Appendix 11

CENWK-ED-HR JUL 14 2015

MEMORANDUM FOR CENWK-OD-R

SUBJECT: 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)

1. Introduction. In a memorandum dated 15 April 2015, CENWK-OD-R requested analysis of bed and water surface elevations to be used in the regulation of commercial dredging activities on the Missouri River. Commercial dredging activities are regulated according to an adaptive management framework outlined in the 2011 Record of Decision. The purpose of this memorandum is to provide an analysis of hydrographic survey data and water surface elevation data that may be used to assess the level of degradation or aggradation that has occurred since 2009. Section 2 describes the data sources used in the analysis. Section 3 presents the analysis of bed change. Section 4 presents the analysis of water surface elevation change. Section 5 examines the correlation between dredging intensity and local bed change. Section 6 compares the total volume of bed change and total volume of dredging extraction. Section 7 quantifies the variability in bed change measurements.

2. Data Sources. Table 1 presents the data used in this analysis. Hydrographic surveys in 2008 and 2014 were provided by the dredging industry with the remainder of the surveys provided by the Kansas City District. Water surface profiles were collected during the summer when flows approximated Construction Reference Plane (CRP) discharges, and were adjusted to a consistent CRP discharge as documented in the U.S. Army Corps of Engineers (USACE) (2010).

Table 1. Survey Description

Year	Data Type	# of Cross-sections (Spacing) / Water Surface Measurements
2008	Hydrographic survey	7326 (250 ft)
2009	Hydrographic survey	10550 (250 ft)
2012	Hydrographic survey	1302 (2000 ft)
2013	Hydrographic survey	10548 (250 ft)
2014	Hydrographic survey	5263 (500 ft)
1990	Water surface profile	180
2009	Water surface profile	164
2012	Water surface profile	174
2014	Water surface profile	174

In addition to the surveys in Table 1, surveys were collected during and immediately after the 2011 flood but were not included in this analysis due to their limited geographic coverage. Information from these surveys can be found in the 2011 flood Perishable Data report (USACE 2013). Prior to the analysis presented in this memorandum, Temporary Bench Mark (TBM) elevations were analyzed for accuracy, and where warranted, corrected. Compared to the other surveys, the bathymetric survey from 2012 had significantly fewer and unevenly spaced cross-sections which precluded its use in the 5-mile reach analysis in Section 3. However, the 2012 survey was included in the total volume analysis presented in Section 6.

3. Bed Change. Bed change at a cross-section was computed by the following procedures:

a. Compute the cross-sectional area change between surveys (i.e. 2009 and 2013 or 2009 and 2014). For a valid comparison, only the lateral extent of the cross-section covered by both surveys was used to compute the area change. (For reference, the average width for the common lateral extent from 2009 to 2014 is 987 ft, which is a sufficient width to describe the channel change). This step was automated by using the XS Viewer calculator on the Missouri River bathymetry data base.

b. Divide the area change computed at each cross-section by the width to yield an average bed change at the cross-section.

c. Average the bed changes that occur between the upstream and downstream river miles for a particular reach or hotspot. Because the cross-sections are approximately evenly spaced, a mean rather than a distance-weighted average was used.

Tables 2 and 3 present the average bed change over the larger authorized dredging reaches and the hot-spots defined in the 2011 dredging EIS (USACE 2011).

Table 2. Average Bed Change over EIS Dredging Reaches

Segment Name	St. Joseph	Kansas City	Waverly	Jefferson City	St. Charles
River Miles	391 to 498	357 to 391	250 to 357	130 to 250	0 to 130
2009 to 2013 (ft)	-1.62	-0.41	0.13	0.08	-0.41
2009 to 2014 (ft)	-1.40	-0.36	0.30	0.28	-0.04

