Effects of Dike Fields on Channel Characteristics of the Lower Mississippi River

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Abstract

Dike fields were initially constructed along the Lower Mississippi River (LMR: Cairo, IL to below Natchez, MS) in the late-1950s through the early-1970s to control channel alignment and to maintain a 9-ft deep low-flow navigation channel. Dike construction and extension continue to the present day. This study combines an empirical analysis of 35 dike fields along the Lower Mississippi River (LMR) with 2D numerical-modeling experiments of a single dike system (three adjacent dike fields) to evaluate the role of dikes on channel characteristics and water-surface elevations. Using time-series surveys at 21 dike systems, as well as stage and discharge observations, this study shows that the dikes function as intended, and that is to maintain a navigable low-flow channel that exceeds the minimum 9-ft depth requirement at low flow. We find no evidence that the dike fields alone increase flood discharges and bank-full elevations, as proposed by other researchers. The marginal increases in water-surface elevations at the highest modeled flow, 1,275,000 cfs (approximating bankfull) in 1973 and 2013 indicate that the impact of the dikes themselves on water-surface elevations are minimal, if not within survey and model error. The spatial and temporal trends of channel adjustments along LMR are largely attributed to the meander-cutoff program (1929-1942), which shortened the reach by about 45%, leading to upstream incision and downstream aggradation. Other engineering activities such as levees, revetments, and dam construction have contributed to long-term, broad adjustment processes on the LMR. Adjustments to main-channel depth at +0 Low Water Reference Plane (LWRP), and total channel depths and cross-sectional areas at +35 LWRP (at or near bankfull) indicate that dikes assist with maintenance of a uniformly deep, navigable channel. On average, bankfull discharges today are about 20% greater than before the cutoff program and roughly equivalent to the post-cutoff values of the late 1950s when dike construction began. Results of 2D numerical modeling of a dike system between Vicksburg and Natchez show marginal differences in water-surface elevations with and without dikes.

Discussion of Study and Results

This paper is an abridged version of a much larger report by the same authors produced for the U.S. Army Corp's Engineer Research and Development Center (Simon et al., in press). That study provides copious details of the empirical and numerical-modeling aspects of the research to determine the role of dike fields on channel characteristics and flood stage on the Lower Mississippi River (LMR) (Figure 1).

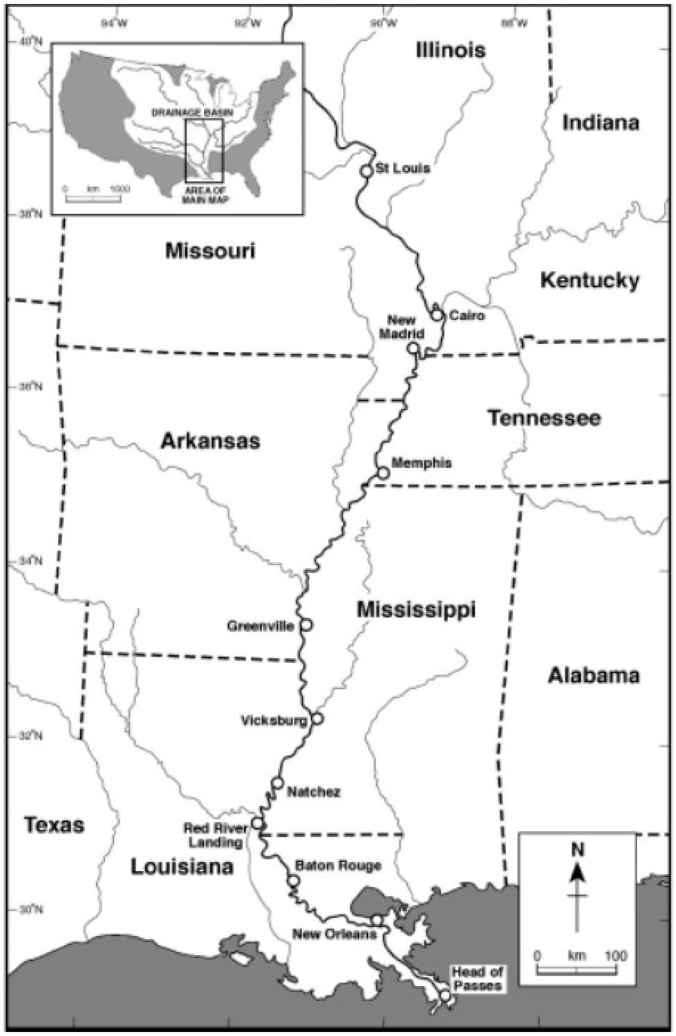

Figure 1. General location map of the Lower Mississippi River (LMR), considered to extend below Cairo, IL.

