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Empirical Analysis of Effects of Dike Systems on Channel Morphology of the Lower Mississippi River

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Empirical Analysis of Effects of Dike Systems on Channel Morphology of the Lower Mississippi River

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Abstract

A phased study of the dike fields within the Vicksburg and Memphis Districts of the US Army Corps of Engineers was conducted to document the channel morphology trends since dike construction on the Lower Mississippi River (LMR). This included the development of the hydrographic survey database and methodology utilized to identify changes in channel geometry in response to dike construction. A subsequent report will provide further refinements to the approach and results of the comprehensive assessment.

Recent Mississippi River Geomorphology and Potamology program efforts have employed the database developed by Mr. Steve Cobb to assess the geomorphic changes in 21 dike systems along the LMR. Previous studies using this database have indicated that the dike fields have not caused a loss of channel capacity. Furthermore, these efforts suggested that the trends in the dike fields are closely related to the long-term geomorphic trends along the LMR. Previous efforts using the Cobb database provided considerable insight into the dike effects on the LMR, but they were limited spatially and temporally. In this study, a database and protocols were developed to allow for a more robust assessment of dike field impacts and to extend the spatial and temporal extents of the analysis.

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Preface

The research documented in this report was conducted for the Mississippi Valley Division, Science and Technology Office, as part of the Mississippi River Geomorphology & Potamology (MRG&P) program, 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, Mississippi Valley Division (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.

The work was performed by the River and Estuarine Engineering Branch of the Flood and Storm Protection Division, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication of this report, Mr. David May was Chief of the River and Estuarine Engineering Branch, and Dr. Cary Talbot was Chief of the Flood and Storm Protection Division. The Acting Deputy Director of ERDC-CHL was Ms. Ashley E. Frey, and Dr. Ty V. Wamsley was the Director.

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

1 Introduction

1.1 Background

River training structures, specifically dikes, have been used on the Lower Mississippi River (LMR) as a navigation aid since the 1960s. These structures have proven extremely effective in reducing the maintenance dredging along the river; however, the debate about the hydraulic and morphological impacts of these structures continues (Watson et al. 2013).

Mississippi River Geomorphology and Potamology (MRG&P) studies conducted several years ago have utilized a database developed by Mr. Steve Cobb, a biologist at the Mississippi Valley Division in the 1990s, to assess the geomorphic changes in 21 dike systems in the Memphis and Vicksburg Districts. These studies relied on the historical changes in surface area, depth, and volume calculated by Cobb. Results of these studies have indicated that the dike fields have not caused a loss of channel conveyance, but rather, in most cases, the total channel conveyance has either remained steady or actually increased[*] (Simon et al. 2020).

While previous assessments using the database developed by Cobb (herein referred to as the *Cobb database*) are considered valid studies that generally have captured the effects of the dike structures, there are concerns about moving forward with the Cobb database as the basis for future, more detailed efforts. Most notably, the original working files and mapping from which the studies' calculations were made are not available, and therefore it can be difficult to reproduce these historical results. It is also difficult to develop datasets for the more recent time periods (mid-1990s to present) that are consistent with the original Cobb calculations. While this is a valuable database that has yielded considerable insight into the effects of dike systems, it has become apparent that a more robust and replicable approach is needed that reflects engineering and geomorphic principles and takes advantage of the capabilities offered by Geographic Information Systems applications.

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[*] Biedenharn, D. S., L. Hubbard, and P. H. Hofman. 2000 (Unpublished report). *Historical Analysis of Dike Systems on the Lower Mississippi River*. US Army Corps of Engineers Draft Report to US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

1.2 Objectives of study

The objectives of this study were to (1) construct a new ArcGIS database of historical surveys and dike data for the Vicksburg and Memphis Districts, (2) develop a reproducible methodology using this database for assessing morphological trends, and (3) apply the methodology to assess its efficacy as a reproducible and defendable approach for identifying correlations between observed morphological trends and the construction of training dikes.

1.3 Approach

In order to meet the assessment objectives, a number of datasets had to be gathered and evaluated. This report describes procedures used in the analyses of hydrographic survey data, channel delineations, changes over different time periods, cross-section data, volumetric data, and dike data. Each of these analyses are explained in more detail in Chapter 2 Methodology.

2 Methodology

A description of the data, time periods, and the methodology used to evaluate the effects of the dike systems is provided in this section.

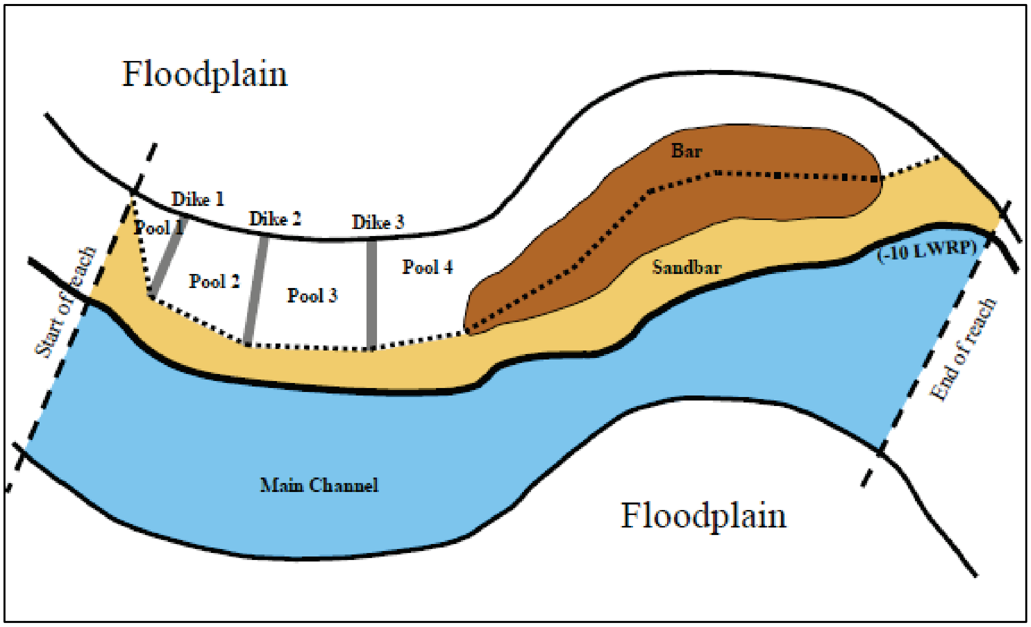
2.1 Hydrographic survey data

A combination of annual and comprehensive hydrographic surveys from the Vicksburg and Memphis Districts was used to develop the time-series database in this study. The hydrographic survey data came in varying formats and were converted to Triangulated Irregular Network (TIN) formats in ArcGIS 10.3.1 (herein referred to as *ArcGIS*). Currently, the database includes data based on approximately 31 individual hydrographic surveys ranging in collection date from 1948 to 2015. The survey periods of 1988 and 2013–2015 were utilized in the analysis of this study to demonstrate the application and capabilities of the new methodology. The surveys selected for analysis were based on the overall quality and coverage available for geometric comparisons. The database will continue to be updated and expanded with additional hydrographic surveys as they become available.

2.2 Channel delineation

Previous studies, including the original Cobb database, relied heavily on the delineation templates developed from the methodology described in Cobb and Magoun (1985). The template essentially divided each reach into three areas based on distinct habitat characteristics: (1) pools, (2) sandbars, and (3) main channel (Figure 1). Cobb and Magoun (1985), distinguished the three areas as (1) dike field pools, which are the areas between the dikes; (2) the sandbars, which are the areas between the middle bars, if present, and the adjacent main channel going out to the -10 Low Water Reference Plane (LWRP) contour; and (3) the main channel, which is the remainder of the channel up to the -10 LWRP contour.

