Lake Providence to Old River Geomorphic Assessment

Waleska Echevarria-Doyle, Research Hydraulic Engineer, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS, Waleska.Echevarria-Doyle@usace.army.mil

David S. Biedenharn, Research Hydraulic Engineer, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS, David.S.Biedenharn@usace.army.mil

Charlie D. Little Jr., Civil Engineer, Mendrop Engineering Resources, LLC, Vicksburg, MS, clittle@mendrop.net

Abstract

This study integrates information from previous geomorphic studies coupled with new analysis to provide a comprehensive geomorphic characterization of the Lake Providence (River Mile [RM] 487.2 Above Head of Passes [AHP]) to Old River Control Complex (ORCC), (RM 317 AHP) reach from the early 1800s to present. Individual components of this study included: historical geomorphic studies, development of an event timeline, specific gage records, trends in water surface slopes, bed material studies, channel geometry data, and effects of channel improvements (cutoff, dike, revetment, and dredging). These individual assessments were consolidated to develop an overall assessment of how the study reach has evolved since the early-1800s.

Introduction

The Mississippi River has been molded by anthropogenic and natural factors for thousands of years. Early effort by the U.S. Army Corps of Engineers (USACE) to manage the river for navigation began in the early-1800s, with the most comprehensive efforts occurring as a result of the Flood Control Act (FCA) of 1928 following the Flood of 1927. The Mississippi River & Tributaries (MR&T) Project that was authorized from the FCA of 1928 has produced a massive, comprehensive system for flood protection and channel stabilization that includes levees, channel modifications, and floodways, as well as tributary reservoirs and other basin improvements. The first official “Potamology Investigations” were initiated in the mid-1940s. These potamology studies continued as an integral component of the MR&T Program until the 1980s when the program ended. Then, after lost decades of continued potamology advancement and technical expertise, the Mississippi River Geomorphology and Potamology (MRG&P) program was created by the USACE Mississippi Valley Division (MVD) in 2014. MRG&P studies are designed to provide a comprehensive analysis of physical and anthropogenic factors that influence the flood conveyance, navigability, and environmental quality of the Mississippi River. The report presented herein represents one component of the MRG&P Program. This study represents an integration of numerous individual studies that addressed various geomorphic aspects of the Mississippi River combined with new analyses to weave together a more comprehensive understanding of the geomorphic character specifically for the river reach between Lake Providence, LA (RM 487.2 AHP) and the ORCC, (RM 317 AHP). The 1962 river mile system, which reflects miles above the Head of Passes (AHP), is used throughout the report.
Geomorphic Changes Early 1800s to Present

Event Timeline

A chronology of the major river engineering, hydrologic, and anthropogenic events within the study reach was developed for the study time period. The timeline is presented to add insight into the interpretation of the results from other analyses presented in this report. Table 1. summarizes the main events from the early 1800s to present.

Table 1. Major Event Timeline from the early-1800s to present.

<table>
<thead>
<tr>
<th>Early-1800s to late-1800s</th>
<th>Late-1800s to early- 1900s</th>
<th>Mid-1900s to late-1900s</th>
<th>Late-1900s to present</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Massive clearing of streambanks and riparian areas for wood burning steamboats and agriculture. 2) 1811-1812: New Madrid Earthquakes. 3) 1849-1850: Repeated flooding along the Mississippi River Valley. 4) Flood of 1874-Results in creation of Levee Commission. 5) 1879-Mississippi River Commission (MRC) created.</td>
<td>1) 1879-1928: Levees only policy adopted by MRC. 2) 1884-1929: MRC adopts policy to prevent natural neck cutoffs from forming. Natural chute cutoffs were allowed to continue during this period. 3) 1890, 1913, and 1927 Floods. 4) 1928-FCA of 1928 results in creation of the MR&amp;T Project. 5) 1929-MRC allows the Yucatan cutoff to occur naturally, the first natural neck cutoff to occur since 1884.</td>
<td>1) 1930-1934: Low water period. 2) 1931-1942: Cutoff Period (14 neck cutoffs between just south of Natchez, MS and just north of Helena, AR). 3) 1937 Flood. 4) 1940s-Studies indicate potential of Atchafalaya capturing Mississippi River Flow. 5) 1940-1944 and 1952-1972: Low water periods. 6) 1950s-Mid-1990s: Major bank stabilization period. 7) Mid-1960s-early-2000s: Major dike construction period.</td>
<td>1) 1963 ORCC Low Sill Structure in operation 2) 1975 Flood. 3) 1984-1988: Low water period. 4) 1986-ORCC Auxiliary Structure in operation. 5) 1990-ORCC Hydropower Unit in operation. 6) 1993-Flood on upper Mississippi River. 7) Mid-1990s-Dike notching program begins. 8) 1997 Flood. 9) 2000-Low water year. 10) 2008 Flood. 11) 2011 Flood. 12) 2012-2014: Low water period.</td>
</tr>
</tbody>
</table>

