since the early 1980s.

With respect to sediment data, there are two potential opportunities to expand upon previous and ongoing work. First, a concerted effort could be made to mine discrete field measurements of flowrate data that was taken at the same time and place as corresponding water quality data. This could result in a suite of rating curves for the large dataset of suspended sediment concentration data that has been collected throughout the basin over the past five decades (assuming an adequate selection of paired flow-sediment data points are available). The meta-analysis of discrete suspended sediment concentrations shown in this assessment (Figure 19, Figure 20 and in Supplemental Figures - Total Suspended Sediment Histograms) indicates that there are indeed differences in concentration depending on location within the Yazoo, however, the total load and the relative importance of these differences cannot be fully assessed without corresponding flow data. However, peak flowrates at the mouth of the Yazoo River appear to be strongly impacted by flows from the Delta Plain in areas uncontrolled by the upstream flood control reservoirs (Figure 11). From this meta-analysis, it appears that higher suspended sediment concentrations within the Delta Plain may be important for total sediment loading coming from the entire Yazoo basin, given the fact that event flowrate peaks seem to be strongly impacted by flows coming from the Delta Plains. However, other studies have indicated a long-term reduction in baseflow throughout the Delta Plain due to aquifer depletion from irrigation and aquaculture consumptive uses (MDEQ, 2001). Due to these complicating factors, a detailed statistically-based analysis of coupled flow-sediment data sources should be undertaken to assess the importance of these high suspended sediment concentrations on overall sediment load to the Mississippi River from the Yazoo basin.

Collecting additional continuous monitoring data to develop a nested basin dataset

Mining the existing sources of discrete monitoring data could lead to insights and understandings of sediment and water quality constituent loads from the past several decades of monitoring effort, and the widespread discrete sampling efforts should continue into the future to continue to be able to monitor changing conditions in the Yazoo basin. In addition, the placement and operation of continuous flow gages has nearly laid the foundation for a set of nested basins throughout the Yazoo River basin. For example, Figure 11, demonstrates the utility of being able to determine what portions of the basin various flow components are coming from. By placing and continually operating several additional flow gages at key confluences throughout the basin, cumulative flow plots similar to Figure 11 could be developed. Coupled with programmatic suspended sediment sampling (and/or continuous turbidity monitoring), regional sediment load maps could be developed for the entirety of the Yazoo basin. Similar data could be collected for nutrients and other water quality constituents. This could potentially lead to important insights into intra-basin processes that are functions of seasonality/baseflow conditions, dam and flood gate operations, in-channel erosion and sedimentation, and other ecological processes.

Use the data to target effective mitigation efforts and best management practices

Any dedicated data analysis (or additional data collection) should only be conducted with distinct and pre-determined objectives defined up front. Ideally, these analyses should be designed in order to quantify and assess various mitigation strategies that could be implemented within the Yazoo basin; similar to the Demonstration Erosion Control Project which was monitoring suspended sediment concentrations in the Bluff Hills from 1985 through 1993. While the conditions of the Yazoo River basin are dire and daunting, one potential silver lining is that the intensive land use and water management practices within the basin are ripe for the tweaking. The USDA Natural Resource Conservation Service (NRCS) dates back to the Dust Bowl and dedicated land, water, and soil conservation measures are not particularly new challenges. The challenge lies within convincing and incentivizing farmers, land and water managers to implement best management practices: areas that have dedicated funding and outreach programs through the NRCS and agricultural extension services (USDA, 2019). Just south of the Yazoo River basin, in the Amite River watershed located in southeastern Louisiana, land use/land cover changes that have been spurred by incentive and easement programs has led to an increase in forested watersheds and an overall reduction in rainfall-runoff coefficient values (Willson, 2019).

In addition to land use and land management changes, the operation of flood control structures throughout the Yazoo Basin could be examined holistically. Groundwater extraction for extensive irrigation of cropland in the Delta Plain has detrimentally impacted baseflows for streams in this region (MDEQ, 2006). Data analyzed here, however, shows that management of upstream reservoir levels has clear impacts on hydrologic signals throughout the entire basin. Leveraging these upstream reservoirs for scheduled water deliveries for irrigation purposes could help reduce the over-utilization of the regional aquifers in the Yazoo basin.

Changes to land use, as well as to channel geometry and flowrates has led to streambank and streambed erosion of the loess deposits within the Bluff Hills (Whitten and Patrick, 1981); management of water flows throughout the Yazoo Basin should accompany any discussion of large-scale restoration or mitigation plan to best address these issues.

One final suggestion for utilizing a comprehensive flow-adjusted dataset is in order to develop TMDLs for the large number of streams throughout the Yazoo basin that either: are in need of a TMDL but do not yet have one, or have yet to be assessed for water quality use attainment.

Funding avenues

Due to the highly managed waterways and intensive agriculture practices present within the Yazoo River basin – there are several federal agencies and departments that would likely be interested parties in developing comprehensive data monitoring and synthesis program with follow-on work of implementing restoration, mitigation and best management practices. First and foremost, the USGS has a long history of collecting data and conducting studies within the Yazoo basin. Any discussion of monitoring, gage installation, maintenance, data warehousing and analysis should include the scientists and technicians of the USGS. The USDA Agricultural Research Service and Natural Resource Conservation Service should also be involved and would likely be avenues for funding, given the extensive agricultural practices in place in the Yazoo basin. The USDA Forestry Service would also have potential influence, given the fact that the 60,000 acre Delta National Forest sits squarely within the confines of the Yazoo Delta Plain. There are also two national wildlife refuges located within the Yazoo, so the US Fish and Wildlife Service would likely be another key partner in funding such a large undertaking. Last, and certainly not least, the USACE is responsible for many flood control structures throughout the Yazoo Basin, including the operation and control of the four large flood-control reservoirs in the upstream portions of the Bluff Hills.

The above is solely a list of federal agencies that would likely have interest in monitoring and improving the water quantity and quality characteristics of the Yazoo River basin due to active land and water management activities currently underway. The USEPA and MDEQ would also be interested stakeholders due to their history of monitoring water quality throughout the Yazoo Basin, as well as their interest and need for the development of TMDLs for the Yazoo basin (MDEQ, 2018).

The complexities of land and water use management throughout the Yazoo basin, as well as the dire nature of the Yazoo basin waterways, anything short of a dedicated and directed interagency effort led by the federal government will likely result in more of the status quo in the Yazoo basin: periodic detailed monitoring campaigns, widespread discrete water quality sampling and very little in the way of actual improvement to waterbodies of the Yazoo River basin.

References

Bryant, M.D. (2010). *Past and Present Aquatic Habitats and Fish Populations of the Yazoo-Mississippi Delta*. General Technical Report SRS-130. USDA Forest Service – Southern Research Section. Stoneville, MS.

De Cicco, L.A. and Hirsch, R.M. (2014). *The dataRetrieval R package*. United States Geological Survey.

Mississippi Department of Environmental Quality. (2001). *Yazoo River Basin Data Collection Plan 2001-02*. https://www.mdeq.ms.gov/wp-content/uploads/2003/07/YRB-DCP-Final.pdf

Mississippi Department of Environmental Quality. (2006). *Citizen's Guide to Water Quality in the Yazoo Basin*.

Mississippi Department of Environmental Quality. (2018). *State of Mississippi Water Quality Assessment 2018 Section 305 (b) Report*

Parajuli, P.B. and Kim, H. (2012). *Yazoo River Basin Assessment: Preliminary Report. Bulletin 1202*. Mississippi State University, Mississippi Agricultural & Forestry Experiment Station.

Rebich, R.A. (1993). *Preliminary Summaries and Trend Analyses of Stream Discharge and Sediment Data for the Yazoo River Basin Demonstration Erosion Control Project, North-Central Mississippi, July 1985 Through September 1991*. U.S. Geological Survey Water Resources Investigations Report 93-4068.

Rebich, R.A. (1995). *Estimation of Sediment-Discharge Reduction for Two Sites of the Yazoo River Basin Demonstration Erosion Control Project, North-Central Mississippi, 1985-94*. U.S. Geological Survey Water Resources Investigations Report 95-4198.

