US Army Corps
of Engineers
Kansas City District

Appendix 6

CENWK-ED NOV 10 2015

MEMORANDUM FOR CENWK-OD-R

SUBJECT: Engineering Division Recommendations for Commercial Sand Dredging Permit Renewals on the Missouri River

1. References:

a. USACE (2011). Missouri River Commercial Dredging Final Environmental Impact Statement. U.S. Army Corps of Engineers, Kansas City District. Kansas City, MO. Prepared by Cardno-Entrix, Seattle, WA.

b USACE (2015a). Missouri River bed and water surface changes between 2009 to 2014 as they relate to Renewal of Commercial Dredging Permits under Section 404 of Clean Water Act and Section 10 of the Rivers and Harbors Act (Section 404/10 Permits). Memorandum for CENWK-OR-R. Signed July 14, 2015.

c. USACE (2015b). A Sediment Budget Approach to Stable Dredging Levels on the Lower Missouri River, 1994 to 2014. CENWK-ED-HR Memorandum for Record. Signed Oct 1, 2015.

2 Introduction: Commercial sand and gravel aggregate companies currently operating in the Missouri River requested renewal of their current dredging permits which expire on Dec 31, 2015. All companies requested the same quantity of extraction as authorized in their existing (2011 – 2015) permits, except for Holliday Sand and Gravel and Capital Sand who requested an additional annual extraction in the Waverly Segment (River Mile (RM) 250 to 357).

The 2011 Commercial Dredging EIS (USACE 2011) found a strong correlation between dredging levels and the magnitude of bed degradation. For this reason, the 2011 Record of Decision required a bathymetric survey be completed the fourth year of the permit cycle so that the amount of bed change could be quantified and any needed adjustments to permit conditions made.

For this permit cycle, a bathymetric survey was conducted in 2014. A descriptive analysis of the 2014 survey, including a detailed discussion of bed change for every five-mile reach, water surface profile changes, changes over multiple time periods, and a quantification of variability is given in USACE (2015a). This memorandum documents technical recommendations relative to the requested permit renewals.

Based on the degradation predictions from the 2011 Commercial Dredging EIS and analysis of the bathymetric monitoring data required in the 2011 ROD as documented in USACE (2015a)

and USACE (2015b), Engineering Division (ED) recommends the following four actions: (1) Significantly reduce the dredging in the St. Joseph Segment, (2) Maintain the maximum allowable dredging in the Waverly Segment at the current level, (3) Exclude dredging from all 5-mile reaches that have degraded more than 2 feet since 2009, and (4) Consider permitting dredging levels at river-wide sustainable dredging quantities.

3. Bed Change Concepts: Bed degradation occurs when the sum of sediment withdrawals from a portion of the river, which include hydraulic scour, floodplain deposition, and commercial extraction, exceeds the sum of sediment inputs, which include contributions from the upstream channel, tributaries, banks, and the floodplain. Conversely, bed aggradation occurs when the sediment inputs exceed the sediment withdrawals. Commercial dredging is not the only factor influencing bed change on the Missouri River. However, the net effects of the various inputs and withdrawals are generally additive.

4. EIS Projections and Observed Bed Change: The 2011 Commercial Dredging EIS used a "Reference Segment" methodology for computing the predicted level of degradation for various amounts of dredging. The Reference Segment method compared historical levels of dredging and degradation between stable and unstable Segments as the basis of predicting the amount of degradation of various dredging levels. Table 1 indicates the EIS predictions for various levels of dredging in the St. Joseph and Waverly Segments. It should be noted that the EIS did not assess the effects of or provide a prediction of bed change for dredging rates above the currently authorized amount of 1,140,000 tons in the Waverly Segment.