Pre-Cutoff Period (early 1800 to 1929)

Early 1800s to 1880s: The early 1800s was a period of rapid expansion into the Lower Mississippi River (LMR) Valley, and navigation along the waterways was the key to the growth of this region. At the time, the Mississippi River was experiencing substantial geomorphic changes as a result of both natural and anthropogenic factors during this initial period of expansion. According to Winkley (1977), the New Madrid earthquakes (1811 to 1812) contributed to substantial bank instabilities throughout the river causing excessive sediment supply, bar growth and other problems that impacted navigation. Additionally, wood burning steamboats along the Mississippi River were introduced in the early 1880s. These steamboats required
massive amounts of fuel (wood) which was supplied from the numerous woodyards that sprung up along the river during this period and resulted in thousands of acres of streambanks being cleared. This land clearing combined with agriculture along the natural levees accelerated bank erosion and sediment supply to the system (Winkley, 1977).

Six natural neck cutoffs occurred in the study reach between 1776 and 1884, shortening the river by approximately 78 miles (Table 2). Although specific years are listed in Table 2, it should be recognized that these cutoffs typically did not develop instantaneously, but rather, generally took many years to completely develop. Meanwhile, the river was obtaining additional length elsewhere through meander growth, such that, according to Winkley (1977), the overall river lengths for the entire Lower Mississippi River in 1765 (the first map of the Mississippi River) and 1884 were nearly the same.

<table>
<thead>
<tr>
<th>Natural Cutoff</th>
<th>1962 River AHP Mile</th>
<th>Year Cutoff Occurred</th>
<th>River Length Reduction by Cutoff (Miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrapin Neck</td>
<td>462</td>
<td>1866</td>
<td>16</td>
</tr>
<tr>
<td>Yazoo</td>
<td>442</td>
<td>1799</td>
<td>12</td>
</tr>
<tr>
<td>Centennial Lake</td>
<td>438</td>
<td>1876</td>
<td>6</td>
</tr>
<tr>
<td>Davis or Palmyra</td>
<td>422</td>
<td>1867</td>
<td>19</td>
</tr>
<tr>
<td>Waterproof</td>
<td>377</td>
<td>1887</td>
<td>12</td>
</tr>
<tr>
<td>Homochitto</td>
<td>322</td>
<td>1776</td>
<td>13</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>78</strong></td>
</tr>
</tbody>
</table>

The dramatic changes occurring during this time period indicate that the channel was in a period of morphologic adjustments to regain dynamic equilibrium. The magnitude of these changes is illustrated in Figure 1, which shows changes in the average top bank width for the reach of river between Vicksburg (RM 435 AHP) and the Red River (RM 312 AHP). Even with the uncertainty in the surveys during these older time periods, a good approximation of the order of magnitude of the width changes in the river was estimated. Comparison between the 1821 survey with the survey of 1880 showed that the average top bank width in this reach increased approximately 91%. Width increases of this magnitude would not be compatible with the natural meandering processes of a river in dynamic equilibrium but rather would be indicative of a river experiencing severe system instabilities. Identifying all the causes for this systematic instability is difficult, but the New Madrid earthquakes (Winkley, 1994; Winkley, 1977; Schumm et al., 1994), coupled with the clearing of the streambanks and adjacent riparian areas, appear to be the dominant factors during this period.

Flood protection began in the LMR Valley in the early 1700s, but it was localized and discontinuous. Prior to building levees, the LMR Valley was a delta that carried high as well as lower flows into various lowland basins. After the disastrous flood of 1874, a levee commission was created to evaluate and make recommendations for an integrated levee system (D. O. Elliot, 1932). However, it was not until the creation of the Mississippi River Commission (MRC) in 1879 that a more comprehensive approach was adopted.
**Early 1880s to 1927:** The MRC, established in 1879, was created to plan and execute projects to improve navigation along the LMR. Federal funds were assigned to MRC for the construction of levees as part of the navigation improvement program. Other approaches considered included reservoirs, outlets, and cutoffs. After considerable debate, the MRC settled on a “Levee Only Policy”. This approach was based on the assumption that the construction of levees would deepen the channel, thereby providing adequate navigation depths. The construction of levees started in 1882 to complete the gaps along the existing levee system. As the average levee height and crevasses became less pronounced, peak annual stages at Natchez, MS began to increase in the early 1900s up to the 1930s (Winkley, 1977).