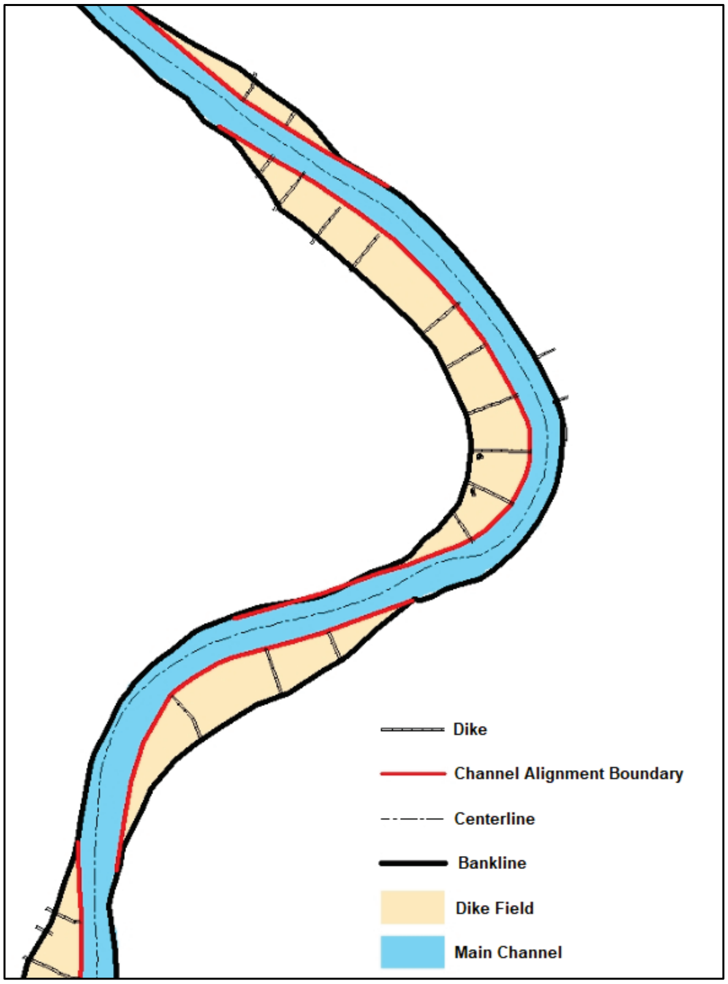
Figure 1. Illustrative example of the channel delineation used in the original Cobb database.



Although the approach is documented, the subjective nature of the delineation process and the overall complexity of the systems have made the templates difficult to reproduce. Since the delineations are based on features of the channel that can change over time, such as individual structures or contours referenced to LWRP, the defined boundaries can only be associated with a single survey or point in time. This has been problematic when attempting to update the Cobb database with new survey data or applying the approach to different (new) systems. Due to the limitations and uncertainty associated with the Cobb database, a more replicable approach that reflects engineering and geomorphic principles is needed to effectively continue long-term geomorphic evaluations in a similar fashion.

The channel delineation employed in this study is based primarily on the channel improvement boundary (channel alignment) set by Vicksburg and Memphis districts. This boundary is set and maintained by the districts to ensure a desirable channel alignment and obtain the most efficient flow characteristics for flood control and navigation. Since the US Army Corps of Engineers (USACE) is responsible for maintaining a safe and dependable navigation channel, it is reasonable to assume that the channel improvement boundary and/or current alignment will not significantly change in the near future. The current channel alignment provides a reproducible delineation boundary that can define the main channel and dike field areas quickly and effectively for the entire study reach. Figure 2 provides a general representation of the channel delineation used in the new methodology.

Figure 2. Illustrative sketch of the proposed channel delineation using channel improvement boundary.



2.2.1 Advantages of the new approach.

Unlike previous methods, using the channel improvement boundary reduces the uncertainty of manually defining channel areas based on specific characteristics (flow, depth, frequency, etc.) and the limitations associated with the location of individual structures, both of which may vary through time. Although the approach is less subjective, it can be more challenging to focus on one specific dike pool section as defined in the Cobb database. This is primarily a result of eliminating the use of individual structures as distinct boundaries. To target specific areas for analysis, the new approach utilizes individual cross sections that are positioned every 0.2 river mile (RM) throughout the entire study reach.

The position and orientation of the individual cross sections are based on the range line templates used in the 2013 comprehensive hydrographic surveys for the Vicksburg and Memphis districts. In some cases, the range lines were extended to ensure the entirety of the channel geometry would be captured for each cross section. The addition of cross sections to the template not only improves the scaling of analysis but also allows for a more robust evaluation of the geometric parameters and overall changes occurring in the channel. With the adjustable scaling and removal of reach boundaries, the data can be collected, grouped, and/or analyzed at various reach lengths ranging from a few miles to hundreds of miles with minimum effort. This eliminates the need for developing individual templates based on specific reach extents or dike systems of interest. With the additional flexibility of the proposed template, the database can now be easily updated and expanded as more survey data become available.

2.2.2 Limitations of the new approach.

Although the advantages of the approach are evident, the method does have its own set of limitations. Similar to the Cobb approach, the data collected and compared remain limited by the available survey coverage, which can vary based on the year as well as the location along the river. Additionally, there are some issues comparing the current main channel and/or dike field areas with earlier hydrographic surveys using the channel alignment. Since the current channel alignment is primarily a result of the river training structures, there are segments of the river where the alignment has shifted dramatically from past alignments found in early survey periods. Overall, changes in channel pattern have been minimal because of river stabilization revetments in the study reach, but local adjustments are evident in 1960–1970 survey periods. In some cases, sections that are currently defined as dike field areas were once considered part of the main channel alignment. In these scenarios, comparing the data for individual sections (such as percent change in dike field cross-section area) will often result in large discrepancies between the survey years. However, this issue can be easily resolved through careful inspection of the data. There was no effort to document changes in channel alignment or survey coverage issues as part of this phase of the study, but the limitations associated with each should be recognized when interpreting the preliminary results. Note also that these issues would be problematic using the Cobb method if applied to the entire LMR as in this study.

The dike pool and sandbar areas from the Cobb method will be more or less combined when using the channel alignment boundary as the defining border. This reduces the uncertainty and inefficiency of manually delineating these areas, but it removes an important aspect from a habitat perspective. The focus of this study was the volumetric and geometric changes throughout the channel, specifically dike fields and the main channel area, which is why the sandbar area was not a priority for this effort. However, the template could be improved upon and/or supplemented with additional templates to incorporate more features for habitat characteristics in the future.

2.3 Time periods

The database can be used to evaluate geometric parameters such as cross-sectional area, width, hydraulic depth, conveyance, volume, water surface area, and variations of these parameters over time to determine the presence of discernable trends. Since the delineation process in this study is not based on specific channel characteristics or individual structures, the database does not require set base templates from specific years for geometric comparisons. This provides the potential to assess changes between various periods without the concerns of re-producing templates for the specific periods and allows the database to be easily expanded with the addition of new survey data. Currently, the database includes data based on annual and comprehensive hydrographic surveys ranging from 1948 to 2015. Preliminary investigations of the survey data indicated that there were issues with survey coverage in many reaches that, if not accounted for, would potentially produce spurious results. To address these problems, further examination would be required to make any corrections or modifications deemed necessary to ensure valid comparisons. To reduce the issues associated with survey coverage and channel pattern, the selected period for this study was the 1988 to 2015 period. The period being compared in this study still contains areas with survey issues, but the problematic reaches are considered to be minimal and do not jeopardize the overall legitimacy of the results. Therefore, the analysis presented in this study should be considered a preliminary assessment with the intentions of demonstrating the efficacy of the methodology.