Table 1. Dredging EIS Degradation Predictions for Different Dredging Levels

Segment	Dredging Rate (tons/year)	Short Term Bed Change (5-years)	Long Term Bed Change (50 years)
St. Joseph	0	0 to 4 ft Aggradation	0 to 4 ft Aggradation
St. Joseph	330000	2 ft Aggradation to 2 ft Degradation	0 to 2 ft Degradation
St. Joseph	350000	2 ft Aggradation to 2 ft Degradation	0 to 2 ft Degradation
St. Joseph	860000	0 to 2 ft Degradation	0 to 4 ft of Degradation
Waverly	0	2 ft Aggradation to 2 ft Degradation	2 ft Aggradation to 2 ft Degradation
Waverly	500000	2 ft Aggradation to 2 ft Degradation	2 ft Aggradation to 2 ft Degradation
Waverly	680000	2 ft Aggradation to 2 ft Degradation	2 ft Aggradation to 2 ft Degradation
Waverly	1140000	2 ft Aggradation to 2 ft Degradation	0 to 2 ft Degradation

The Environmentally Preferred Alternative selected 860,000 tons in the St. Joseph Segment and 1,140,000 tons in the Waverly Segment as the maximum allowable annual dredging level. However, these amounts have not been extracted over the last 5 years or any year prior. Actual dredging levels and actual bed change, 2009 to 2014, is given in Table 2. Negative values indicate degradation and positive values indicate aggradation.

Table 2. Actual Dredging and Bed Change, 2009 to 2014

Segment	Permitted Dredging (tons/year)	Actual Average Dredging Rate (tons/year)	Bed Change 2009 to 2014 (ft)		
			Full Segment Average	Most Degraded 5-miles	Most Aggraded 5-miles
St. Joseph	860,000	174,283	-1.40	-4.33	-0.12
Waverly	1,114,000	622,022	0.30	-0.96	1.85

Note: Because every 5-mile reach in the St. Joseph Segment degraded, the "most aggraded" 5-mile reach in the St. Joseph Segment is actually the "least degradational."

5. Recommendations:

a. St. Joe Segment Recommendation

Holliday Sand and Gravel is requesting 860,000 tons in the St. Joseph Segment, which is the currently authorized level, but represents a 493% increase over the actual average annual amount dredged between 2011 and 2015 (Table 4).

Table 4. Actual Tonnage Dredged in the St. Joe Segment, 2011-2015

YEAR	TONNAGE	% of Authorized
2011	130,722	15%
2012	176,347	21%
2013	164,228	19%
2014	202,118	24%
2015	198,000	23%
SUM	**871,415**	
AVERAGE	**174,283**	20%

As shown in Table 2, this Segment of river experienced 1.40 feet of degradation over the entire Segment, with individual 5-mile reaches degrading between 0.12 and 4.33 ft. The reach that is actively dredged, rm 445 to 455, degraded 1.41 feet.

The actual annual tonnage extracted from 2011 to 2015 (174,283 tons) is significantly less than the authorized tonnage (860,000 tons) and the actual bed change was more degradational than predicted, with reaches degrading up to 4.33 ft.

The St. Joseph Segment has been degrading since 1990 as evidenced by a plot of water surface profiles (WSP) (Figure 1). In addition, as seen in Figure 2, which is also a plot of WSP, the amount of degradation for the actively dredged reach from 2009-2015 (five years) is almost equal to the amount of degradation from 1990-2009 (19 years). Hence, at least for the 2011-2015 permit cycle, the rate of degradation has increased substantially from the previous 19 years.

Figure 3 illustrates that the degradation in the river in Kansas City migrated upstream 25 to 30 miles from 2009 to 2014. A continuation of this trend will increase maintenance costs for the Bank Stabilization and Navigation Project and induce a host of other infrastructure and environmental damages.