In 1884, the MRC adopted the “no cutoff” program with the goal of preventing natural neck cutoffs from occurring. Natural neck cutoffs occur when the river flow breaches between the two bends of a meander creating a new channel alignment. This was accomplished by implementing bank stabilization in areas where a natural neck cutoff was considered likely. As a result of this program, the Waterproof cutoff (RM 377 AHP), which occurred naturally in 1884, was the last neck cutoff allowed until 1929. Since six natural neck cutoffs occurred in the 108 year period prior to 1884, it is reasonable to assume that more natural neck cutoffs would have occurred in the 45 year period between 1884 and 1929 without the intervention of the MRC program. Chute cutoffs were allowed during this period. According to Winkley (1977), chute cutoffs occur as a result of recurring large flows across the inside of point bars. The chute cutoffs shortened the river by approximately 45 miles from Cairo, IL to Vicksburg, MS. As a consequence, the river only increased in length in this reach by approximately 14 miles between 1884 and 1929 (Winkley, 1977).

Winkley (1977) suggested that the LMR prior to 1927 was losing channel capacity (due to aggradation) at all gages. Specific gage records, developed at Lake Providence and Vicksburg were examined to determine if aggradational trends were evident during this period at high flows. Unfortunately, historical data prior to the 1930s were not available at the St. Joseph and Natchez gages. As shown in Figure 2, the channel does appear to be slightly aggradational at high flows (1,500,000 cubic feet per second [cfs]) prior between 1900 and 1930.

Numerous floods occurred during this period, and although there were some issues, the overall levee system under the Levee-only approach seemed to perform satisfactorily. This all changed with the devastating flood of 1927. As a result of this major flood, the MRC recognized that a more comprehensive approach was going to be needed to provide adequate flood protection and navigation on the LMR.
Cutoff Period (early 1929 to 1942)

The advantages and disadvantages of artificial cutoffs on the Mississippi River had been debated without consensus by river engineers since the mid-1880s. However, following the 1927 flood, the MRC again revisited the idea of incorporating artificial cutoffs on the river as one component of the MR&T Project. In 1929, the first natural neck cutoff since 1884 was allowed to occur at the Yucatan Bend downstream of Vicksburg as part of a study to evaluate the response of the river to a neck cutoff. After monitoring the Yucatan cutoff for 2 years, the MRC initiated the cutoff program in 1931. Through this program, the USACE constructed 14 artificial cutoffs and allowed 2 natural cutoffs (Yucatan and Leland) to develop between 1929 and 1942 on the LMR (Table 3). These cutoffs shortened the river between Memphis, TN, and Old River, LA, by approximately 152 miles. Since 1942, no neck cutoffs have been constructed or allowed to develop. However, between 1932 and 1955, chute cutoffs were constructed at 40 locations between Cairo, IL, and Natchez MS, further shortening the river by another 55 miles. Following the artificial cutoffs, meander migration continued as the river attempted to regain some of its length. This continued until the 1960s when further meander migration was essentially terminated by the revetment program. However, according to Winkley (1977), these length increases were offset by the chute cutoffs so that the river is still approximately 150 miles shorter today than prior to the cutoffs.

The study reach (Lake Providence to ORCC) included 7 cutoffs: Willow, Marshall, Diamond, Yucatan, Rodney, Giles, and Glasscock. These cutoffs shortened the study reach by approximately 62 miles. However, during the cutoff period, the dominant response was channel degradation. Winkley (1977) presents specific gage records that show the stage reductions at Vicksburg were in the range of 10 to 12 ft, while farther downstream at Natchez, the stage reductions were slightly less (5 to 7 ft).
Table 3. Man-made neck cutoffs, 1929-1942 (adapted from Winkley [1977]).

