Mississippi Valley Division

Engineer Research and Development Center

US Army Corps of Engineers®

Effects of Geologic Outcrops on Long-Term Geomorphic Trends

New Madrid, MO, to Hickman, KY

MRG&P Report No. 38 • June 2021

MRG&P
Mississippi River
Geomorphology &
Potamology Program

Mississippi River Geomorphology and Potamology Program

MRG&P Report No. 38
June 2021

Effects of Geologic Outcrops on Long-Term Geomorphic Trends

New Madrid, MO, to Hickman, KY

Travis A. Dahl, Justin S. Giles, Kathleen A. Staebell, and David S. Biedenharn

Coastal and Hydraulics Laboratory
US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Joseph B. Dunbar

Geotechnical and Structures Laboratory
US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for Mississippi River Geomorphology & Potamology Program (MRG&P)
US Army Corps of Engineers, Mississippi Valley Division
Vicksburg, MS 39181-0080

Under Project No. 470711

Abstract

The Mississippi River between New Madrid, MO, and Hickman, KY, is of particular interest because of divergent trends in water surface profiles at the upstream and downstream ends of the reach. This report documents the investigation of the bathymetry, geology, and hydraulics of this segment of the river. The report shows that the area near River Mile 901 above Head of Passes strongly affects the river stages at low flows. This part of the river can experience high shear stresses when flows fall below 200,000 cfs, as opposed to most other locations where shear stress increases with flow. One-dimensional hydraulic modeling was also used to demonstrate that an increase of depth at a single scour hole, such as the one downstream from Hickman near River Mile 925, is unlikely to cause reach-wide degradation.

Contents

Figures and Tables

Figures

Tables

Preface

The research documented in this report was conducted for the Mississippi River Geomorphology & Potamology (MRG&P) Program, U.S. Army Corps of Engineers, Mississippi Valley Division, under Project No. 470711. The MRG&P program is part of the Mississippi River and Tributaries Project and is managed by the US Army Corps of Engineers, MVD, and districts. At the time of publication of this report, the MRG&P Program Director was Dr. James W. Lewis. The MVD Commander was MG Diana Holland, and the MVD Director of Programs was Mr. Edward E. Belk.

At the time of publication of this report, Dr. Cary A. Talbot was Chief, Flood and Storm Protection Division, and Mr. David P. May was Chief, River and Estuarine Engineering Branch. The Director of CHL was Dr. Ty V. Wamsley, and the Deputy Director was Mr. Keith Flowers.

COL Teresa A. Schlosser was Commander of ERDC, and the Director was Dr. David W. Pittman.

1 Introduction

Background

The area around Hickman, KY, was singled out for analysis because of the presence of a deep hole near River Mile (RM) 921. The bed material in this area is also very resistant to erosion, based on both anecdotal reports and recent attempts at collecting bed samples[1]. These two factors have led to the area being referred to as the “Hickman hard point.” At the outset of this study, the prevailing belief was that this area acts as a geomorphic control, preventing upstream migration of the degradation experienced further downstream.

A detailed background of historical investigations on the Lower Mississippi River can be found in Biedenharn et al. (2014). This includes a history of the cutoff program that shortened the Mississippi River between Memphis, TN, and Red River Landing, LA, by nearly 30%, significantly increased the river slope, and led to upstream migration of a degradational zone on the river.

A comprehensive specific gage analysis of the Lower Mississippi River by Biedenharn et al. (2017) looked at three gages in or near the report study area: Caruthersville (RM 844.4), Tiptonville (RM 872.4), and Hickman (RM 922). Stages at all three of these gages were relatively constant for overbank flows (~1,300,000 ft^3/s)[2] between 1950 and 2013. Since the 1990s, lower flows (650,000 ft^3/s, 350,000 ft^3/s, and 175,000 ft^3/s) have been associated with decreasing stages at Caruthersville and Tiptonville. Since the late-1990s, the stages corresponding to these lower flows appear to also have started to decline at Hickman.

This area of the river has also been influenced by recent tectonic activity, including earthquakes. Schweig and Van Arsdale (1996) cover the neotectonics of the Mississippi Embayment and conclude that the Reelfoot Scarp in this region caused the New Madrid earthquakes of 1811–1812.

---

[1] S. J. Smith, ERDC-CHL, personal communication, January 16, 2018.

[2] For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

This was not the first occurrence of ground shaking in the New Madrid Seismic Zone. The 2000 years leading up to the events of 1811 had at least three significant earthquakes, and following 1812, there was an event large enough to cause damage in Charleston, MO, in 1895.

Knickpoint or headcut migration, where a distinct point of erosion moves upstream, is a common mechanism in rivers and streams. These can range in size from small drops of less than a foot to Niagara Falls. There are currently no dramatic drops of this type on the Lower Mississippi River, but one theory is that the hole near Hickman, KY, may be a fully submerged knickpoint. There are many papers that discuss knickpoint migration and headcutting (e.g., Bressan et al. 2014; May 1989), but they mostly assume a free-overfall condition. Bressan et al. (2014) discuss submerged jets as an erosional mechanism when the downstream water level rises.

Separate studies funded by the Mississippi River Geomorphology & Potamology program are currently (as of December 2017) investigating the presence of a deep hole at Hickman, KY, and coincident erosion-resistant outcrop. These studies are looking at the surficial and subsurface geology, as well as the erodibility of the riverbed at this location. Biedenharn et al. (2018) note that there have been multiple groundings at this location, and removal of the outcrop has been suggested as a potential remedial measure.

Objective

Previous studies have produced a wealth of knowledge about the general geologic setting in the Mississippi River basin, and this knowledge has been applied to a number of engineering studies. However, detailed studies of the exact role of the geologic features, particularly with respect to retarding or halting long-term degradation processes along the river, have not received much attention. One feature that could have a significant impact on the migration rate and ultimate amount of incision resulting from the degradation is the presence of natural geologic outcrops along the channel. Developing an understanding of how geologic controls may affect the long-term morphology and environmental sustainability of the Mississippi River (particularly the degradational potential) is critical to the effective management of the system. The effects of geologic outcrops in small streams have been studied for years, and their functionality as potential grade control has been well documented. However, the effects of outcrops in large rivers such as the Mississippi River, where the outcrops may be significantly submerged, have received little attention. This study primarily focused on how these features may impact future channel morphology, particularly with respect to long-term degradation and the selected study site.

Approach

This study explored the potential impacts of geologic outcrops by analyzing the existing bathymetric data (Section 2); looking at the geology of the study area, including the bed material of the river (Section 3); and using a one-dimensional (1D) hydraulic model to look for points that exhibit strong controls on the hydraulic behavior of the river and the impact of submerged knickpoints (Section 4). The conclusions of the study are summarized in Section 5.

Study location

This study focused on a stretch of the Mississippi River encompassing New Madrid, MO, and Hickman, KY. The New Madrid gage is located at 1962 RM 889 above Head of Passes (RM 889) while the gage at Hickman, KY, is at RM 922. Figure 1 shows the location of the study area relative to the surrounding states and the confluence of the Ohio and Mississippi Rivers. Figure 2 shows the specific area of interest, including the location of river engineering structures such as dikes and revetments.

Figure 1. Location map for the study area, indicated by the green cross sections.