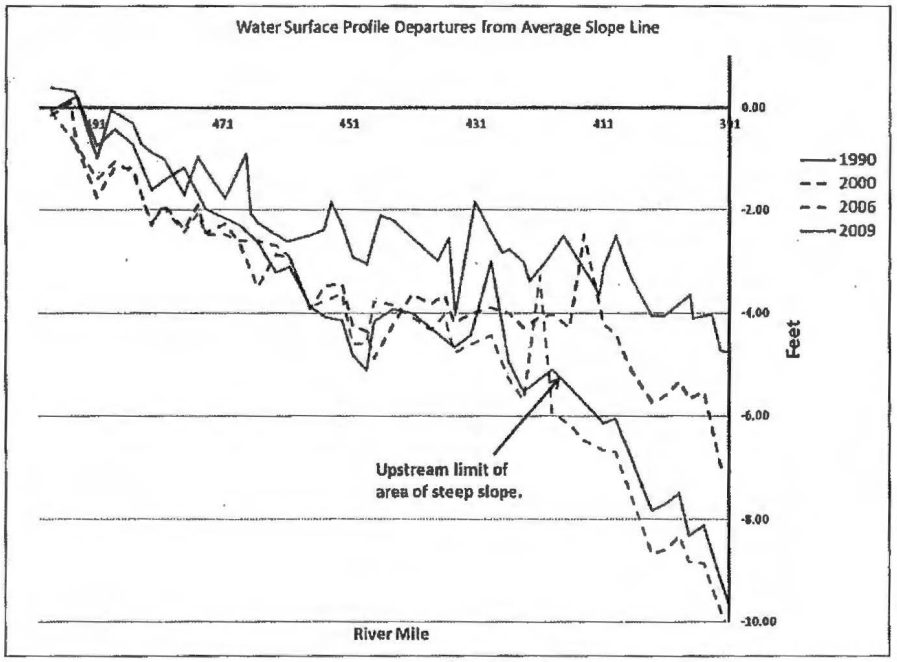

Figure 1. Plot of Water Surface Profiles

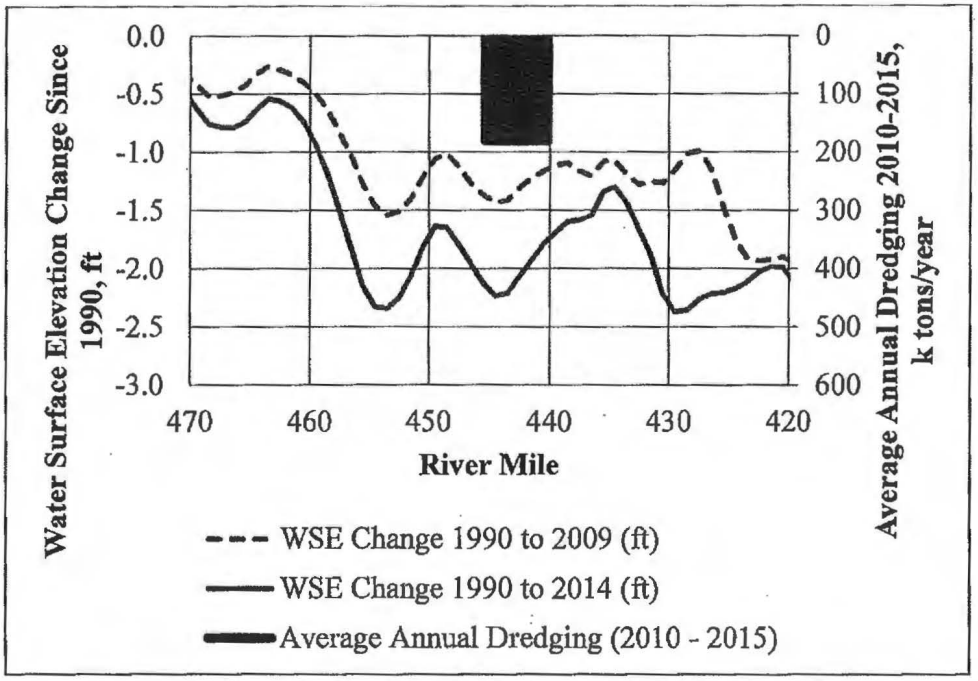

Figure 2. Water Surface Elevation Change for Two Time Periods

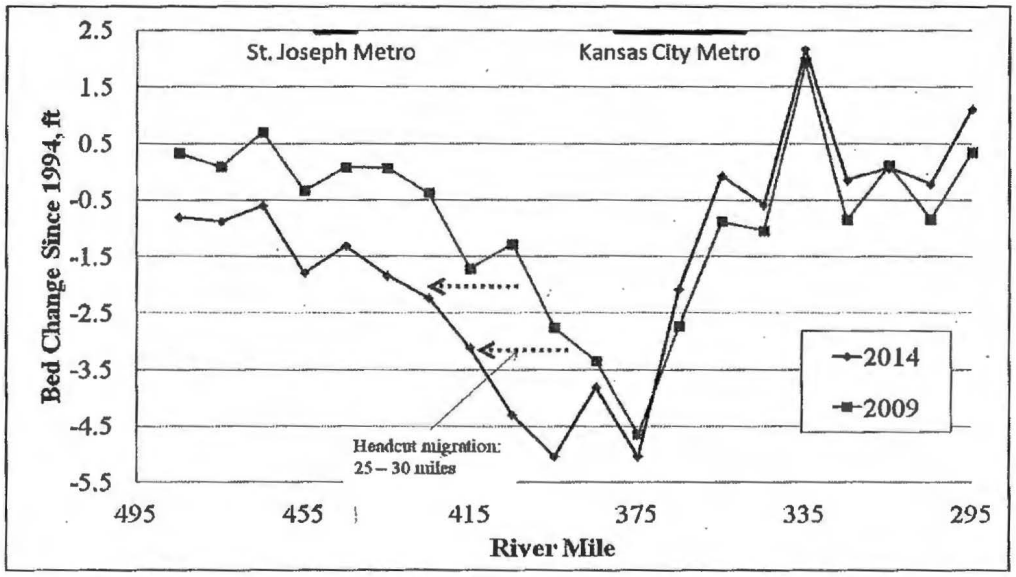

Figure 3. Headcut Migration Upstream as a Result of the 2011 Flood. Each point represents the average bed change over a ten-mile reach.

Recommendation: ED recommends that the permitted tonnage be significantly reduced or dredging suspended in the St. Joseph Segment. This recommendation is based on the

bathymetric monitoring data required in the 2011 ROD, which shows that (1) Significant degradation has occurred in the St. Joseph Segment, even at an average dredging level of 20% of the currently permitted amount, (2) Bed changes in some 5-mile reaches exceeded even the long-term maximum prediction in the EIS of 4 ft, and (3) Degradation has migrated upstream towards the St. Joseph urban area.

b. Waverly Segment Recommendation

Capital Sand and Holliday Sand are both requesting an increase in their permitted tonnage within the Waverly Segment. The requested amount is 237% of the average dredged from 2011 to 2015. Table 3 lists the average and total tonnage dredged over the last five years, the tonnage requested for the next five years, and the percent change from the average tonnage dredged over the last 5 years.

Table 3. Actual Dredging Tonnage and Proposed Tonnage

2011 - 2015 Actual			2016 -2020 Proposed		
Tonnage Dredged		% of Authorized**	Tonnage Requested		% Increase over 2011 - 2015 Average
Year	**Tons**		**Year**	**Tons**	
2011	309,026	27%	2016	1,140,000	183%
2012	467,680	41%	2017	1,299,500	209%
2013	715,055	63%	2018	1,541,500	248%
2014	828,351	73%	2019	1,618,500	260%
2015*	790,000	69%	2020	1,778,000	286%