Runner, M.S., Turnipseep, D.P., and Coupe, R.H. (2002). *Streamflow and Nutrient Data for the Yazoo River below Steele Bayou near Long Lake, Mississippi, 1996-2000*. U.S. Geological Survey Water Resources Investigations Report 02-4215.

Shields Jr., F.D., Testa III, S. and Cooper, C.M. (2009). *Nitrogen and phosphorus levels in the Yazoo River Basin, Mississippi*. Ecohydrology. 49(1). https://doi.org/10.1002/eco.49

U.S. Army Corps of Engineers. (2019a). *Arkabutla Lake History*. USACE, Vicksburg District. Accessed online April 20, 2019. https://www.mvk.usace.army.mil/Missions/Recreation/Arkabutla-Lake/History-and-Mission/

U.S. Army Corps of Engineers. (2019b). *Grenada Lake History*. USACE, Vicksburg District. Accessed online April 20, 2019. https://www.mvk.usace.army.mil/Missions/Recreation/Grenada-Lake/History-and-Mission/

U.S. Army Corps of Engineers. (2019c). *Sardis Lake History*. USACE, Vicksburg District. Accessed online April 20, 2019. https://www.mvk.usace.army.mil/Missions/Recreation/Sardis-Lake/History-and-Missions/

U.S. Army Corps of Engineers. (2019d). *Enid Lake History*. USACE, Vicksburg District. Accessed online April 20, 2019. https://www.mvk.usace.army.mil/Missions/Recreation/Enid-Lake/History-and-Mission/

U.S. Army Corps of Engineers. (2019e). *Yazoo River Basin Stations*. Accessed online April 20, 2019. http://rivergages.mvr.usace.army.mil/WaterControl/new/layout.cfm.

U.S. Department of Agriculture. (2019). *Healthy Forest Reserve Program*. USDA Natural Resource Conservation Service. Accessed online May 4, 2019. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/forests/?cid=nrcs143_008387

U.S. Environmental Protection Agency. (2000). *Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria Rivers and Streams in Nutrient Ecoregion IX*. U.S. EPA Office of Water. https://www.epa.gov/sites/production/files/documents/rivers9.pdf

U.S. Environmental Protection Agency. (2001). *Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria Rivers and Streams in Nutrient Ecoregion X*. U.S. EPA Office of Water. https://www.epa.gov/sites/production/files/documents/rivers10.pdf

U.S. Environmental Protection Agency. (2013). *Level III and IV ecoregions of the continental United States*. Corvallis, Oregon, U.S. EPA National Health and Environmental Effects Research Laboratory. https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states.

U.S. Geologic Survey. (2019). Stream Trace Detailed Report: Yazoo River. USGS Streamer. Accessed online February 25, 2019. https://txpub.usgs.gov/DSS/Streamer/api/3.14/js/report/report.html?debug=false&caller=streamer_report_detailed&session_id=222255880183&basemap=terrain&basemapOpacity=1&UsaMask=true&UsaMaskOpacity=0.5&traceDir=up&StreamID=20090752&xWebMerc=-10118888.8471&yWebMerc=3806999.0062&reportType=detailed

Whitten, C.B., Patrick, D.M. (1981). *Engineering geology and geomorphology of streambank erosion; Report 2, Yazoo River Basin Uplands, Mississippi*. U.S. Army Engineer Waterways Experiment Station Geotechnical Laboratory. Technical Report GL-79-7.

Willson, C. *(2019). Land cover in the Upper Amite watershed and impacts on rainfall-runoff values*. Personal communication with graduate student of Dr. Clint Willson at the LSU Civil Engineering Graduate Research Symposium. April 5, 2019. Baton Rouge, LA.

Supplemental Figures - Daily flowrate data

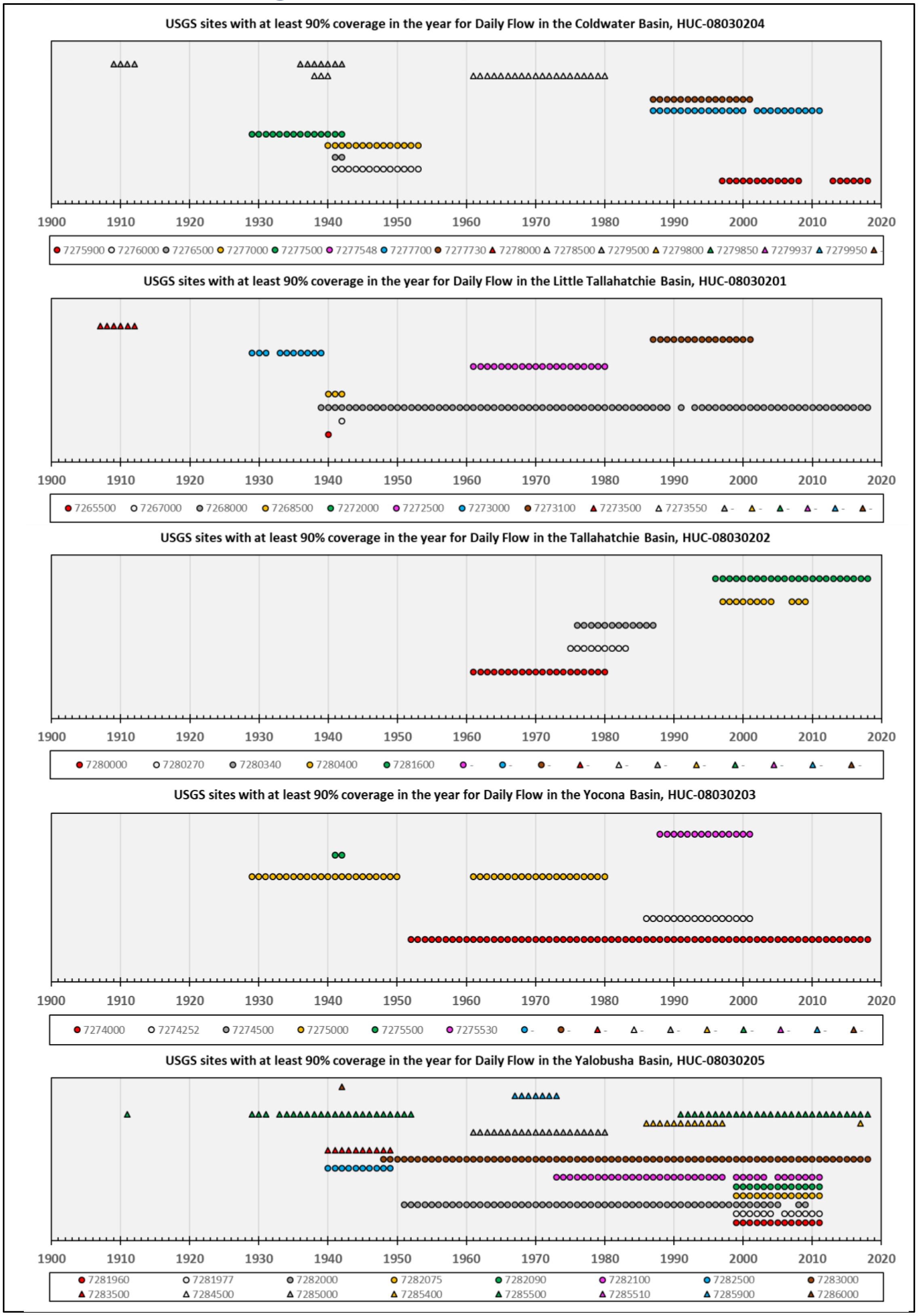

Figure S-21. Inventory of sites within HUC-8 basins in the Bluff Hills with high coverage of daily flowrate data.