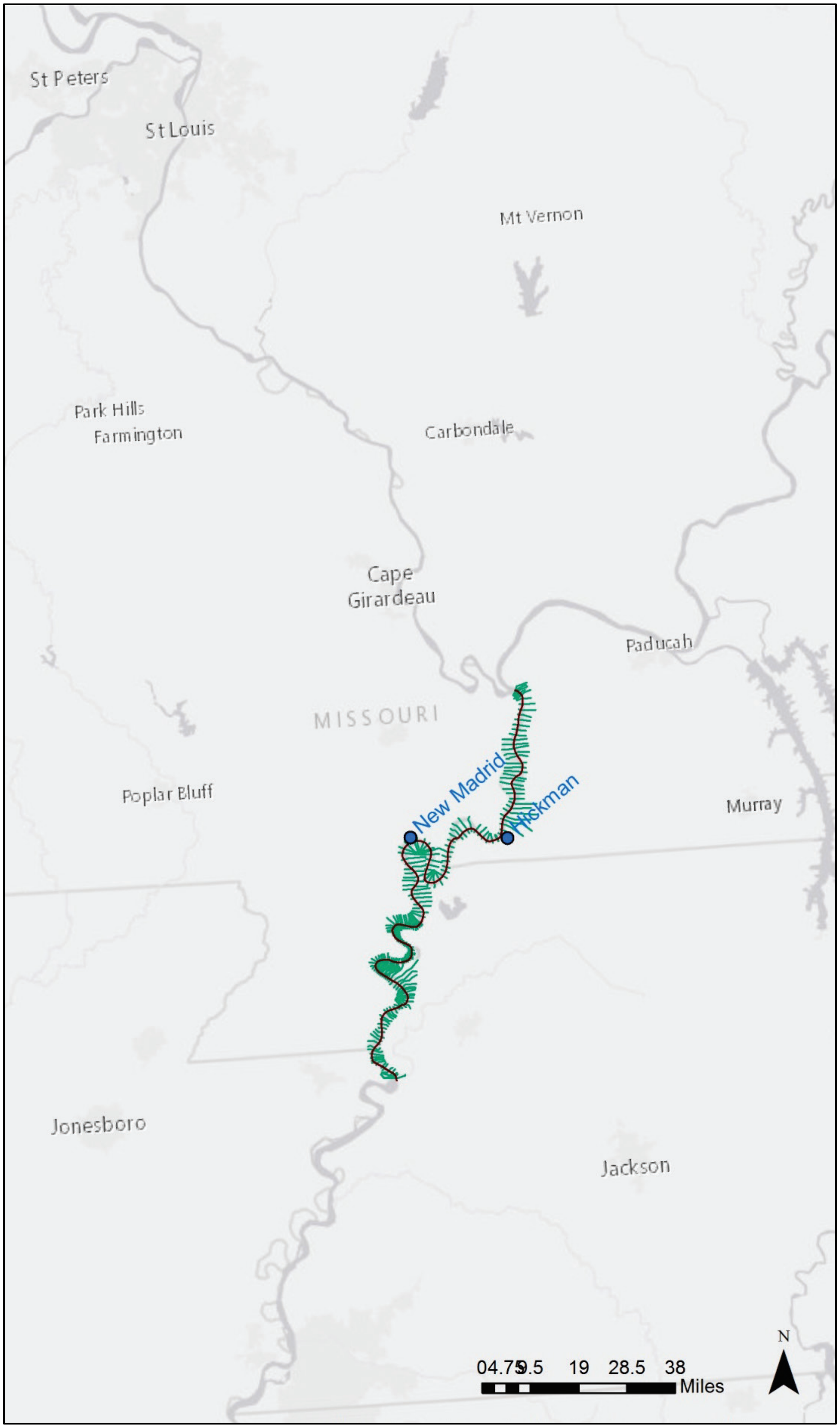
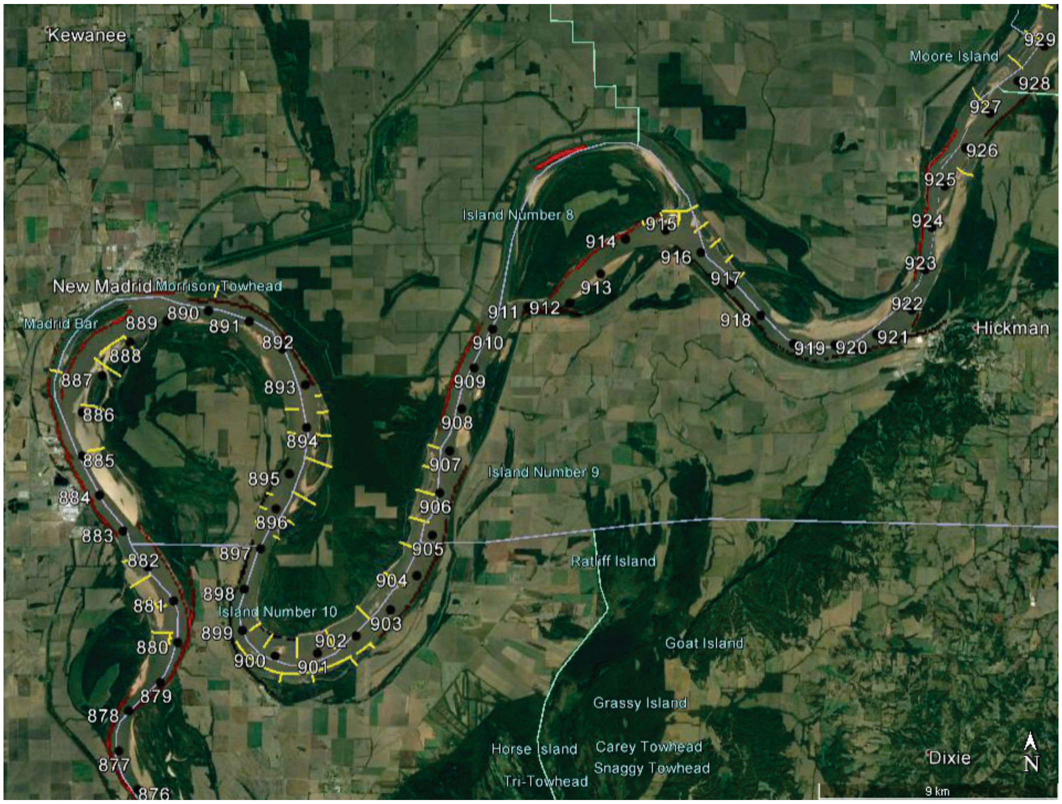


Figure 2. Detailed image of the study area. The numbers corresponding to the black dots indicate the 1962 River Miles Above Head of Passes. The yellow lines are dike fields, and the red lines indicate placement of articulated concrete mat (ACM) for bank and toe protection.



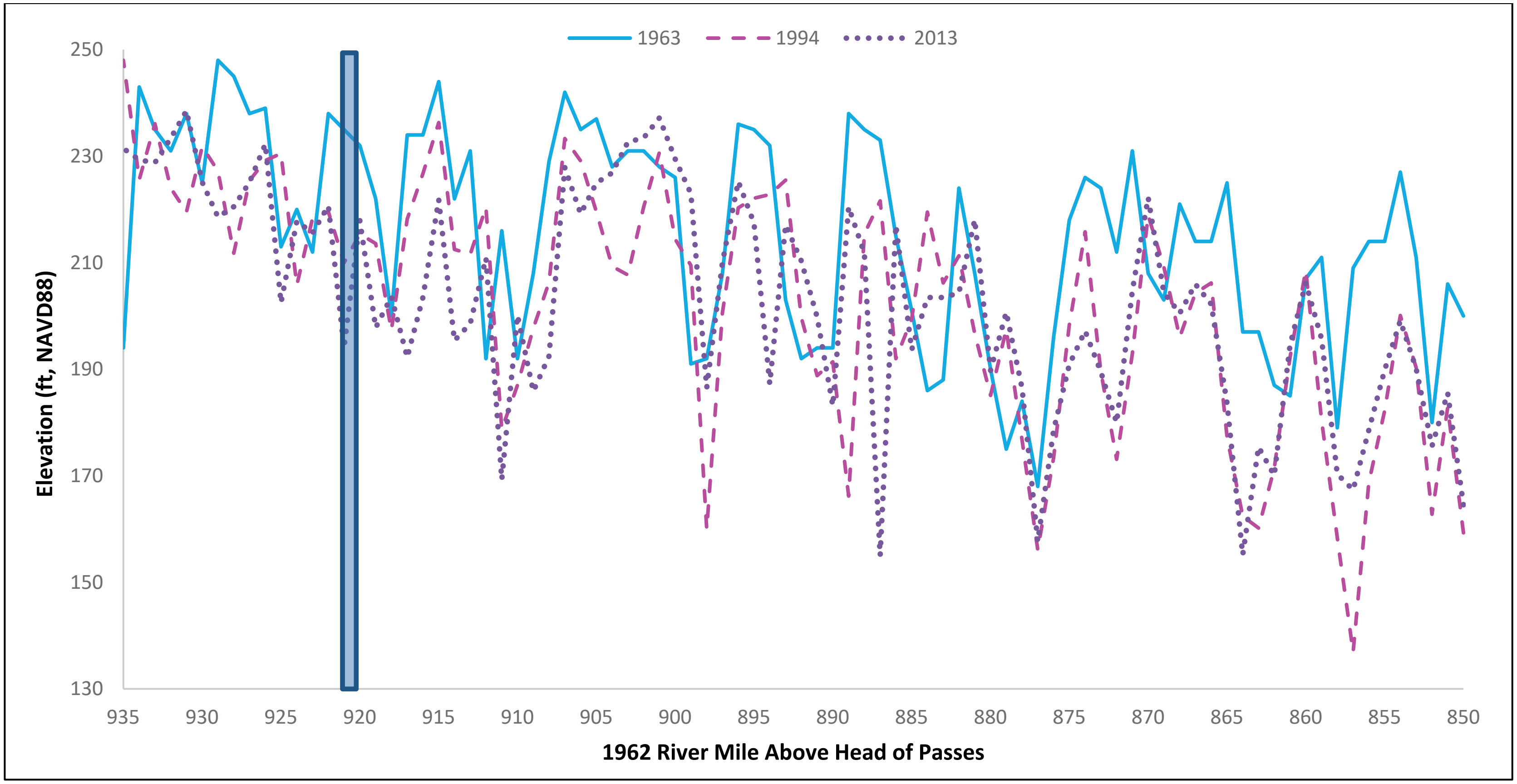
2 Analysis of Bathymetric Data

Bathymetric surfaces developed from Mississippi River hydrographic surveys collected by the Memphis District of the US Army Corps of Engineers (USACE) were utilized for this study. The approximate years of the surveys used were 1963, 1994, and 2013. Triangulated irregular network (TIN) surfaces were developed in a Geographic Information System (GIS). Thalweg elevations were then extracted from the TINs at 1-mile intervals between RM 850 and RM 935 (Figure 3; Appendix). Note that changes in individual thalweg elevations as presented here should not be used as the sole evidence for channel change since they represent only the deepest point at each cross section. They may not be representative of the cross section as a whole.

