Appendix A

Existing Condition of the Bank Stabilization and Navigation Project Structures, River Miles 330 and 400

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US Army Corps
of Engineers ®
Kansas City District

Existing Condition

Of the

Bank Stabilization and Navigation Project Structures

River Miles 330 and 400

March 2016

ED-HR

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1. Purpose of Report

The Missouri River between Leavenworth, river mile (rm) 400, and Napoleon, rm 320 (hereafter called the ‘subject reach’) has been part of the Missouri River Bank Stabilization and Navigation Project (BSNP) since the project was authorized in 1945. (Note that the ‘subject reach’ described in this appendix is a sub-reach of the larger ‘focused reach’ used in the main report.) Construction of the BSNP had a profound effect on the planform of the river and was declared officially complete in 1980. The project has been in an operational and maintenance (O&M) mode since that time. The subject reach has experienced bed degradation since around 1990 that has caused multiple adverse impacts; most notability for the BSNP itself, degradation affects the relative crown heights of the BSNP rock structures. This report: reviews the timeline and magnitude of the degradation trends, reviews the BSNP structure maintenance criteria history, documents structure maintenance actions since 1974, provides an estimate of structure heights in selected years, and documents the condition of the BSNP structures in December 2013.

2. Background

2.1 History of Stage Trends in Subject Reach

Stage trends for the USGS gage at Kansas City on the Missouri River have been decreasing for discharges below 100,000 cfs since around 1940. The trend is evident in Figure 1.

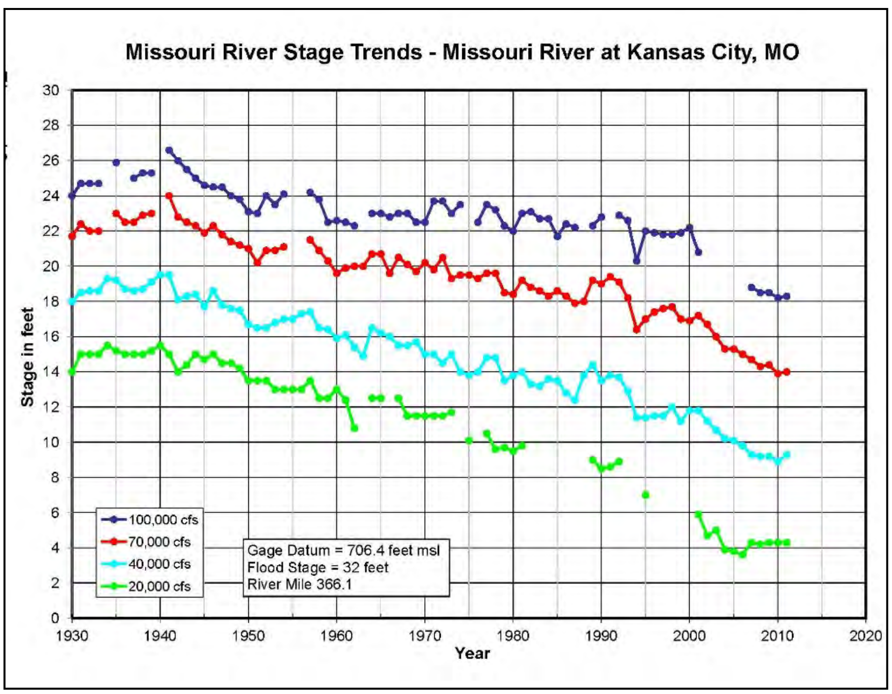

Figure 1. Stage trends for discharges below 100,000 at Kansas City

Water surface Profiles (WSP), which measure the water surface elevation when the river's discharge is at or near the construction reference plane (CRP – defined in section 2.3 below) discharge, show that the downward stage trends are not just confined to the immediate vicinity of the Kansas City gage, but have occurred over almost the entire subject reach (Figure 2). The x-axis (at y=0) represents an average, constant slope drawn between the CRP elevations at rm 0 and rm 498. Therefore, moving along a single profile in the downstream direction, increasing departures from the x-axis mean the river has a higher slope than average, and decreasing departures from the x-axis mean the river has a lower slope than average. The difference between profiles indicates a change in WSP elevations over time. For clarity purposes, not all available profiles are shown.