Table 3. Average Bed Change over EIS Hotspot Reaches

Hotspot RMs	Bed Change 2009 to 2013 (ft)	Bed Change 2009 to 2014 (ft)
15 to 20	-0.48	-0.16
25 to 30	-0.27	0.36
30 to 35	-0.02	0.87
90 to 95	-0.40	-0.59
95 to 100	-0.48	0.54
140 to 145	-0.73	-0.61
145 to 150	0.76	0.87
355 to 360	1.09	0.97
360 to 365	1.13	0.75
365 to 370	0.41	-0.13
370 to 375	-1.58	-1.29
375 to 380	-0.86	-0.55
380 to 385	-1.25	-0.90
385 to 390	-0.71	-0.33
390 to 395	-2.89	-2.07
445 to 450	-1.76	-1.46
450 to 455	-1.55	-1.36

As seen in Tables 2 and 3, the St. Joseph reach was the most degradational of the larger authorized dredging reaches, with an overall degradation of 1.4 ft since 2009. Of the hotspot locations, Hotspot 390 to 395 degraded the most, 2.07 ft since 2009.

Figure 1 presents bed change averaged over 5-mile increments centered on each river mile in the lower 500 miles. For example, the bed change shown at RM 350 is a mean of bed change values from cross-sections from river miles 352.5 to 347.5. As seen, the river bed degraded significantly upstream of the Kansas River, but experienced deposition in Kansas City downstream of the Kansas River. The 5-mile reaches that degraded more than 2 ft from 2009 to 2014 are listed in Table 4.

Table 4. 5-mile Reaches with Degradation Greater Than 2 ft (2009 to 2014).

Reach RMs	Bed Change 2009 to 2014 (ft)
390 to 395	-2.07
391 to 396	-2.07
392 to 397	-2.36
393 to 398	-2.41
394 to 399	-2.48
395 to 400	-2.35
396 to 401	-2.17
401 to 406	-2.42
402 to 407	-3.34
403 to 408	-3.95
404 to 409	-4.33
405 to 410	-4.19
406 to 411	-3.46
407 to 412	-2.82
408 to 413	-2.30
426 to 431	-2.23
427 to 432	-2.45
428 to 433	-2.44
429 to 434	-2.10

3. Adequacy of Cross Section Spacing. This section discusses the adequacy of cross-sectional measurements for describing changes on the order of 0 to 4 ft, given that the river has bedforms with amplitudes of up to 10 ft. Two factors allow for this. First, a given cross-sectional measurement encompasses multiple bedforms across the lateral extent of the cross section, which immediately decreases the effects of hitting a peak or a trough on a single bedform. Second, at 500-ft spacing, a 5-mile reach includes 52 to 53 cross-sections, which averages out local variability (i.e. "peak" cross-sections are cancelec out by "trough" cross-sections.) As seen in Figure 1, the variability in 5-mile reaches is much less than in individual cross-sections for bed change from 2009 to 2014. The adequacy of the 500 ft cross-section spacing for describing changes over 5-mile reaches was quantitatively assessed by comparing the calculated 2009 to 2013 bed change using all cross sections (250 ft spacing) to the 2009 to 2013 calculated bed change using only every other cross section (500 ft spacing). The difference was 0.00 ft

on average with a 0.05 ft average absolute difference in 5-mile reaches. These results indicate no systemic bias and only a slight gain in accuracy by decreasing spacing to less than 500 ft.

4. Low Water Surface Elevation Change. Water surface elevations were collected in multiple years and adjusted to a common discharge condition as documented in USACE (2010). This is the same procedure as was used in the 2011 Dredging EIS. Figure 2 presents water surface elevation changes from 2009 to 2014. Locations of water surface and bed aggradation and degradation generally agree, but the magnitudes of change do not.

The flood of 2011 significantly rearranged bed sediments in the lower Missouri River with the general result of moving headcuts upstream. This is evident in Figure 3 near river mile 450, which compares the 2009 and the 2014 water surface profiles to the 1990 water surface profile. The 2011 Dredging EIS (see USACE 2011, Figure 3.4-30) compared all profiles to the 1990 water surface profile.