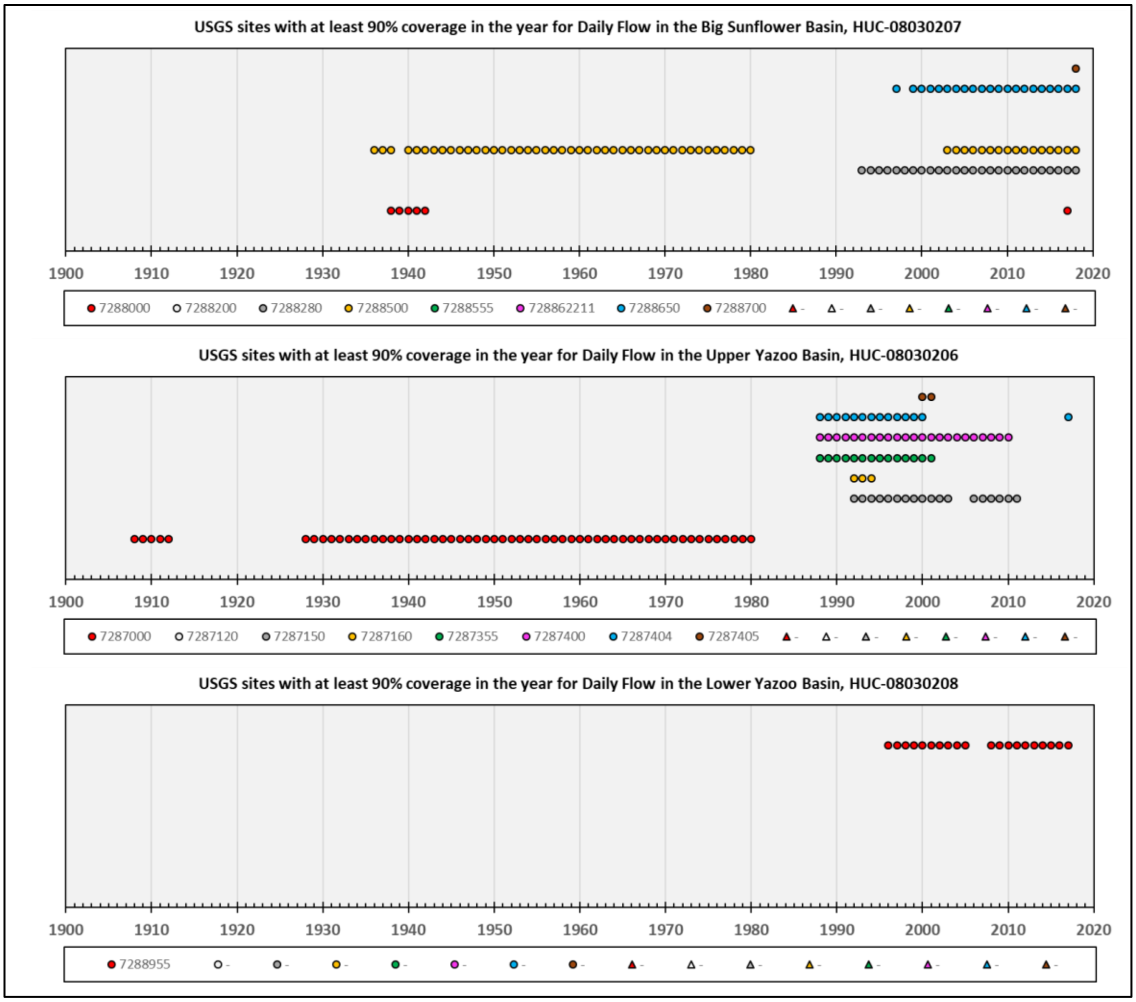

Figure S-22. Inventory of sites within HUC-8 basins in the Delta Plain with high coverage of daily flowrate data.

Table S-2. USGS sites selected as representative flow data for the two regions (Delta Plain and Bluff Hills) with daily data coverage greater than 90%. Sites for each region were selected so that at least one site per region was located downstream of a flood control reservoir and one site per region did not have any large flood-control reservoirs upstream.

Map ID	*Site*	*Basin Location*	*USGS NWIS Number*
A	Coldwater River near Olive Branch, MS	Bluff Hills with no dams upstream	07275900
B	Little Tallahatchie River at Etta, MS	Bluff Hills with no dams upstream	07268000
C	Big Sunflower River at Sunflower, MS	Delta Plain with no dams upstream	07288500
D	Yalobusha River at Grenada, MS	Bluff Hills with dam(s) upstream	07285500
E	Tallahatchie River at Money, MS	Delta Plain with dam(s) upstream	07281600
F	Yazoo River below Steel Bayou near Long Lake, MS	Delta Plain with dam(s) upstream	07288955
G	Yazoo River at Greenwood, MS	Delta Plain with dam(s) upstream	07287000

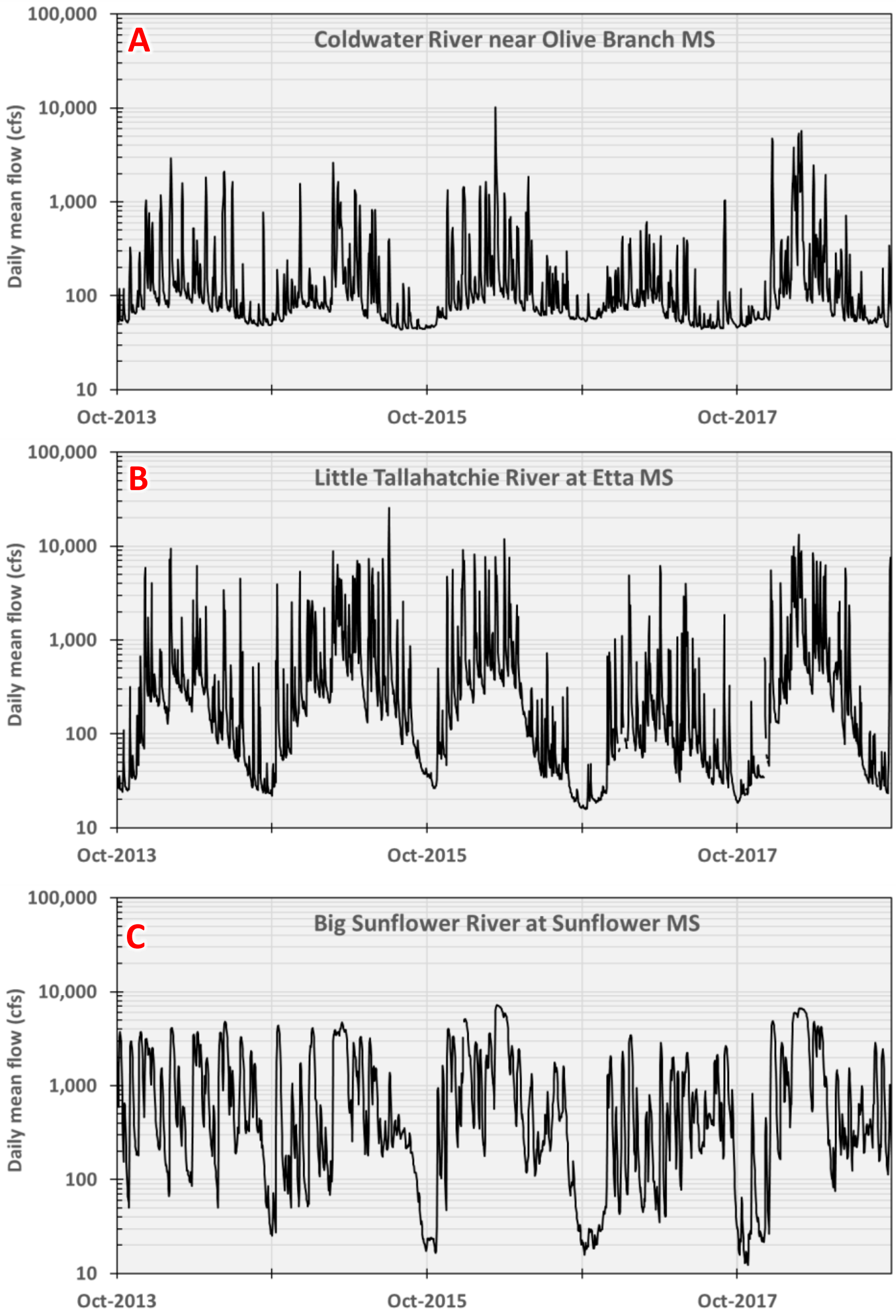

Figure S-23. Five years of daily mean flowrate (cfs) for three gages that do not have any flood-control reservoirs/dams located upstream; two sites (A – Coldwater River and B – Little Tallahatchie) are located in the Bluff Hills, one site (C – Big Sunflower River) is located in the Delta Plain.

