Appendix N

Future With Project Model Projections

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US Army Corps of Engineers
Kansas City District

Missouri River Bed Degradation Study

Technical Appendix

Future With Project Model Projections

DQC DRAFT 01 FEB 2017

1. Introduction

The purpose of this appendix is to document the degradation projections conducted in conjunction with the Missouri River Bed Degradation Feasibility Study for the Future With Project condition. The model creation and calibration process are described in the *Missouri River Bed Degradation Study Mobile Bed Model Calibration Appendix*. Model parameters and boundary conditions are all the same as for the Future Without Project analysis, as described in the previous appendix.

Analysis for nine alternatives are presented in this appendix. Each alternative includes of three structural actions, indicated by a number designation, and one of three dredging (channel mining) conditions, indicated by a letter designation.

2. Structural Actions

The three structural actions are listed in Table 1. Additional measures and alternatives were considered but eliminated from further analysis, including sediment augmentation of varying amounts and sizes, bed armoring, and other iterations of structure modifications and grade control. These were eliminated for various reasons including early sensitivity tests showing little response in bed elevations, interference with authorized uses such as commercial navigation, and other reasons. Further discussion of the eliminated measures can be found in the project report.

Table 1. Description and Structural Actions

Structural Action	Description
1	No Structural Action – Future Without Project Condition
4	Lower the dike portion of the dike structure and excavate land from RM 391 to 449 to – 5 CRP for 200 feet landward of the rectified channel line.
5	Bed sill grade control structures (crest at -11 from the 1973 CRP) from RM 393.63 to 443.39.

Structural action 4 (Figures 1 and 2) consists in lowering the BSNP dike and sill structures to -5 CRP from the rectified channel line (RCL) to 200 ft landward of the RCL, including land excavation where necessary. This action applies from St. Joseph, Missouri (RM 449) to the Platte River (391). In addition to the benefit to bed degradation, this action slightly improves channel conveyance, which may have a positive benefit for flood protection. This option also creates approximately 1400 acres of shallow aquatic habitat.

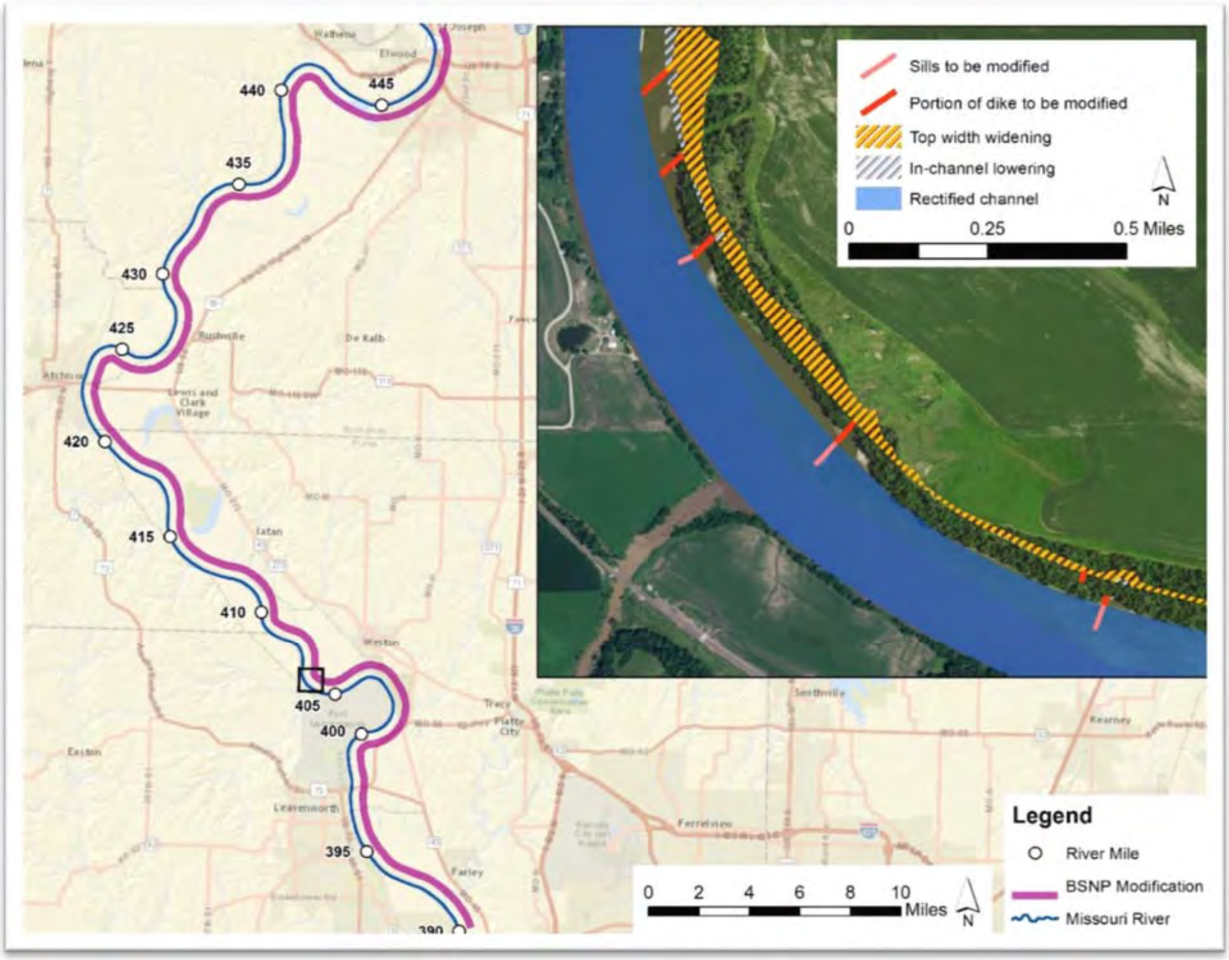

Figure 1. Geographic extent of Action 4.

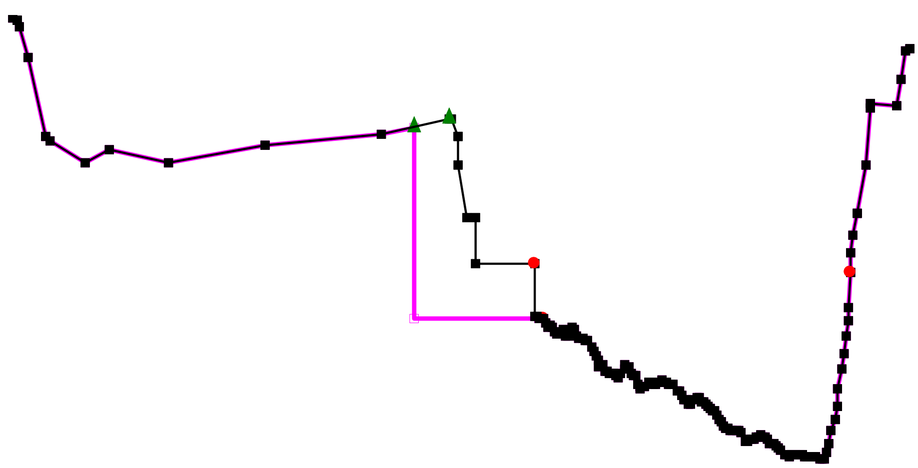

Figure 2. Example cross-section for Structural Action 4 (Dike and Sill Lowering) in magenta compared to Structural Action 1 (No Structural Changes) in black.

Action 5 (Figure 3) consists in building low-head grade control structures from RM 443 to RM 409. This appendix presents the modeling results for 6 structures, which are sufficient to demonstrate the effectiveness. As explained later in this appendix, between 37 and 38 structures are required to maintain the navigability of the river.