2.4 Cross-section data

A cross-section shape file template was developed in ArcGIS based on range line templates used in the 2013 comprehensive hydrographic surveys for the Vicksburg and Memphis districts. The cross sections were created along the entire study reach at approximately 0.2-mile intervals with 50 ft[*] spacing between station points along each cross section. Each point within a cross section was assigned a Section ID based on the point's XY-location referenced to the channel classification template. The bathymetric data for each survey surface were extracted in ArcGIS and exported for geometric computations. An illustration of the process can be seen in Figure 3. Due to the size of the extracted datasets, a computer script was developed in RStudio 3.6.1 to quickly sort through the data and make all geometric computations required for the analysis. Since all station points have an assigned Section ID value, geometric computations were made for each delineated area individually and for the combined total channel. Computations were made for cross-section area, top width[†], hydraulic depth (mean depth), and conveyance at elevations that correspond to LWRP, LWRP +10 ft, LWRP +20 ft, and LWRP +30 ft based on the 2007 LWRP profile. After computations were made, RStudio was utilized for further analysis, visual assessment, and generation of comparative plots.

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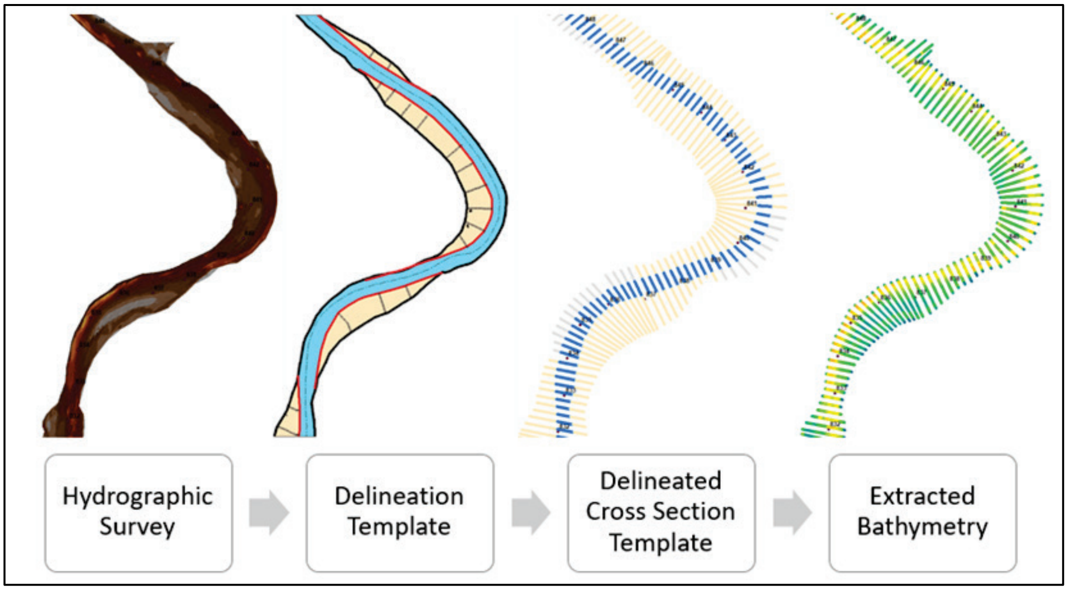
[*] For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

[†] To clarify, the top width is associated with each specific water surface elevation. It excludes any areas above the referenced water surface elevation, including perched middle bar areas.

Figure 3. Schematic of the process used to extract bathymetric data for cross-section analyses using the channel classification template.



2.5 Volumetric data

Polygon shape files were created in ArcGIS to cover the full channel width for the entire study reach at 1-mile intervals. The shape files were then divided into multiple sections using the channel classification template. Average LWRP elevations and the Section ID values were determined for each polygon, similar to the cross-section shape file. The Polygon Volume tool from the 3D Analyst toolbox in ArcGIS was used to compute the volume (and water surface area) of each polygon at the LWRP-referenced elevations for each hydrographic survey. The computed data were then imported into RStudio 3.6.1 for inspection, analysis, and generation of comparative plots.

2.6 Dike data

Basic engineering design, construction, and maintenance data were collected for every functional dike and dike system that had been constructed in the LMR from RM 320 to RM 953. The data compiled for each dike included information such as year of construction, location, type, length, changes in length, changes in height, and notching efforts. For this preliminary effort, the dike data primarily used were the year of construction, length, and location of each dike along the LMR. Currently, the dike data for the Vicksburg District are characterized by dike systems instead of individual dike structures. This potentially reduces the distribution of data along the reach, which may lead to unrealistic representations, such as reaches with no value and/or large values for the linear feet of dike construction. Although future efforts using these data will need to be refined, it should be acceptable for this assessment based on the reach scales. As a preliminary investigation, the study attempted to incorporate the dike data along with the computed geometric data to illustrate the relationship between the construction of dikes and changes in the geometric parameters of the channel through time.

2.7 Data analysis

The scale and complexity of the database required a combination of approaches for the analysis of the data and presentation of observed changes. First, individual analyses were conducted for each delineated channel area as well as the total channel. For the purposes of this study, the left and right bank dike field areas were combined to represent the total dike field area. Measures of change for the geometric and volumetric parameters were determined on a cross section and/or volumetric reach level for each component of the channel. Second, the computed values from the cross section and reach level were compiled into representative reaches. Representative reaches were created by grouping cross sections and volumetric reaches using 5-mile intervals from RM 325 to RM 953. At 5-mile intervals, each reach represents a distribution containing the computed values for approximately 25 individual cross sections (geometry) or five 1-mile segments (volumetric). Last, geomorphic regimes were identified for each reach using previously documented results from specific gage analysis (Biedenharn et al. 2017). The reaches were then grouped using the geomorphic regimes to summarize the overall sedimentation trends observed. Additionally, the linear feet of dike construction before and after the base year were compiled for each level of analysis to be qualitatively related to the interpreted sedimentation trends.

After consideration of possible alternatives, it was determined that using percent change between time periods would be an acceptable method for observing the trends of change for the cross-section analyses. In addition to making the measures of change more comprehensible, the main benefit of using percent change was the normalization of change between cross sections. The percent change was determined for the total channel, main channel, and dike field areas for each cross section. The computed values were then grouped into the 5-mile reaches. The median values (median of differences) were then determined for each of the distributions (reaches) to provide a general representation of the dominant processes occurring on a reach level. Plots of the median percent change by reach were developed for the total channel and main channel areas.

For the volumetric analysis, cumulative volume change curves were developed to complement the main plots. Previous studies (Little et al. 2017) have found cumulative volume change curves to be effective in determining the spatial extents of the average volumetric change rates over time. The curve can be developed by plotting the cumulative volume change along a reach between successive hydrographic surveys. Positive (+) slopes along the curve represent reaches of erosion while negative (-) slopes represent reaches of deposition. The slope of the curve represents the average rate of erosion or deposition per mile for the reach. Using similar procedures presented by Little et al. (2017), the cumulative volume change curves can be applied to the new template and enhanced by creating curves for each delineated section. The curves developed using the new template allow for further examination of the dike fields in relation to the overall changes occurring along the reach.