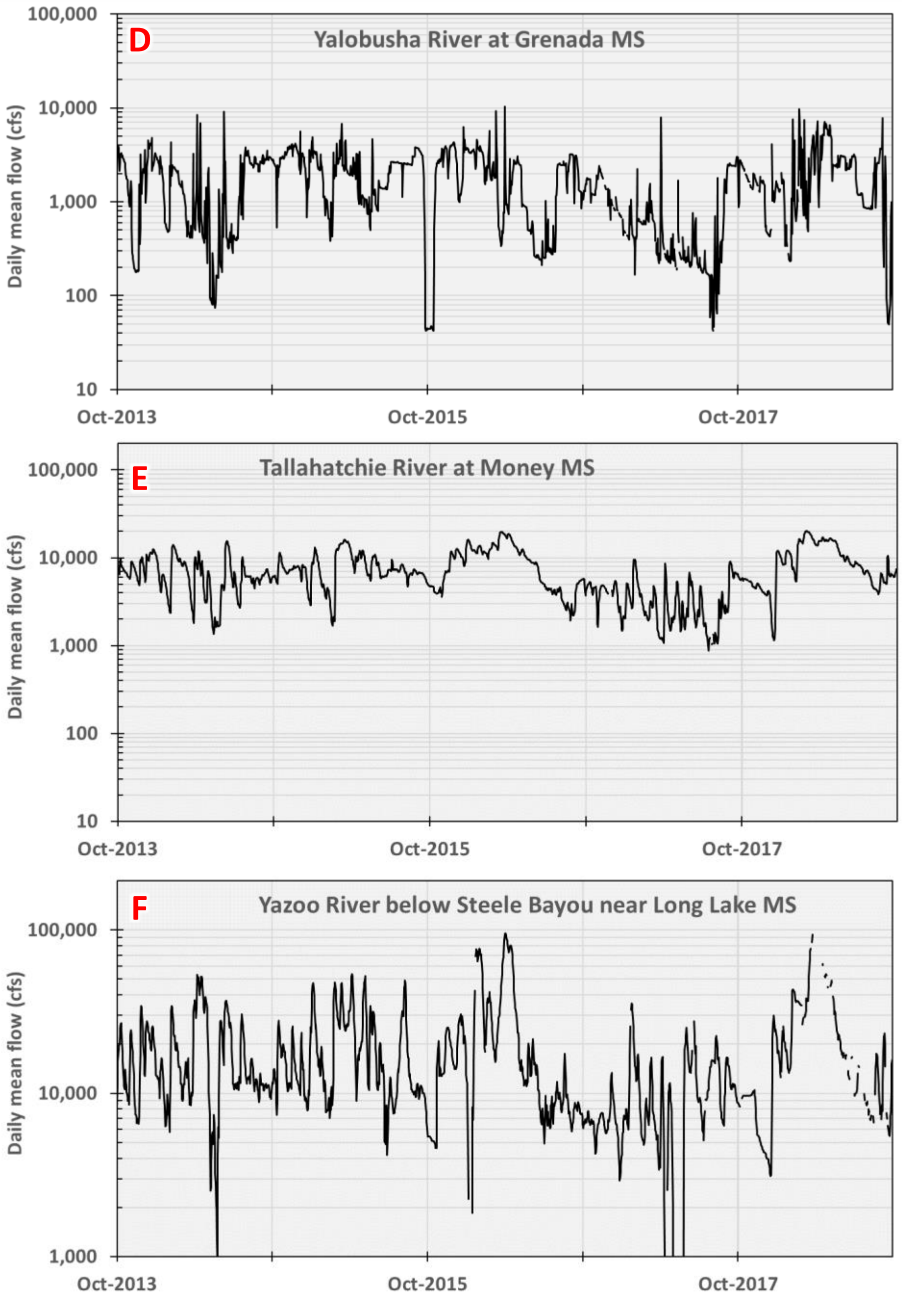

Figure S-24. Five years of daily mean flowrate (cfs) for three gages that have flood-control reservoirs located upstream; one site (D – Yalobusha River) is located in the Bluff Hills, and two sites (E – Tallahatchie River at Money and F – Yazoo River at Greenwood) are located in the Delta Plain. Note that the Yazoo River below Steele River (F) is subject to backwater flow from the Mississippi River, and negative flowrates are not shown on the log-10 axis used here.

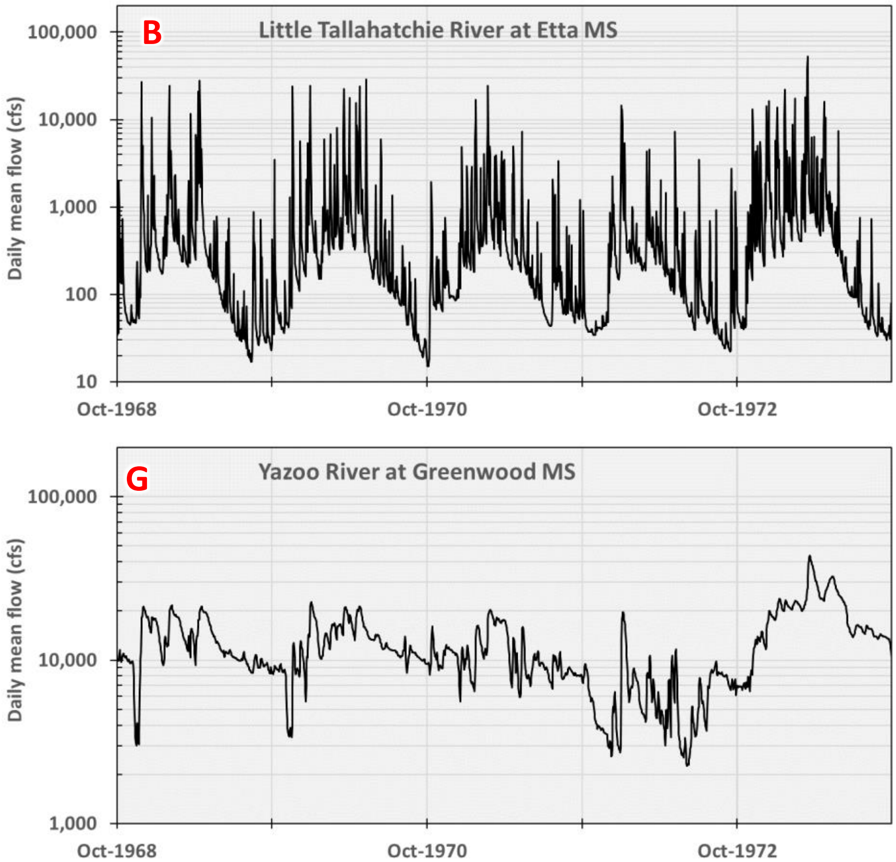

Figure S-25. Five years (1968 – 1973) of daily mean flowrate (cfs) for Little Tallahatchie River at Etta, MS (B) – upstream of any flood control reservoir and in the Yazoo River at Greenwood, MS (F), which is downstream of the four flood control reservoirs. Note that in 1973, the reservoirs overflowed via flood control spillways for the first time since completion of the dams.