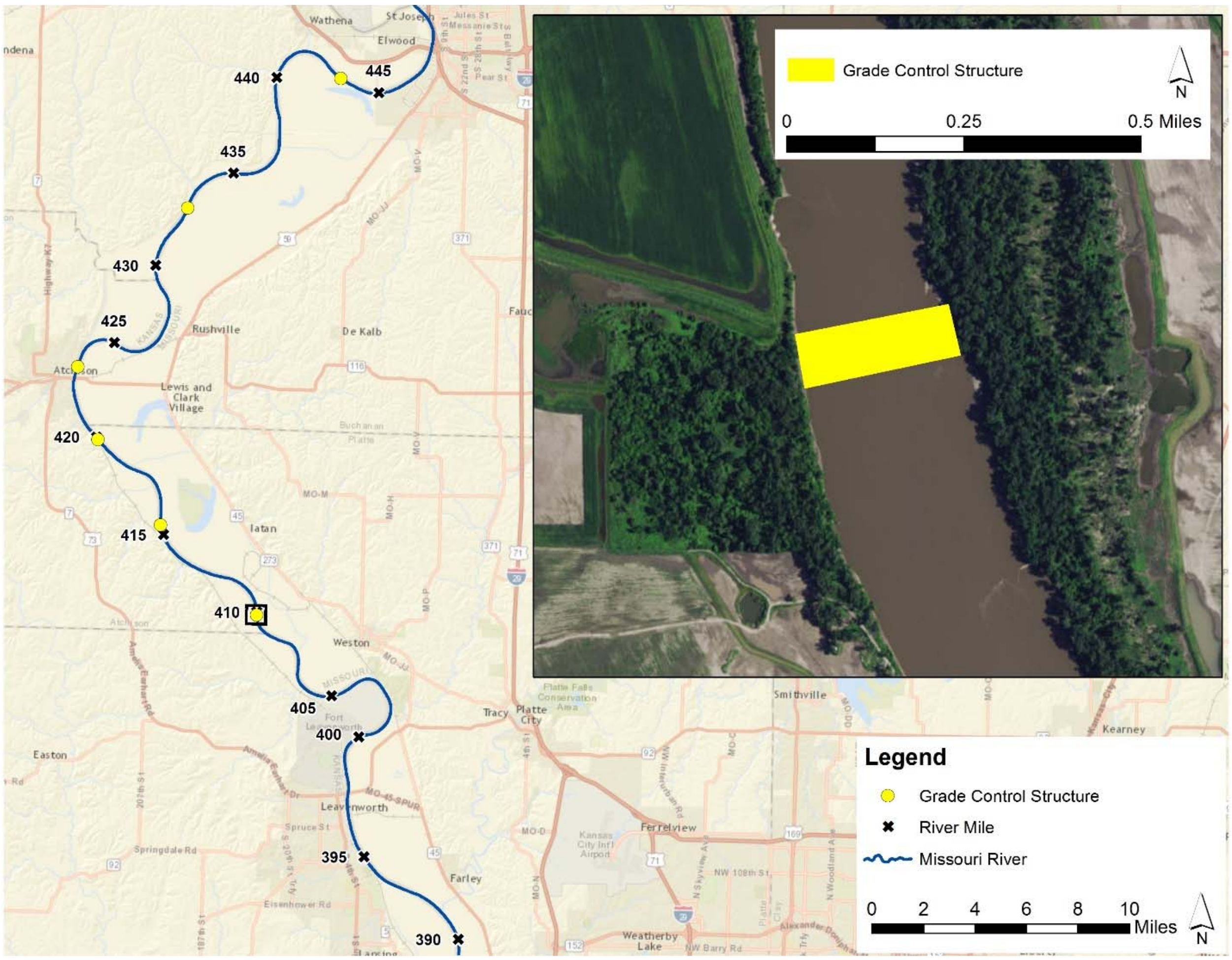

Figure 3. Geographic extent of Action 5. The six modeled structures are indicated.

The grade control crests are set to 11 ft below the 1973 CRP with a 450 ft crest width, as indicated in Figure 4. (Note: the heights are set based on the NGVD elevations for the 1973 CRP, which differ from the NAVD 88 datum used for the rest of the by about 0.3 ft.) The structures transition from the native bed elevation upstream of the structure to the crest elevation at a 5:1 slope, maintain a flat crest for 100 ft, then descend at a 50:1 slope, as depicted in Figure 5.

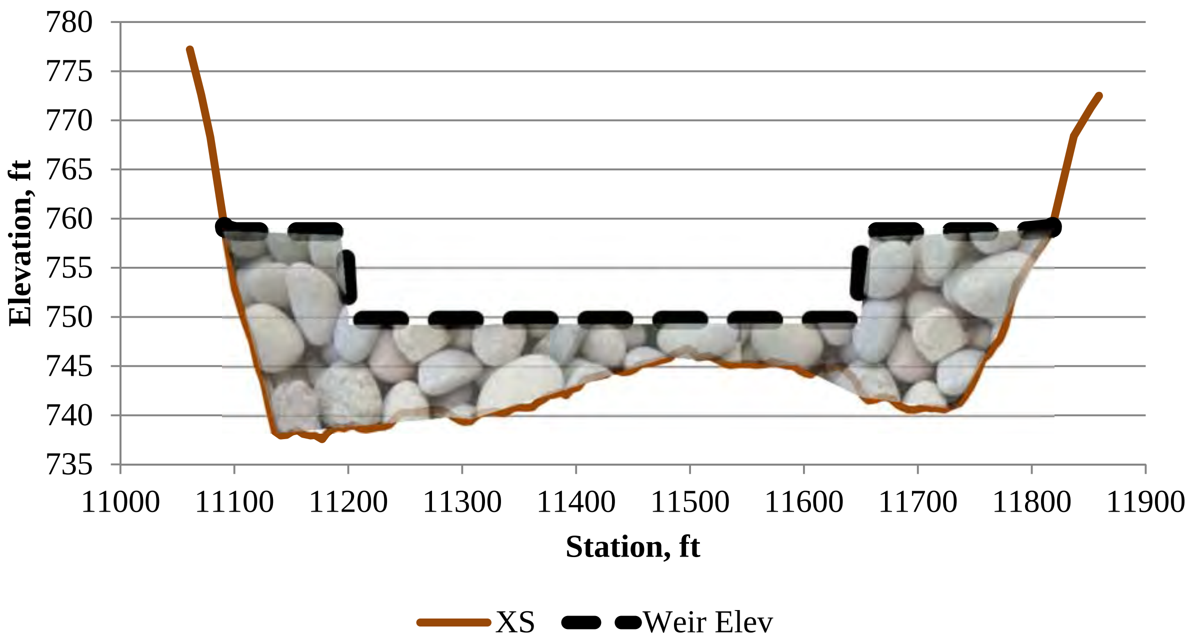

Figure 4. Action 5. Cross-section and profile of grade control structure at RM 407.19. Top of rock indicated by dashed line.

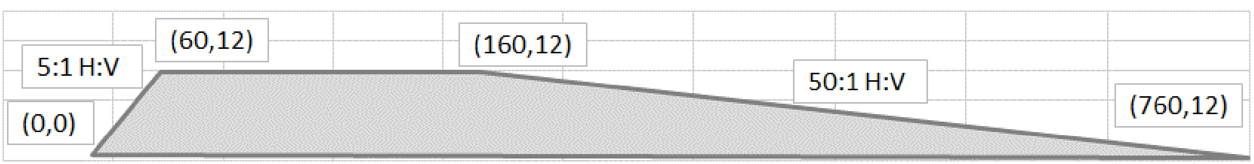

Figure 5. Action 5. Grade control structure profile. River stations correspond to structure at RM 407.19.

The structures are designed to return the low water surface profile to pre-degradation levels and prevent further upstream headcutting. The channel constriction allows 9 ft of depth over the structures at navigation discharges. The gentle slope on the downstream side of the structure allows fish passage and reduces the impact on navigation. For purposes of sediment modeling, the grade control structures were modeled as inline structures. This was not intended as a final design of the structures, but rather an assessment of the effectiveness of the structures in preventing bed and water surface degradation.