Average	**622,022**	55%	**Average**	**1,475,500**	237%
*estimated tonnage		** Authorized = 1,140,000 tons			

The average bed change in the Waverly Segment since 2009 is + 0.3 ft (USACE 2015a). Bed change within 5-mile reaches in the Waverly Segment varied from -0.96 ft to +1.85 ft, which fall within the predicted range in the EIS of +/- 2 ft for 1,140,000 tons. However, only 55% of the 1,140,000 tons was actually dredged, and predicting the effects of dredging rates above 1,140,000 tons/year will necessitate additional analysis beyond what is in the 2011 EIS.

Recommendation: ED recommends that the tonnage be maintained at the currently permitted level, which represents a 183% increase over the average dredged from 2011-2015. The rationale for this recommendation is (1) Observed aggradation is very slight, (2) 1,140,000 tons/year is the upper bound of dredging analyzed in the EIS. (3) The actual dredged amount from 2011 to 2015 was 55% of the authorized amount, which provides insufficient empirical evidence to correlate the 2009 to 2014 bed response to dredging levels above (or even at) the 2011-2015 authorized level.

c. 5 mile Reach Recommendation

A number of 5 mile reaches have experienced degradation of more than 2 feet with some reaches experiencing degradation of up to 4.33 feet (USACE 2015a). River miles 390 to 413 and 426 to 434 fall within this category. These river miles are at the lower end of the St. Joseph dredging reach in an area of the river that has degraded significantly since 1990 (Figure 1) and that have an average slope higher than anywhere else on the river. The increased slope can lead to high velocities during flood events which can mobilize a large amount of bed material. No dredging has taken place within these river miles over the last 5 years.