The LMR is a dynamic alluvial river that has been subjected to a range of environmental and anthropogenic factors that have resulted in spatial and temporal adjustments to its channel characteristics. These include, but are not limited to, floods and sustained high flows, the meander-cutoff program, installation of revetments, maintenance dredging, construction of levees, and the closing of dams on the Missouri River and other major tributaries. Dikes represent still another anthropogenic factor imposed on the river. These structures were designed to increase and maintain main-channel depths by constricting or contracting flow and thereby increasing the ability of the river to entrain and transport sediment in the main-channel section of the river. The primary purpose was to maintain a navigation channel 300-ft wide by 9-ft deep, therefore, reducing the need for maintenance dredging.

This study focused on the effects of the 21 dike systems (composed of 35 individual dike fields) constructed along the LMR. Morphologic data were available from the late-1950s through the mid-2010s. Results pertain to changes over this period and only to in-channel conditions, excluding floodplain characteristics and any imposed changes there.

Empirical Analysis of the 21 Dike Systems:

As an alluvial river, the Mississippi, like any other responds to changes in the balance between the amount and character of the hydraulically-controlled sediment (sand-sized material and coarser) delivered from upstream, and the transport capacity of the flow in a given reach. Because of the myriad of imposed in-channel factors and the river's subsequent responses, it is often difficult to isolate the effects of a single factor. Such is the case with the dike fields and dike systems. Interpretation of morphologic data in these reaches was placed in the context of broader adjustments operating along the river. Winkley (1977), Biedenharn et al. (2015), and others clearly describe the far-reaching effects of the meander-cutoff program on temporal and spatial trends of aggradation and degradation in the LMR. Thus, recorded changes in the total conveyance (at the +35 Low-Water Reference Plane Elevation, approximately bankfull; LWRP) in the dike-system reaches likely reflect the broader adjustment trends described by specific-gage analysis (Biedenharn et al. 2015).

Conveyance at a fixed reference elevation such as the +35 LWRP is indicative of the ability of the river to transmit water at that water-surface elevation. Changes in conveyance with time thus reflect the influence of anthropogenic changes imposed on the LMR as well as any adjustments to those changes (e.g. responses to the cutoff program, etc.). Not surprisingly then, total conveyance was shown to decrease by about 20% from pre-dike conditions to the mid 2010's in those downstream reaches characterized by deposition and aggradation (between about RM 375 to RM 450). With distance upstream in the adjacent, reaches (RM 490 to RM 546), changes in total conveyance shift from small decreases (-4% to -7%) to small increases (+7%) in the equilibrium reach, and then show up to 10% increases further upstream in the erosional reach. From the qualitative interpretation of the longitudinal trends in total conveyance with documented changes in specific-gage elevations, the dike systems appear to have little effect on total conveyance at +35 LWRP. Today, the greatest conveyance along the LMR occurs in the transitional zone and not at the furthest point downstream.

Changes in main-channel depth and main-channel boundary shear stress, however, provide a more useful metric in determining the effect of the dike systems on channel characteristics. Measures of main-channel depth, which are primary metrics to evaluate the effectiveness of the dike fields, show significant increases at both +0 and +35 LWRP. Compared to pre-dike and base conditions at +0 LWRP, the average increase in main-channel depth for all of the studied dike systems was 32.5% and 35.3%, respectively. Results show general increases in main-channel depth even in the downstream depositional areas. This is an indication that the dike systems are having their intended effect on deepening of the main channel. There are indications of greater increases in depth in some sub-reaches of the erosional zone compared to the aggradational and transitional reaches. This suggests that the effects of the dike fields may be being enhanced by the larger-scale erosional conditions within these reaches.