Examination of the thalweg elevations shown in Figure 3 reveals that there are several high points in the riverbed downstream of the erosion resistant outcrop at Hickman, KY. These high points (indicating shallow cross sections in the river) are typically where the thalweg crosses from one side of the river to the other and likely control the hydraulics of the river. These areas are referred to as “crossings” and tend to move downstream over time as part of the natural geomorphic evolution of rivers. The movement of crossings is more limited in the Mississippi River because of river engineering efforts. The effect of these control points was investigated using a 1D hydraulic model (Section 4).

The crossing thalweg elevations from 1994 and 2013 are generally lower than those from the 1963 data, with the exception of the peak near RM 901. This is consistent with the analysis of Little et al. (2017) that found increased cross-sectional areas (below the Low Water Reference Plane) between 1970 and 2013 for this same vicinity. Their results indicated that there were no consistent trends in channel width change for RM 850–940 and no trends in hydraulic depth change for RM 850–895. They did find increases in hydraulic depth from approximately RM 895 to RM 950 over this period.

Figure 3. Thalweg elevations near New Madrid, MO, and Hickman, KY. The shaded box indicates the approximate location of the erosion-restant outcrop near Hickman, KY.



3 Geology

Geologic setting

The geology near New Madrid, MO, and Hickman, KY, is predominantly Holocene alluvium (11,500–12,000 yr ago). The alluvium is comprised of clay, silt, sand, and gravel sourced from the Mississippi River and tributaries. Surrounding the area and below the alluvium lies the Mississippi Embayment. The Mississippi Embayment is a syncline plunging in the southwesterly direction, made up of Cretaceous and Tertiary fluvial and marine sediments. Tertiary-age sediments that are found in this area contain materials from the Jackson Group and Wilcox Formation that are part of the Mississippi Embayment. The Jackson Group near the focus area contains Yazoo clay which contains calcareous clays largely bedded, ranging in color from yellow to green. The Wilcox Formation is made up of shale and sandstone. Biedenharn et al. (2018) provide a more detailed overview of the geology of the Lower Mississippi River Valley.

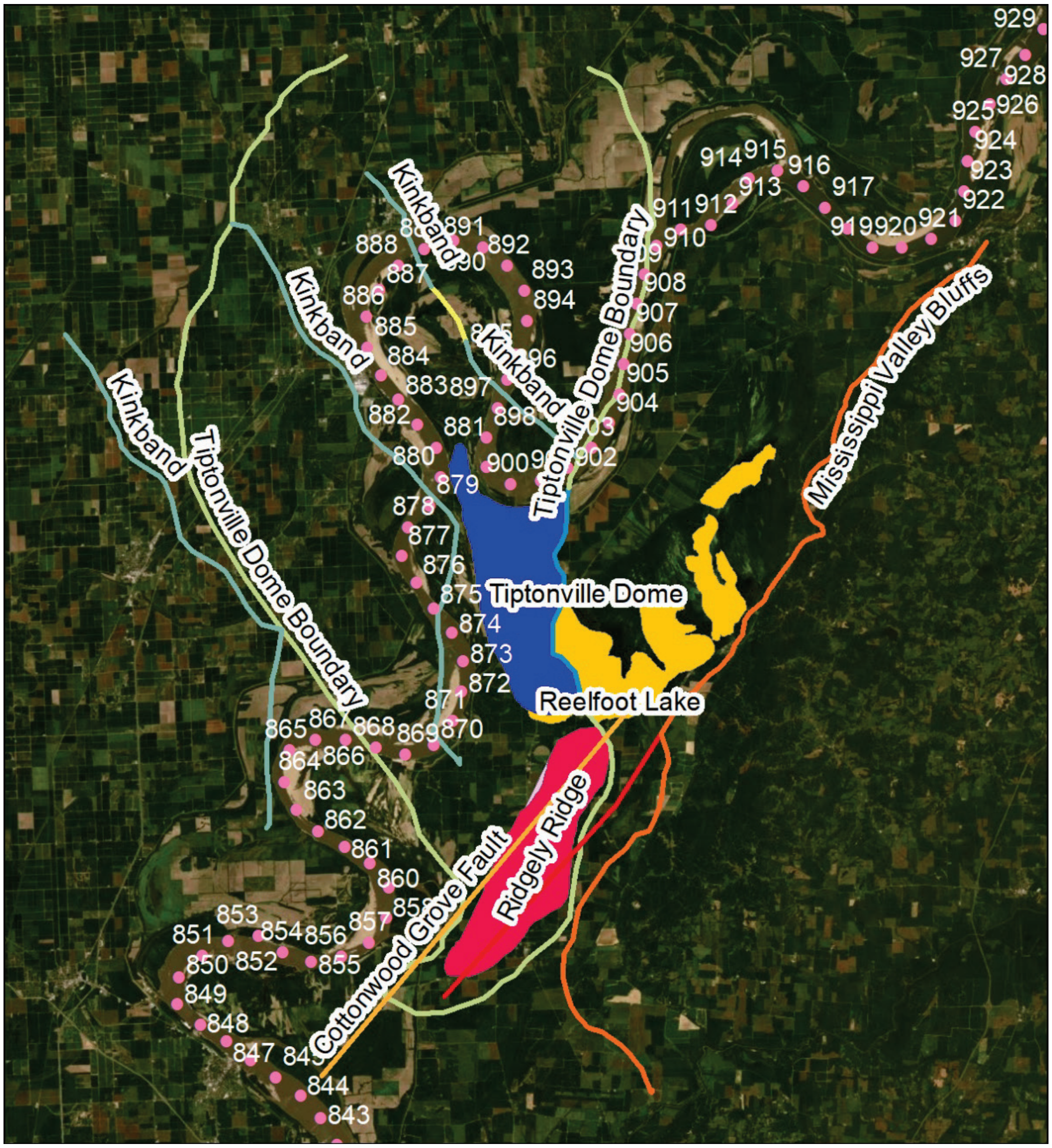
In the study area, most of the Claiborne Formation that stratigraphically lies between the Wilcox Formation (below) and Jackson Group (above) has been eroded by the Mississippi River. The Holocene alluvium contains multiple abandoned channels or clay plugs from former paths of the Mississippi River. These clay plugs have proven to be quite non-erosive and may be part of the resistant sediments in this reach (Fisk 1947).

New Madrid, MO, is also home to the historical New Madrid Seismic Zone. In the winter of 1811–1812, New Madrid experienced some of the largest earthquakes ever felt in the continental United States (Johnston and Schweig 1996). These earthquakes were said to have sent the Mississippi River flowing backwards and caused significant damage to the surrounding area. New Madrid is located at the epicenter of the seismic zone, experiencing the greatest magnitude of the events. There are a number of geologic features associated with the New Madrid Seismic Zone, including the Reelfoot Rift and Lake County Uplift (Figure 4).

The Reelfoot Rift is a reverse fault that dips to the southwest, and it lies below the Mississippi Embayment. It is said to be responsible for observed seismic activity in the area during the modern era. Clastic sediments of the

Precambrian and carbonates from the Paleozoic fill the rift. Through micro-seismicity, the angle of the Reelfoot Rift and the Reelfoot scarp were determined by Purser and Van Arsdale (1998), and it appears that the scarp face is much steeper than the fault plane of the rift. They determined that, with the fault displacement increasing with depth, this serves as an indicator of reactivation within the area. The Reelfoot scarp is a monoclonal feature that is the upper portion and surface expression of the Reelfoot Rift. It also divides the Reelfoot Lake Basin and the Lake County Uplift region, as seen in Figure 4. The Lake County Uplift occurred due to deformation of the hanging wall of the Reelfoot Rift and is comprised of the Tiptonville Dome, Ridgeley Ridge, and Sikeston Ridge. With this knowledge, further studies found that there are still minor amounts of uplift occurring as the fault moves along its fault plane. Reverse faults experience compression and can be identified when the hanging wall is thrust upward in relation to the footwall. The footwall of the reverse fault is the Reelfoot Lake Basin, and the Lake County Uplift is the hanging wall.

Figure 4. Map of New Madrid Seismic Zone features, including the Lake County Uplift (after Purser and Van Arsdale 1998).