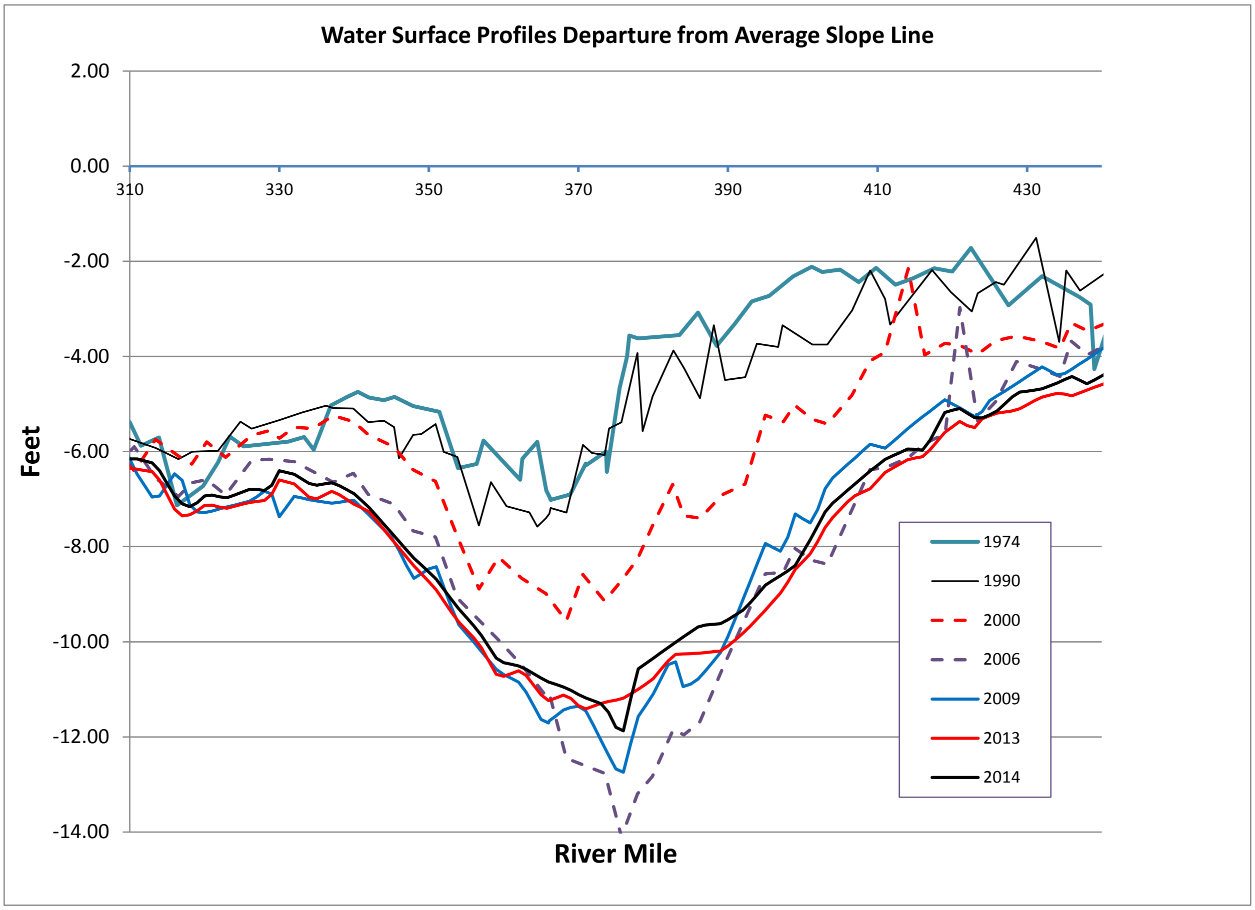

Figure 2. Water Surface Profile Comparison

Figure 3 displays an average WSP stage trend decrease compared to 1974 over the entire subject reach for all years with a recorded WSP.

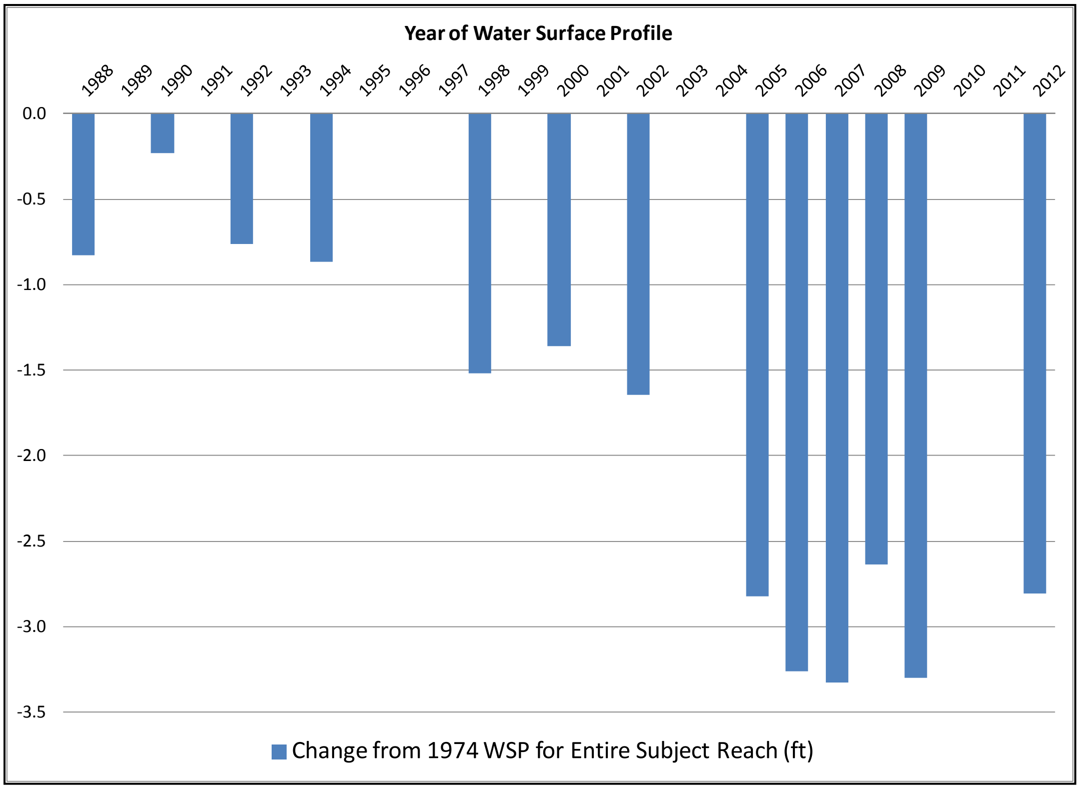

Figure 3. Average WSP stage decrease between rm 310 and rm 440

Both the Stage Trend data and the WSP data show: the CRP discharge stage was relatively stable between 1974 and 1990, dropped significantly between 1990 and 2006, and has been relatively stable between 2006 and 2012.

2.2 History of Bed Degradation

Hydrographic surveys of the BSNP have been collected periodically over the subject reach since at least 1942. Most of the survey data is available in hard copy BSNP maps. The earliest available map is 1942. The last published map was 1994 and displays a survey collected that year. These surveys are only in hardcopy form and hence do not easily lend themselves to comparison of river bed elevations over more than a few cross sections. Surveys collected after 1998 are in a digital format that allows for relatively easy comparison of surveys over the entire extent of the surveys. The 1998 survey was collected on a random zig-zag pattern with cross sections spaced approximately every 300 ft. In 2007, defined cross section locations were established. All surveys since 2007 were collected at these same cross section locations. Digital surveys that cover the entire subject reach were collected in 1998, 2007, 2008, 2009, 2011, 2012, and 2013. Multiple surveys of lesser extent were also collected during the 2011 flood.

Due to the lack of survey data in a digital format prior to 1998, direct comparison of bed elevations for multiple years prior to 1998 has only been completed at a few locations. Figure 4 and Figure 5 show two such comparisons.