3. Dredging Conditions

In this appendix, the term "dredging" is used to indicate channel mining. The three dredging conditions included in project alternatives are listed by dredging reach (as defined in the 2011 dredging EIS) in Table 2.

Table 2. Dredging Conditions Included in Alternatives

Dredging Reach	Dredging Condition (tons/year)		
	A- Baseline Dredging	B- Reduced Dredging	C- No Dredging
St. Joseph* (RM 391 to 450)	330,000	0	0
Kansas City (RM 357 to 391)	540,000	451,367	0
Waverly** (RM 294 to 357)	1,730,430	305,765	0
Total (RM 450 to 294)	2,600,430	757,133	0

*All the St. Joseph dredging is assume to occur within the model space.
** The full Waverly reach extends to RM 250. The dredging amounts in this table correspond to the model space only.

The locations and relative magnitudes of dredging from 2010 to 2015 establish the distribution of dredging within each dredging reach for modeling purposes. Dredging condition A is the Future Without Project scenario based on the currently permitted level of commercial dredging, as defined by the 2015 permit record of decision (USACE 2015b). It includes a "ramping up" period until 2020 (described in the Future Without Project Appendix) and the steady annual value thereafter listed in Table 2.

Dredging condition B is a reduced level of dredging based on the stable dredging rate computed via the sediment budget analysis provided in USACE 2015. The USACE (2015) analysis suggests a river-wide annual limit of 2,417,000 tons per year over the lower 498 miles of river. Using the same tons/mile rate equates to 753,133 tons from St. Joseph to Waverly. In dredging condition B, the St. Joseph tonnage is shifted to Kansas City which minimizes degradation in St. Joseph. The same "ramping up" period in dredging condition A is assumed until 2020. The reduced tonnages are assumed to take effect starting in 2021.

Dredging condition C eliminates dredging in all three modeled reaches, starting in year 2021. It includes the same "ramping up" dredging until 2020 as in dredging condition A and B.

Structural Actions 1, 4, and 5 were combined with dredging conditions A, B, and C to yield nine alternatives (1A, 1B, 1C, 4A, 4B, 4C, and 5A, 5B, 5C.) The following section summarizes the effects of degradation for each alternative in 5-mile reaches and at the end of 50 years to indicate overall differences and trends. As with the Future Without Project, degradation outputs provided to the economic model are computed based on the two bounding cross sections (not averaged over 5 miles) and are provided as the minimum elevation in each year (not only at the end of 50 years).

4. Degradation Response with Respect to Current Bed Elevations

Figures 6 to 9 present the model projections for bed elevation at the end of the 50-year simulation. These projections are given with respect to 2015 (i.e. after one year of model spin-up). Figure 6 compares three structural measures at the currently permitted dredging level at the end of the 50-year simulation. Alternative 1A represents the FWOP.

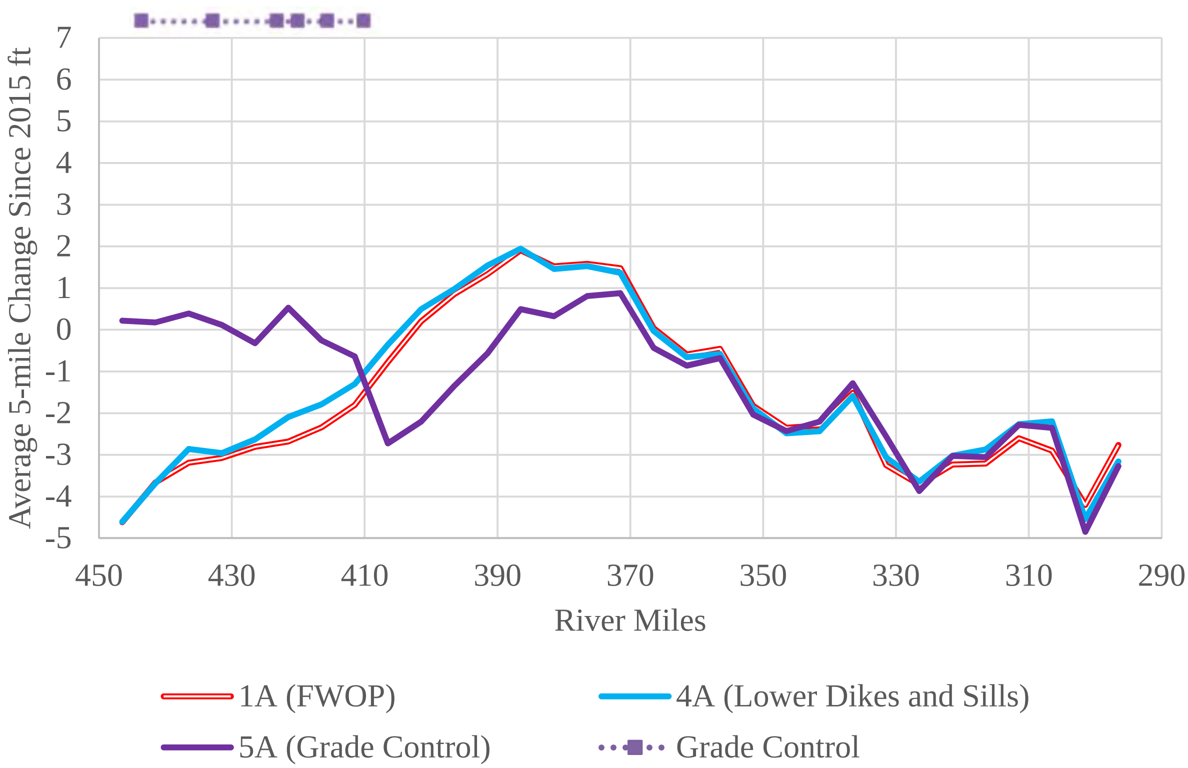

Figure 6. Degradation projection for year 2065 under three structural measures and the baseline dredging condition (Alternatives 1A, 4A, and 5A), compared to the 2015 bed elevation levels.

As shown in Figure 6, Alternative 4A (dike and sill lowering) is only slightly better than taking no structural action in terms of long-term degradation. As this, the most extensive dike lowering structural measure, prevents so little long-term degradation, the more moderate dike lowering measures (2 and 3) were not modeled. This also confirms that the model choice of not "dynamically adjusting" dikes over the calibration time period introduces only minor error. Alternative 5A (grade control) effectively stabilizes the bed upstream of the grade control structures. This will prevent significant damages in the vicinity of St. Joseph, Missouri. However, as seen in Figure 6, Alternative 5A shifts the degradation to downstream of the most downstream grade control structure. The effect of the shifted degradation decreases with distance downstream, but induces a more degraded condition in Kansas City than would be realized under the Future Without Project alternative (1A).

Figure 7 compares the three structural measures at a reduced dredging level at the end of the 50-year simulation. Alternative 1A (FWOP) is added for reference.