Based on the most recent surveys conducted in the mid-2010s, main-channel depths at +0 LWRP range from a maximum of 40.5 ft at the Catfish dike system (RM 568) to a minimum of 21.1 ft in the Above Loosahatchie dike system (RM 742). On average, the main-channel at +0 LWRP for the surveyed dike systems was 27.6 feet, indicating that main-channel depths in the dike-system reaches have been maintained well above the minimum 9-ft value required. This result, in combination with general indications of significant increases in main-channel depth, support the premise that the dike systems have been largely effective at increasing and maintaining main-channel depths above the 9-ft requirement that is stipulated for the navigation channel along the LMR.

Similar to changes in main-channel depths, changes in average boundary shear stress reflect the increases in depth, resulting in average increases from base conditions of about 9 and 17% for the whole channel and main channel at +35 LWRP, respectively. These changes indicate that transport capacity has increased in both the whole-channel cross section and within the main channel over the survey periods. This provides further evidence that overall, sediment-transport capacity in the main-channel sections have increased since the dike systems were constructed.

Summaries of how specific channel characteristics have changed throughout the LMR are provided for general reference. Here, we bring together data on how characteristics of the entire channel have changed relative to pre-dike (Table 1) and to base-year conditions (Table 2). Data on changes relative to pre-dike conditions are not available for several dike systems and, therefore, these cells are left blank in Table 1.

Table 1. Summary of changes in total-channel characteristics at +35 LWRP relative to pre-dike conditions.

Dike System	Location (RM)	Change in Depth	Change in Cross-Sectional Area	Change in $AD^{2/3}$	Change in Discharge	Change in Slope	Change in Conveyance	Change in Shear Stress
		(%)	(%)	(%)	(%)	(%)	(%)	(%)
Waterproof	377	-2.5	6.4	7.6	-16.0	9.6	-21.8	9.7
Bondurant	392	-6.4	1.5	-1.1	-9.4	15.8	-20.7	0.4
Marshall Cutoff / Forest Home	448							
Baleshed	490	-7.5	-13.4	-15.2	-2.2	4.4	-4.1	-15.2
Wilson Point	498	3.3	-6.7	-12.1	-4.4	2.4	-5.4	-4.6
Lower Cracraft	507	5.7	-34.7	-26.9	-6.1	1.0	-6.6	-3.3
Island 86	518	13.4	-14.9	-4.4	-2.4	3.2	-3.6	3.8
Ashbrook	546	21.3	-1.4	8.1	-10.5	-12.6	-6.5	7.5
Chicot	560	20.3	-5.2	13.0	-5.0	-22.3	6.8	29.6
Catfish	568	14.7	3.3	13.4	-5.9	-22.8	7.3	-14.4
Island 70	607	0.4	-35.6	-30.2	4.6	3.2	4.8	10.1
Island 62/63	638							
Cat Island	708	18.1	-2.5	12.8	11.2	3.5	5.8	39.8
Dismal	721							
Above Loosahatchie	742	22.6	-5.3	10.4	14.6	2.8	9.9	28.5
Randolph	747	9.7	10.7	21.2	11.4	3.0	6.9	6.9
Densford	755	8.6	1.7	12.3	7.9	1.8	7.1	12.9
Forked Deer	798	4.3	-0.6	7.7	6.2	2.7	0.2	6.3
Island 25	803	-8.0	9.2	9.0	3.9	1.6	-2.1	11.6
Wrights Point	819	1.8	-7.8	-1.3	7.7	3.3	1.9	4.5
Pritchard / Island 1	944							
Average		**7.0**	**-5.6**	**1.4**	0.3	0.0	**-1.2**	**7.9**
Standard deviation		**10.2**	**-2.5**	**14.8**	8.8	10.1	**9.3**	**14.5**

Table 2. Summary of changes in total-channel characteristics at +35 LWRP relative to base-year conditions.