5. Dredging Intensity and Bed Change Location. Figure 2 compares the cumulative dredging tonnage and dredging locations for the years 2010 to 2014 to the bed and water surface change for the years 2009 to 2014. Each dredging data point represents the sum of all dredging tonnage from 2010 to 2014 that occurred in a 5-mile reach centered on the point. For example, the value at RM 144.5 includes all dredging from RM 142 to 147. No correlation between dredged tonnage and 5-mile reach bed change or water surface change is evident over this time period. This lack of spatial correlation is best explained by the significant geomorphic changes induced by the 2011 flood rather than by dredging or changes to dredging that occurred over the time period.

6. Dredging Volume and Bed Change Volume. Volume change in the lower 500 miles of Missouri River was computed by the following procedure. These steps were automated using the XS Viewer calculator with the Missouri River bathymetry data base.

a. Compute the cross-sectional area change at each cross-section that exists in both surveys (i.e. 2009 and 2012, 2009 and 2013, or 2009 and 2014). Only the lateral extent of the cross-section covered by both surveys was used to compute the area change.

b. Multiply the area change by half the length to the previous and next cross-sections to yield a volume.

c. Sum all the volume changes for the lower 500 miles.

The total change in bed elevation volume compared to the volume of bed material extracted for commercial dredging is presented in Figure 4. As seen, the lower 500-miles degraded significantly between 2009 and 2012, mostly as a result of the 2011 flood. Since 2012, the bed overall has recovered somewhat, though not all the way back to the 2009 level. Total dredging remained fairly constant over the time period. As of 2014, the total volume of bed loss since 2009 is approximately equal to the total volume of bed material extraction by commercial dredging at approximately 13.7 million cubic yards. This indicates that the level of commercial dredging was significant compared to the total degradation. However, given the dominant effects of the 2011 flood, the equivalency between degradation rate and dredging rate over the 2009 to 2014 time period is likely coincidental. Since the lateral extents of the surveys covers a significant portion of the river bed, the source of the material leading to recovery of the bed is unknown. Likely sources are material in transit from upstream, material eroded from the banks, or material from the tributaries. However, due to the relatively dry conditions in the lower basin between 2012 and 2014, material from the tributaries was probably limited.

7. Year-to-Year Variability. As described in section 4 above, uncertainty caused by migratory bedforms can be overcome by using a sufficient number of cross-sections. However, the Missouri River exhibits natural variability in bed elevations which may be indicative of other temporary features, such local depressions during dredging operations, hysteresis in sediment loads (rising vs. falling limb of the hydrograph), survey timing compared to tributary inflow events, etc. The potential for year-to-year variability which is real but not indicative of permanent change was quantified by assessing bed change between 2008 and 2009. On average, the bed rose 0.04 ft from 2008 to 2009. As expected, 5-mile reaches (an average of 105 cross-sections) are much less variable than individual cross-sections (Figure 5). Figure 6 indicates the percent of the cross-sections or 5-mile reaches that have bed changes less than a given threshold. For example, 86% of 5-mile reaches had a change of less than +- 1 ft, compared to only 65% of individual cross-sections. Ninety-nine percent of 5-mile reaches had year-to-year variability of less than 2 ft. This suggests that a 2 ft threshold is sufficient for determining persistent geomorphic change in a 5-mile reach. Longer reaches would further decrease the year-to-year variability.

8. Summary. Degradation from 2009 to 2014 on the lower 500-miles of the Missouri River followed the predictable pattern seen during and after previous major floods—degradation during the flood followed by post-flood recovery to levels lower than before the flood. The distribution of the degradation from 2009 to 2014 was dominated by the effects of the 2011 flood, not by the locations or intensity of dredging extraction. While degradation since 1990 is still most pronounced in Kansas City, since 2009 the bed has continued to degrade upstream of the Kansas River and has experienced some

aggradation immediately downstream of the Kansas River. Degradation since 2009 (2009 to 2014) in hotspot RM 390 to 395 exceeded 2 ft at 2.07 ft. The most degradation over any 5-mile reach occurred at RM 404 to 409 at 4.33 ft. Individual cross-sections can be highly variable, but this variability is reduced by averaging bed change or summing volumes over reaches with multiple cross-sectional measurements.