3 Analysis

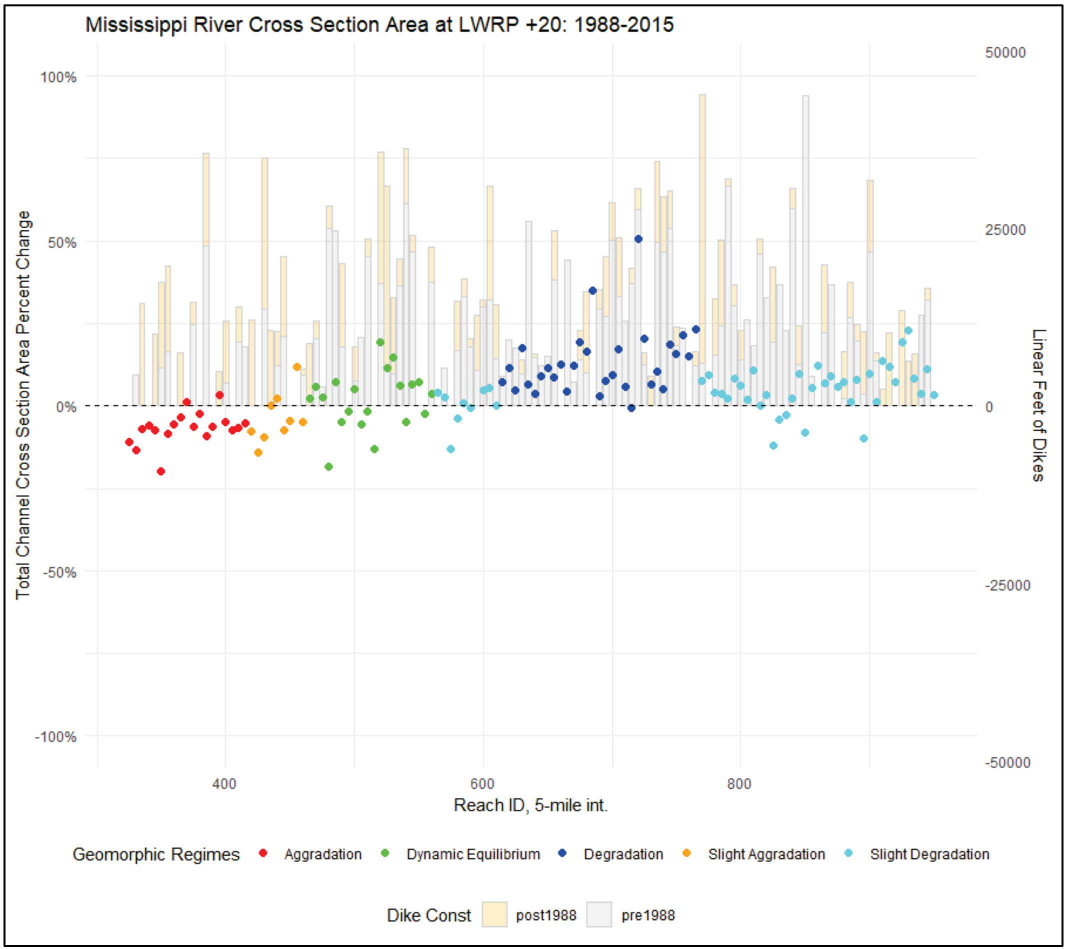
The first step in this study was the development of the database and an improved methodology for assessing long-term morphologic trends and their association with the construction of dike structures. The next step was to apply the approach to the LMR to test the methodology and to make some preliminary assessment of the effects of dike structures on the observed morphological trends in the river. It must be emphasized that although this is a massive database that represents a major advancement in the ability to assess the morphologic trends in the LMR, it is by no means considered complete. Rather, it should be viewed as a framework that can continue to be built upon. For example, there are a large number of older surveys (many in hard-copy form only) that need to be added to the database. Additionally, a complete quality control check of all the data has not been performed, and therefore there may be some cross sections that are problematic and need to be addressed. For these reasons, the analyses presented herein should be considered as a preliminary assessment, which can be further enhanced as the database continues to be expanded and improved.

3.1 Cross-sectional analysis

The database allows for the analysis of all cross-sectional parameters (area, depth, width, and conveyance) over various time periods from 1948 to 2015 and for different LWRP elevations. In this section, the results of cross-sectional area changes between the 1988 and 2015 surveys at the +20 LWRP are presented.

Figure 4 shows the percent change in total cross-sectional area referenced to LWRP +20 between the survey years 1988 and 2015. The individual points in Figure 4 represent the median values for 5-mile-long reaches. The color coding of the individual points reflect the broad geomorphic trends of the LMR as identified by Biedenharn et al. (2017) through specific gage analysis. The percent change in cross-section area for each 5-mile reach generally follows the trends of the broader geomorphic regimes. As shown in Figure 4, the changes in cross-sectional area for the downstream reaches (downstream of about RM 465) have almost entirely been negative, which would be associated with a depositional regime. This reach also corresponds to the aggradational reach identified by Biedenharn et al. (2017). Between approximately RM 465 and RM 605, the data are scattered about the 0% change line, indicating that there is no dominant increasing or decreasing trend. This reach also closely corresponds to the dynamic equilibrium reach identified by Biedenharn et al. (2017). The majority of the median values between approximately RM 605 and RM 770 are positioned well above the 0% change line. This trend suggests that the reaches have undergone a period of general channel incision during the time span. This also agrees well with the specific gage analysis results reported by Biedenharn et al. (2017) that indicate that this was a degradational reach. Upstream of approximately RM 770, the data are mainly positioned above the 0% change line, although less pronounced when compared to severely degradational reach just downstream. Again, these trends agree well with the slight degradational trends identified by Biedenharn et al. (2017).

Figure 4. Percent change in total cross-section area at LWRP +20 from 1988 to 2015 for LMR RM 325 to RM 953.



An interesting aspect of Figure 4 is the secondary bar plot, which refers to the linear feet of dikes constructed within each reach. While the plot shows that the distribution of dike construction is highly variable from reach to reach, there is no clear correlation between the amount (linear feet) of dikes in a reach and change in total cross-section area for this time period. This is illustrated in Figure 5, which shows a plot of percent change in total cross-sectional area between 1988 and 2013–2015 and linear feet of dike constructed. As shown in Figure 5, there is no clear trend between length of dikes constructed and changes in cross-sectional area. These observations indicate that there are factors other than dikes that are the dominant driver of morphological trends in the river.

Figure 5. Percent change in total cross-section area at LWRP +20 from 1988 to 2015 for LMR RM 325 to RM 953 versus linear feet of dike construction after 1988.