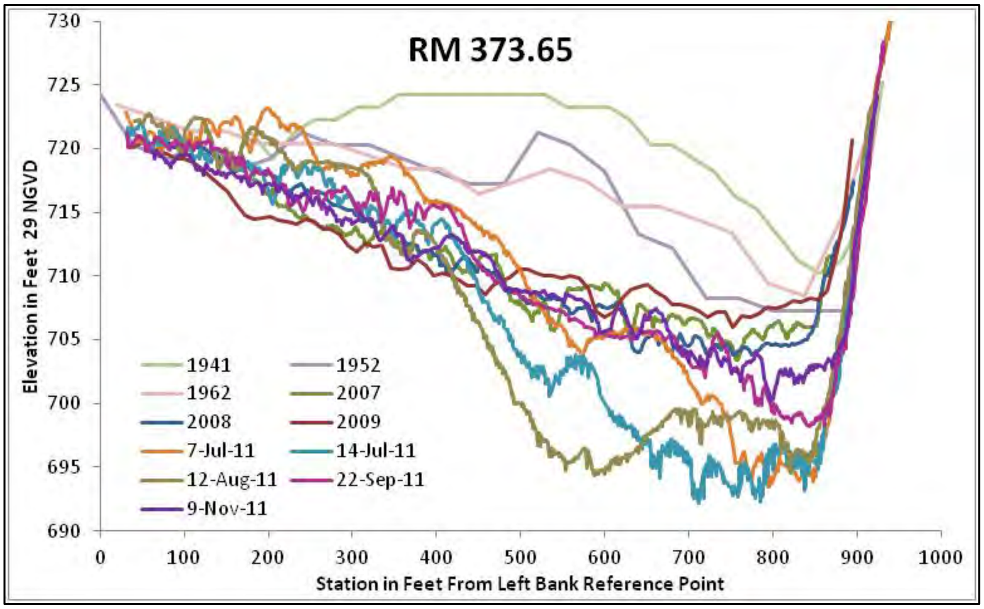

Figure 4. Cross section comparison at rm 373.65

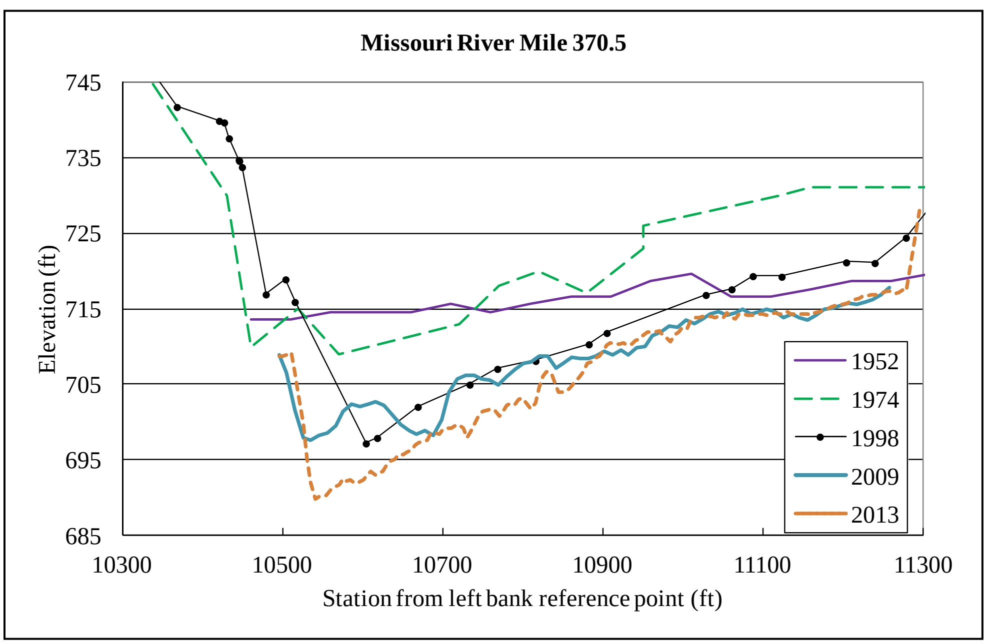

Figure 5. Cross section comparison at rm 370.5

Survey comparisons over the entire spatial extent of the subject reach were completed for the following surveys; 1998 and 2007, 2009 and 2012 (Figure 6), 1987 and 2009, 1987 and 2011 (Figure 7). The 1987 hardcopy data was manual entered into an electronic format.