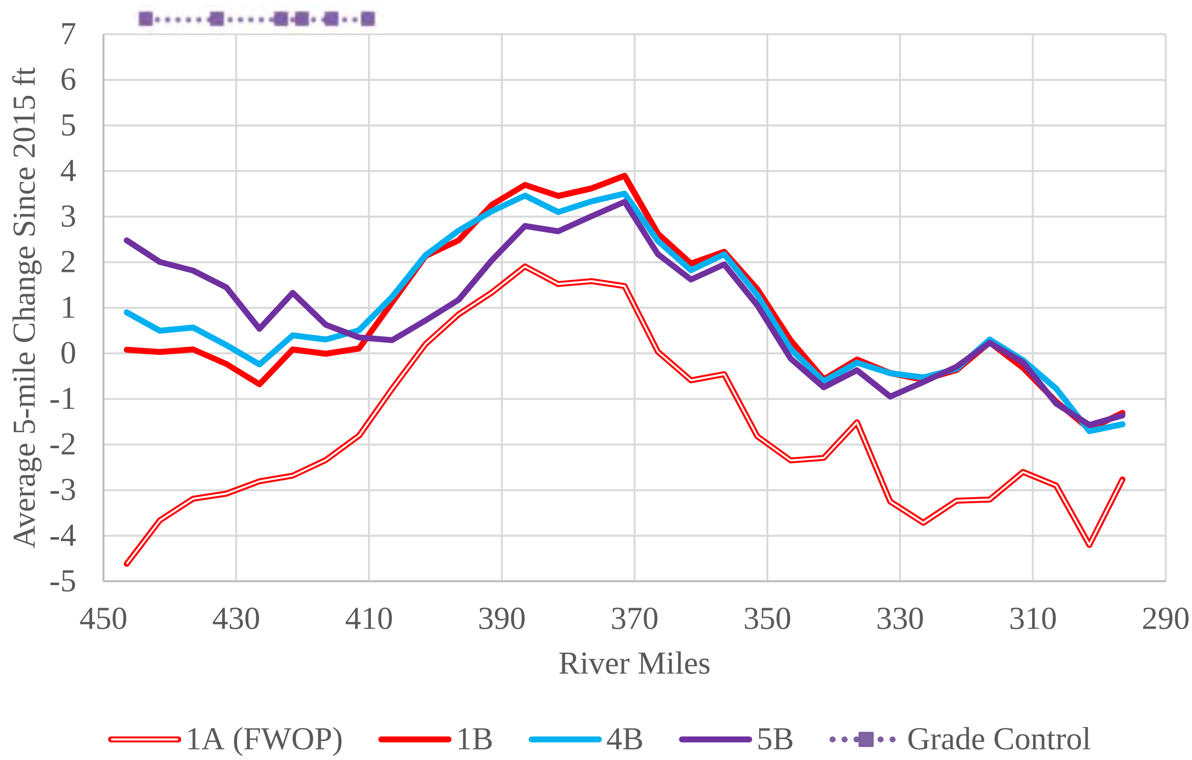

Figure 7. Degradation projection for year 2065 under three structural measures and a reduced level of dredging (dredging condition B). Alternatives 1B, 4B, and 5B.

As shown in Figure 7, Alternatives 1B, 4B, and 5B result in significantly less degradation for compared to the FWOP. Again, the structural action of lowering the dikes and sills is only very slightly better than no structural changes. The impact of reducing dredging (as evidenced by comparing Alternative 1B to 1A) is very significant, with approximately 4.5 ft of degradation prevented by a reduction in dredging at St. Joseph and nearly two feet over the rest of the model space.

Alternative 5B (grade control at a reduced dredging level) provides significant stabilization near St. Joseph, MO, resulting in nearly 2 ft of bed recovery rather than the 4.5 ft of degradation seen in the FWOP. This grade control alternative still shifts degradation downstream, but the effect is offset by the reduced dredging level, such that the degradation is not significantly worse than in the FWOP condition immediately downstream from the final grade control structure. The abrupt drop in bed elevation downstream from the most downstream structure may be a navigation impediment—an effect which is discussed later in this appendix.

Figure 8 compares the three structural measures at the no dredging level at the end of the 50-year simulation. Alternative 1A (FWOP) is added for reference.

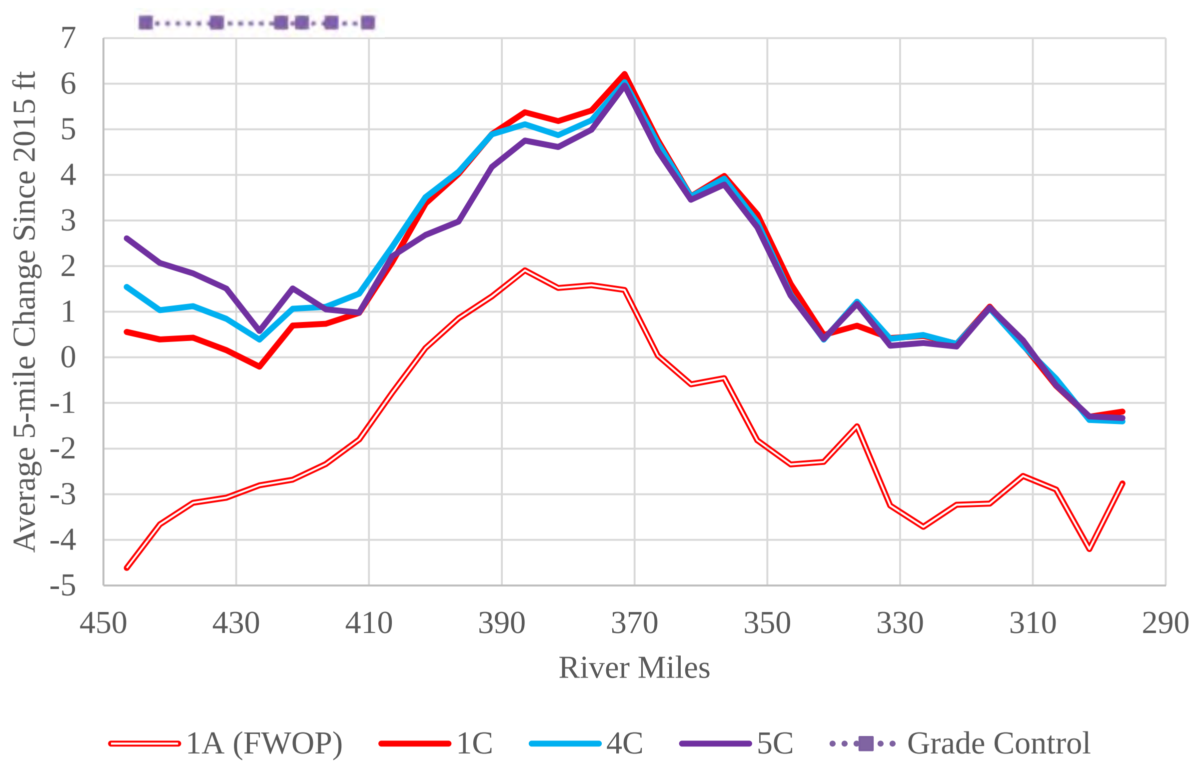

Figure 8. Degradation projection for year 2065 under three structural measures and no dredging (dredging condition C). Alternatives 1C, 4C, and 5C.

As shown in Figure 8, Alternatives 1C, 4C, and 5C result in very significantly less degradation for most of the model space compared to the FWOP. Again, the structural action of lowering the dikes and sills is only slightly better than no structural changes. The impact of eliminating dredging (as evidenced by comparing Alternative 1C to 1A) is very significant, with approximately 5 ft of degradation prevented by a reduction in dredging at St. Joseph.

Alternative 5C (grade control at the no dredging level) provides significant stabilization near St. Joseph, MO, resulting in approximately 2.5 ft of bed recovery rather than the 4.5 ft of degradation seen in the FWOP. This grade control alternative still shifts degradation downstream, but the effect is more than offset by the elimination of dredging, such that the degradation is less than in the FWOP condition immediately downstream from the final grade control structure. No abrupt drop is evident in Figure 8, but this will be analyzed more fully later in this appendix.

The previous plots indicate the ineffectiveness of dike lowering for the prevention of long-term degradation. The grade control options effectively protect infrastructure in St. Joseph by shifting the degradation downstream.

Figure 9 presents model projects with no structural action under the three dredging conditions. As seen, dredging reduction or elimination is sufficient to significantly reduce degradation and increase bed recovery in all of the model space. The overall level of degradation and bed recovery is strongly a function of the level of dredging. Note that the "reduced dredging" scenario includes the cessation of dredging in the St. Joseph reach, a slight reduction in the Kansas City reach, and a large reduction in the Waverly reach.