Dike System	Location (RM)	Change in Depth	Change in Cross-Sectional Area	Change in $AD^{2/3}$	Change in Discharge	Change in Slope	Change in Conveyance	Change in Shear Stress
		(%)	(%)	(%)	(%)	(%)	(%)	(%)
Waterproof	377	-2.4	6.3	7.4	-15.8	9.4	-21.4	9.5
Bondurant	392	-6.3	1.4	-1.0	-9.2	15.3	-21.0	0.4
Marshall Cutoff / Forest Home	448	-14.1	-38.3	-42.3	-9.6	-6.9	-7.8	-19.5
Baleshed	490	-7.3	-12.9	-14.6	-2.1	4.2	-3.9	-14.6
Wilson Point	498	3.3	-6.6	-11.9	-4.3	2.4	-5.3	-4.5
Lower Cracraft	507	5.5	-34.1	-26.4	-6.0	1.0	-6.4	-3.2
Island 86	518	12.4	-13.5	-4.1	-2.3	2.9	-3.4	3.7
Ashbrook	546	19.5	-1.3	7.5	-9.8	-11.8	-6.1	6.9
Chicot	560	19.8	-5.1	12.7	-4.9	-22.0	6.6	28.7
Catfish	568	14.3	3.2	13.0	-5.8	-22.4	7.1	-14.1
Island 70	607	0.4	-33.7	-32.0	4.7	3.2	4.9	9.2
Island 62/63	638	24.9	-24.0	-6.4	6.4	0.4	9.4	24.9
Cat Island	708	17.3	-2.4	12.3	11.0	3.5	5.7	37.9
Dismal	721	17.2	18.6	35.0	6.3	3.4	1.8	17.2
Above Loosahatchie	742	21.3	-5.0	9.8	13.8	2.7	9.3	26.6
Randolph	747	9.1	10.0	19.9	10.8	2.8	6.6	6.5
Densford	755	8.1	1.6	11.7	7.5	1.7	6.7	12.2
Forked Deer	798	4.1	-0.5	7.4	5.9	2.6	0.2	6.0
Island 25	803	-7.7	8.6	8.8	3.7	1.6	-2.0	11.1
Wrights Point	819	1.7	-7.5	-1.3	7.3	3.1	1.8	4.3
Pritchard / Island 1	944	20.4	18.3	36.7	2.3	1.7	7.6	31.7
Average		**7.7**	**-5.6**	**2.0**	0.5	0.0	**-0.5**	**8.6**
Standard deviation		**11.2**	**-2.4**	**19.7**	8.2	8.9	**8.9**	**15.4**

The effectiveness of the dike fields and dike systems in maintaining main-channel depths and reducing the need for maintenance dredging is supported by the inverse relation between the amount of dredging and the cumulative length of constructed dikes along the LMR (Figure 2). Maintenance dredging which peaked in the late-1960s at more than 60 million yd^3 in the Memphis, Vicksburg and New Orleans Districts, has decreased to about 10 million yd^3 in the 2000s. This coincides with the ever-increasing length of dikes starting in the late-1950s and continuing through to the present day.

In summary, it can then be concluded that the dike systems are functioning as intended to provide for greater sediment-transport capacity, main-channel flow depths, and reduce the need for maintenance dredging. Longitudinal trends in total channel depths and cross-sectional areas at +35 LWRP (at or near bankfull) indicate that dikes assist with maintenance of a uniformly deep, navigable channel. Cases where total conveyance has decreased appears to be the result of longer-termed, broad adjustment processes related to other factors along LMR. Finally, to quantify the specific hydraulic and sediment-transport effects of the dike systems independent of the broader responses of the LMR, two-dimensional hydraulic modeling should be conducted. This deterministic approach, combined with data on bed-material composition would provide compelling evidence of the effects of the dike systems on channel characteristics of the LMR.

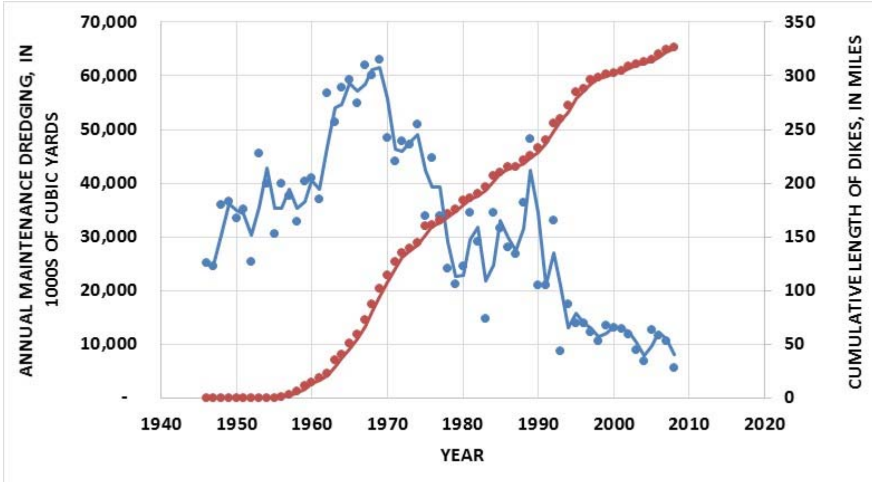

Figure 2. General inverse relation between annual maintenance dredging and the cumulative length of dike fields (in red) along the LMR. Trend lines are two-point moving averages. Data from Biedenharn, written comm. (2018).