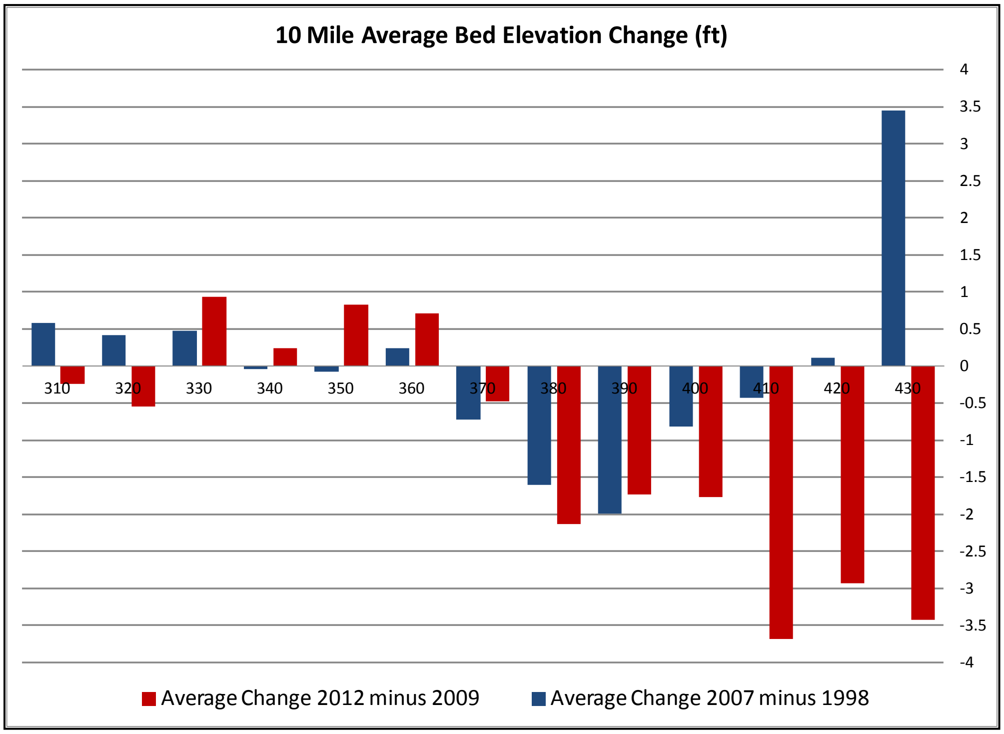

Figure 6. Ten mile average bed change for selected surveys

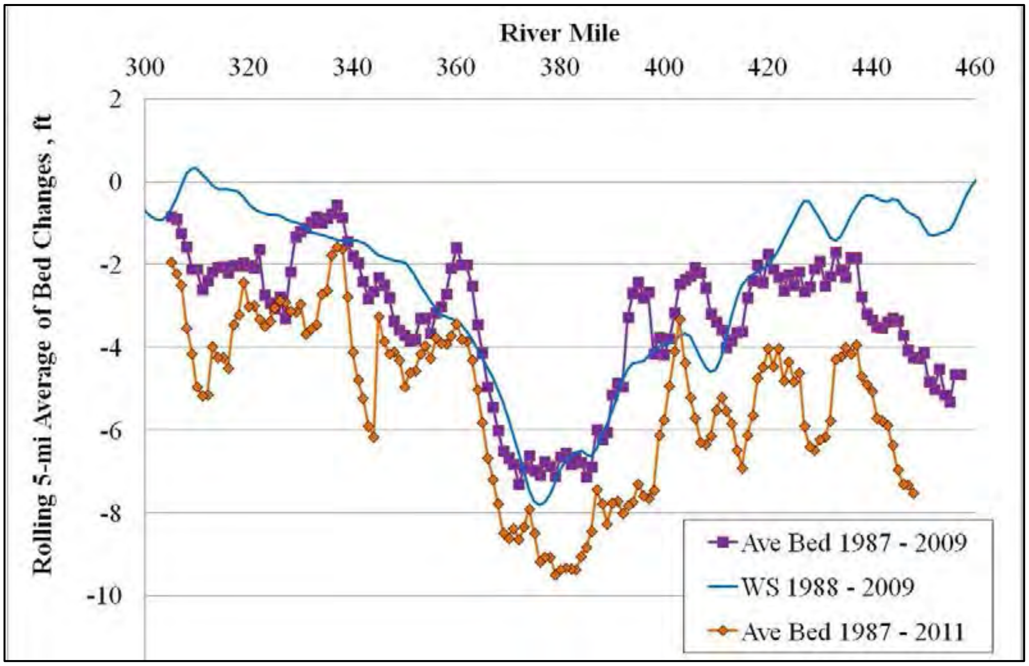

Figure 7. Comparison of average bed elevation change for selected surveys.

Hydrographic survey data and WSP follow similar trends when analyzed over multiple years and multiple river miles. While degradation has occurred over the entire subject reach since 1990, the degradation is most severe upstream of rm 360 and appears to be moving in an upstream direction. Degradation downstream of rm 360 appears to have slowed or perhaps temporarily stabilized.

2.3 Construction Reference Plane

The crown elevations of the BSNP rock structures are maintained to heights relative to the Construction Reference Plane (CRP). Since 1973, the CRP has been defined as the sloping water surface elevation of a discharge that is exceeded 75% of the time during the navigation season. The CRP can change in two ways; the CRP discharge can change as the river's discharge frequency changes over time, or the water surface elevation that represents the CRP discharge can change as the bed of the river changes over time. Table 1 shows the history of CRP revisions since the 1982 CRP. CRP revisions prior to 1982 used slightly different methodologies and therefore cannot be compared to 1982 and after CRP revisions.

Table 1. History of CRP Revision

Year of CRP Revision	Discharge Revised	Elevation Revised
1982		X
1990		X
2002	X	X
2005	X	X
2010		X

Table 2 shows the CRP discharge at each of the three USGS gages in the subject reach for the different CRP. The difference between the discharges at each gage is partially due to differences in methodology for each discharge revision. The 2002 revision used reservoir model regulated data for a period of record of 1898 to 1997 whereas the 2005 revision used observed flows from 1967. Prior CRP discharges were estimates of post-dam flow frequencies.

Table 2. CRP Discharge at USGS Gages

USGS Gage	1982, 1990 CRP Discharge	2002 CRP Discharge	2005, 2010 CRP Discharge
St. Joe	37,500	41,200	40,600
Kansas City	43,000	46,000	44,200
Waverly	43,500	46,800	45,100

Figure 8 shows the elevations of all CRP in use since 1982. Note that the 2005 and 2010 CRP discharges are higher than the 1982 thru 1990 CRP discharges, but the 2005 and 2010 CRP elevations are lower. The profiles in Figure 8 were not adjusted to a common discharge because the CRP elevations are used to reference structure heights regardless of the CRP discharge. CRP trends follow water surface profile and bed elevation trends discussed in previous sections.

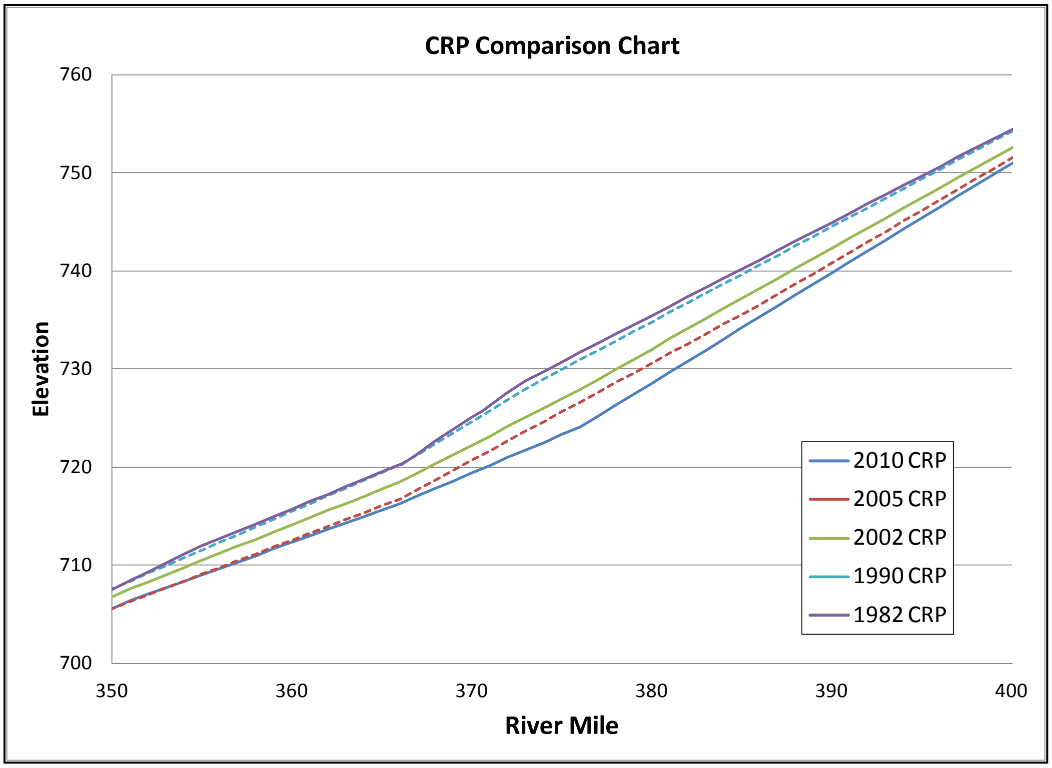

Figure 8. CRP plots for subject reach.