9. Point of contact for this memorandum is Mr. John Shelley at 816-389-2310.

Encl

DAVID L. MATHEWS, P.E. 7/14/15
Chief, Engineering Division

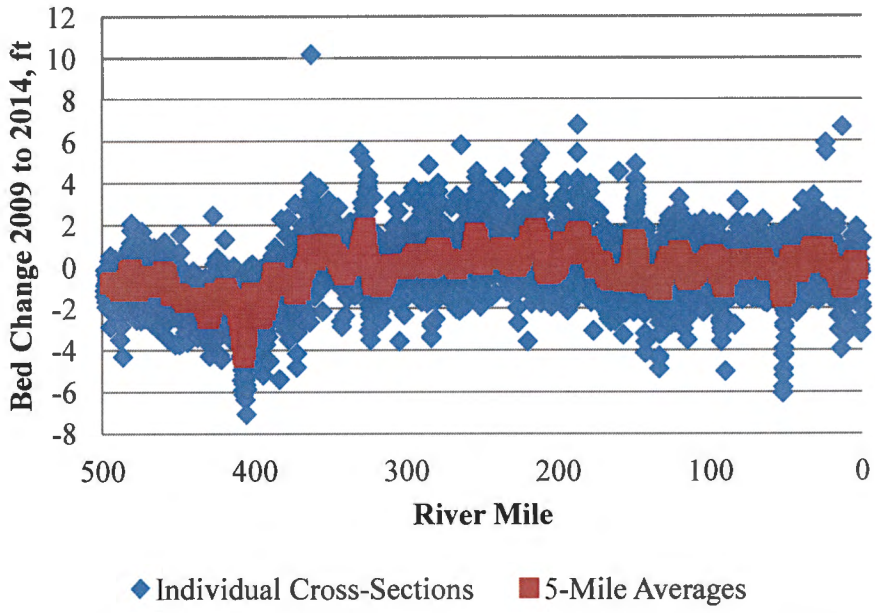

Figure 1. Comparison of individual cross-sectional bed change vs. bed change averaged over 5-mile reaches for 2009 to 2014.