Supplemental Figures - Total Kjeldahl Nitrogen Histograms

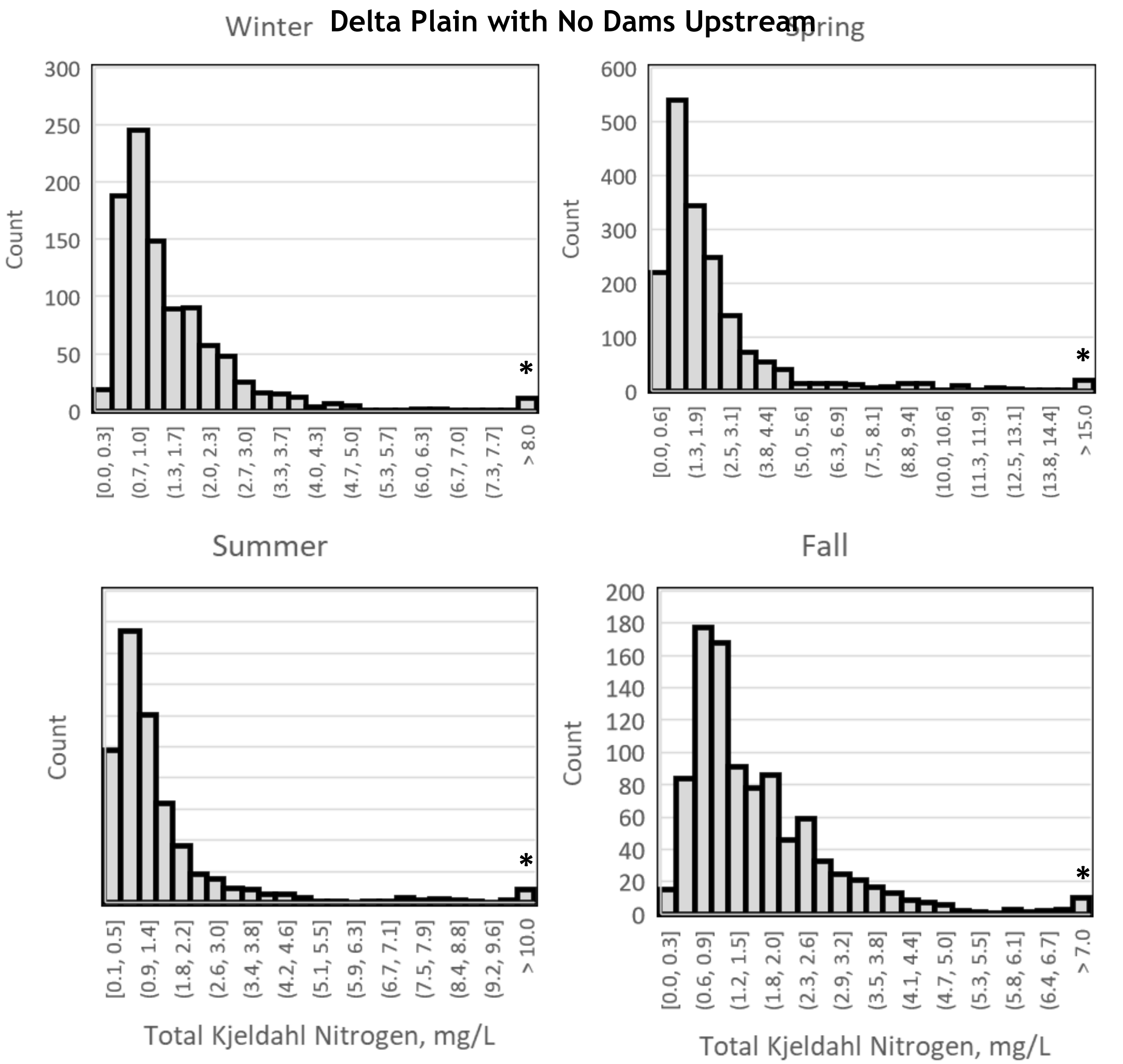

*Figure S-26. Seasonal Total Kjeldahl Nitrogen (TKN) histograms for Delta Plain with no reservoirs/dams located upstream. *Note that these data are strongly right-skewed; therefore, the highest-magnitude bin lumps all values above the listed threshold together into the final "overflow bin".*

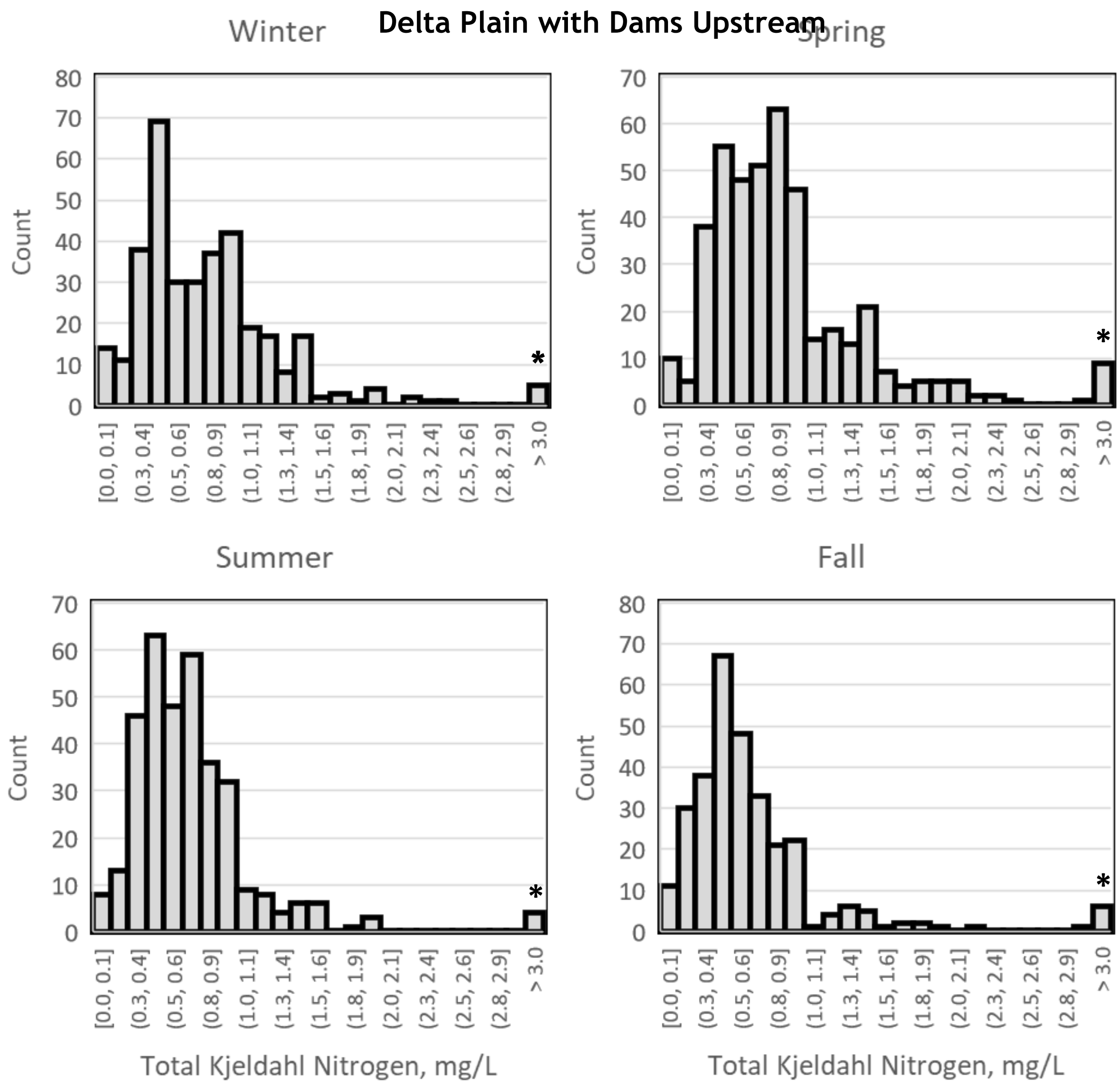

*Figure S-27. Seasonal Total Kjeldahl Nitrogen (TKN) histograms for Delta Plain with upstream reservoirs/dams. *Note that these data are strongly right-skewed; therefore, the highest-magnitude bin lumps all values above the listed threshold together into the final "overflow bin".*