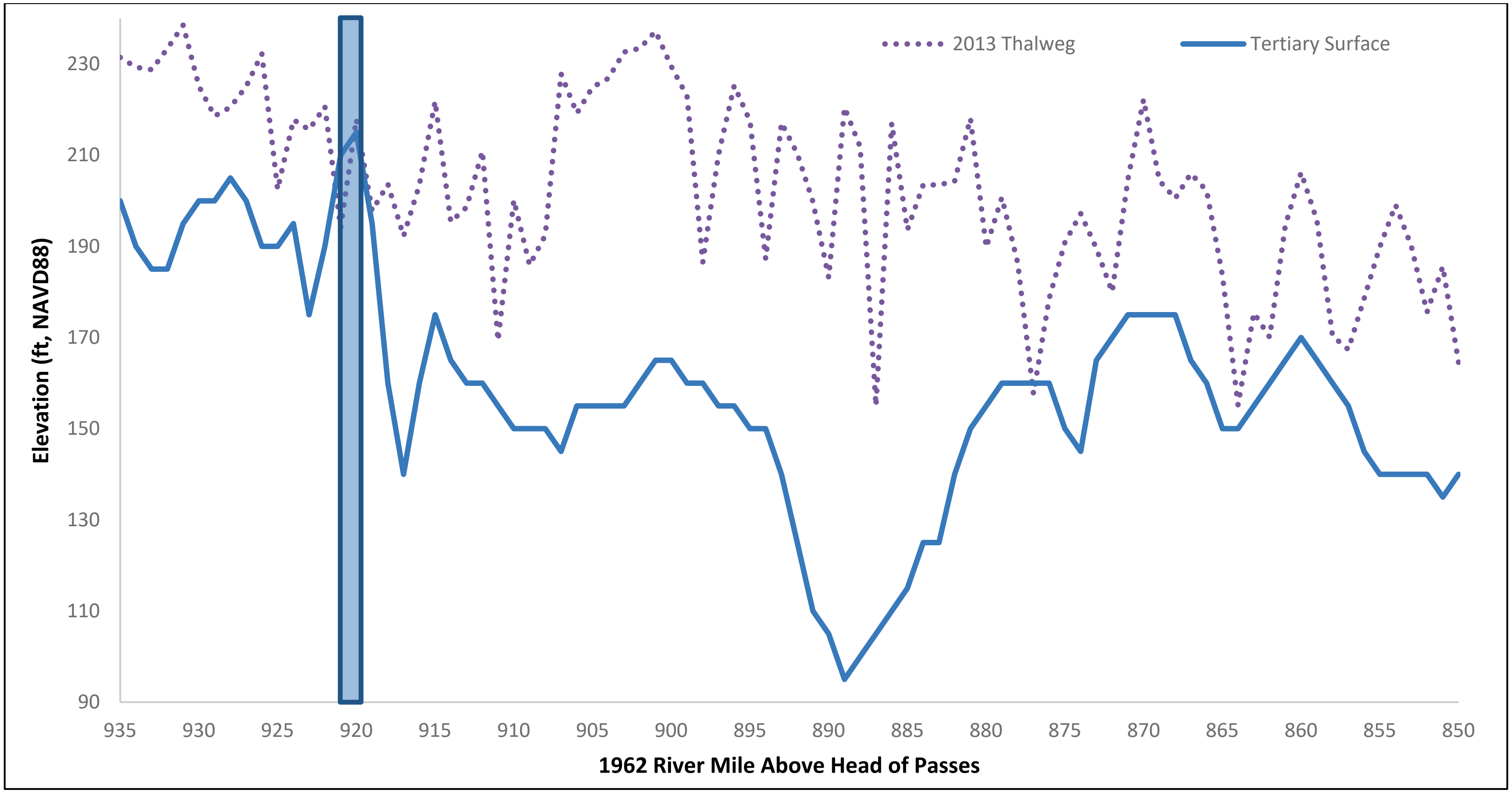


Tertiary surface

Tertiary sediments are any sediments that were deposited during the Paleocene through the Pliocene (66–2.58 Ma). To determine the depth of the Tertiary surface in the region, boring data from the Lower Mississippi Valley (LMV) were obtained from Saucier (1994). These data were originally compiled by geologists in the Geology Branch at the Waterways Experiment Station as part of a 50 yr long geological mapping program of the alluvial valley at the 15 min (0.25°) scale in the LMV for the Mississippi River Commission (MRC) (see http://lmvmapping.erdc.usace.army.mil/ for geological maps and reports of investigations). Boring data used in the legacy 15 min geological mapping program were obtained from a variety of sources, including the USACE, private engineering companies, and other federal and state agencies with highway, bridge, and water-well borings to produce geological cross sections for each mapped quadrangle and to compile elevation contour maps for the top of the Tertiary surface. Geological data were used to support engineering activities by the MRC in the LMV.

Saucier (1994) compiled a top of Tertiary boring database as part of the 50 yr anniversary and updated revision of the Fisk (1944) publication of the Geological Investigation of the Alluvial Valley. This surface corresponds to the base of the alluvium, where resistant Tertiary deposits are present. From these boring data, a contour map of the top of Tertiary layer was created for the study area in GIS. With this contour map, the elevation of the Tertiary at each river mile was compiled and plotted against the 2013 thalweg elevation of the Mississippi River, as seen in Figure 5 and the Appendix.

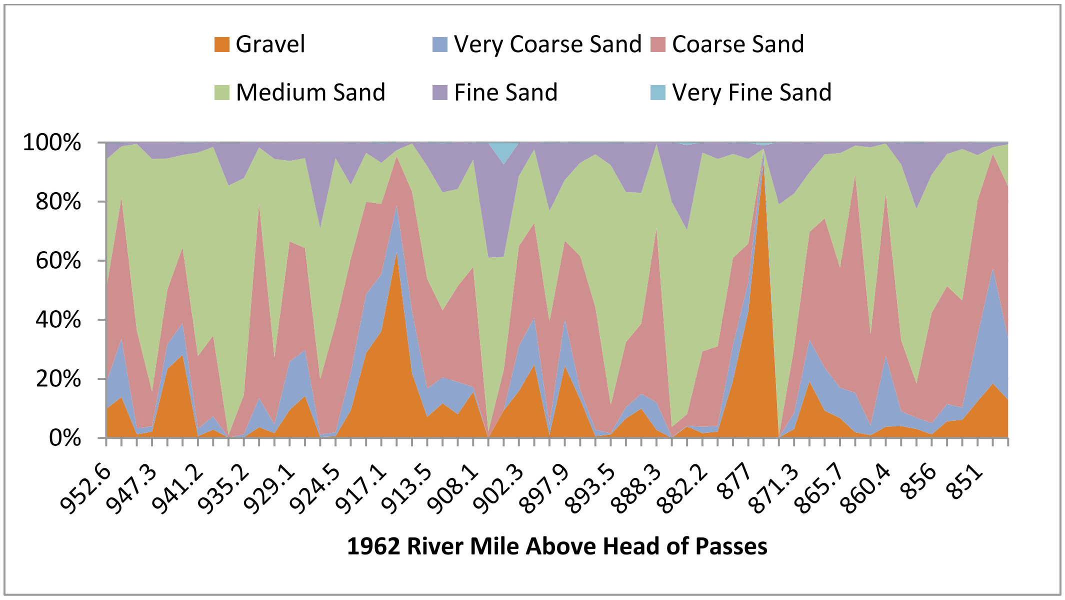
Figure 5. Plot of recent thalweg elevations and the interpolated Tertiary surface at the same geographic location. The shaded box indicates the approximate location of the erosion-resistant outcrop near Hickman, KY.



Bed material

Bed material data for the study area collected in a 1989 survey were previously reported by Nordin and Queen (1992) and are shown in Figure 6. The longitudinal bed gradation samples had an average spacing of 1.8 mi and a maximum of 3.9 mi in the current study area. This report also compared the 1989 measurements to similar ones collected in 1932.

Figure 6. 1989 bed material gradations from Nordin and Queen (1992).

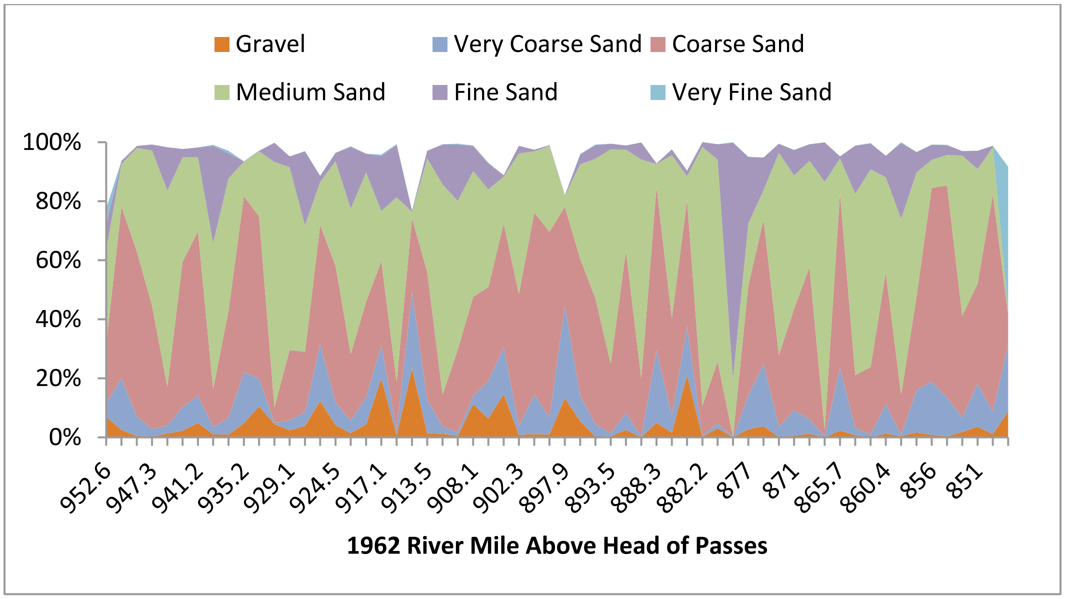


The bed material over most of the study area was composed primarily of very coarse to fine sand, as shown in Figure 6. Two areas also had significant amounts of gravel present. The downstream area, RM 875.7–878.1, had bed material composed of up to 94% gravel. The bed material of the more upstream location, RM 915.4–919.1, contained up to 63% gravel. This second location is located immediately downstream of Hickman, KY. Both locations where significant proportions of gravel were found in the bed material are either at or immediately downstream of points where the tertiary surface may be intersecting the river bed (Figure 5). It is possible that the tertiary outcrops affect the hydraulics in these locations and allow for selective winnowing of the sand size material.