Role of Dike Fields on Water-Surface Elevations via Two-Dimensional Numerical Modeling:

One of the central questions of this part of the work was to ascertain the direct role of dikes on water-surface elevations, particularly at the higher flows. This was critical because in much of the empirical analysis reported earlier in this report, it was very difficult to separate channel adjustments that could be attributed exclusively to the dikes due to all of the things imposed on the LMR. Here however, two-dimensional numerical experiments using AdH provided a framework for separating out these causes. The 13-mile model reach is aggradational, situated about halfway between Natchez and Vicksburg, MS (RM 393 to RM 406). Starting in the mid 1970's and continuing over a span of about 26 years, eleven dikes (three dike fields) were installed in the model reach (Figure 3). Following calibration for the *No Dike* and *With Dikes* conditions, simulations were conducted for five years where surveys were available: 1973 (Pre-Dike), 1977, 1988, 2004 and 2013.

Results show marginal increases (0.6 to 0.8 ft) in water-surface elevations between 1973 and 2013 at the highest modeled flow, 1,275,000 cfs (approximating bankfull), indicating that the impact of the dikes themselves on water-surface elevations are limited, if not within survey or model error. This conclusion can be clearly seen in viewing the difference in water-surface profiles at 1,275,000 cfs that show (Figure 4):

- Marginal differences between the 1973 *No Dike* and the 1973 *With Dikes* (hypothetical) scenarios, without and associated channel adjustment (Figure 4, Top);
- Marginal differences between the 2013 *No Dike* (hypothetical) and 2013 *With Dikes*, using channel geometry after 40 years of adjustment on the LMR (Figure 4, Middle); and

- Relatively small differences (< 1 ft) between the 1973 *No Dike* and the 2013 *With Dikes* condition, representing channel adjustments due to both the dike fields (which are shown to be marginal) and overall channel adjustment (aggradation) in this part of the LMR (Figure 4, Bottom).

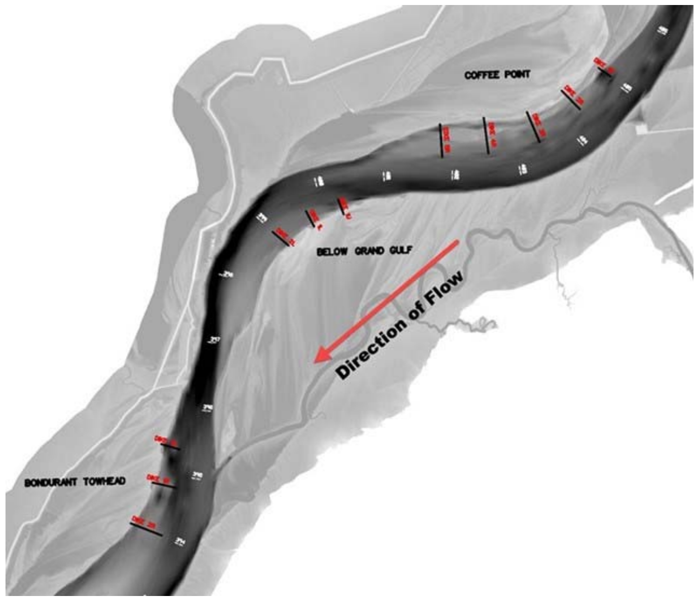

Figure 3. Overview of model reach showing the three dike fields after installation of all dikes by 2001.

The increases in peak water-surface elevations over the 40 years represented by the 2D simulations can be mostly attributed to broad, systematic channel-adjustment processes active in this section of the LMR. The impact of the dike fields at 1,275,000 cfs is quite small in comparison. The influence of the dike fields on increasing water-surface elevations does increase with decreasing discharge (and flow depth). These results are applicable to this dike system in an aggradational reach of the LMR. Additional research in a degradational reach of the river is merited to test whether these conclusions are applicable under those circumstances as well.