Recommendation: ED recommends that river miles that have experienced more than 2 feet of degradation since 2009 be closed to dredging in order to increase the likelihood of bed recovery. The data collected at the end of each permit cycle will provide insight into the long-term bed trends in these reaches.

d. River-Wide Dredging Quantity Recommendation

The 2011 EIS for commercial dredging did not assess the cumulative effect of dredging multiple, consecutive Segments and therefore the dredging in each Segment was treated independently of the dredging in other Segments. However, a river wide cumulative assessment of all segments could provide a sustainable dredging amount based on a sediment budget approach. USACE 2015b documents such a cumulative sediment budget assessment by comparing dredging extraction rates to the elevation change at 7,075 cross-sections over the lower 500 river miles of the Missouri River between the years 1994 and 2014. The results of this sediment budget assessment showed that the river degraded by 73,779,000 tons while 122,114,000 tons were dredged. Using these numbers, a sustainable dredging rate is likely 2.4 million tons/year. The actual dredging rate was 6.1 million tons/year, which resulted in average bed degradation of 3.7 million tons/year.

Recommendation: ED recommends that sustainable dredging levels be considered when permitting dredging amounts for this permit cycle and future permit cycles and the analysis in USACE 2015b be updated for each future permit renewal. Sustainable dredging levels will allow for an overall stable river bed and provide more certainty of permitted quantities between permit cycles by reducing the likelihood that extracted volumes cause degradation that necessitate reductions in permitted dredging levels.

6. Summary: Based on the degradation predictions from the 2011 Commercial Dredging EIS and analysis of the bathymetric monitoring data required in the 2011 ROD as documented in USACE (2015a) and USACE (2015b), ED recommends the following four actions: (1) Significantly reduce the dredging in the St. Joseph Segment, (2) Maintain the maximum allowable dredging in the Waverly Segment at the level in the current permit

cycle, (3) Exclude dredging from all 5-mile reaches that have degraded more than 2 feet since 2009, and (4) Consideration be given to river wide sustainable dredging quantities.

7. POC for this memorandum is Mr. Mike Chapman at 816-389-3310.

11/10/15

DAVID L. MATHEWS, P.E.
Chief, Engineering Division

CENWK-ED-HR Oct 2015

MEMORANDUM FOR RECORD

SUBJECT: A Sediment Budget Approach to Stable Dredging Levels on the Lower Missouri River, 1994 to 2014

1. References

a. Morgan, J.A. (2013). Bed Degradation on the Lower Missouri River. M.S. Thesis, University of Missouri- Kansas City.

b. USACE (1995). EM 1110-2-4000. Engineering and Design: Sedimentation Investigation of Rivers and Reservoirs, Section V "Channel Mining." 15 Dec, 1989. Updated 31 Oct, 1995.

c. USACE (2009). Missouri River Bed Degradation Reconnaissance Study Section 905(b) (Water Resources Development Act of 1986) Analysis. U.S. Army Corps of Engineers, Kansas City District. Kansas City, MO.

d. USACE (2011). Missouri River Commercial Dredging Final Environmental Impact Statement. U.S. Army Corps of Engineers, Kansas City District. Kansas City, MO. Prepared by Cardno-Entrix, Seattle, WA.

e. USACE (2015). Missouri River Bed and Water Surface Changes between 2009 and 2014 as They Relate to Renewal of Commercial Dredging Permits under Section 404 of Clean Water Act and Section 10 of the Rivers and Harbors Act (Section 404/10 Permits). Memorandum for CENWK-OR-R. July 14, 2015. U.S. Army Corps of Engineers, Kansas City District.