<table>
<thead>
<tr>
<th>Cutoff Name</th>
<th>River Mile</th>
<th>Year Opened</th>
<th>Distance River Shortened (Miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardin</td>
<td>678</td>
<td>1942</td>
<td>16.9</td>
</tr>
<tr>
<td>Jackson</td>
<td>628</td>
<td>1941</td>
<td>8.7</td>
</tr>
<tr>
<td>Sunflower</td>
<td>625</td>
<td>1942</td>
<td>10.4</td>
</tr>
<tr>
<td>Caulk</td>
<td>575</td>
<td>1937</td>
<td>15.2</td>
</tr>
<tr>
<td>Ashbrook</td>
<td>549</td>
<td>1935</td>
<td>11.4</td>
</tr>
<tr>
<td>Tarpley</td>
<td>541</td>
<td>1935</td>
<td>8.6</td>
</tr>
<tr>
<td>Leland*</td>
<td>539</td>
<td>1933</td>
<td>9.8</td>
</tr>
<tr>
<td>Worthington</td>
<td>514</td>
<td>1933</td>
<td>4.3</td>
</tr>
<tr>
<td>Sarah</td>
<td>504</td>
<td>1936</td>
<td>5.3</td>
</tr>
<tr>
<td>Willow</td>
<td>463</td>
<td>1934</td>
<td>7.7</td>
</tr>
<tr>
<td>Marshall</td>
<td>448</td>
<td>1934</td>
<td>4.2</td>
</tr>
<tr>
<td>Diamond</td>
<td>424</td>
<td>1933</td>
<td>12</td>
</tr>
<tr>
<td>Yucatan*</td>
<td>408</td>
<td>1929</td>
<td>9.6</td>
</tr>
<tr>
<td>Rodney</td>
<td>388</td>
<td>1936</td>
<td>5.9</td>
</tr>
<tr>
<td>Giles</td>
<td>366</td>
<td>1933</td>
<td>11.1</td>
</tr>
<tr>
<td>Glasscock</td>
<td>343</td>
<td>1933</td>
<td>10.8</td>
</tr>
</tbody>
</table>

* Natural Cutoffs

Total = 151.9

Post-cutoff Period (1943 – present)

Channel Improvements (revetments, dikes, and dredging): The period from the mid-1940s through the mid-1960s was one of extensive adjustments on the LMR as the river responded to the cutoffs. As the river was adjusting to a higher channel slope and stream power after the cutoffs, bank erosion increased as the channel attempted to regain channel length. During this initial period following the cutoffs, the revetment program was initiated in an attempt to stabilize channel alignments. The revetments construction began in the 1940s, reaching a peak in the 1950s and 1960s. By the mid-1960s, most of the major meander bends had been stabilized, thereby fixing the alignments in place. After the mid-1960s, construction was mostly associated to extensions of existing revetments. Winkley (1973) presents accumulated annual average bank caving volumes for the Arkansas River to Old River LMR reach during three time periods: 1877 – 1892, 1931 – 1942, and 1965 – 1972 (Figure 3). These curves were developed by calculating the area associated with the bankline movement between surveys. An average bank height of 40 ft was assumed for the volumetric computations. Using these curves, an estimate of the average annual bank caving volumes in the reach from Lake Providence to the ORCC were reduced approximately from 350,000,000 cy/year in the pre-revetment period (average of the two time periods 1877 - 1892 and 1931 – 1942) to approximately 30,000,000 cy/year in the post-revetment period. This is a reduction in sediment delivery from the channel banks to the system of approximately 90%. However, because the size distribution of these sediments was not reported, the significance of these sediment reductions on the morphological changes in the river system is not clear.
The cutoffs also imposed a new alignment on the channel system that altered the historic crossing patterns in the river. These alignment changes combined with the increased sediment delivery from bed material upstream resulted in increased maintenance dredging throughout the system. After 1970, the amount of maintenance dredging began a long-term decreasing trend on the LMR as a result of two interrelated factors. The first was the revetment program, which imposed planform alignments with more orderly pool-crossing patterns. The next, and most important factor, was the construction of dikes. The purpose of these dike structures is to provide adequate navigation depths by constricting the channel width, closing off secondary channels and chutes to reduce divided flow, and adjusting channel alignment.