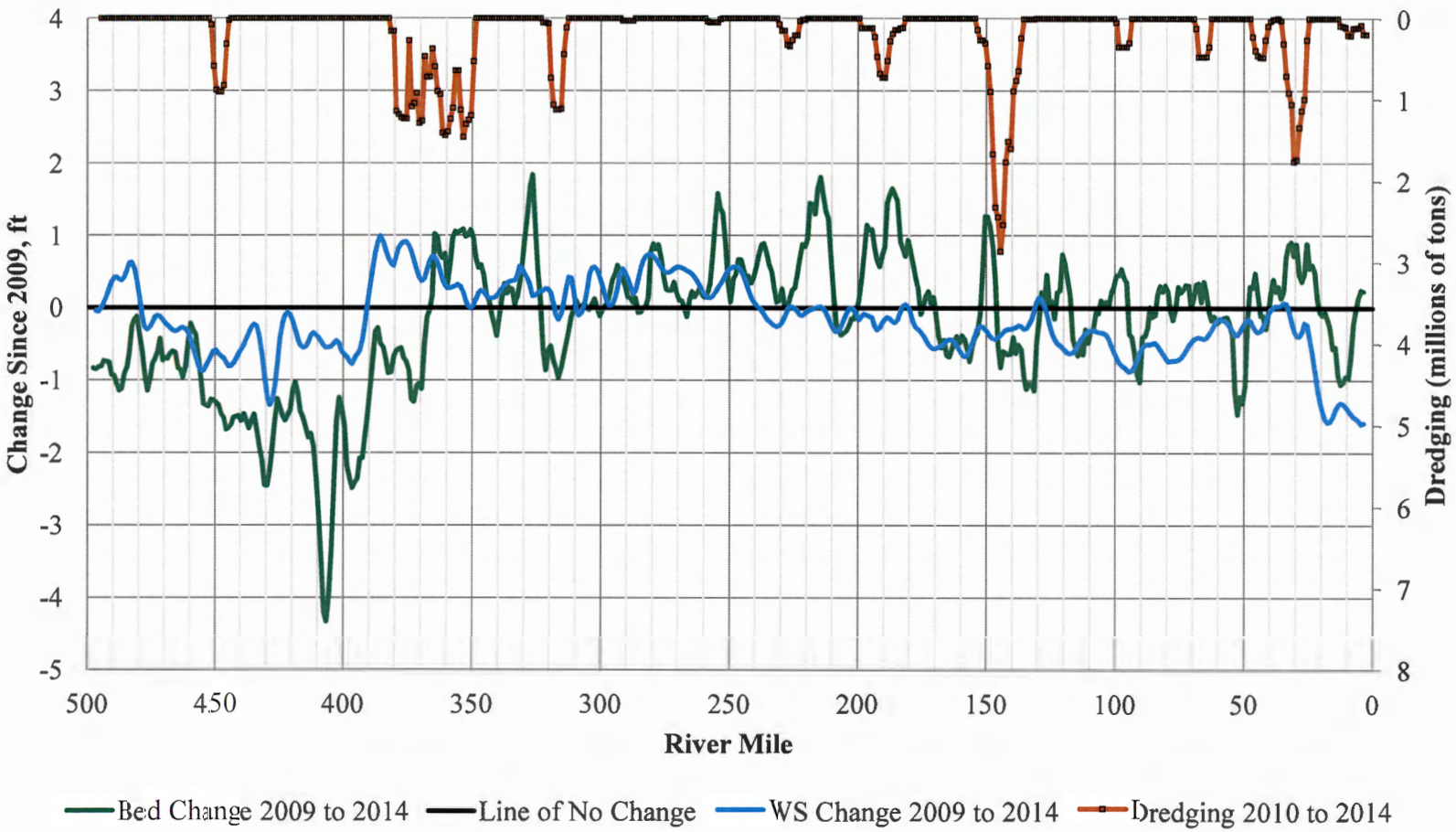

Figure 2. Changes Since 2009 (Rolling 5-mile Average): Bed Elevations, CRP-Flow Water Surface Elevations, and Cumulative Dredging