2. Introduction

Commercial sand and gravel mining (referred to herein as dredging) has been identified as a major cause of bed degradation on the lower Missouri River (USACE 2009, USACE 2011, Morgan 2013). A 2011 Environmental Impact Statement on commercial dredging (USACE 2011) utilized a reference-reach approach to correlate degradation levels with various levels of dredging as a percentage of bed material load. However, the cumulative effect of dredging multiple, consecutive reaches was not assessed. The purpose of this memo is to document the cumulative, stable level of commercial dredging for the entire lower 500 miles of Missouri River. Numerical modeling is the

standard of practice for establishing allowable dredging rates and is necessary to determine the location, magnitude, or timing of impacts and to assess the interplay between potential causes (USACE 1995). However, when sufficient bathymetric data are available, a sediment budget approach can be useful for a large-scale analysis. This memo documents the analysis and determination of the stable level of commercial dredging for the lower 500 miles of the Missouri River based on bed change and dredging data from 1994 to 2014.

3. Physical Principles

For a river to be stable while being dredged, the dredging rate must equal the natural aggradation rate (ΔS_{nat}), which is the mass rate of sediment accumulation in the river bed with no dredging. The natural aggradation rate is defined as sum of the mass of sediment entering the reach (Ms_{IN}) minus the mass of sediment leaving the reach (Ms_{OUT}).

$$DREDGE_{stable} = \Delta S_{nat} \qquad \text{Eq (1)}$$

$$\Delta S_{nat} = Ms_{IN} - Ms_{OUT} \qquad \text{Eq (2)}$$

The actual aggradation rate over any given time period (ΔS_{act}) includes the effects of channel dredging ($DREDGE_{act}$).

$$\Delta S_{act} = Ms_{in} - Ms_{out} - DREDGE_{act} \qquad \text{Eq (3)}$$

Making the assumption that the bed material transport flux into and out of the reach are independent of the channel dredging (i.e. ignoring geomorphic feedbacks), Equation (3) rearranges to the following:

$$\Delta S_{act} = DREDGE_{stable} - DREDGE_{act} \qquad \text{Eq (4)}$$

$$DREDGE_{stable} = \Delta S_{act} + DREDGE_{act} \qquad \text{Eq (5)}$$

Equation 5 can be annualized to determine the annual stable rate of extraction:

$$DREDGE_{stable} = (\Delta S_{act} + DREDGE_{act})/n_{years} \qquad \text{Eq (6)}$$

Equation 6 requires the computation of the actual aggradation rate, which can be accomplished using bathymetric surveys from different years. The simplification that the rate of sediment transport is independent of the channel dredging is reasonable

when the boundaries of the reach in question extend beyond the zone of geomorphic influence of the dredging operation, which could be true for an analysis of a very large reach. This type of analysis cannot be used to isolate the locations of impacts, as at the local scale the dredging does significantly impact the sediment transport rate.

4. Missouri River Stable Extraction Rate

The actual aggradation rate was computed between 1994 and 2009 and 2009 and 2014 using cross-section data. Figure 1 provides an example of the cross-section data.

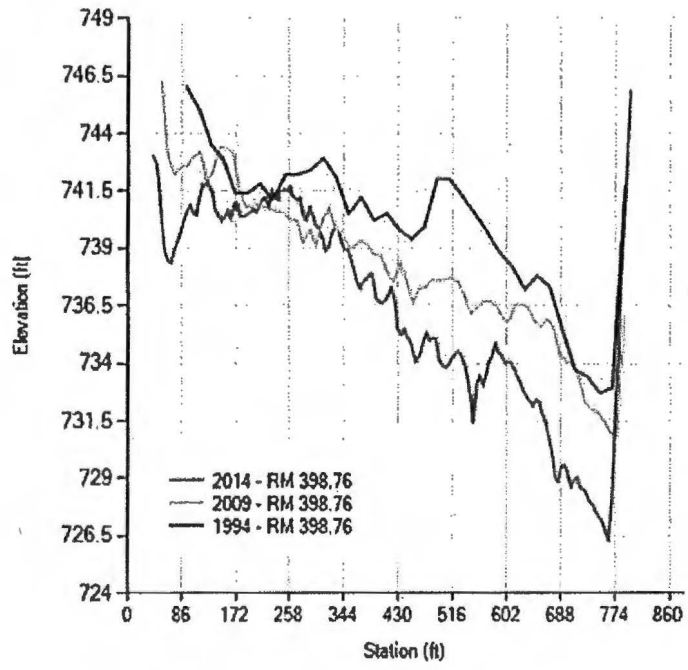

Figure 1. Example of Cross-Section Data (RM 398.76)

Table 1 indicates the number and average spacing of cross-sections used in the analysis. For consistency, only cross-sections present in both the start and the end year (1994 and 2009 or 2009 and 2014) and only the region of channel covered by both years were used in the computation of the aggradation rate.