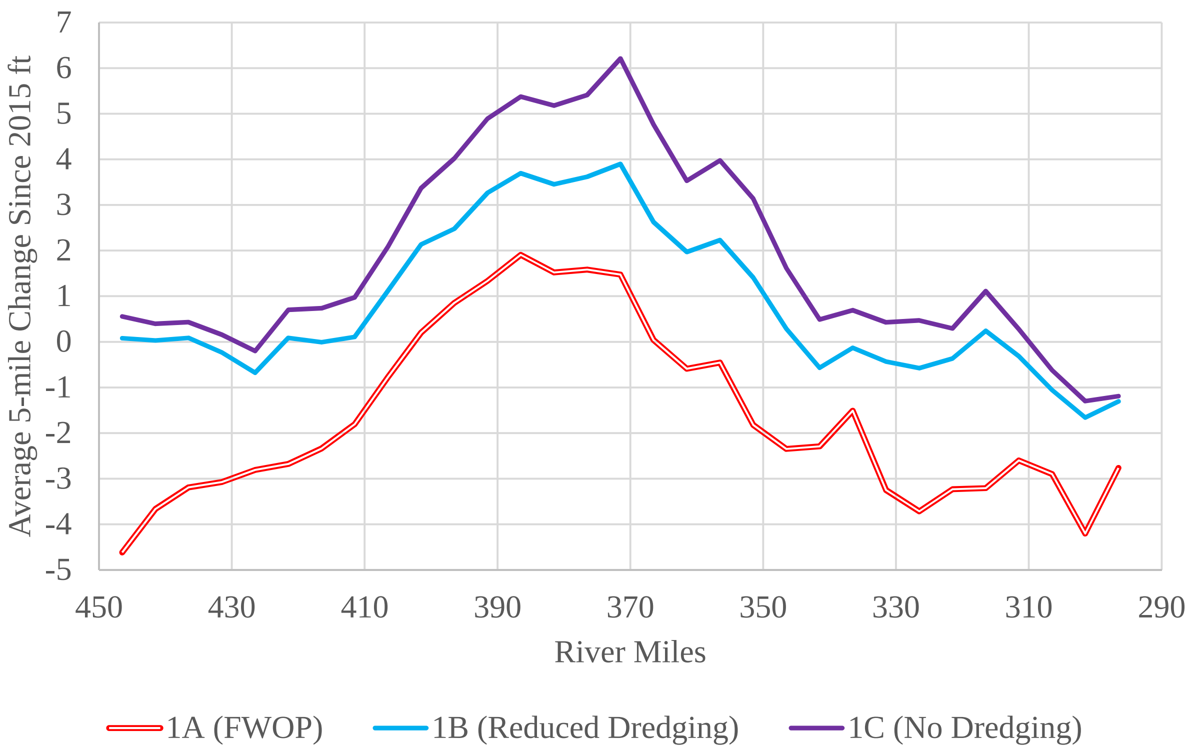

Figure 9. Degradation projection for year 2065 with no structural action under three dredging conditions.

Figures 10 – 12 plot the model projections over time, averaged into three large reaches. Measured bed elevations from 1987 to 2014 are provided for historical context. Note that in all models for years 2015 to 2020, the dredging level is set to permitted levels as of December 2015. Differences in dredging conditions start in year 2021.

Figure 10 compares model projections for RM 392 to 448. Consistent with previous figures, Figure 10 indicates only a slight benefit from structural action 4 (dike and sill lowering) compared to action 1 (no structural action). Grade control effectively stabilizes the bed, which represents a large difference under dredging condition A (as currently permitted), but a much smaller difference at dredging conditions B and C (both of which eliminate dredging in the St. Joseph reach). Potential bed recovery in this reach is still far below the 1987 bed elevations.

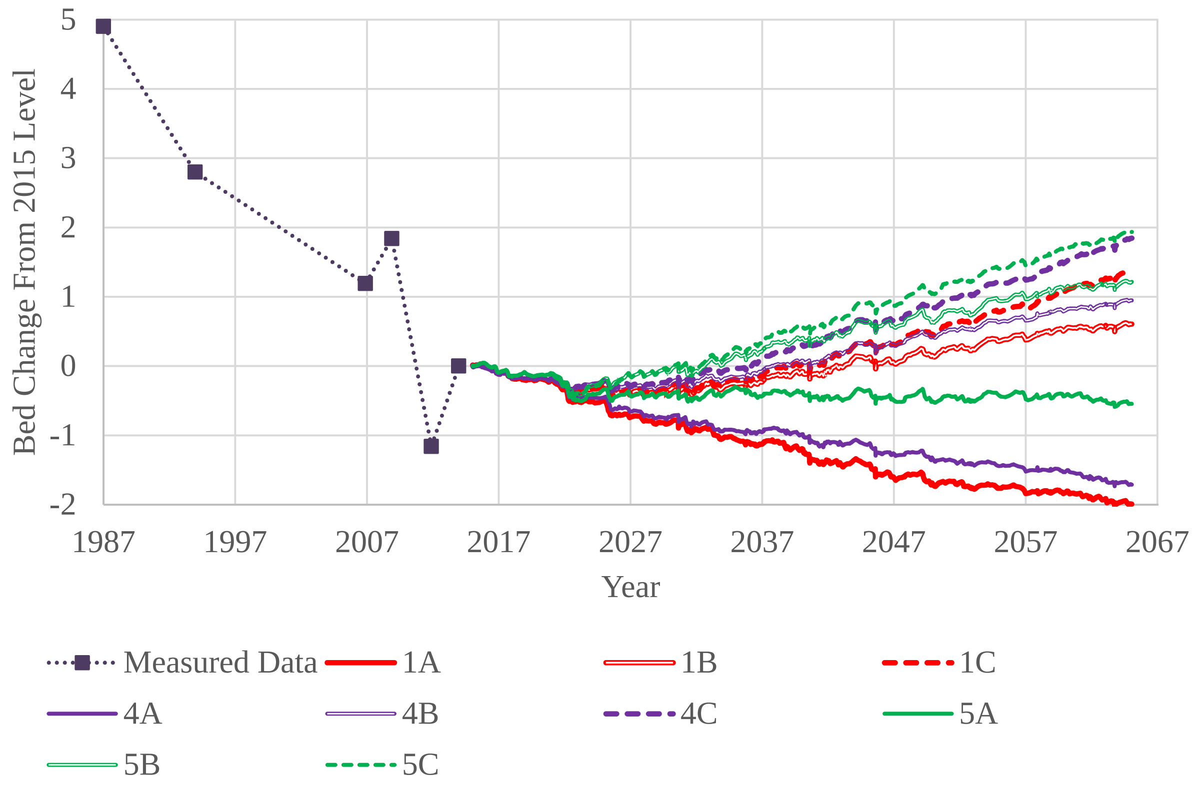

Figure 10. Bed Elevation Changes from RM 392 to 448 Over Time. This reach encompasses the St. Joseph metro area and is where the structural actions are located.

Figure 11 compares model projections over time for RM 350 to 391, which encompasses the Kansas City metro area. As expected, structural actions that prevent the hydraulic component of degradation in the upstream reach lead to lower bed elevations in this reach. Less sediment erodes from the upstream bed which decreases the incoming load to this reach.

As seen in Figure 11, in the future without project condition (Alt 1A) the model projects slight bed recovery in Kansas City until about the year 2022, then a return to a degradational trend. The new degradational trend is caused by upstream migration of the degradation induced by dredging operations downstream of Kansas City. As expected, Alt 4A, which prevents a very slight amount of degradation upstream (see Figure 10), equates to slightly less bed recovery in Kansas City than the FWOP (Alt 1A). Likewise, Alt 5A, which prevents more substantial degradation upstream, results in nearly a foot less bed recovery in Kansas City.