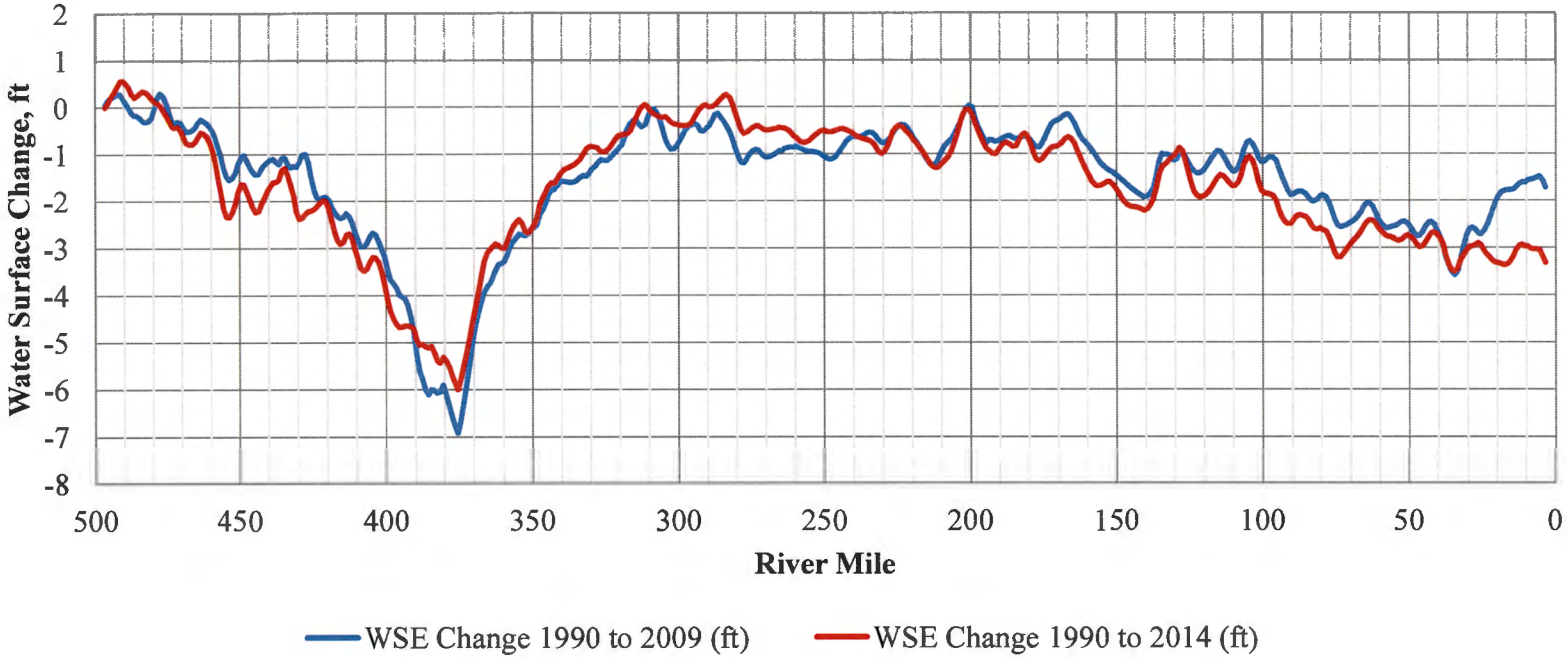

Figure 3. Changes Since 1990 (Rolling 5-mile Average): CRP-Flow Water Surface Elevations

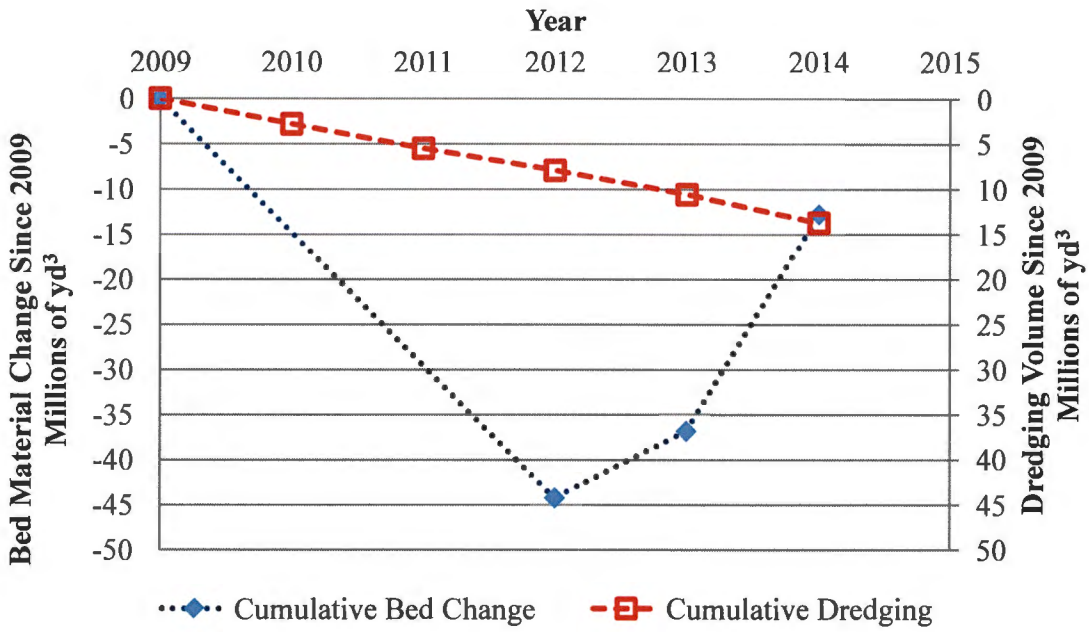

Figure 4. Cumulative volume of bed material loss in the lower 500 miles.