Supplemental Figures - Total Suspended Sediment Histograms

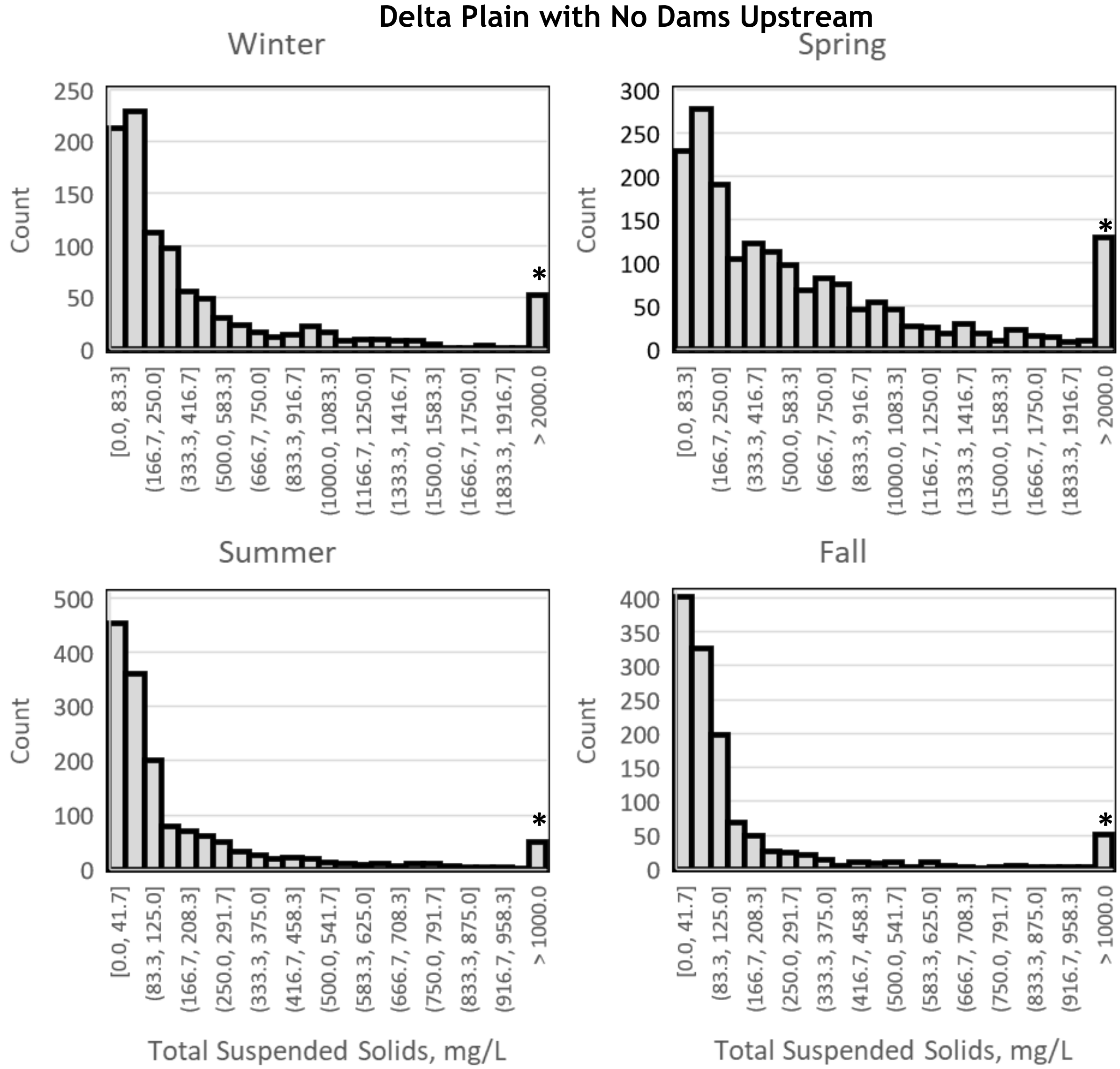

*Figure S-28. Seasonal Total Suspended Sediment (TSS) histograms for Delta Plain with no reservoirs/dams located upstream. *Note that these data are right-skewed; therefore, the highest-magnitude bin lumps all values above the listed threshold together into the final "overflow bin".*

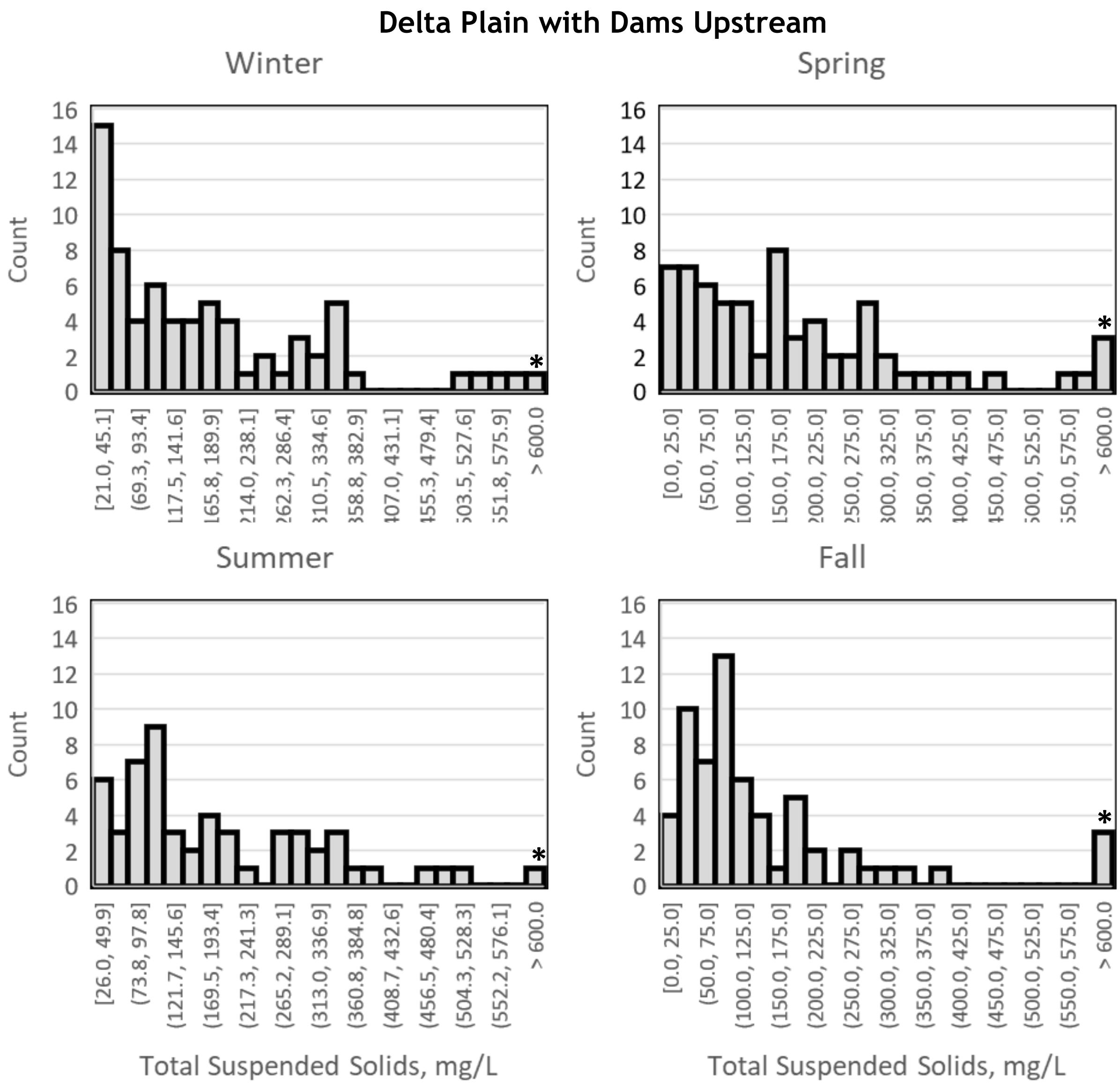

*Figure S-29. Seasonal Total Suspended Sediment (TSS) histograms for Delta Plain with reservoirs/dams located upstream. *Note that these data are right-skewed; therefore, the highest-magnitude bin lumps all values above the listed threshold together into the final "overflow bin".*