**Specific gage records:** Specific gage analysis is an effective tool used by river engineers and scientists to assess the historical behavior of rivers. Watson et al. (2013) provides a detailed description of the specific gage analysis. Fundamentally, a specific gage record is simply a plot of river stage versus time for a specific discharge. The specific gage records in this study were developed using the *rating curve method*. Stage data recorded at the Lake Providence gage (secondary station, RM 487.2 AHP, bankfull stage = 37 ft) were combined with discharges measured at Vicksburg (RM 435.7 AHP) using a 1-day lag time to generate the specific gage record from 1906 to 2014 (Figure 4). The channel degradation, which began in the early-1930s after the cutoffs, continued through the late-1940s to early-1950s. Since then, there have been some fluctuations in stage, but overall stages have remained relatively stable. The specific gage analysis for the Vicksburg gage (primary station, RM 435.7 AHP, bankfull stage = 43 ft) extends from 1903 to 2016. An abrupt decrease in stages for all flows occurred during the early-1930s, and this decreasing trend continued throughout the 1940s and early-1950s. Since then, stages for all flows greater than 200,000 cfs have fluctuated around what appears to be a generally increasing trend. In contrast, stages for a discharge of 200,000 cfs have been relatively stable since the 1950s. The specific gage analysis for the St. Joseph gage (secondary station, RM 396.4 AHP, bankfull stage = 40 ft) extends from 1935 to 1996. The specific gage record was developed by coupling daily stages observed at St. Joseph with discharges measured at Natchez using a 1-day time lag. As shown in Figure 4, a decreasing trend in stages began in the mid-1930s and persisted into the early-1940s. Between the mid-

![Figure 3](image-url)
1940s and the end of the period of record in the mid-1990s, stages for all but the lowest discharge exhibited an increasing trend. Stages for 200,000 cfs remained relatively stable. The specific gage analysis for the Natchez gage (primary station, RM 393.3 AHP, bankfull stage = 48 ft) extends from 1935 to 2016. The stages for all flows at this gage decreased abruptly in the late-1930s and continued to display a downward trend during the early-1940s. Since the mid-1940s, a general, increasing trend is evident in the stages associated with all selected flows.

The study reach is responding in an expected manner following a series of cutoffs. At the upstream end of the reach, represented by the Lake Providence gage, the stages have been relatively stable since the early-1950s. Moving farther downstream, the gages (Vicksburg, St. Joseph, and Natchez) become progressively more aggradational. This suggests that the reach from Lake Providence to Vicksburg may be a transition reach between dynamic equilibrium and the aggradational trends that exist farther downstream.

Water surface slope trends: Water surface slope provides a representation of the energy in a channel system. Slope is closely associated with the sediment transport capacity. Therefore any changes in channel slope can be used to infer morphologic changes in a channel system. Slope trends on the LMR are extremely important because of the substantial increases that occurred immediately after the cutoffs. Tracking these slope changes in the Pre- and Post-cutoff Periods provides valuable insight into the morphology of the study reach. Water surface slopes were calculated between the following sub-reaches: (1) Lake Providence to Vicksburg; (2) Vicksburg to St. Joseph; (3) St. Joseph to Natchez; and (4) Vicksburg to Natchez. Daily water surface slopes were calculated using daily stage data and the distance between the gaging stations. Average annual slope values were then calculated for each year.

Figure 5 shows the trends in average annual water surface slopes for the Lake Providence to Vicksburg, Vicksburg to St. Joseph, St. Joseph to Natchez, and Vicksburg to Natchez. The events
that caused the distance change between the gages (cutoffs, meander activity, gage location change, etc.) and their respective time periods were taken into consideration to estimate the water surface slope. Beginning in the mid-1930s and continuing through the mid-1940s, there was a dramatic increase in slope in the Lake Providence to Vicksburg reach (Figure 5). During this period, slopes increased from approximately 0.000054 to 0.000078, an increase of approximately 44%. From the mid-1940s through the mid-1970s to early-1980s, the slopes fluctuated but generally exhibited a decreasing trend. Since the early-1980s, the slopes have been relative stable, with an average slope of approximately 0.000063. The present-day slopes (early-1980s to present) are approximately 16% higher than the pre-cutoff slopes.