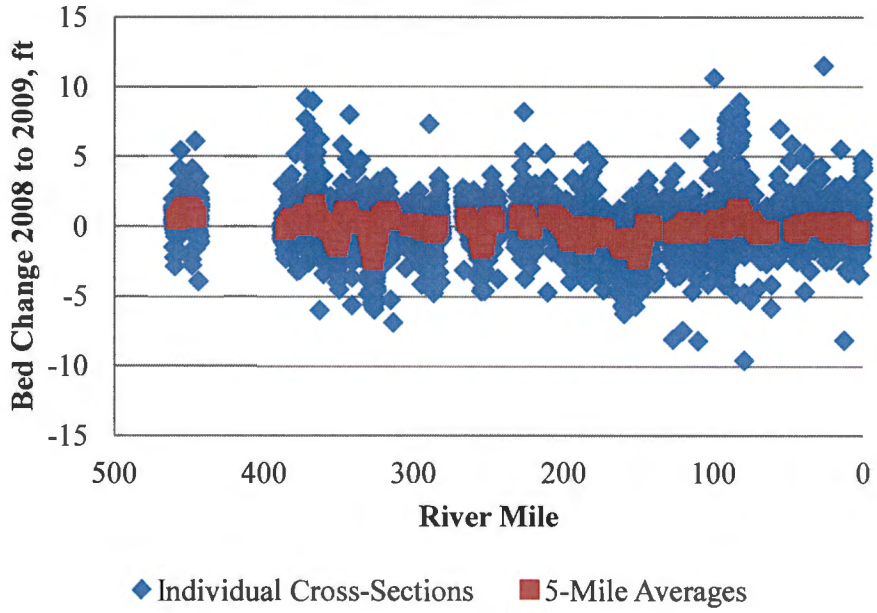

Figure 5. Comparison of individual cross-sectional bed change vs. bed change averaged over 5-mile reaches

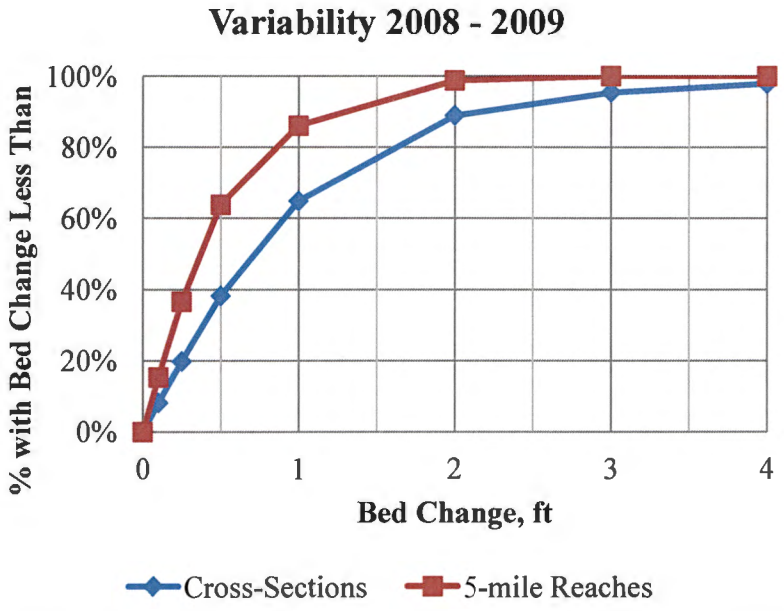

Figure 6. Summary of the variability of bed change at individual cross-sections vs. averaged over 5-mile reaches for 2008 to 2009.