Alt 1B (no structural action, reduced dredging) yields bed recovery to just above the 1994 bed elevations by the end of 50 years. Alt 1C (no structural action, no dredging) yields bed recovery to elevations between the 1994 and 1987 bed elevations. The amount of bed recovery is strongly a function of the level of commercial dredging. By the end of 50 years, none of the model projections for any alternative indicate a bed fully recovered to 1987 levels.

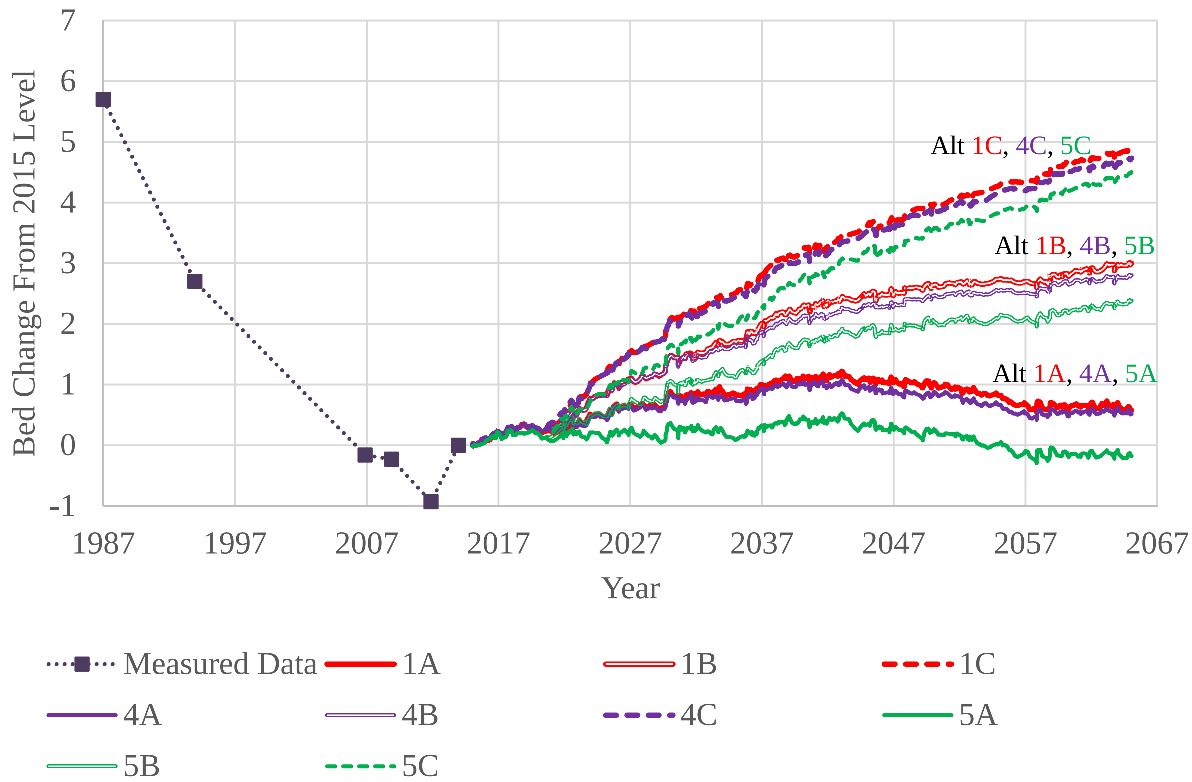

Figure 11. Bed Elevation Changes from RM 350 to 391 Over Time. This reach encompasses the Kansas City metro area and is downstream from the structural actions.

Figure 12 compares alternatives over RM 294 to 349, the most downstream reach. The structural actions occur sufficiently far upstream from this reach that they have minimal effect on this most downstream reach. However, this reach is very sensitive to the dredging condition. At dredging condition B (reduced dredging), this reach is generally stable at 2015 bed levels. At dredging condition C (no dredging) slight recovery is expected but the bed remains well below the 1987 levels.

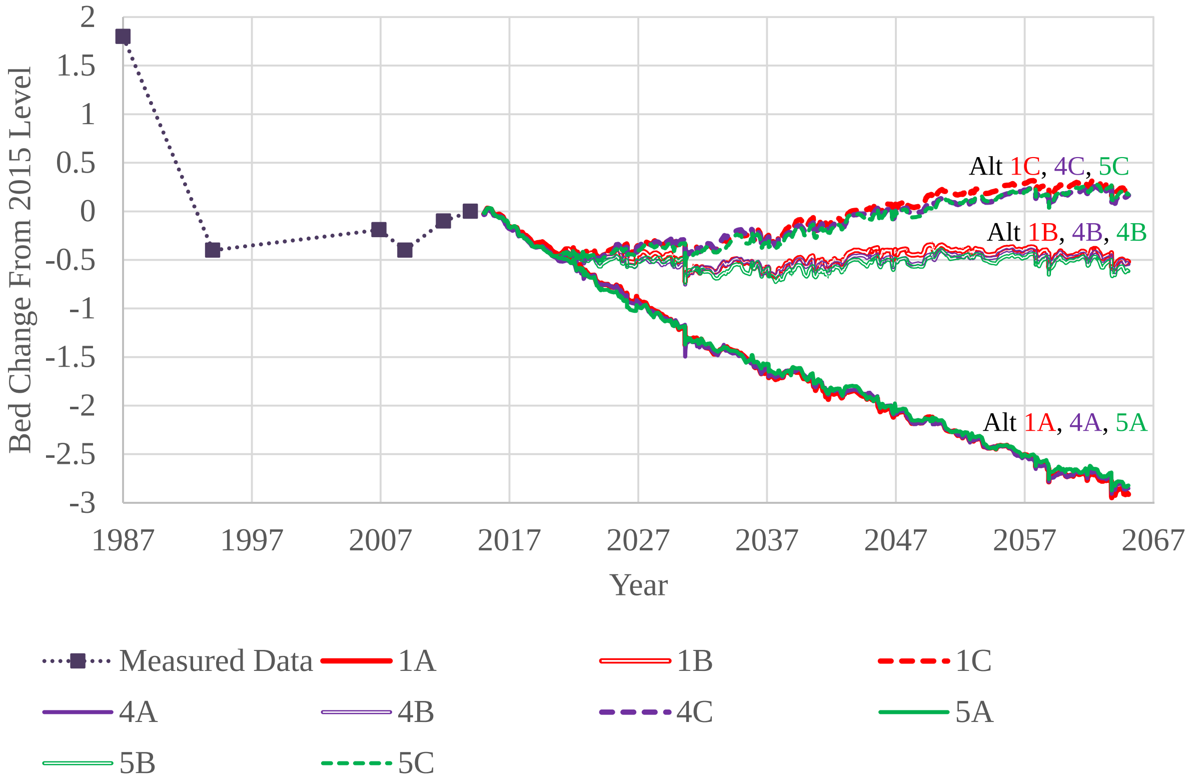

Figure 12. Bed Elevation Changes from RM 294 to 349 Over Time. This reach is the most downstream reach modeled.

5. Navigation Considerations for Grade Control Structures

Navigability over the grade control structures proposed in Action 5 was assessed by modeling the minimum service navigation flow water surface profile at the start and end of the 50-year simulation period (Figure 13). The model indicates a drop in water surface over each structure ranges from 1.2 to 3.8 ft at the start of the simulation period. While these structures are effective at arresting degradation, drops of this magnitude over individual structure lengths may pose a navigation impediment. Intermediate structures are needed to minimize the drop over each structure. At the end of 50-years, the drop over the upstream structures has increased only slightly, but the drop over the most downstream structure has increased to 6.6 ft, which requires additional structures. The number of additional structures needed for navigability depends on the ability of barges to navigate up the increased velocities caused by a drop over the grade control structure which depends on a myriad of factors including the characteristics of the towboat itself as well as both the number of barges and the weight of the cargo. Detailed analysis on this point was not conducted. Rather, 1 ft of allowable drop was assumed. It is possible that this level of drop still negatively impacts the navigation industry.