A subsequent study of bed material along the Mississippi collected in 2013 (Gaines and Priestas 2016) generally found less gravel in these areas, although the area near RM 915.4 still had significantly more gravel than the nearby sampling locations (Figure 7). In this more recent study, no anomalous gravel was found near RM 875, but the sample upstream at

RM 884 showed a large amount of gravel. The tertiary surface is significantly below the river thalweg at RM 884 (Figure 5) and is unlikely to be the cause of gravel enrichment at this location.

Figure 7. 2013 bed material gradations from Gaines and Priestas (2016). Samples were obtained from the same locations as in 1989 (Figure 6) whenever possible.



4 Hydraulic Model Investigation

Hydraulic model development

The investigation of the geologic outcrop at Hickman, KY, utilized a Hydrologic Engineering Center River Analysis System (HEC-RAS) model to aid in understanding the system. The study model was based on the MVD Mississippi River Flowline Model. The Flowline model was created using the most accurate data available, which consisted of LIDAR data for the overbanks and multi-beam bathymetric data for the rivers. The Flowline model was calibrated to a range of flows for the purpose of examining water surface elevations and potential flooding. Manning's roughness values range from 0.029 to 0.033 in the main channel and are typically 0.09 to 0.11 in overbank areas. The model was modified by trimming it to the area surrounding Hickman, KY. All of the other aspects of the Flowline model (geometry data, roughness data, levee data, etc.) remained constant in the Hickman model, except as noted below. Lewis et al. (2018) provide a detailed discussion of the Flowline model.

The upstream extent of the Hickman model is located at the confluence of the Mississippi River and Ohio River (RM 954), and the downstream extent is located at the confluence of the Mississippi River and Obion River (RM 820). The model layout can be seen in Figure 8. The model extents were far enough removed from the primary area of interest that any uncertainties in the downstream boundary condition would not affect the results (Figure 9). The maximum stage difference at Hickman was 0.25 ft, and there was no discernable difference in stage at the New Madrid gage. The average spacing of the original cross sections around Hickman was approximately 5,500 ft. With this spacing, the scour hole at Hickman, KY, was not captured by the geometry of the 1D model. Two cross sections were added to the model to better represent the true size of the scour hole. Hydraulic properties for the new cross sections were properly set, and the model was again rerun to ensure model stability and calibration.

Figure 8. Schematic of the Hickman HEC-RAS model. The green lines are the individual cross sections. The blue areas are storage areas in the model. Flow is from top to bottom in the graphic.

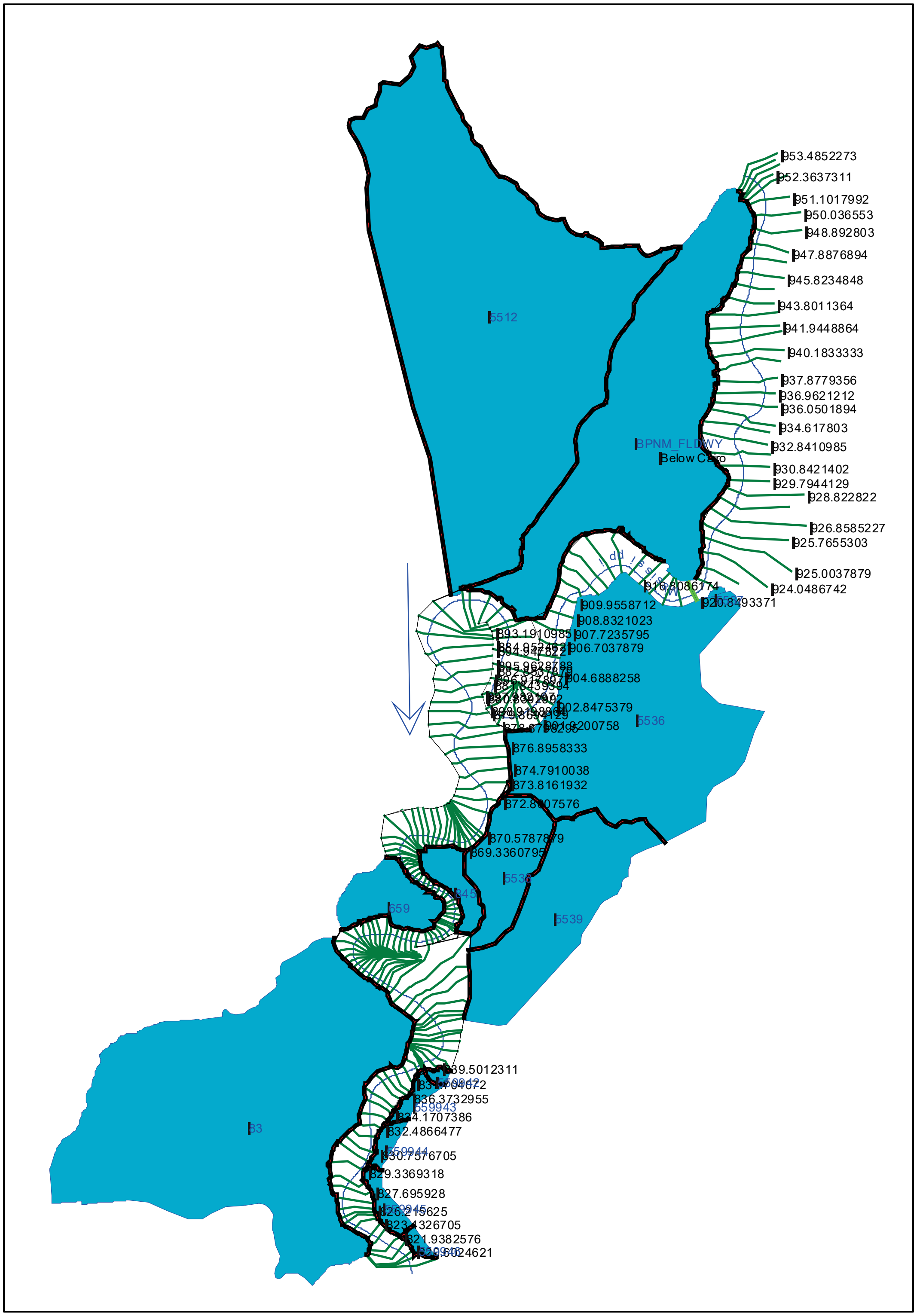
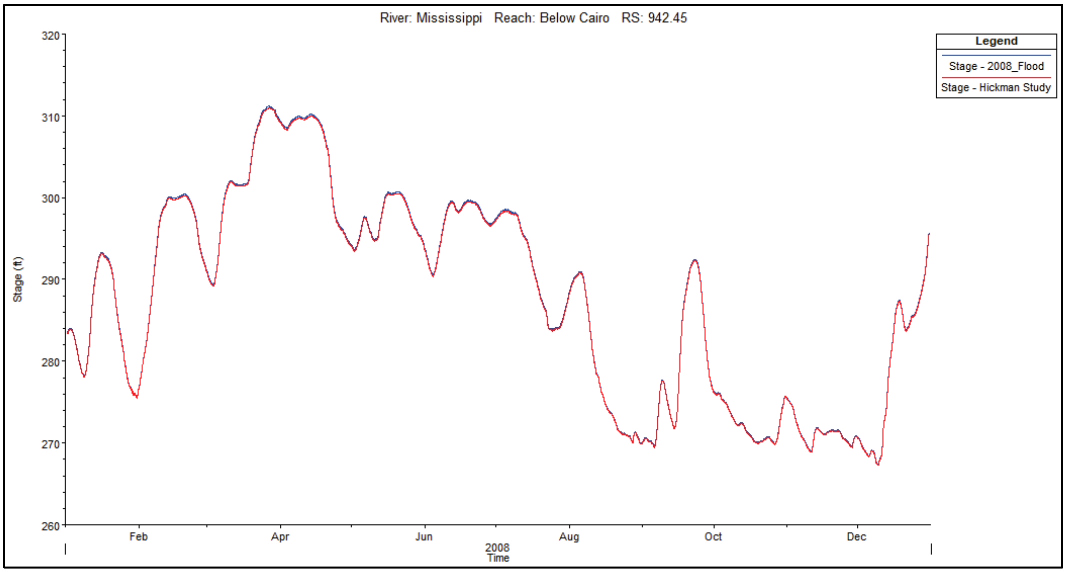
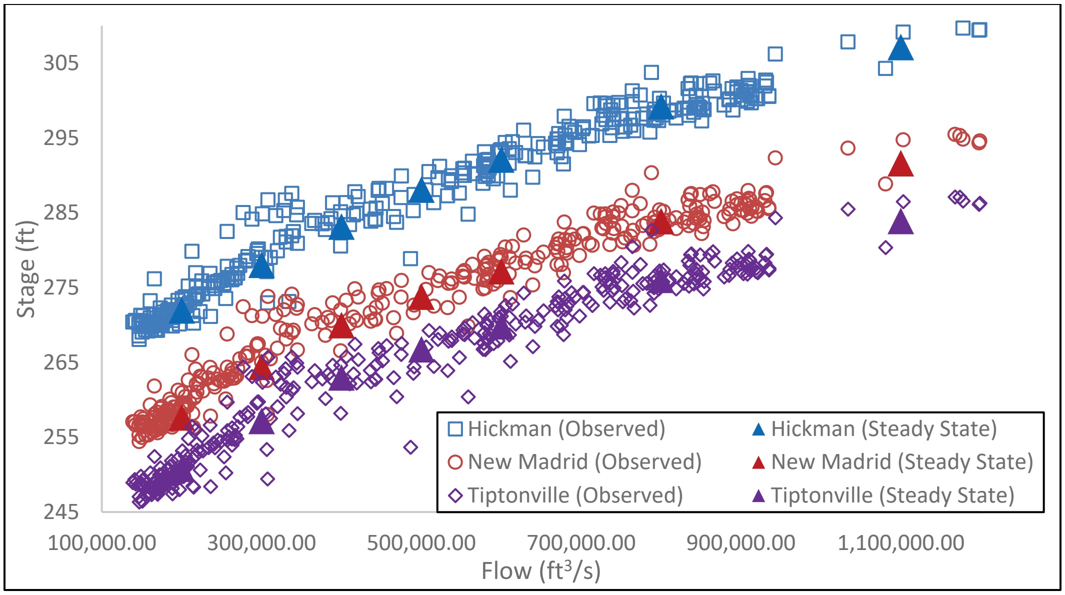