2.4 Structure Design Criteria

The 'Missouri River Navigation Project Structure Design Criteria' (SDC) provides a guideline for the heights of the different types of BSNP rock structures relative to CRP (Figure 9).

MISSOURI RIVER NAVIGATION PROJECT
STRUCTURE DESIGN CRITERIA

December 1973

	Channel Width	Channel Width to Sills	Dike Height Concave	Dike Height Convex	Revetment L-Head	Revetment SFR	Sills	Crossing Control Structures
Sioux City-Platte R. (Mile 734 to 594)	600'	500'	+1.0	0	0	+1.0	0 to -5	+2.0
Platte River-Rulo (Mile 594 to 498)	600'	500'	+2.0	+1.0	+1.0	+2.0	0 to -5	+3.0
Rulo-Kansas River (Mile 498 to 367)	800'	550'	+3.0	+1.0	+1.0	+3.0	-2.0	+4.0
Kansas R-Grand River (Mile 367 to 250)	900'	600'	+3.0	+1.0	+1.0	+3.0	-2.0	+4.0
Grand R-Osage River (Mile 250 to 130)	1000'	650'	+4.0	+2.0	+2.0	+4.0	-2.0	+5.0
Osage R-Mouth (Mile 130 to 0)	1100'	750'	+5.0	+3.0	+3.0	+5.0	-1.0	+6.0
Percent of time proposed height criteria is exceeded during the navigation season	--	--	30%	50%	50%	30%	> 95%	20%

NOTE: The above structure height criteria is referenced to Q_{75} (CRP) as determined from a 1972 Summer Rating Curve. Q_{75} = Discharge occurring 75 percent of time. CRP = Construction Reference Plane (Computed Sloping Plane for referencing structure elevations)

Station	$Q_{75} = Q_{CRP}$	CRP Elev.	Q_{20}	Q_{30}	Q_{50}	$Q_{>95}$
Ponca (754)	30,000	1100.9	37,000	33,000	40,000	25,000
Sioux City (734.8)	30,000	1077.9	37,000	33,000	40,000	25,000
Omaha (615.9)	31,000	964.8	39,000	36,000	43,000	26,000
Rulo (498.0)	36,500	847.9	55,000	50,000	43,000	30,000
St. Joseph (448.2)	37,500	798.4	56,000	52,000	44,000	30,500
Kansas City (366.1)	43,000	721.9	74,000	63,000	52,000	32,000
Waverly (293.4)	43,500	657.0	76,000	65,000	53,000	32,500
Boonville (197.1)	46,000	574.9	88,000	74,000	58,000	37,000
Hermann (97.9)	54,000	489.6	110,000	92,000	71,000	41,000

TABLE 8 - STRUCTURE DESIGN CRITERIA (1973)

Figure 9. Structure Design Criteria

Structure heights vary by type of structure and by location in the river. However, for a given type of structure, the percent of time the flow exceeds the structure height during the navigation season is the same no matter where in the river the structure is located. Therefore, a structure located above the Platte River has the same relative overtopping height as the same type of structure located below the Osage River. This approach provides uniformity in structure heights over the full 734 miles of the BSNP.

Figure 9 is dated 1973 in the 1980 Potamology Investigation- Missouri River. On page 11, the report states “By 1960, the channel had been essentially stabilized into one channel and construction had advanced to the refinement stage. As a result, the design height of new structures was lowered from previous design criteria.” The report then states that the SDC is the “optimum elevation” and allows “the structures to function adequately in maintaining the navigation channel at minimum height, which has less effect on flood heights, less adverse environmental effects, and is more economical to build.” It is not known what the SDC was prior to 1960, or if the 1973 SDC was originally published in 1960.

Although the 1973 SDC provides a guideline for uniform structure heights, occasionally the heights of individual structures or groups of structures intentionally deviate from the 1973 SDC due to navigation channel shoaling (usually higher), bank instability issues (usually higher), or environmental concerns (usually lower) such as loss of flow conveyance or loss of aquatic habitat.

3. Structure History

The following sections review the construction and repair history of the BSNP structures in the subject reach. The data used in these sections was pulled from either the 1980 Potamology Investigation report or the IMERO database which contains the construction/repair/modification history of all BSNP structures. Figure 10 shows a typical layout of the various types of BSNP structures.

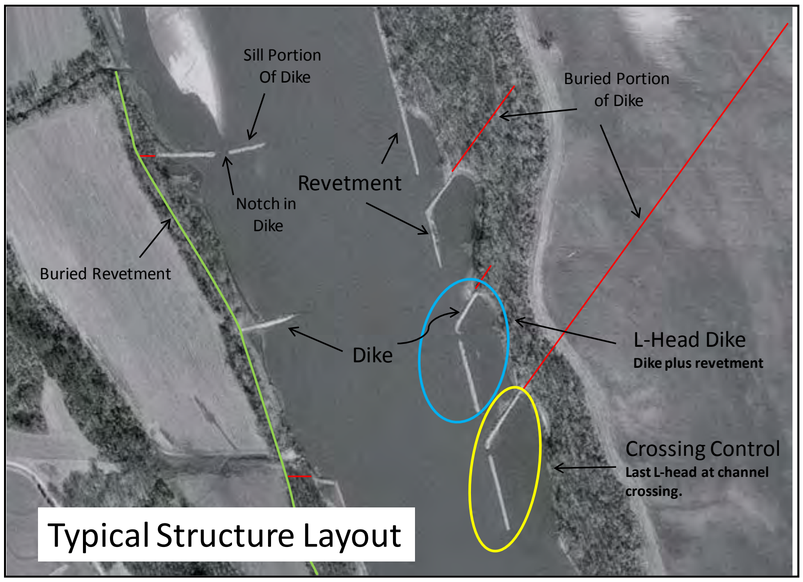

Figure 10. Typical Structure Layout

3.1 Structure Construction History

Figure 11 displays a timeline of new dike, dike extensions, and revetment construction for the subject reach. The data in Figure 11 was pulled from the 1980 Potamology Investigation- Missouri River which presents historical data up to 1978. Sills and L-head revetments were introduced in 1960 as structure features and account for a large amount of the dike extensions and revetment construction after that year.