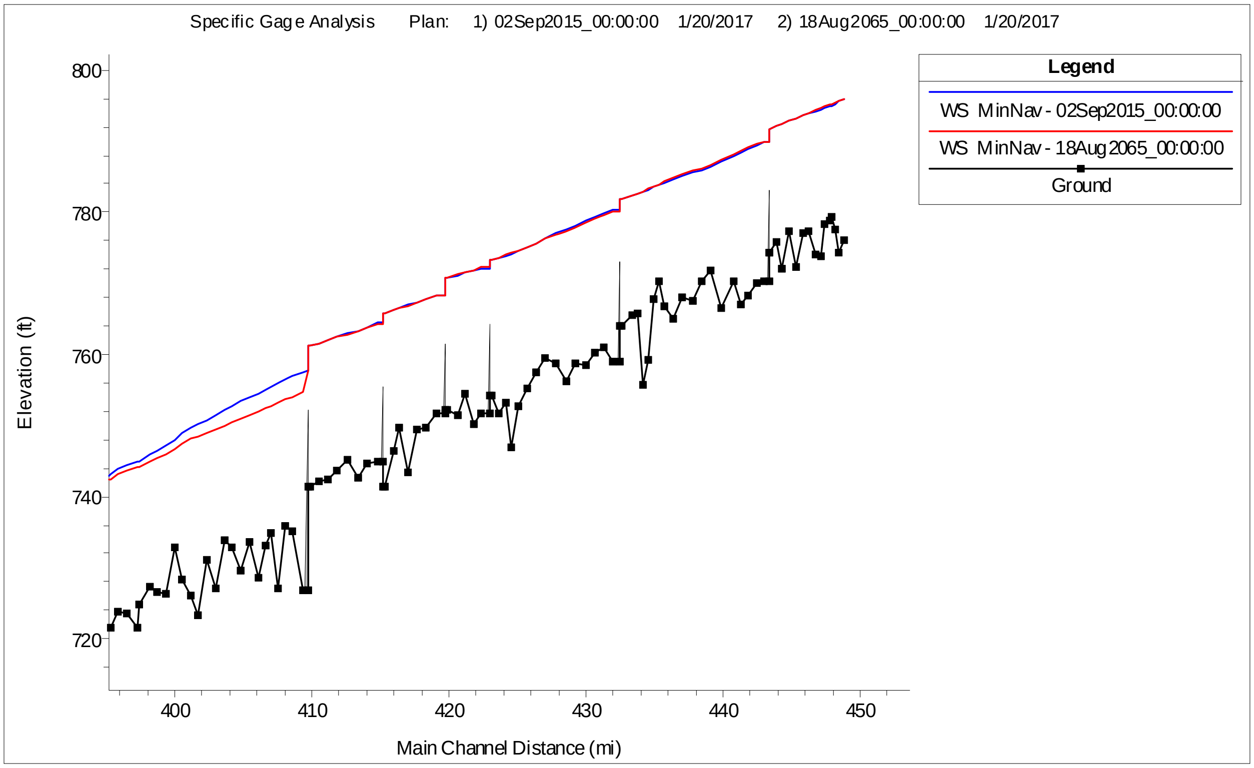

Figure 13. Alternative 5A- Water Surface Profile for Minimum Service Navigation Flows in Year 2015 and 2065 Showing The Initially Modeled 6 Structures. Upstream is on the right of the graph.

In order to maintain the required 9 ft of depth at navigation flows and to limit the drop over any structure to a 1 ft maximum, it is necessary for backwater from each structure to extend up to the base of the next upstream structure. This would require 31 structures from RM 410 to 443. (Additional structures are needed downstream of RM 410, as described in the next paragraph.) This number of structures would fundamentally change the character of the river to a series of slack-water pools and rapids when discharges are at or below minimum navigation flows. At higher flows the effect of the structures diminishes. The drop over the most downstream structure at the start of the simulation can be smoothed by installing three additional structures with decreasing crest heights, as shown in Figure 14.

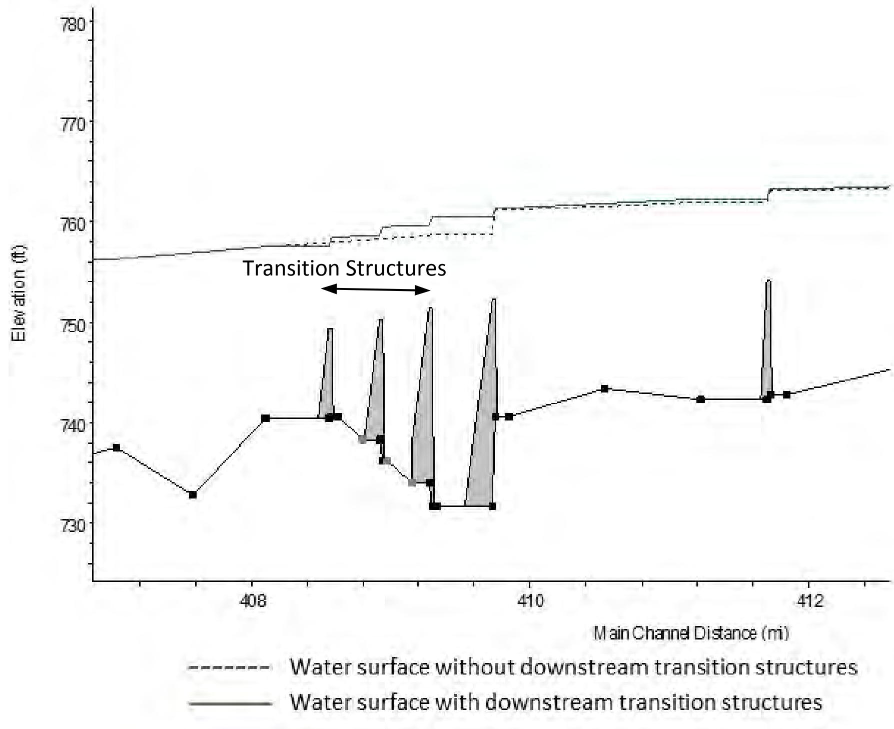

Figure 14. Additional structures to smooth the drop over the downstream structure at the start of simulation. Upstream is on the right of the graph.

Over time, the drop over the most downstream structure increases because the upstream channel is protected while the downstream channel is not. This reduces the degradation in the protected reach, which reduces the sediment supply to the downstream reaches. The degradation is effectively shifted to channel downstream from the structures. Additional structures will be required as the drop over the most downstream structure continues to grow.

The rate of growth of this final drop is a function of the level of commercial dredging. Figure 15 plots the drop over the most downstream structure in Alternative 5A, 5B, and 5C. These alternatives include identical grade control structures but varying dredging levels. As seen in Figure 15, the drop over all three structures grows to 6 ft in all three scenarios because all scenarios include dredging at the 2015 permitted levels through 2020. After 2020 the effects of different dredging levels begin and over time influences whether the drop continues to increase or whether the drop decreases. For purposes of limiting the drop to no more than 1 ft over the most downstream structure, the number of structures needed in the downstream transition for Alternatives 5A, 5B, and 5C are 6, 6, and 7 respectively. The total number of structures required for these grade control alternatives becomes 37, 37, and 38 for Alternative 5A, 5B, and 5C, respectively. In Alternative 5A, degradation continues beyond the 50-year period, requiring additional structures to be built which have not been quantified. Under reduced or eliminated dredging (Alternatives 5B and 5C), the downstream channel recovers sufficiently that additional structures are not required.