Figure 9. The trimmed HEC-RAS model shows no significant differences in stage at Hickman when compared to the results from the source model.



This study used the Hickman HEC-RAS model to perform a series of 1D steady flow analyses. The roughness values were increased by 0.001 to 0.005 to compensate for the absence of momentum loss in the steady state simulations (Figure 10). This increased main channel Manning's roughness values to 0.031 to 0.038. The steady-state approach allowed a large number of scenarios to be rapidly run and while focusing on the longitudinal variation in hydraulic forces.

Figure 10. Modeled steady-state stages from the reduced model are within the range of the observed data.



Impacts of submerged knickpoints and scour holes

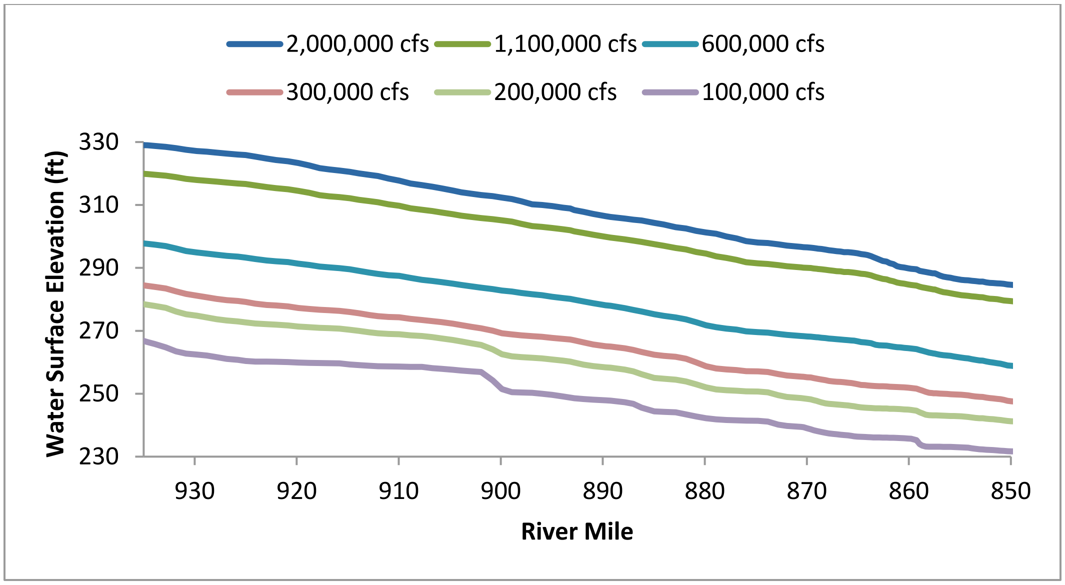
Water surface and slope control points

Slope and depth are two of the primary drivers for shear and sediment transport. A series of steady flows were run through the HEC-RAS model to identify points where there are marked changes in water surface elevations and slope. Starting with a flood flow of 2,000,000 cfs, the flow was reduced until a noticeable break in water slope was identified (Figure 11). This occurred at a flow of between 300,000 and 200,000 cfs, which is above the historical low flows on the river in this area. At these flows, there is a distinct drop on water surface at low flows between RM 902 and RM 900, 20 mi downstream from the Hickman hardpoint location. This area (RM 900–902), located in a tight bend of the river, corresponds to a local high point in the 2013 bathymetry (Figure 3). There are also dike fields on both banks of the river at this bend.

There is a second location downstream (at Island 14, RM 859) with a similar, albeit less dramatic, decrease in water surface at low flows. The decrease in modeled water surface here may be the result of the relatively deep and narrow low-flow channel on the outside of the meander bend. The local flow dynamics at this location in the model may also not be representative of actual river conditions because much of the former river channel on the left descending side of Island 14 is included in a storage area rather than the model cross sections.

High flows, greater than 1.1 million cfs, only have an obvious change in slope near RM 865. This is an area where the available floodplain increases from approximately 3 mi across to 10 mi.

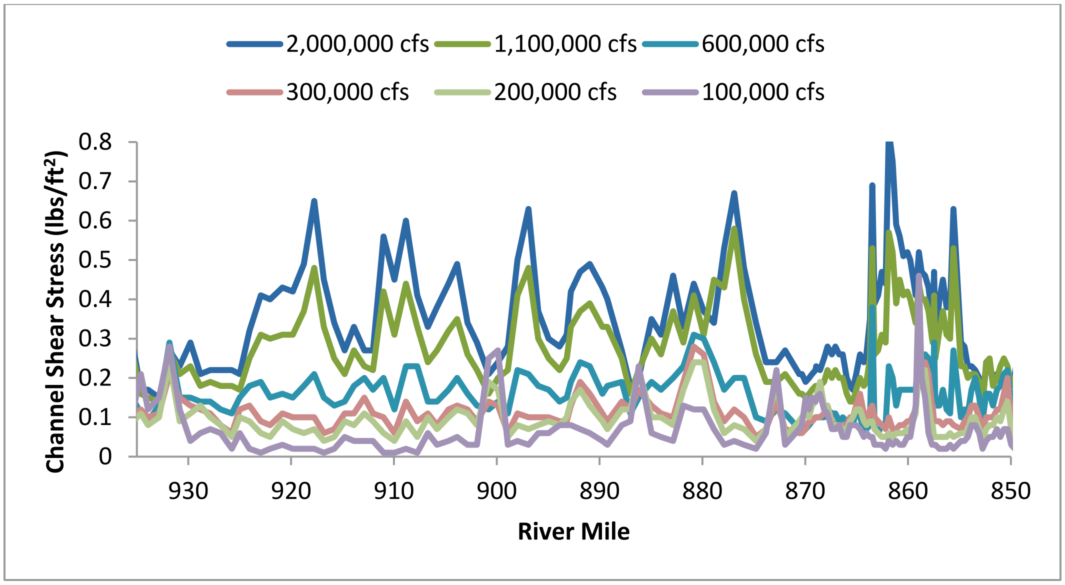
Figure 11. Water surfaces at a wide range of flows in the study reach.



Shear stress estimates

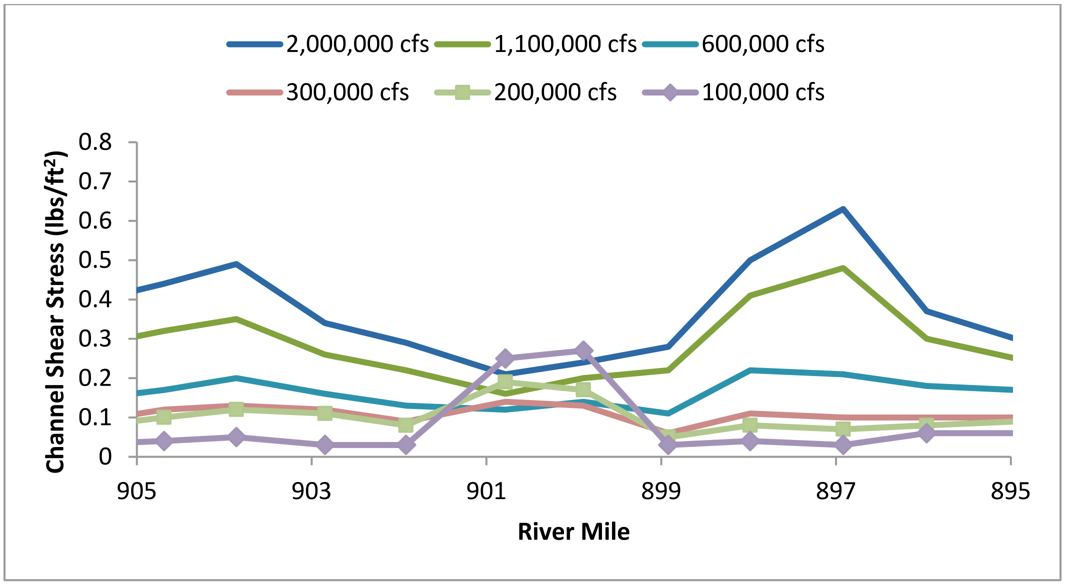
Shear stress is a proxy for sediment transport potential. A higher average shear is more likely to be able to move or erode individual sediment particles. The HEC-RAS model provided calculated in-channel shear stresses at each cross section in the model domain (Figure 12). This output represents the average shear in the channel at each flow condition. The results show that shear stresses from flood flows (greater than 1 million cfs) are highly variable, but they begin to increase just downstream from Hickman, below RM 925. The highest shear stresses in the model occur between RM 855 and RM 865 (starting approximately 7 mi downstream of Tiptonville). This is typically when the highest sediment transport rates are expected.