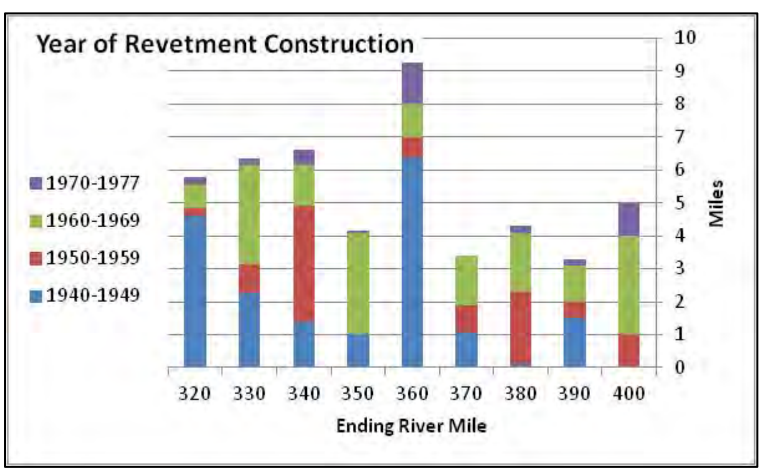

Figure 11. Dike and revetment construction by year, 1940-1977

3.2 Structure Repair Heights between 1974 and 1990

As shown above, the river was relatively stable between 1974 and 1990 and almost all new construction had occurred prior to 1974. For these reasons, 1974 was the year chosen to begin analysis of structure repair heights.

BSNP structures require continual maintenance independent of bed elevation changes. Hydraulic forces, boat impacts, shoaling problems, and other factors cause structures to require repair or other modifications. Figure 12 shows the finished crown heights of all dikes, sills, and crossing control structures maintained in the subject reach after 1973, the first known publish date of the current SDC, and before 1991, the end of the relatively stable river period. Heights are referenced to the 1982 CRP which was the CRP in effect during the middle of this period. Each point on the graph represents one maintenance action on one structure in one year. Some of the same structures received multiple actions during this time period so that one structure may have multiple points on the graph. The revetments were not evaluated since they run parallel to the current and have a lesser impact on the active river bed.

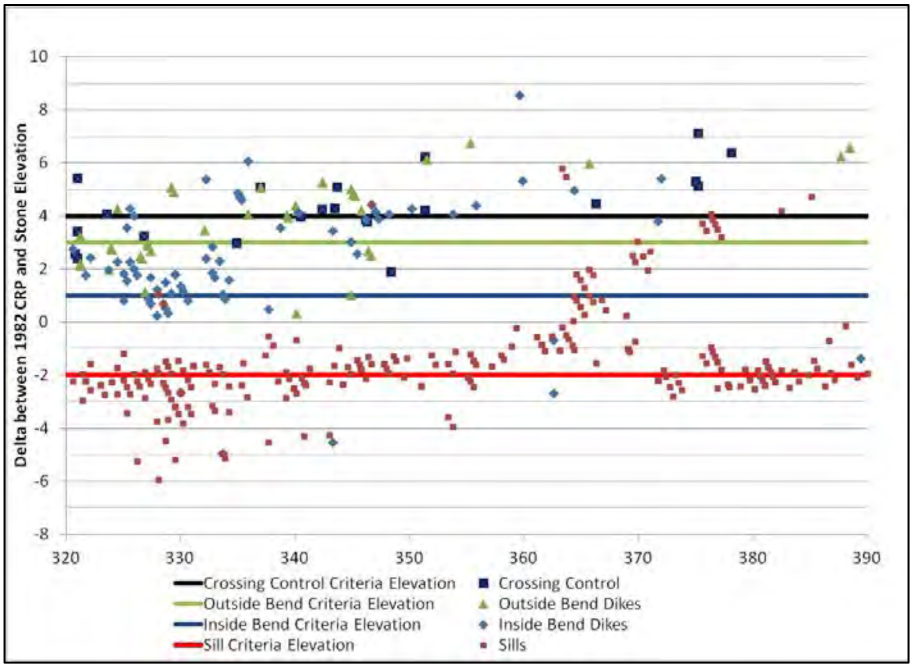

Figure 12. Finished crown heights of maintained structures, 1973 to 1990

The data in Figure 12 was thinned to show only the height for the most recent maintenance action as of 1990 for each portion of all maintained structures (Figure 13).

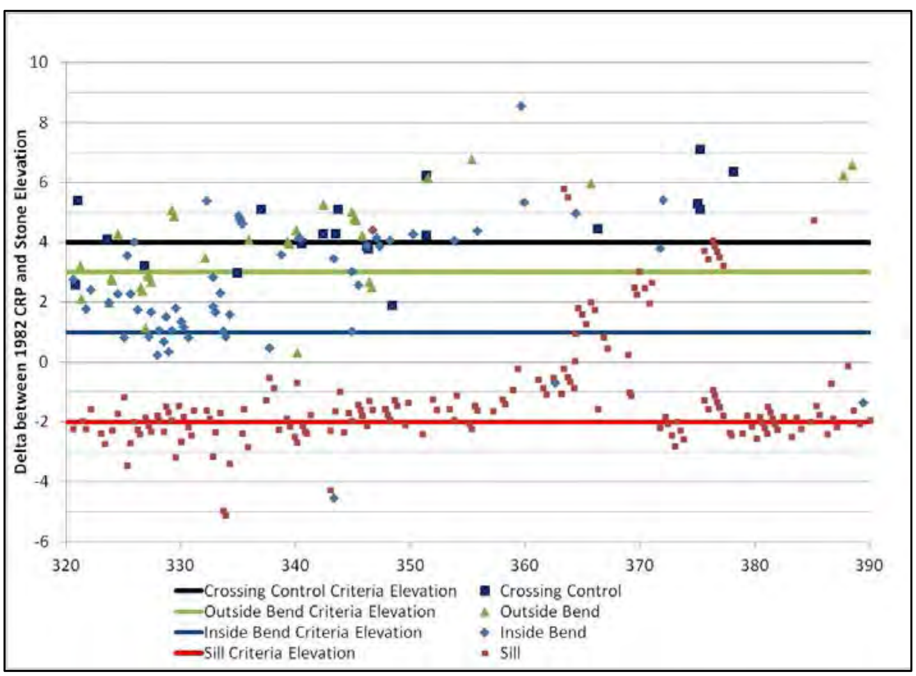

Figure 13. Finished crown height of the most recent iteration of repair, 1974 to 1990

As is evident in Figure 12 and Figure 13, some of the structure heights intentionally deviated from the 1973 SDC. Most of the intentional deviation was between rm 360 and rm 380 where the Federal Levees are in close proximity to the river and where the navigation channel experienced shoaling due to the confluence of the Kansas River and the unusually straight reach immediately downstream. The intentional deviation was to rectify the navigation issue and to protect the levee foreshore from river induced bank erosion during flood events.

Figure 14 shows the finished height of all repairs by year during this time period. Note that most sill repairs that exceeded the 1973 SDC were constructed by 1982 and a small number of inside bend dike repairs that exceeded the 1973 SDC were constructed between 1985 and 1988.