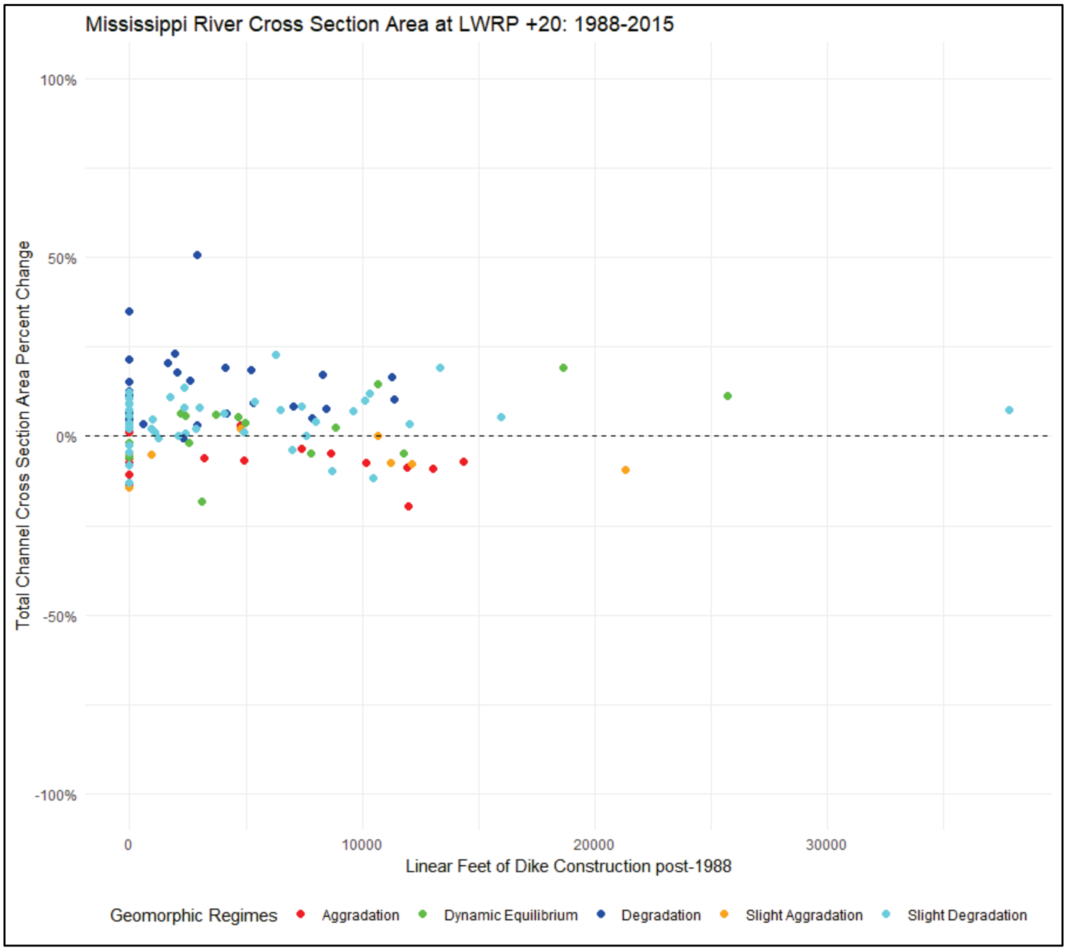
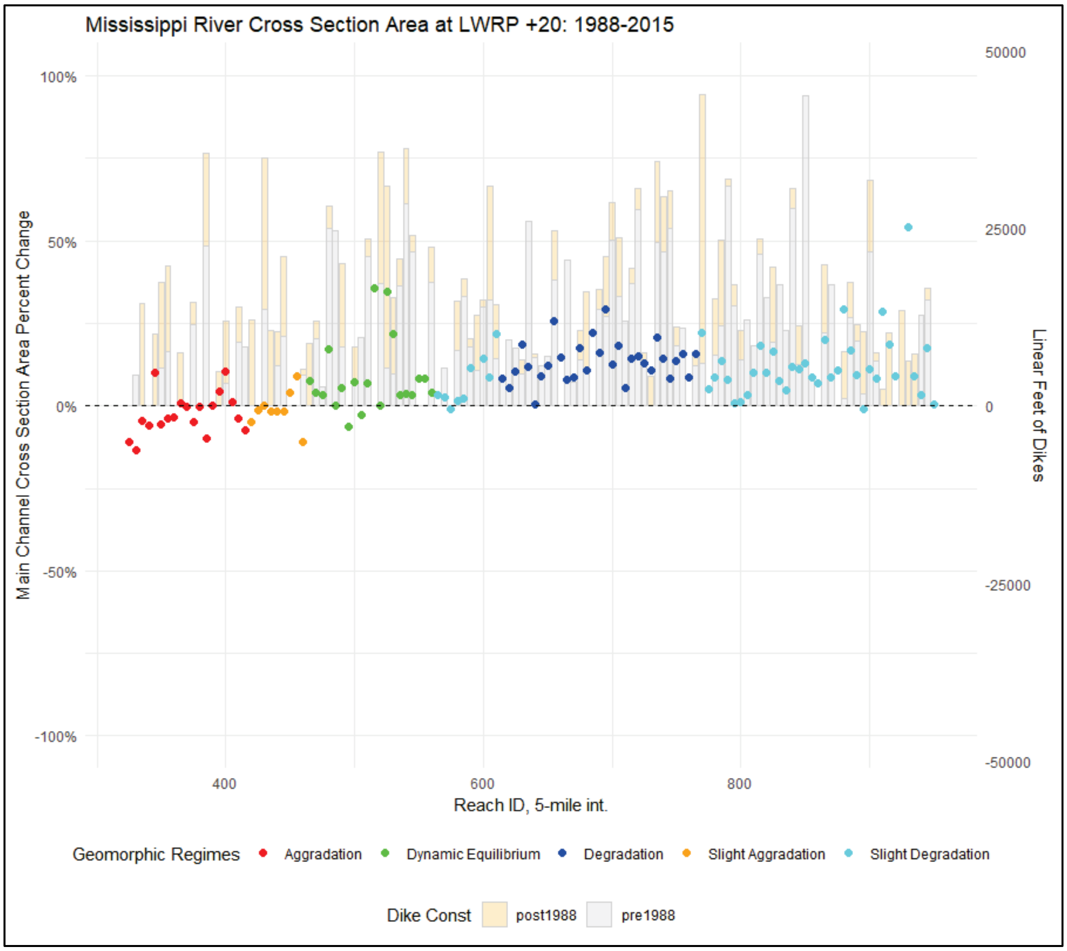


Figure 6 represents the percent change in main channel cross-section area referenced to +20 LWRP between the survey years 1988 and 2015. The overall trends are similar to those discussed previously in Figure 4 for the total channel cross section, albeit the trends are slightly more erosional.

Figure 6. Percent change in main channel cross-section area at LWRP +20 from 1988 to 2015 for LMR RM 325 to RM 953.



In most of the reaches seen in Figure 6, the percent change in main channel cross-sectional area is greater than the percent change in total cross-section area regardless of geomorphic regime. Overall, the reaches in the aggradation zone show a slight decrease in cross-sectional area, although there are some that exhibit no change or slight erosion. This suggests that the main channel is still experiencing deposition but possibly at a reduced rate compared to the total cross section. Upstream of this aggradational zone, the main channel cross-sectional area has consistently increased during the period.

Figure 7 represents the same cross-section area data and color scheme as in Figures 4 and 6 but plots the main channel percent change against the total channel percent change. This plot also uses a point-sizing scheme to represent the linear feet of dikes within each reach. The diagonal break line in Figure 7 represents a 1:1 ratio between percent change in cross-sectional area for the main channel and total channel. Although some scatter is evident in the plot, a large portion of the median values is positioned above and/or to the left of this line. A similar plot of the data referenced to LWRP is shown in Figure 8.

Figure 7. Main channel vs. total channel cross-section area percent change at LWRP +20 from 1988 to 2015 for LMR RM 325 to RM 953.