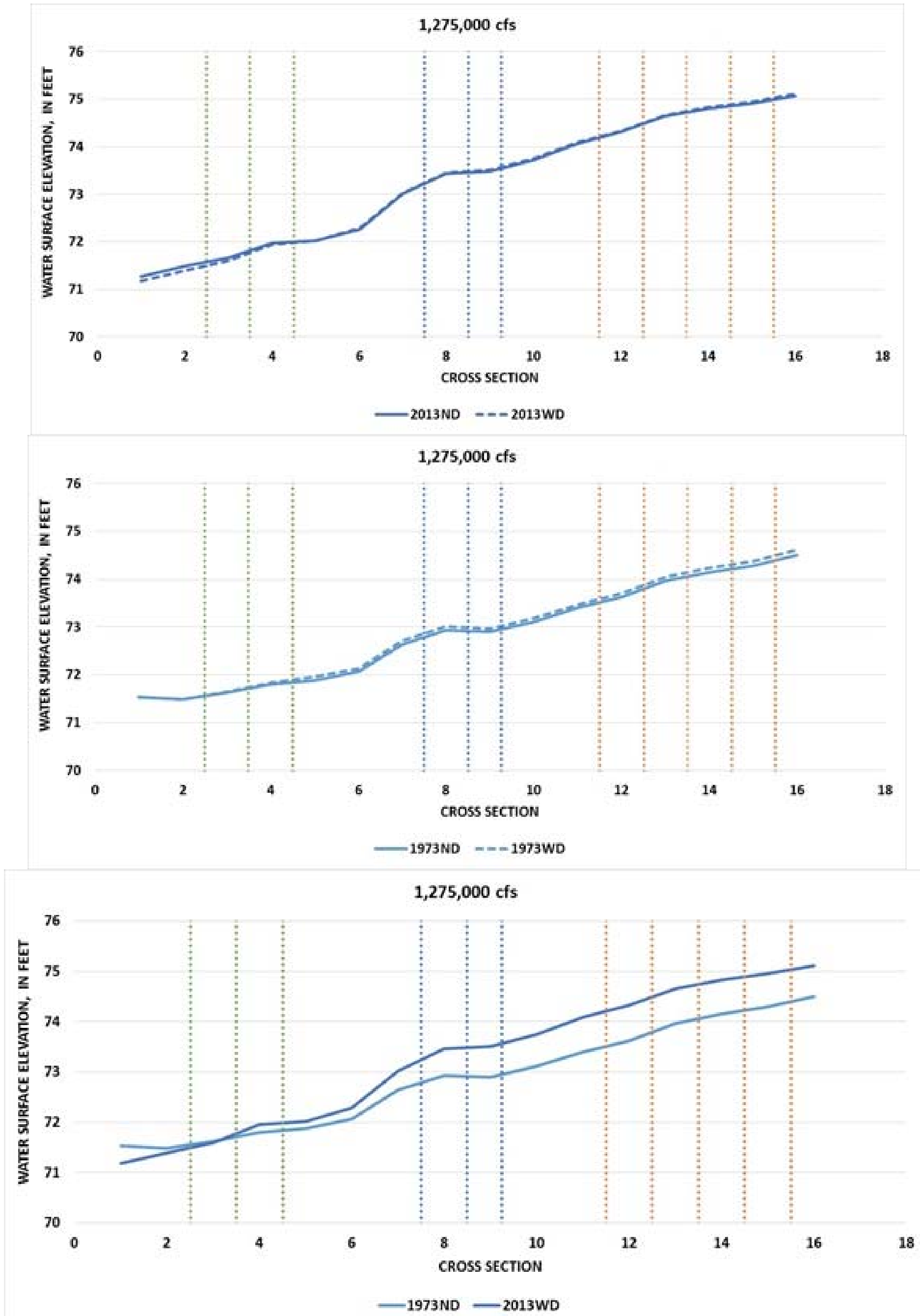

Figure 4. Marginal differences in water-surface profiles between 1973 *No Dike* and 1973 *With Dikes* scenarios (Top) and between 2013 *No Dike* and 2013 *With Dikes* scenarios (Middle); and Small differences between 1973 *No Dike* and 2013 *With Dikes* (Bottom). The upper two plots show differences due solely to the dike fields while the Bottom plot shows difference due to the dike fields and overall channel adjustment (aggradation) in this part of the LMR.

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