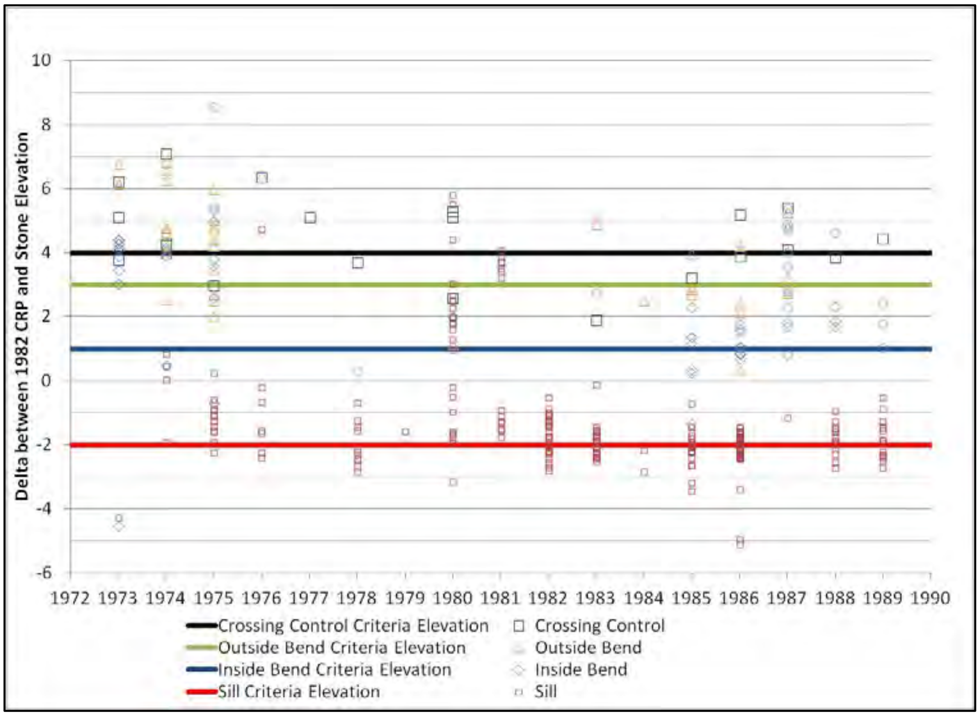

Figure 14. Structure repair height by year and by type of structure

Table 3 shows the percent of structures in Figure 13 where the crown height exceeded the SDC by more than 1 ft. One foot of tolerance was chosen due to rounding to whole numbers in the database.

Table 3. Percent of structure repairs, 1974 to 1990, that exceeded SDC

Type of Structure	Total Existing	Number Above Criteria	Percent Above
Sills	243	45	19%
Outside Bend Dikes	81	25	31%
Inside Bend Dikes	251	35	14%
Crossing Control	42	10	24%

3.3 Structure Repair Heights Between 1990 to 2002

As shown in Figure 8, CRP elevations dropped fairly rapidly after 1990. This period experienced higher than normal flows that includes the 1993 flood. There were 50 structure repairs during this period. As shown in Figure 15, almost all the inside bend dikes and sill repairs were to criteria, and 9 outside bend dikes were repaired above criteria. The outside bend dikes repaired above criteria were at the location of 1993 flood scour holes and the intentional SDC deviation was to prevent further overbank scour in the event of subsequent high water. The revetments were not evaluated in Figure 15 since they run parallel to the current and have a lesser impact on the active river bed.

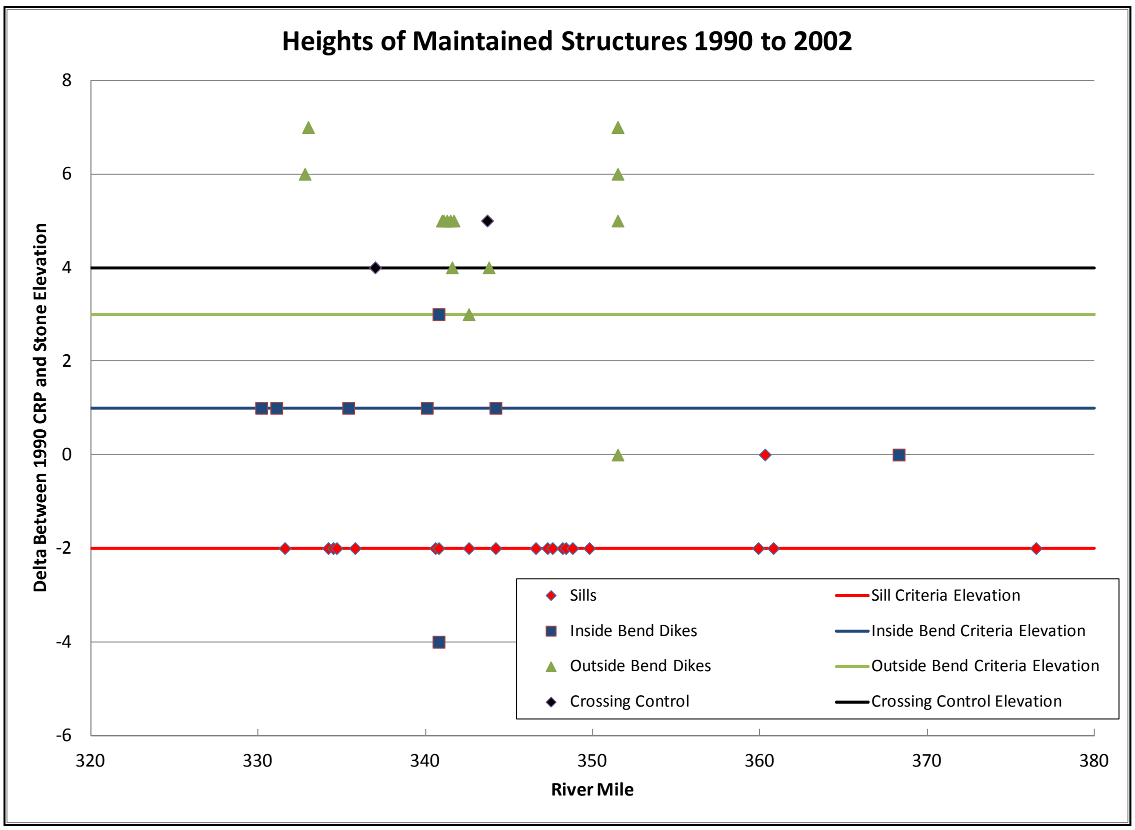

Figure 15. Finished heights of maintained structures, 1990 to 2002

3.4 Sill Heights In 1990 and 2002

As the CRP elevation dropped after 1990, the erosion rate of the crowns of the structures did not keep pace with the falling CRP elevation and the heights of the structures relative to the CRP elevation increased. The structures had become 'perched' in that the structure crowns were at heights in excess of the 1973 SDC or intentional SDC deviations.