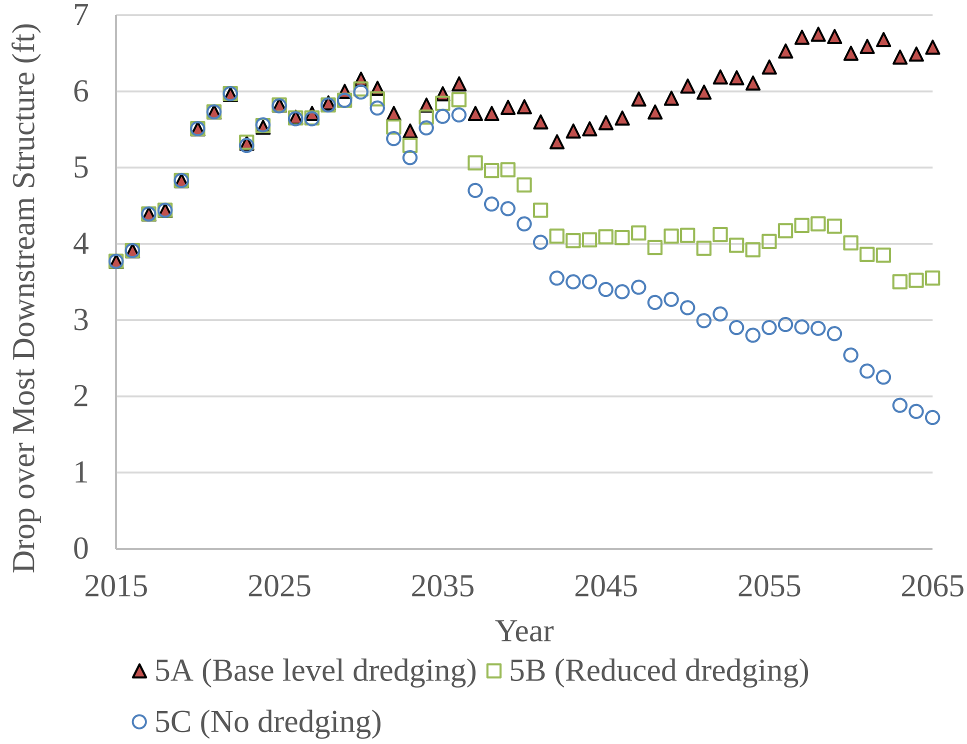

Figure 15. Water surface drop over the most downstream grade control structure under three dredging scenarios

This look at navigability indicates that 37 – 38 structures are required to reduce the water surface drop over any structure to a maximum of 1 ft. It is possible that a 1 ft drop is still too large to avoid navigation impacts and that even more structures would be required.

6. Bed Recovery in Kansas City

Figure 11 demonstrated the degradation trend in Kansas City (see also Figures 13 and 14 in the Future Without Project appendix.) Two major factors have reversed the recent trend of bed degradation trend in Kansas City to a trend of bed recovery. First, the 2011 Record of Decision (USACE 2011) reduced the allowable dredging in Kansas City from the peak of 4.9 million tons in 2002 (which included extraction for federal levee L385) to 500,000 tons/year. The significant effect that decreases in dredging quantity has on bed elevation is evident in the Future Without Project appendix, Figures 24 and 25 and in Figure 9 of this appendix. Second, the flood of 2011 caused the zone of degradation to headcut upstream (see Figures 13 and 15 in the Future Without Project Appendix) which supplies additional sediment to the reach downstream of the headcut (in this case, to the Kansas City reach). As demonstrated previously, by the end of 50 years, none of the model projections for any alternative indicate a bed fully recovered to 1987 levels.

Bed degradation and bed recovery primarily impact low water elevations but do impact flood heights to a lesser extent. During floods, the active channel conveys a relatively smaller proportion of flow, which causes flood elevations to be less affected by bed elevation changes. In the longer-term, a degrading bed induces geomorphic changes such as channel narrowing and vegetation recruitment on bars which somewhat offset conveyance gains from bed degradation. The reverse is also true. Bed recovery causes a small decrease in hydraulic conveyance in the short term. In the long term, channels may widen and newly recruited vegetation may be inundated, die, and eventually erode away, which somewhat offsets the conveyance loss. Historically, flood heights have increased despite the lowering of the bed, which makes it difficult to correlate changes in flood heights with changes in the elevation of the active bed.

This mobile-bed model was developed to project long-term trends for bed and low flow water surface elevations. For long-term degradation projections, levee over-toppings, timing of tributary inputs, and other unsteady flow effects during large floods are insignificant. These factors become important, however, for predicting flood heights. The Kansas City District has developed additional modeling tools which include these effects and would be appropriate for assessing future flooding scenarios. This assessment has not been undertaken as part of the Degradation Feasibility Study.

7. Future With Project Modeling-- Conclusion

This technical appendix documents the effectiveness of the intermediate array of alternatives for reducing Missouri River degradation. The degradation projections use the base-case conditions as defined in the Future Without Project appendix. The intermediate array of alternatives includes four structural actions (1-no structural action, 2-sill lowering, 3-dike lowering, 4-dike and sill lowering, and 5-grade control). Of these, actions 1, 4, and 5 were modeled. Actions 2 and 3 are similar to action 4, but of a lesser magnitude.

Structural actions 1, 4, and 5 were paired with one of three dredging levels (A-as currently permitted, B-reduced dredging, and C-no dredging) to yield nine modeled alternatives. Model results found the dike lowering/channel widening alternatives ineffective at preventing significant degradation at the reach scale. Accordingly, the less robust dike modifications (structural actions 2 and 3) were not modeled and Alternatives 2A, 2B, 2C, 3A, 3B, 3C, 4A, 4B, and 4C were removed from further consideration. The grade control alternatives were found effective at eliminating degradation, but in order to maintain navigability 37 to 38 structures would be required. This would fundamentally change the hydraulic conditions of the river from a free-flowing river to a series of pools and rapids, which is not the least-environmentally damaging way to prevent degradation. Moreover, grade control shifts the degradation back to Kansas City.

The remaining viable alternatives reduce or reverse degradation by limiting or eliminating commercial sand and gravel extraction. Dredging restrictions constitute the only effective and acceptable means of slowing or stopping degradation. Dredging Option B includes no dredging in the St. Joseph dredging reach, close to the currently permitted level in Kansas City dredging reach, and a reduced level in the Waverly dredging reach. This level of dredging effectively stabilizes the bed in St. Joseph and greatly reduces degradation in the Waverly reach. Some degradation in the Waverly reach still occurs before the dredging reduction is applied in year 2021. Eliminating dredging from these three dredging reaches altogether leads to a slight recovery trend in the St. Joseph and Waverly segments and increased bed recovery in the Kansas City segment.

Kansas City is projected to continue a bed recovery trend until approximately the year 2022, at which time recovery continues (under a reduced or eliminated dredging condition) or the bed begins a new degradational trend (under the currently permitted dredging condition). Bed degradation and bed recovery primarily impact low water elevations but do impact flood heights to a lesser extent which has not been quantified for inclusion in this appendix.

The status of all intermediate alternatives are provided in Table 1. As seen, all but two, plus the Future Without Project alternative have been eliminated. These three alternatives (1A, 1B, 1C) constitute the final array of alternatives.

Table 1. Intermediate Array of Alternatives

Structural Action	Dredging Condition A (Currently Permitted Dredging)	Dredging Condition B (Reduced Dredging)	Dredging Condition C (No Dredging)
1	1A (FWOP)	1B[1]	1C[1]
2	2A[2]	2B[2]	2C[2]
3	3A[2]	3B[2]	3C[2]
4	4A[2]	4B[2]	4C[2]
5	5A[3]	5B[3]	5C[3]

Subscripts: 1 = Retained as viable alternatives
2 = Eliminated due to lack of effectiveness
3 = Eliminated due to shifting degradation towards Kansas City and for environmental considerations

8. References

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