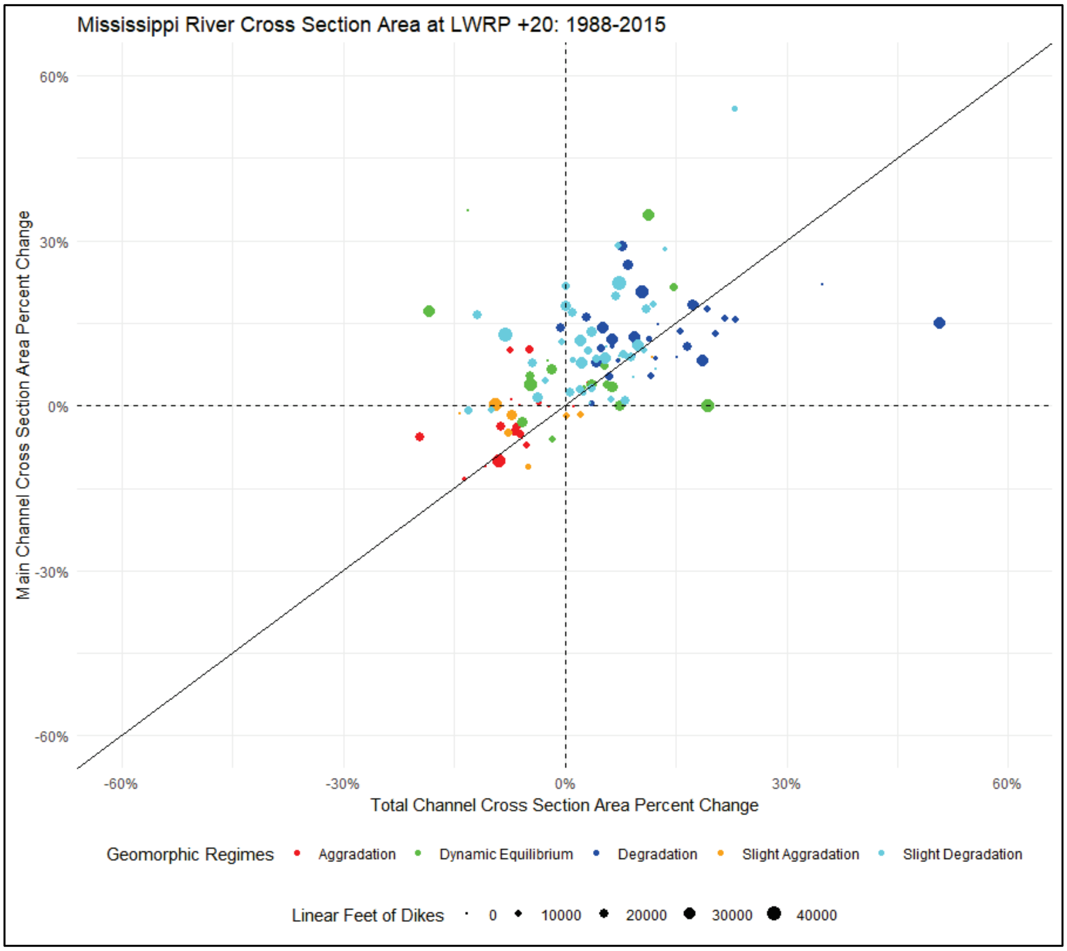
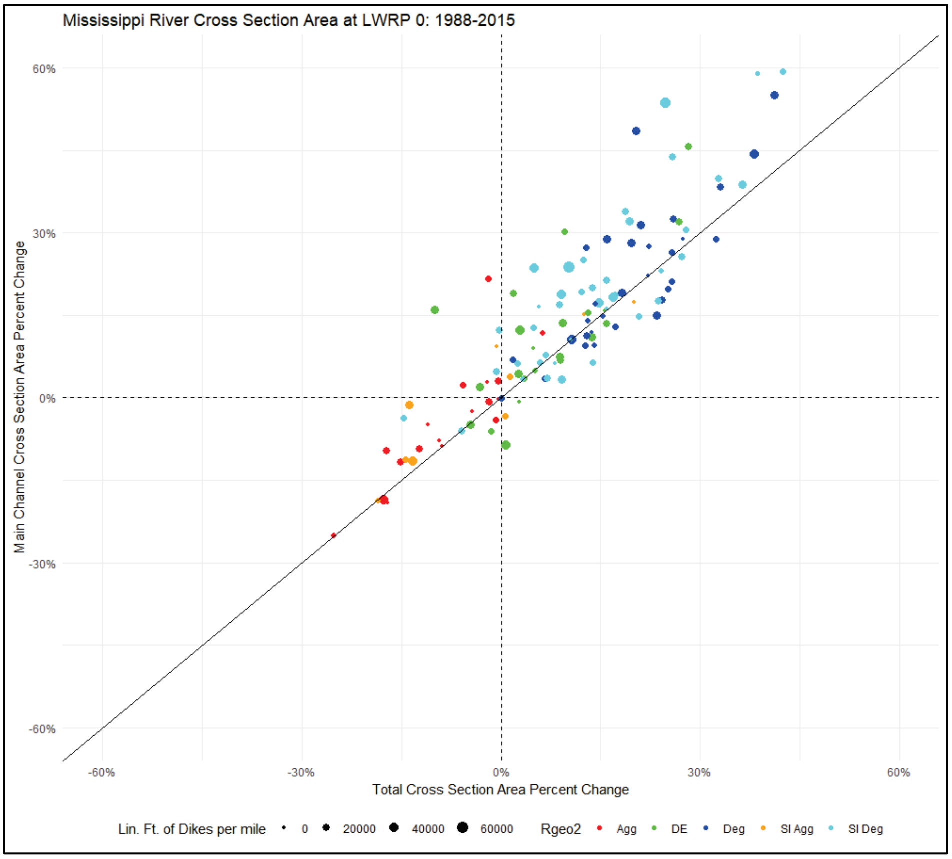


Figure 8. Main channel vs. total channel-cross section area percent change at LWRP from 1988 to 2015 for LMR RM 325 to RM 953.



Although there is no defined spatial reference for the points in Figures 7 and 8, the color groupings in the plots clearly demonstrate the transitions between geomorphic regimes. For reaches characterized by aggradation (red/orange), the points are predominantly positioned in the fourth quadrant (lower left) representing a loss in total channel and main channel cross section area. However, the position of the points in relation to the 1:1 break line indicates that the loss of cross-section area in the main channel is typically less pronounced than the overall channel. Conversely, the erosional reaches (cyan/blue) are positioned mainly in the first quadrant (upper right) representing a net gain in total channel and main channel cross-section area. Similar to the results for the depositional reaches, the vertical position of the points in relation to the 1:1 break line suggests that most of the gain in cross-section area is occurring in the main channel section.

While the transitions between geomorphic regimes are evident, there is no distinct relationship between the point size, which refers to the linear feet of dikes within the reach, and the positions on the plot. This further supports the indication that the morphological trends in the river are primarily driven by factors other than the dikes. However, the changes in the main channel compared to the total cross section may indicate that the dike fields are working locally in conjunction with the broader, long-term processes by dampening the aggradation effects in the downstream reaches while accenting the degradation effects in the upstream reaches. Further investigation would be required to confirm this situation.

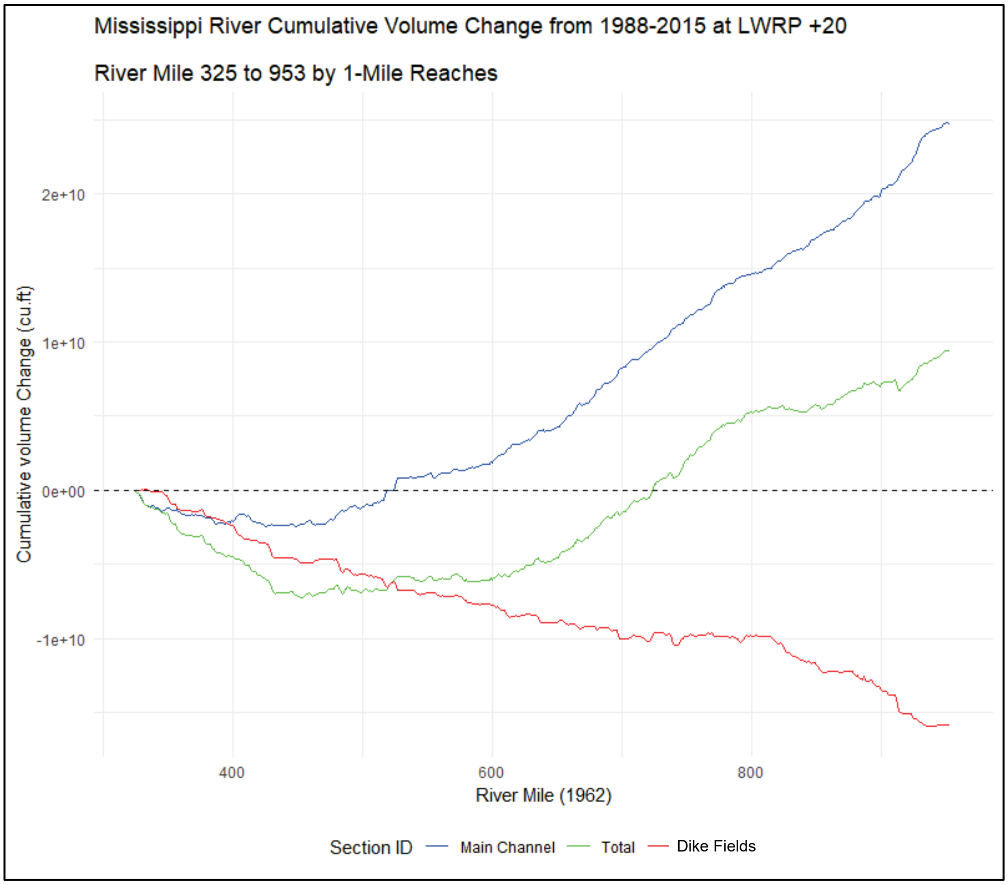
3.2 Volumetric analysis

In this section, the volumetric changes observed between the 1988 and 2015 surveys for the +20 LWRP elevation are presented.