![Figure 5. Average annual surface slopes for: 1) Lake Providence to Vicksburg, 2) Vicksburg to St. Joseph, 3) St. Joseph to Natchez, and 4) Vicksburg to Natchez.](image)

The changes in the average annual water surface slopes for the Vicksburg to St. Joseph reach are also shown in Figure 5. Note that there are no data after 1996 due to the discontinuance of the St. Joseph gage. Water surface slopes increased dramatically between the mid-1930s and the mid-1940s. The channel slopes were approximately 24% higher immediately after the cutoffs (mid-1930s to mid-1940s) compared to the Pre-cutoff slopes. After the mid-1940s, the slopes began a decreasing trend, which generally continued until the early 1960s. From the early-1960s to 1995, channel slope exhibited alternating periods of increasing and decreasing trends but remained within an approximate range between 0.00006 and 0.000067 with an average slope of approximately 0.000063. Comparison of the Pre-cutoff and Post-cutoff (mid-1980s to 1995) data shows that the Post-cutoff slopes are still approximately 17% higher than the Pre-cutoff slopes. Following the cutoffs in the mid-1930s, the slope from St. Joseph to Natchez increased abruptly reaching a peak in approximately 1936. After this, the slopes decreased until approximately 1940 when the slope began to increase again. The slopes remained elevated until the mid-1950s when they decreased again. These initial slope increases, which persisted through the mid-1950s, were approximately 45% higher than the Pre-cutoff slopes. Since the mid-1960s up to 1996, the slopes have remained relatively stable with an average slope of approximately 0.000053, which is approximately 29% higher than the Pre-cutoff slopes.
Figure 5 also shows the slope trends for the Vicksburg to Natchez reach. The advantage of considering the Vicksburg to Natchez reach is that it has a much longer period of record than the St. Joseph gage. However, it must be recognized that the slope calculations cover a much longer reach and therefore represent a somewhat more broad-scale view of the system. The Pre-cutoff slopes in this reach averaged approximately 0.000049. In the mid-1930s, the slopes increased and remained elevated through the late-1940s with an average slope of approximately 0.000064. This was an increase of approximately 31% relative to the Pre-cutoff slopes. Between the late-1940s and late-1960s, there was a decreasing trend in the slopes. From the late-1950s through the late-1980s, the slopes exhibited some fluctuations but were overall relatively stable. Since the late-1980s, the slopes appear to have been on a slightly decreasing trend with an average slope of approximately 0.000056. The present day slopes (late-1980s to present) are approximately 16% higher than the slopes in the Pre-cutoff Period.

In summary, initial increases in water surface slopes after the cutoffs ranged from approximately 24% to 45%. These increases in slope also increased sediment transport capacity, resulting in channel degradation throughout the reach. Although the slopes have decreased from their initial peak conditions immediately after the cutoffs, the present-day slopes in the study reach are still higher (generally approximately 17%) than in the Pre-cutoff Period.

**Bed material characteristics:** Gaines and Priestas (2016) compared bed material gradations collected in 2013 to bed material gradations for 1932 (WES 1935) and 1989 (Nordin and Queen 1992). The findings documented in the report are based on 754 bed material samples collected in November 2013 at 496 locations spaced at intervals of 2 to 3 miles along the Mississippi River between Grafton, IL, and Head of Passes, LA. Data collection procedures in 2013 were matched as closely as possible to the procedures used for the collection of bed material samples in 1932 and 1989. Figure 6 shows the downstream trends in median (D$_{50}$) grain sizes measured in November 2013 in the LMR between Cairo, IL, and Head of Passes, LA. River miles between Lake Providence and Old River are within the red box. According to the regression line in Figure 6, the D$_{50}$ at Vicksburg and Natchez is approximately 0.36 and 0.3 mm, respectively. Additionally, Gaines and Priestas (2016) compared bed material grain size distributions in the LMR in 1932, 1989, and 2013. Based on this comparison, the study reach had a higher amount of very coarse sand and gravel (2 mm or larger) in 1932 when the bed material grain size distributions are compared with the 1989 and 2013 gradations. It is also noticed that very fine sand (0.0625 mm – 0.125 mm), coarse silt (0.004 mm – 0.062 mm), and clay (< 0.004 mm) have decreased over time. In fact, in 1989 and 2013, there was essentially no bed material finer than very fine sands in the bed, with the exception of a very small amount near the downstream end of the reach in 1989. However, the amount of medium sand within the study reach has increased relative to the 1932 sampling.

Robbins (1977) published a study of the suspended sediment and bed material trends within the Vicksburg District reach to identify possible trends in the datasets that might have relevance for navigation and flood control. Using the Robbins (1977) data, Thorne et al. (2017) conducted a detailed analysis of the spatial and temporal bed material trends. The data presented herein are summarized from these two reports. As part of the USACE Vicksburg District’s Potamology Program, the Vicksburg District reach was divided into 25 potamology reaches. Between 1966 and 1974, the district conducted extensive data collection and analyses in these reaches. Typically, data that were collected (sometimes several times per year) included hydrographic surveys, suspended sediment samples, bed material samples, slope measurements, and discharge measurements. Fourteen of the 25 reaches were included within the study reach
between Lake Providence and Old River. In each reach, bed sediment samples were collected at specific sediment study ranges. At each range, between 4 and 12 bed material samples were collected, depending on the width of the cross section. The extensive sampling conducted in the potamology reaches over the 9 year period provides valuable insight into the variability of the bed material composition.