Figure 12. Calculated shear stress at multiple flows in the study reach.



The cross section near RM 901 is an exception to the shear stress and flow trends in the rest of the study area. The highest modeled shear stresses at this cross section occur during low flows, near 100,000 cfs (Figure 13). The high-flow shear stresses at this point in the model are also lower than the upstream and downstream forces. This is consistent with the placement of dike systems that indicate deposition concerns, and it implies that the most likely time for erosion near RM 901 is during extreme low flows.

Figure 13. The hydraulics near RM 901 create the unusual situation of increasing shear stresses at low flows. Note that shear stresses for flows of 100,000 to 200,000 cfs are as high or higher than for flows of 2,000,000 cfs at this location.



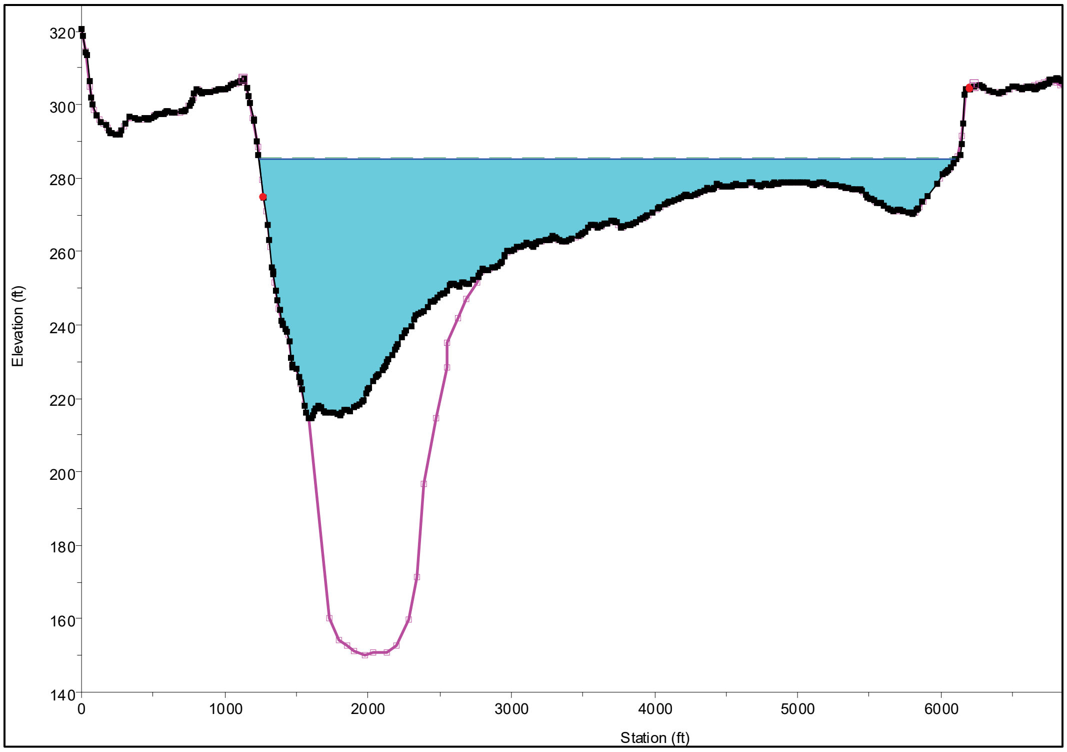
The shear stresses in the model are also very sensitive to the choice of friction slope method. The results above were calculated using the average friction slope, which is the method that was used in the original, unsteady flow model. The average conveyance method for friction slope calculation, the default for steady-state models, increases the estimated low-flow shear stress near RM 901 by 33% to 40%, without recalibrating the model. Further investigations of the shear stresses and sediment transport in this area should keep in mind the effect of the choice of friction slope method.

Effects of scour holes

The deep hole at Hickman, KY (near RM 921), has been proposed as a potential knickpoint that could advance upstream, based on the analogy of a sub-aerial waterfall. The original Flowline model did not include the scour hole, so the geometry of the hole was translated to the closest cross section in the model, 0.5 mi upstream. Cross sections were also added to this area to better define the geometry and volume of the scour hole. To remain consistent with the original cross sections, each of the new cross sections were created using the same LIDAR and bathymetric data as the Flowline model.

At a mid-range flow of 500,000 cfs, the hole is at least 70 ft deep. To explore the potential effects of deepening the scour hole, the model was modified to deepen the cross section at the scour hole by over 65 ft, or approximately 135 ft deep at a flow of 500,000 cfs. Figure 14 shows the cross section before and after the simulated deepening. The resulting water surfaces and shear stresses were then compared in the vicinity of the scour hole.

Figure 14. Comparison of original (black) and enlarged (pink) Hickman knickpoint model geometries used in the investigation of scour hole effects.



The maximum water surface increase at the deepened cross section was 0.17 ft, which occurred at the high flow of 2 million cfs. This backwater effect is a product of the expansion and contraction of the flow through this deepened cross section in the 1D model. Consistent with the step-backwater calculations used in a steady-state HEC-RAS model, there was no change in water surface elevations downstream from the altered cross section. Immediately upstream of the deepened cross section, the maximum water surface increased by only 0.04 ft. This increased water surface tapered to 0.02 ft at the upstream boundary of the model, over 30 mi upstream. These small increases in water surface are within the uncertainty of the model.

The change in water surface elevation at the deepened cross section reduces the local slope enough to cause a decrease in shear stress of 0.15 lb/ft^2 at a flow of 2 million cfs. The decrease in shear stress varies between 0.15 and 0.03 lb/ft^2 for flows at or above 100,000 cfs. The reduced shear stress is localized to the single cross section at the location of the hole.

The results of the hypothetical deepening of the scour hole indicate that a deepening of the hole does not present a significant concern when viewed from a 1D sediment transport perspective. It is likely, however, that multi-dimensional processes played a role in the formation of the current hole. The potential feedbacks between these multi-dimensional processes and any deepening or migration of the current scour hole at Hickman are beyond the scope of this report.

5 Conclusions

The multiple lines of investigation in this study indicate that the area near RM 901 deserves further consideration because of its effect on river stage and local slope at low flows. The bathymetric data show that the bend near RM 901 is the one crossing in the study reach that has experienced an increase in thalweg elevation, making it the shallowest cross section within 30 mi upstream or downstream. The 1D hydraulic modeling shows that at low flows, below 300,000 cfs, there is a noticeable drop in water surface elevation above and below RM 901. The model also demonstrates that shear stresses near RM 901 are expected to be greatest at low flows. Based on this evidence, the USACE should consider increased monitoring of the area near RM 901, especially following prolonged low flow periods. These findings should also be considered when maintaining or adding to the Donaldson Point (RM 899–907) and Below Island 9 (RM 899–902) dike systems that are located at this bend.

The 1D HEC-RAS model results indicated that any increase in the depth of the hole at RM 921 (near Hickman, KY) is unlikely to impact reach-scale degradation. This study did not look at the multi-dimensional hydraulics and sediment transport associated with the hole, nor did it consider an upstream migration of the hole. Both of these phenomena should be considered for future studies, particularly prior to any attempts to deepen the channel in the vicinity of Hickman, KY.

This study brought together several disparate data sets to look at the bathymetry, tertiary surface, and bed material of the Mississippi River. Generally, the crossing elevations are decreasing throughout the study reach. Currently, there appear to be only two points where the thalweg of the Mississippi River may be intersecting with the tertiary geology: the outcrop near Hickman, KY, and in a pool near RM 877. The bed material near these two locations contains a higher proportion of gravel than the rest of the study area, but it is unclear whether this is because the tertiary material is the source of the gravel or the hydraulic conditions that eroded to the tertiary material winnowed away more of the sand in these locations. The effect of the outcrops and the impact of "knick zones," where multiple outcrops of resistant material are spread over a wide area, should be considered for future research.