The cumulative volume change plot between 1988 and 2015 from RM 325 to RM 953 is presented in Figure 9. The cumulative curve for the total channel, represented by the green curve, shows a constant negative slope from approximately RM 325 to RM 450. This suggests that the lower reach was depositional during the time period at a relatively constant rate. After RM 450, the slope of the total channel curve changes to a positive value and continues to the end of the study reach RM 953. The rate of change is not constant for this stretch but can be reduced into segments with similar rates. There are at least three noticeably different segments for the positive slope portion of the total channel curve including RM 450 to RM 615, RM 615 to RM 770, and RM 770 to RM 953. The lower segment from approximately RM 450 to RM 615 is characterized by a slight positive slope. This could be an indication of a transitional state between the depositional and erosional reaches. The reach from approximately RM 615 to RM 770 is characterized by a much steeper positive slope than all other portions of the curve. This suggests the reach is experiencing the most severe rate of degradation for the entire study reach. The upper segment from approximately RM 770 to RM 953 shows a positive slope that is steeper than the lower portion, but more gradual than the middle segment.

In a similar manner, the cumulative volume change curves can be developed and evaluated based by the delineated main channel (blue) and dike field (red) sections included in Figure 9. However, note that the calculations for dike fields in some reaches may be based on just a few cross sections, depending on the reach boundaries. While this is suitable for analyzing cumulative changes, it can have a tendency to over or under emphasize observed changes when making comparisons between individual reaches. As in the total channel curve, the dike fields and main channel sections can both be approximated as negative slopes from RM 325 to RM 450. This suggests that deposition was occurring in both sections of the channel during the time period. However, there are clear differences in the rates of change for the two sections within this portion of the reach. Comparing the slopes of the curves suggests the main channel was experiencing deposition at a much lower rate than either the dike fields or in the total channel.

Figure 9. Cumulative volume at LWRP +20 from 1988 to 2015 for LMR RM 325 to RM 953.



There are clear differences between the main channel and dike field curves when compared to the portion of the total channel curve characterized by the positive slope. The dike field curve is described by a continuous negative slope for the entire reach. This suggests the dike fields were generally experiencing deposition for the period, even in areas where the channel is gaining volume overall. The main channel curve is characterized by a positive sloping line from RM 450 to RM 953. There are slight similarities between the rate changes in the main channel and total channel, although far less pronounced in the main channel curve. This suggests the main channel section in the reach was erosional for the time period with the highest rate of change occurring between RM 600 to RM 953. The dike field curve from approximately RM 800 to RM 953 shows a significant increase in the rate of decline, which is also reflected in the total channel curve. Note that the approach is still limited by the survey quality and coverage available for a specific time period. This portion of the curve could be an indication of survey issues present in this section and therefore may not be a true representation of the change in volume between the two survey periods.

3.3 Overall trends

The summary of changes in cross-sectional area between the 1988 and 2013–2015 period for the total channel, main channel, and dike fields are presented in Tables 1-3. The data in Tables 1-3 reflect a total of 125 reaches approximately 5 miles in length. Each 5-mile reach was assigned one of five categories based on the predominant percent change that occurred over the period: (1) Sizable increase, (2) Moderate increase, (3) Negligible change, (4) Moderate decrease, and (5) Sizable decrease. A sizeable increase or decrease was assigned when the predominant percent change for the reach parameter was greater than 15% relative to the base year. A moderate increase or decrease was assigned when the predominant percent change for the reach parameter was between 5% and 15%. Negligible change was assigned when the percent changes were less than 5%.

The values in Table 1 represent the number of 5-mile reaches that meet a specific criteria based on the spatial location and category of change. In Table 1, each row represents the spatial location of the 5-mile reaches while the columns define the categories of change. As an example, the first row represents the 5-mile reaches located between RM 325 and RM 420. Based on the values for the row, the reaches located between RM 325 and RM 420 account for 19 of the 125 reaches. In a similar manner, the columns in Table 1 distinguish the reaches further based on the categories of change that occurred over the period. For example, the 5-mile reaches described by negligible change for the period and located between RM 325 to RM 420 account for 5 of the 125-reach total. Last, the dominant trends were determined for each row based on the proportion of reaches within each major category of change. For the row representing the 5-mile reaches located between RM 325 to RM 420, 14 of the 19 reaches experienced decreases for the period. As a result of this majority, the dominant trend observed from RM 325 to RM 420 was defined as a decrease in Table 1.

Table 1. Summary of changes in cross-section area between the 1988 and 2015 period for the total channel.

Reach Location (RM)	Geomorphic Regime	Increase			Decrease		Dominant Trend
		SI*	MI	NC	MD	SD	
325-420	Aggradation			5	13	1	Decrease
420-465	Sl. Aggradation		1	3	5		Decrease
465-565	Dynamic Eq.	1	8	8	2	1	Increase
565-615	Sl. Degradation		1	7	1		No Change
615-770	Degradation	12	14	5			Increase
770-953	Sl. Degradation	2	19	13	3		Increase
	Total Change	58 (46.4%)		41 (32.8%)	26 (20.8%)		

*SI: sizable increase; MI: moderate increase; NC: negligible change; MD: moderate decrease; and SD: sizable decrease.

As shown in Table 1, only 20.8% of the 125 reaches exhibited a decreasing trend in cross-sectional area for the total cross section. From the reaches that did show decreasing totals, approximately 19 of the 26 were located in the downstream reaches characterized by deposition and aggradation (RM 325–RM 465). In addition, Table 1 indicates that 79.2% of the reaches exhibited either no change or increases in the total cross-sectional area for the period. The greatest increases for the period were in the upstream reaches characterized by erosion and degradation (RM 615–RM 770) while the greatest variability was seen in the reaches transitioning from aggradation to degradation (RM 465–RM 565). The dominant trends determined for two of the reaches (RM 465–RM 565; RM 565–RM 615) did not align with the broader long-term trends documented in the specific gage analysis.

Table 2. Summary of changes in cross section-area between 1988 and 2015 period for the main channel areas.

Reach Location (RM)	Geomorphic Regime	Increase			Decrease		Dominant Trend
		SI	MI	NC	MD	SD	
325-420	Aggradation		2	11	6		No Change
420-465	Sl. Aggradation		1	7	1		No Change
465-565	Dynamic Eq.	4	6	9	1		Increase
565-615	Sl. Degradation	1	3	5			No Change
615-770	Degradation	11	19	1			Increase
770-953	Sl. Degradation	11	19	7			Increase
	Total Change	77 (61.6%)		40 (32%)	8 (6.4%)		

Similar to the changes in the total channel, the trends for the main channel areas showed that the reaches generally experienced increases or negligible change in cross-section area for the period, as shown in Table 2. However, 61.6% of the 125 reaches showed increases in cross-section area suggesting the dominant process in the main channel areas was degradation over the period. Within the main channel, only 6.4% of the 125 reaches showed a loss in cross-sectional area. Again, the few reaches that had a loss of cross-sectional area were primarily located in the downstream reaches characterized by aggradation. While the lower reaches generally show decreasing trends for the totals, the majority of the main channel areas were within the negligible category for the period.