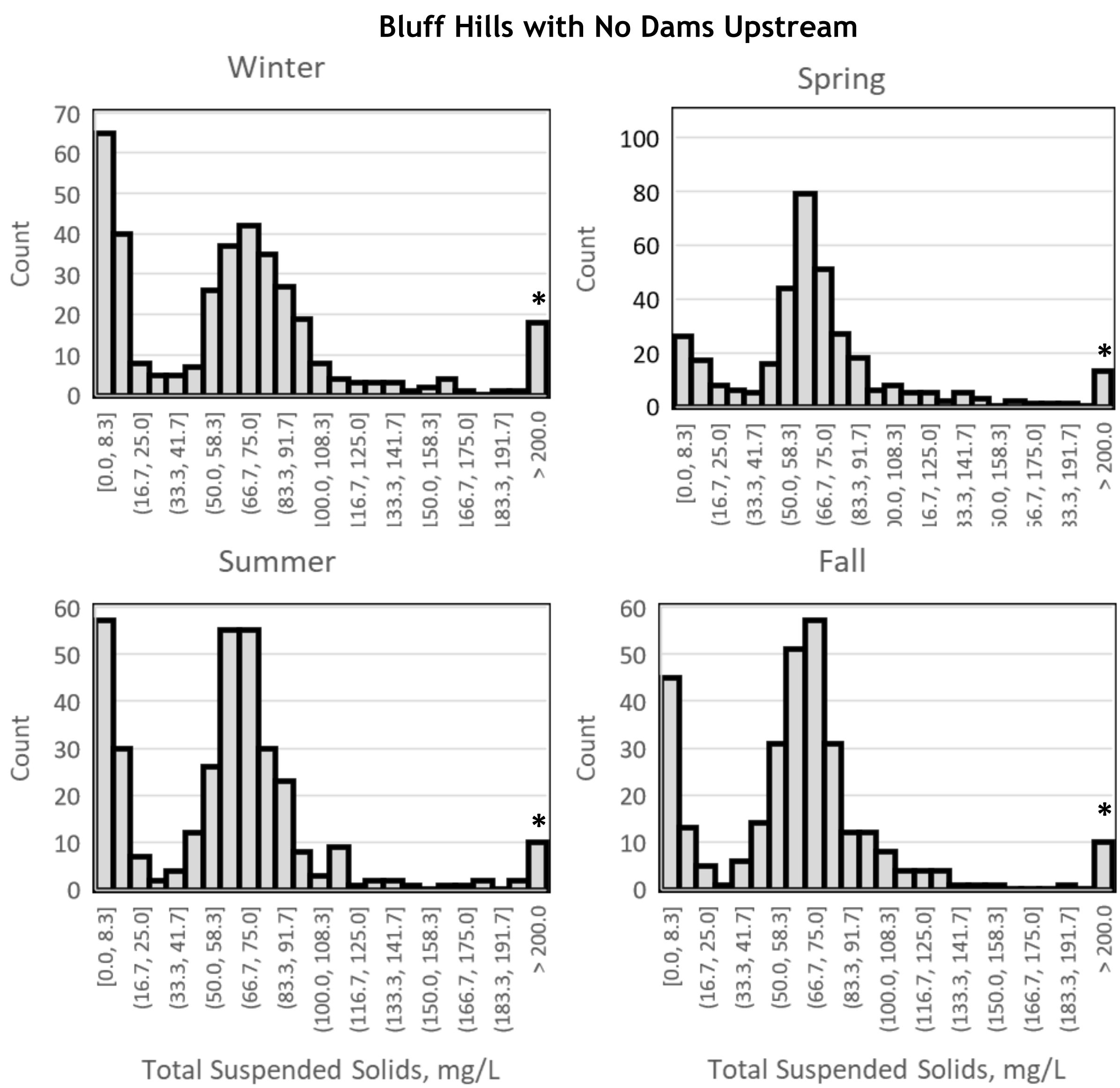

*Figure S-30. Seasonal Total Suspended Sediment (TSS) histograms for Bluff Hills with no reservoirs/dams located upstream. *Note that these data are right-skewed; therefore, the highest-magnitude bin lumps all values above the listed threshold together into the final "overflow bin".*

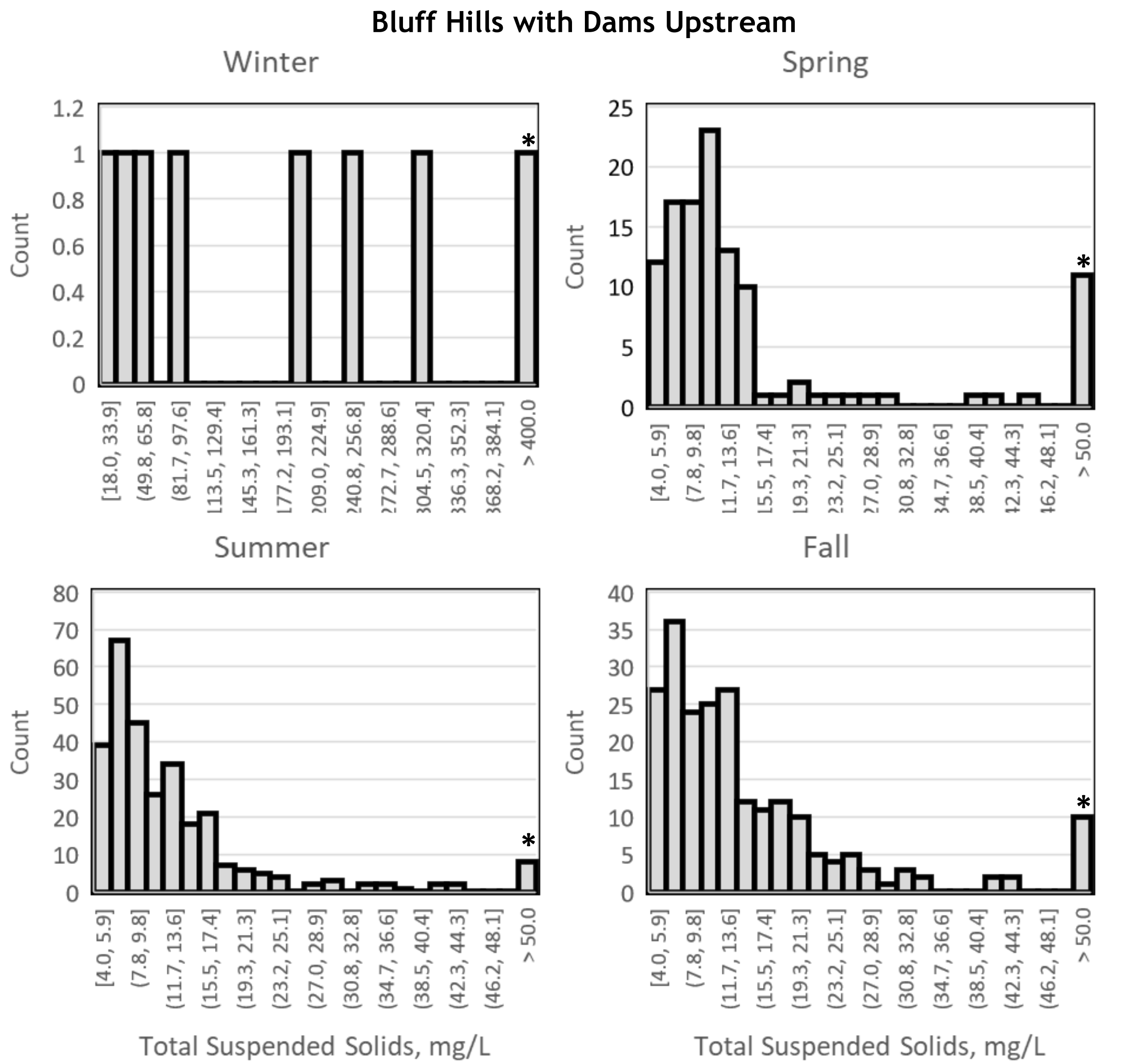

*Figure S-31. Seasonal Total Suspended Sediment (TSS) histograms for Bluff Hills with reservoirs/dams located upstream. *Note that these data are right-skewed; therefore, the highest-magnitude bin lumps all values above the listed threshold together into the final "overflow bin".*