References

Biedenharn, D. S., M. A. Allison, C. D. Little, Jr., C. R. Thorne, and C. C. Watson. 2017. *Large-Scale Geomorphic Change in the Mississippi River from St. Louis, MO, to Donaldsonville, LA, as Revealed by Specific Gage Records*. MRG&P Report No. 10. Vicksburg, MS: US Army Engineer Research and Development Center. http://dx.doi.org/10.21079/11681/22744

Biedenharn, D. S., J. B. Dunbar, R. A. Gaines, and C. D. Little, Jr. 2018. *The Influence of Geology on the Morphologic Response of the Lower Mississippi River*. MRG&P Report No. 17. Vicksburg, MS: US Army Engineer Research and Development Center.

Biedenharn, D. S., W. A. Stroupe, and J. H. Brooks. 2014. *A Review of the Lower Mississippi River Potamology Program*. MRG&P Report No. 1. Vicksburg, MS: US Army Engineer Research and Development Center.

Bressan, F., A. N. Papanicolaou, and B. Abban. 2014. “A Model for Knickpoint Migration in First- and Second-Order Streams.” *Geophys. Res. Lett.* 41: 4987–4996, doi:10.1002/2014GL060823

Fisk, H. N. 1944. *Geological Investigation of the Alluvial Valley of the lower Mississippi River*. Vicksburg, MS: US Army Corps of Engineers, Mississippi River Commission.

Fisk, H. N. 1947. *Fine-Grained Alluvial Deposits and Their Effects on Mississippi River Activity*. MRC-WES-2000-2-48, two volumes: July (Volume One) and paperback (Volume Two). Vicksburg, MS: War Department, US Army Corps of Engineers, Mississippi River Commission, Waterways Experiment Station.

Gaines, R. S., and A. M. Priestas. 2016. *Particle Size Distribution of Bed Sediments along the Mississippi River, Grafton, Illinois, to Head of Passes, Louisiana, November 2013*. MRG&P Report No. 7. Vicksburg, MS: US Army Engineer Research and Development Center.

Johnston, A. C., and E. S. Schweig. 1996. “The Enigma of the New Madrid Earthquakes of 1811-1812.” *Annual Review of Earth and Planetary Sciences* 24: 339–384.

Lewis, J., E. Howe, C. A. Cruz, M. L. Dove, W. A. Crosby, R. J. Taylor, D. A. Ramirez, M. S. Dircksen, and R. Gambill. 2018. *Mississippi River and Tributaries Flowline Assessment Hydraulics Report*. MRG&P Report No. 24, Vol. 3. Vicksburg, MS: US Army Engineer Research and Development Center.

Little, C. D., D. S. Biedenharn, C. C. Watson, M. A. Allison, T. McCullough, and K. Wofford. 2017. *Channel Geometry Trends of Mississippi River, Old River Control Complex to St. Louis, MO*. MRG&P Report No. 11. Vicksburg, MS: US Army Engineer Research and Development Center. http://dx.doi.org/10.21079/11681/22801

May, J. H. 1989. *Geologic and Hydrodynamic Controls on the Mechanics of Knickpoint Migration*. Technical Report REMR-GT-3. Vicksburg, MS: US Army Engineer Waterways Experiment Station.

Nordin, C. F., and B. S. Queen. 1992. *Particle Size Distributions of Bed Sediments Along the Thalweg of the Mississippi River, Cairo, Illinois to Head of Passes, September 1989*. Potamology Program (P-1) Report 7. Vicksburg, MS: US Army Engineer Research and Development Center.

Purser, J. L., and R. B. Van Arsdale. 1998. “Structure of the Lake County uplift: New Madrid Seismic Zone.” *Bulletin of the Seismological Society of America* 88: 1204–1211.

Saucier, R. T. 1994. *Geomorphology and Quaternary Geologic History of the Lower Mississippi Valley*. Two volumes, December: text, 398 p. (Volume I) and 26 oversized maps (plates) in six series (Volume II). Vicksburg, MS: US Army Engineer, Waterways Experiment Station.

Schweig, E. S., and R. B. Van Arsdale. 1996. “Neotectonics of the Upper Mississippi Embayment.” *Engineering Geology* 45: 185–203.

Appendix: Thalweg Elevations

Table 1. Thalweg elevations.

1962 River Mile Above Head of Passes	1963 Bathymetry (ft)	1994 Bathymetry (ft)	2013 Bathymetry (ft)	Top of Tertiary (ft)
850	200	159.3	164.56	140
851	206	182.8	185.57	135
852	180	162.8	175.58	140
853	211	190.3	190.11	140
854	227	200.1	199.1	140
855	214	182.2	189.87	140
856	214	168.7	178.55	145
857	209	136.9	167.36	155
858	179	158.4	170.31	160
859	211	180.4	195.69	165
860	207	208.6	206.21	170
861	185	192.3	194.59	165
862	187	171.4	170.08	160
863	197	160.2	175.42	155
864	197	162.4	155.15	150
865	225	177.3	183.66	150
866	214	206.2	202.21	160
867	214	204.3	205.99	165
868	221	196	200.51	175
869	203	209.2	204.39	175
870	208	218.9	222.23	175
871	231	192.9	204.71	175
872	212	173.1	179.98	170
873	224	189.6	189.55	165
874	226	215.8	197.2	145
875	218	198.3	190.85	150
876	196	173.4	178.54	160
877	168	156.1	157.68	160
878	184	176.7	186.42	160

1962 River Mile Above Head of Passes	1963 Bathymetry (ft)	1994 Bathymetry (ft)	2013 Bathymetry (ft)	Top of Tertiary (ft)
879	175	197.5	200.73	160
880	190	185.1	189.78	155
881	208	196.7	218.08	150
882	224	211.3	204.31	140
883	188	206.2	203.47	125
884	186	219.5	203.47	125
885	201	199.4	193.66	115
886	215	192	217.04	110
887	233	221.6	155	105
888	235	215.4	211.8	100
889	238	166.2	220.45	95
890	194	191.4	183.15	105
891	194	188.8	199.78	110
892	192	199.7	210.35	125
893	203	225.5	217.11	140
894	232	222.8	187.25	150
895	235	222.1	217.45	150
896	236	220.3	225.26	155
897	208	200.6	210.05	155
898	192	160	186.51	160
899	191	209.5	222.97	160
900	226	214.4	229.47	165
901	228	230.7	237.19	165
902	231	220.5	233.43	160
903	231	207.7	232.65	155
904	228	209.3	226.86	155
905	237	219.6	224.96	155
906	235	229.1	219.18	155
907	242	233.3	227.85	145
908	229	206.3	192.45	150
909	208	197.7	185.86	150
910	192	187	200.13	150

1962 River Mile Above Head of Passes	1963 Bathymetry (ft)	1994 Bathymetry (ft)	2013 Bathymetry (ft)	Top of Tertiary (ft)
911	216	178.7	169.29	155
912	192	220.4	210.88	160
913	231	211.6	198.58	160
914	222	212.5	195.38	165
915	244	236.3	221.83	175
916	234	226.7	203.48	160
917	234	218.2	192.23	140
918	200	197.3	203.64	160
919	222	213.6	197.81	195
920	232	215.4	217.9	215
921	235	210	194.06	210
922	238	219.6	220.68	190
923	212	218.3	215.59	175
924	220	205.8	217.8	195
925	213	230.5	202.47	190
926	239	229.2	232.26	190
927	238	225.4	225.11	200
928	245	211.8	220.53	205
929	248	227.2	218.58	200
930	225	231.8	225.11	200
931	238	219.5	238.53	195
932	231	224	233.39	185
933	235	236.1	228.77	185
934	243	225.6	229.31	190
935	194	248	231.45	200

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
miles (US statute)	1,609.347	meters
pounds (force) per square foot	47.88026	pascals

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE
June 2021

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Effects of Geologic Outcrops on Long-Term Geomorphic Trends:
New Madrid, MO, to Hickman, KY

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Travis A. Dahl, Justin S. Giles, Kathleen A. Staebell, David S. Biedenharn, and Joseph B. Dunbar

5d. PROJECT NUMBER
470711

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Coastal and Hydraulics Laboratory
US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Geotechnical and Structures Laboratory
US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
MRG&P Report No. 38

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Mississippi River Geomorphology & Potamology Program (MRG&P)
US Army Corps of Engineers, Mississippi Valley Division
Vicksburg, MS 39181-0080

10. SPONSOR/MONITOR'S ACRONYM(S)
MVD MRG&P

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Funded by Mississippi River Geomorphology & Potamology Program (MRG&P), Mississippi Valley Division

14. ABSTRACT

The Mississippi River between New Madrid, MO, and Hickman, KY, is of particular interest because of divergent trends in water surface profiles at the upstream and downstream ends of the reach. This report documents the investigation of the bathymetry, geology, and hydraulics of this segment of the river. The report shows that the area near River Mile 901 above Head of Passes strongly affects the river stages at low flows. This part of the river can experience high shear stresses when flows fall below 200,000 cfs, as opposed to most other locations where shear stress increases with flow. One-dimensional hydraulic modeling was also used to demonstrate that an increase of depth at a single scour hole, such as the one downstream from Hickman near River Mile 925, is unlikely to cause reach-wide degradation.

15. SUBJECT TERMS
Hickman (Ky.), Hydraulic models, Mississippi River—Geomorphology, New Madrid (Mo.), Outcrops (Geology), River channels

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Travis A. Dahl
Unclassified	Unclassified	Unclassified	SAR	38	**19b. TELEPHONE NUMBER** *(Include area code)* 601-634-2371