Table 3. Summary of changes in cross-section area between 1988 and 2015 period for the dike field areas.

Reach Location (RM)	Geomorphic Regime	Increase			Decrease		Dominant Trend
		SI	MI	NC	MD	SD	
325-420	Aggradation	2	2	2	3	10	**Decrease**
420-465	Sl. Aggradation	1	1	3	1	3	**Decrease**
465-565	Dynamic Eq.	1	2	5	3	9	**Decrease**
565-615	Sl. Degradation	1	1			7	**Decrease**
615-770	Degradation	6	4	10	4	7	**Decrease**
770-953	Sl. Degradation	2	4	10	13	8	**Decrease**
	Total Change:	27 (21.6%)		30 (24%)	68 (54.4%)		

Table 3 presents the summary of changes in cross-sectional area for the dike field areas between the two surveys. Due to the high variability when comparing dike field areas, the limits were modified to establish more conservative ranges for each category. The category ranges for the dike field areas were identified as sizeable increase or decrease for percent changes greater than 25%, moderate increase or decrease for percent changes between 25% and 10%, and negligible change for percent changes less than 10%. As would be expected, the dike fields were much more prone to sediment deposition than the main channel areas. As shown in Table 3, 54.4% of the 125 reaches exhibited a loss in cross-section area while only 21.6% showed an increase in cross-section area. Reaches that showed no change in cross-section area accounted for nearly 24% of the 125 reaches.

4 Summary and Conclusions

The first objective in this study was the development of a database compiled with historical surveys and dike data for the Vicksburg and Memphis districts. The database currently includes data gathered from annual and comprehensive hydrographic surveys ranging from 1948 to 2015. Preliminary investigations of the survey data indicated that there were issues with survey coverage in many reaches, which, if not accounted for, would potentially produce questionable results. To evaluate the effects of dike structures on morphological trends of the LMR with confidence, it was determined that a complete quality control check must be performed on all of the data before a final assessment could be produced. However, it is believed that, after further examination, most of the problems with the database can be corrected or modified to ensure valid comparisons. For instance, there are other hydrographic surveys that can be added to the database to provide supplemental data for problematic areas and/or extend the temporal range of the analyses. Additionally, dike data gathered for the database currently include general construction information and can be further refined spatially and temporally to provide more insights into the relationships between dike construction and geomorphic trends. Although the database represents a major advancement in the ability to assess the morphologic trends in the LMR, it is still considered preliminary and should be viewed as a framework that can be further enhanced as the database continues to be expanded and improved upon.

With the foundation set, the next step was to develop and apply a reproducible methodology that used the database to assess long-term morphological trends. Although previous studies relied heavily on the approach defined by Cobb, there were concerns moving forward using the method. The approach used in this study was developed with the intentions of reducing the limitations and errors found in previous studies by focusing purely on quantitative data analysis. The approach utilized ArcGIS to extract bathymetric data from hydrographic survey TINs to compute geometric and volumetric parameters at various water surface elevations referenced to LWRP. The delineation applied in the approach was based on the channel improvement/alignment boundary set by USACE Vicksburg and Memphis districts. This provided a reproducible method for quickly and effectively defining main channel and dike field areas for the entire study reach. This reduced the uncertainty of manually defining channel areas based on specific, more qualitative channel characteristics. In addition, the method eliminated the need for individual templates based on specific dike systems, which simplified the process and extended the spatial range for the assessments. Although the approach alleviated some of the issues found in previous studies, there were still limitations associated with the quality and coverage of the hydrographic surveys available. For these reasons, the analyses in the study were only presented as a preliminary assessment to demonstrate the utility and efficacy of the database and the proposed methodology. A comprehensive assessment will be conducted as part of a subsequent effort and documented in a separate report, along with any refinements made to the original approach.

The analyses presented in the study focused on changes in the geometric and volumetric parameters between the 1988 and 2013–2015 hydrographic surveys from RM 325 to RM 953 along the LMR. The resulting changes over this period only refer to in-channel conditions and disregard changes associated with floodplain characteristics. Results presented in this study pertain specifically to the changes occurring in the total channel as well as the delineated main channel and dike field areas. The 1988 and 2013–2015 periods were selected with the purpose of minimizing the issues associated with survey coverage and channel pattern as much as possible. The periods compared still contained areas with survey issues, but the problematic reaches were considered negligible and did not seem to jeopardize the overall legitimacy of the broader trends found in the results.

An overall assessment of morphologic changes that occurred between the 1988 and 2013–2015 period was formed by integrating the results of the cross-section geometric data analysis and the volumetric data analysis. The recorded changes in the cross-sectional area and reach volume at +20 LWRP have shown trends mirroring that of the broader adjustments described by specific gage analysis for the LMR. Based on the overall trends between RM 325 and RM 953, approximately 79% of the reaches showed an increase or little change in cross-section area or volume for the total channel area between 1988 and 2013–2015. Those that did show a decrease were predominantly located in the downstream reaches characterized by aggradation. The dike field areas generally showed decrease or little change in the reaches over the period, regardless of the long-term system trends. In contrast, the majority of reaches showed increasing trends in the main channel section, with only 6% of the 125 reaches losing cross-section area for the period.

While there were indications that the dike systems were functioning as intended locally, there were no clear correlations identified between the linear feet of dikes constructed in a reach and the total channel response. This suggests that while the dikes are clearly having a local effect, with scour in the main channel and deposition in the dike fields, their association with the broader system-wide trends in aggradation and degradation is inconclusive. These results are preliminary and should be considered as one component of a systematic research program to assess the morphologic impacts of dike structures on the LMR.

5 Recommendations

- Conduct a comprehensive analysis using all of the data currently included in the database and provide measures of change with respect to other geometric parameters of importance, as a continuation of this effort.
- Expand database to include more historical surveys, many of which are in hard-copy form and may require digitizing.
- Add future surveys to the database as they become available.
- Conduct comprehensive quality control effort to identify problematic areas in the database and either correct the problems or remove from the database.
- Develop procedures to correct for situations where channel migration has occurred. With the current methodology, comparing older surveys (primarily 1960s and 1970s) to more recent survey years is sometimes problematic due to channel migration that may have occurred between surveys.
- Develop procedures to add the floodplain topography to the channel survey. This would allow for assessment of changes up to beyond-top-bank conditions.
- Enhance the methodology/template to incorporate more site-specific information (e.g., planform information, habitat characteristics, secondary channels, crossings, inside/outside bends, curvature, flow characteristics, dike fields).
- Extend the analysis to include shorter reaches and individual dike fields. The study described herein was a broad-scale study that focused on relatively long reaches.
- Expand the study to include water surface slope, which would allow for the quantification of stream power and shear stress trends, both of which are extremely important parameters related to sediment transport and morphologic change.

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Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (US statute)	1,609.347	meters
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters

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14. ABSTRACT

A phased study of the dike fields within the Vicksburg and Memphis Districts of the US Army Corps of Engineers was conducted to document the channel morphology trends since dike construction on the Lower Mississippi River (LMR). This included the development of the hydrographic survey database and methodology utilized to identify changes in channel geometry in response to dike construction. A subsequent report will provide further refinements to the approach and results of the comprehensive assessment.

Recent Mississippi River Geomorphology and Potamology program efforts have employed the database developed by Mr. Steve Cobb to assess the geomorphic changes in 21 dike systems along the LMR. Previous studies using this database have indicated that the dike fields have not caused a loss of channel capacity. Furthermore, these efforts suggested that the trends in the dike fields are closely related to the long-term geomorphic trends along the LMR. Previous efforts using the Cobb database provided considerable insight into the dike effects on the LMR, but they were limited spatially and temporally. In this study, a database and protocols were developed to allow for a more robust assessment of dike field impacts and to extend the spatial and temporal extents of the analysis.

15. SUBJECT TERMS

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