Table 1. Actual aggradation rate for the Missouri River from RM 500 to 0. Negative numbers imply degradation. Values rounded to the nearest thousand.

Time Period	# Cross-Sections Pairs	Average Spacing (ft)	ΔS_{act} (ft^3)	ΔS_{act} (tons)
1994 to 2009	1,812	1,439	-1,175,873,000	-57,048,000
2009 to 2014	5,263	500	-344,869,000	-16,731,000

The Missouri River bed degraded a total of 73,779,000 tons from 1994 to 2014. Over the same time period, 122,114,000 tons were dredged from the river bed. By Equation 6:

$$DREDGE_{stable} = (-73{,}779{,}000\ tons + 122{,}114{,}000\ tons)/20\ years$$

$$DREDGE_{stable} = 2{,}417{,}000\ tons/year$$

This analysis suggests that the stable extraction rate for the Missouri River from 1994 to 2014 was approximately 2.4 million tons/year. The actual dredging rate was 6.1 million tons/year, which resulted in average bed degradation of 3.7 million tons/year. The degradation was not evenly distributed. The most severe degradation in the 1994 to 2009 occurred at the locations of the most intense dredging (USACE 2011), particularly in Kansas City. The most severe degradation in the 2009 to 2014 time period occurred slightly upstream of the previous Kansas City degradation, which was likely the effect of the 2011 flood acting on the antecedent degradation (USACE 2015).

5. Considerations/Limitations

The starting year of the analysis, 1994, is one year following the historic flood of 1993. Thus, the tendency towards aggradation (in the natural, non-dredging aggradation rate) seen from 1994 to 2014 may reflect the expected process of rebound following a major flood, and may not be a good indicator for a long-term trend sufficient to assess the stable dredging rate for future years. If the analysis is repeated for only the more recent 2009 to 2014 time period, the stable dredging rate is a significantly lower 75,000 tons/year. However, the most recent time period also includes a historic flood, so it may also be unrepresentative of future conditions.

Whether or not continued dredging at $DREDGE_{stable}$ rates would yield channel stability in the future depends on a myriad of factors, including how similar hydrologic and sediment loading in future years are to those from 1994 to 2014. Also, this analysis

does not address the local or reach effects that would be a function of the location and spatial concentration of the 2.4 million tons/year. An estimation of magnitude and location of bed change in specific reaches of the lower 500-miles necessitates numerical modeling (USACE 1995). Given the uncertainties involved in any approach to determining the effects of channel dredging, a robust monitoring program with adaptive management of dredging levels is warranted.

Finally, bed recovery to pre-degradation levels would create a more resilient system and may be a more appropriate short-term goal rather than stability. The current channel in its degraded form is highly susceptible to extreme floods and droughts. For example, temporary bed scour during the 2011 flood event necessitated emergency rock placement in two locations in Kansas City at a cost of over 1.4 million dollars. Moreover, water supply infrastructure is dependent on supplemental flow releases out of the mainstem reservoirs to maintain sufficient water surface elevations in the winter. Both of these problems would be lessened by promoting short-term bed recovery in the most degraded reaches.

6. Conclusion

This memo provides a river-wide analysis of the level of dredging the lower Missouri River can support. Based on an analysis of elevation changes at 7,075 cross-sections, the rate of dredging that would not have caused degradation over the lower 500 miles from 1994 to 2014 is 2.4 million tons/year.

7. Point of contact for this memo is Mr. John Shelley at 816-389-2310.

SHELLEY.JOHN.E.1395403610

Digitally signed by SHELLEY.JOHN.E.1395403610
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John Shelley, Ph.D., P.E.
Sedimentation Specialist