Supplemental Figures – Temperature Statistics

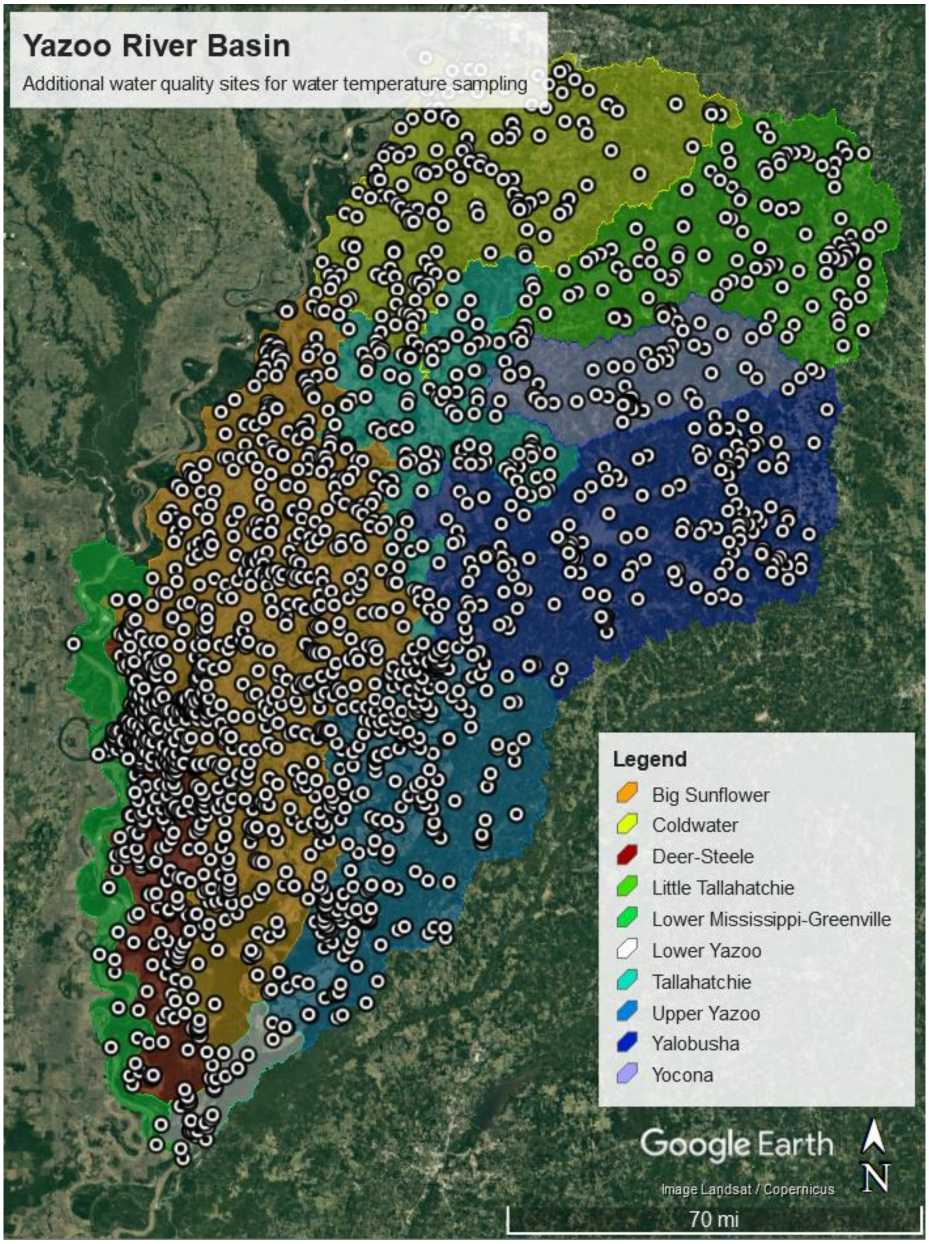

Figure S-32. Map of temperature observations - all sites are shown, however only data from surface water samples were analyzed.

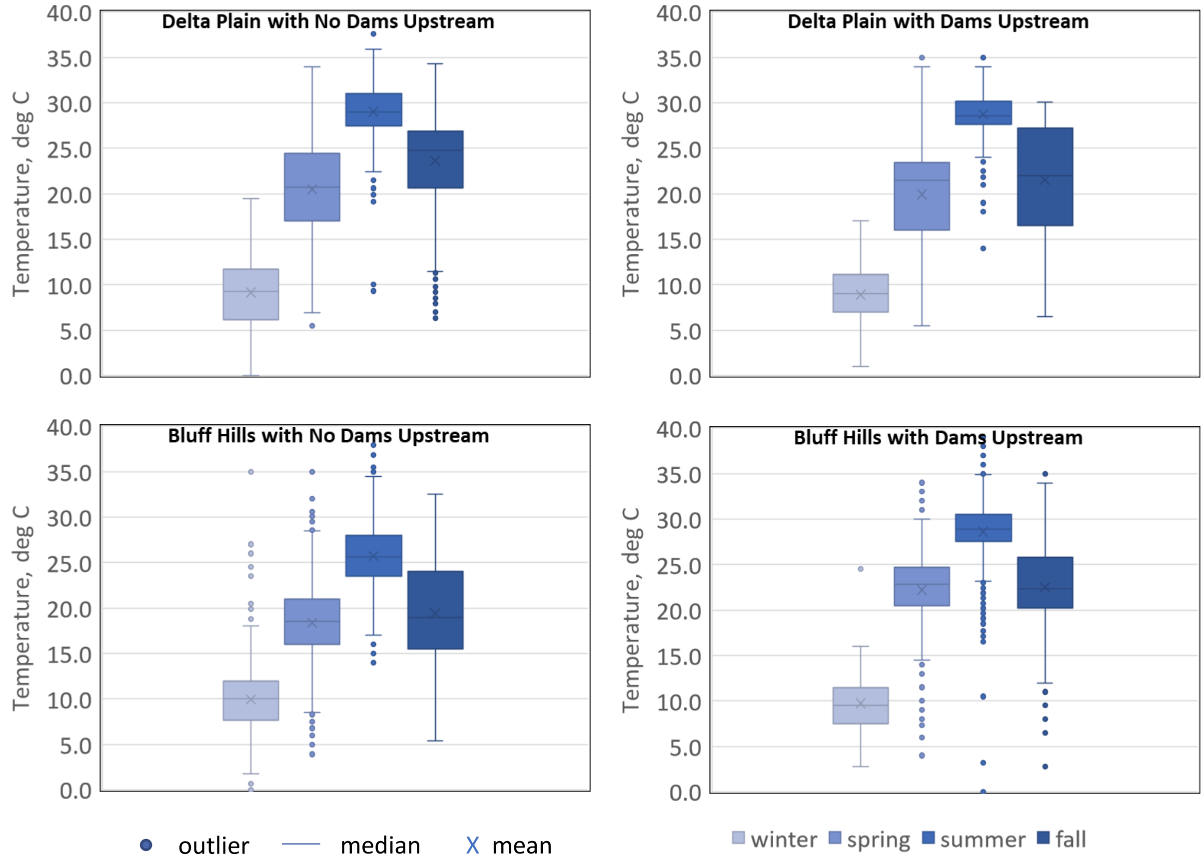

Figure S-33. Seasonal temperature box-and-whisker plots for Delta Plain (top) and Bluff Hills (bottom) both with no reservoirs/dams located upstream (left) and with upstream reservoirs/dams (right).