Figure 6. Downstream trends in D50 in November 2013 – Study reach outlined in red (Gaines and Prietas, 2016).

Figure 7. Selected bed material gradation curve in the research study.

Figure 7 shows the variability between years in the bed material gradations for four selected reaches. Examination of these plots clearly shows that there is considerable temporal variability in the bed material gradation. However, no downstream, decreasing trends in the data were observed. The Robbins (1977) data indicate that the dominant bed size is sand with an average D50 of approximately 0.31 mm.
**Channel geometry trends:** Little et al. (2017) conducted a detailed geometric data analysis for the Mississippi River from ORCC to St. Louis, MO, or approximately RM 325 AHP to RM 180 Above Mouth of the Ohio River. This study documented the long-term trends in the dimension, pattern, and profile of the LMR and Middle Mississippi River. Hydrographic survey data from 1975 to 2013 were used to determine spatial and temporal variations in channel geometry and volume. Trends of geometric change (area, depth, width, conveyance, and channel volume) were identified along defined geomorphic reaches of the river. The following is a brief summarization of the results specifically for the Lake Providence to Old River reach.

Little et al. (2017) reported a decreasing trend for the period 1975 to 2013 in channel area, hydraulic depth, conveyance, and channel volume for the portion of the study reach from approximate RM 325 AHP to RM 435 AHP in the vicinity of Vicksburg. In this study, they examined the pools and crossings individually and found the patterns of decreasing trends to be similar for both. They attributed these decreases to the general depositional trends in this portion of the river. The absence of significant cross-sectional and volumetric changes in the reach from approximately Vicksburg (RM 435 AHP) to Lake Providence (RM 487 AHP) led Little et al. (2017) to classify this reach as a transition zone from the depositional trends downstream to more stable conditions (dynamic equilibrium). The cumulative volume change plots developed by Little et al. (2017) help visualize the observed trends discussed above. These plots allow the spatial extent of the average volumetric change rates over time to be readily determined. The cumulative volume change plots referenced to the Low Water Reference Plane (LWRP) for the entire Vicksburg District reach are shown in Figure 8. The study reach is highlighted in the red box. A negative slope of the cumulative volume change curve indicates deposition (negative cumulative volume change) while a positive slope indicates erosion (increasing cumulative volume). If the cumulative volume change curve is neither increasing nor decreasing over some time period, then this is an indication of dynamic equilibrium. As shown in Figure 8, the reach from approximately RM 325 AHP to approximately RM 425 AHP near Vicksburg exhibited a consistent rate of channel volume decrease (negative slope) for the 1975 to 2013 time period, indicating that this was a depositional zone during this period. From Vicksburg (RM 435 AHP) up to Lake Providence (RM 487 AHP), the cumulative channel volume change fluctuated but remained fairly constant in magnitude, indicating that there was no significant net erosion or deposition during this time period.

In summary, the analysis of the channel geometry parameters indicate that the river channel in the lower portion of the study reach (RM 325 AHP to near Vicksburg RM 435 AHP) was in a depositional or aggradational state for the 1975 to 2013 time period. The reach upstream of Vicksburg to Lake Providence appears to be a transition reach of little to no change in the channel geometry. This suggests that this reach may be approaching dynamic equilibrium.
Figure 8. Cumulative volume change curves for the Vicksburg District. Study area outlined in red.

Summary

Pre-cutoff Period: The LMR between the early-1800s to the late-1870s was undergoing substantial morphological changes as a result of both natural and anthropogenic factors during this initial period of expansion. The instabilities in the river aggravated early navigation problems making navigation in the LMR a challenge. In an effort to improve the existing levee system and the assumption that a more robust levee system would deepen the channel to improve navigation, the MRC settled on a Levees-Only policy. Later in 1884, the MRC adopted a no-cutoff program to prevent natural neck cutoff from occurring. As a result, Waterproof cutoff was the last neck cutoff allowed until 1929 when the MRC decided to allow the Yucatan cutoff just south of Vicksburg to develop. The river in the post-1880s was still a dynamic river; although compared to the pre-1880s period, the rates of change had slowed considerably. Although data are sparse in this period, it does appear, based on specific gage records and historical references (Winkley 1977), that the river in the study reach was slightly aggradational during this period. As a result of the 1927 flood, the MRC decided to revise the levees-only approach. With the FCA of 1928, the MR&T was initiated. The MR&T produced a massive, comprehensive system for flood protection and channel stabilization that includes levees, channel modifications, and floodways as well as tributary reservoirs and other basin improvements.

Cutoff Period: The advantages and disadvantages of artificial cutoffs on the Mississippi River had been debated without consensus by river engineers since the mid-1880s. In 1929, the first neck cutoff since 1884 was allowed to occur at the Yucatan Bend downstream of Vicksburg as part of a study to evaluate the response of the river to a neck cutoff. After monitoring the Yucatan cutoff for 2 years, the MRC initiated the cutoff program in 1931. Through this program, the USACE constructed 14 artificial cutoffs and allowed 2 natural cutoffs (Yucatan and Leland) to develop between 1929 and 1942 on the LMR. Seven cutoffs were constructed in the study...
reach between Lake Providence and just south of Natchez. These cutoffs shortened the reach by approximately 62 miles. During the cutoff period between 1929 and 1942, the dominant response in the study reach was channel degradation and slope increase. The stage reductions due to degradation after the cutoffs were in the range of 10 to 12 ft at Lake Providence and Vicksburg. Farther downstream at St. Joseph and Natchez, the stage reductions were slightly less, in the 5 to 7 ft range. Substantial slope increases in the study reach occurred after the cutoffs. Initial increases in water surface slopes ranged from approximately 25% to 45%. These increases in slope increased sediment transport capacity significantly, resulting in channel degradation throughout the reach.

**Post-cutoff Period:** The period from the mid-1940s through the mid-1960s was one of extensive adjustments on the LMR as the river responded to the cutoffs. As the river was adjusting to a higher channel slope and stream power after the cutoffs, bank erosion increased as the channel attempted to regain channel length. It was during this initial period following the cutoffs that an aggressive revetment program was initiated in an attempt to stabilize channel alignments. By the mid-1960s, most of the major meander bends had been stabilized, thereby fixing the alignments in place. The revetment program not only provided for an improved and stable channel alignment but also significantly reduced the sediment loading to the river from streambank erosion (Winkley, 1973). Further studies are needed to determine what percentage of this material would be considered wash load or bed material load in the river system.

The cutoffs imposed a new alignment on the channel system that altered the historic crossing patterns in the river. These alignment changes combined with the increased bed sediment delivery from upstream resulted in increased maintenance dredging throughout the system, which peaked in the late-1970s. After 1970, the amount of maintenance dredging began a long-term decreasing trend as a result of two factors: (1) the revetment program imposed much better planform alignments with more orderly pool-crossing patterns and (2) the construction of training structures (dikes).

At the upstream end of the reach, represented by the Lake Providence gage, the specific gage trends have been relatively stable since the early 1950s. Moving farther downstream, the gages (Vicksburg, St. Joseph, and Natchez) become progressively more aggradational. This suggests that the reach from Lake Providence to Vicksburg may be a transition reach between dynamic equilibrium and the aggradation trends that exists farther downstream. The analysis of channel geometry parameters between 1975 and 2013 support these same trends. As previously noted, initial channel slopes increased substantially after the cutoffs (25% to 45%). Although these slopes have decreased from their peak conditions in the 1940s, the present-day slopes in the study reach are still higher (generally, approximately 17%) than in the Pre-cutoff Period.

Analysis of bed material data indicates that the bed throughout the study reach is predominantly formed of sand, with the $D_{50}$ being squarely in the medium sand range. Long-term (decadal) scale analysis by Gaines and Priestas (2016) showed a significant reduction in the amount of gravel in the 1989 and 2013 surveys relative to the 1932 sampling. The Gaines and Priestas (2016) analysis also showed that while the 1932 bed did contain sediments in the very fine sand, silts, and clay ranges, these fine sediments were not found in any appreciable amounts in the 1989 and 2013 data. It is difficult to assign definitive causal links between the observed bed material changes and natural and anthropogenic factors. The slopes today are almost 20% higher than they were in 1932. With slope increases of this magnitude, it is very conceivable that the finer sediments (very fine sand and finer) are being transported through the reach acting as wash load and are therefore not being found in the bed in appreciable quantities.
References