To understand how the relative heights of the structures changed after 1990, it is useful to plot the heights of sills in 1990 and again in 2002. The sills were chosen for this analysis because they are the riverward end of the dikes, perpendicular to flow, not buried in the bank under accretion, rarely notched, and hence have a significant impact on the hydraulic aspects of the river. To ascertain the sill heights, the last repair elevation of all sills in the subject reach was plotted and a crown erosion factor of 0.1 ft for each year between the repair year and either 1990 or 2002 was applied. The 0.1 ft number was derived by reviewing repair cycle timelines in the IMERO database.

Figure 16 plots estimated sill heights in 1990 relative to the 1973 SDC and the 1990 CRP. Except for sills between rm 363 to rm 383, the average height of the sills was at or below the 1973 SDC as shown by the trendline. The high elevation sills between rm 363 and rm 383 are the sills repaired in 1980 and 1981 (Figure 14) to correct the navigation problem below the Kansas River.

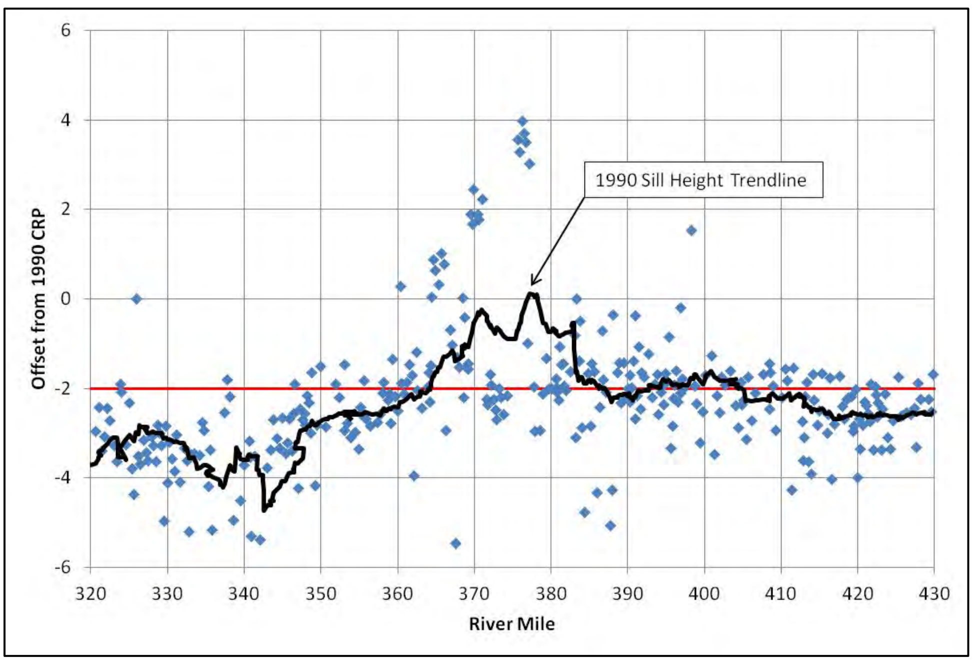

Figure 16. Estimated height of sill in 1990 relative to the 1990 CRP

When the CRP was revised in 2002, the height of the sills increased relative to the 1973 SDC (Figure 17). The '1990 Sill Height Trendline Degraded 0.1' per year' in Figure 17 is the estimated height the sills would have been in 2002 had the CRP not been revised due to falling WSP. The delta between the '1990 Sill Height Trendline Degraded 0.1' per year' and the '2002 Sill Height Trendline' represents the perched condition of the sills due to falling CRP elevations. Thus, by 2002, the sills were perched due to falling CRP elevations, not due to intentional SDC deviations.

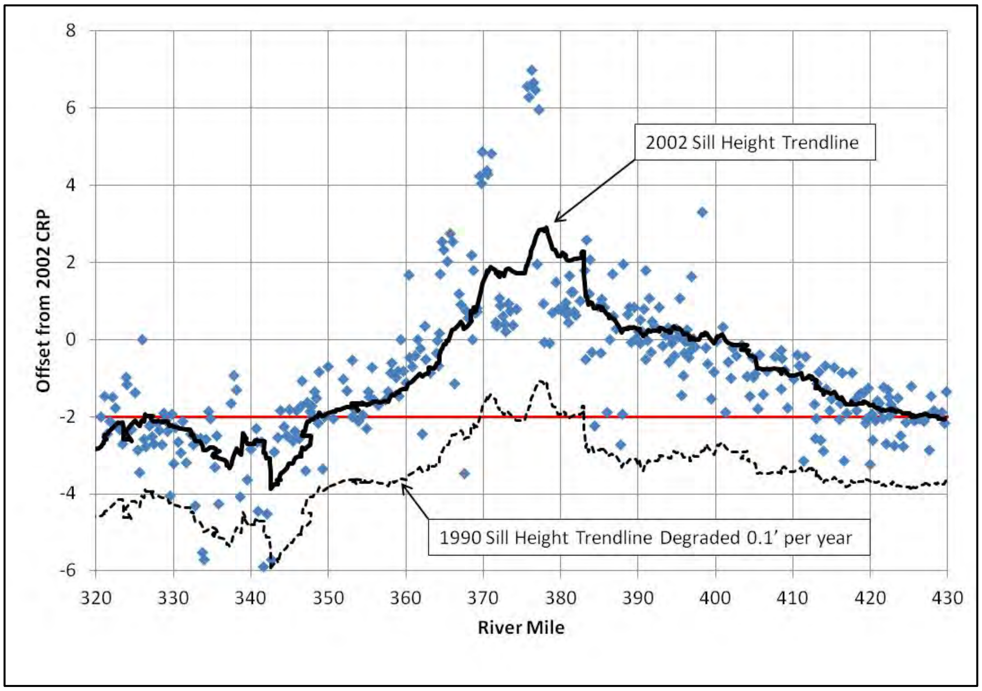

Figure 17. Estimated height of sills in 2002 relative to the 2002 CRP

3.5 History of Structure Lowering

Structure lowering and structure notching are the physical action of removing rock from the crown of the structures resulting in a lower crown height. Notching removes rock over a short (generally 75 ft or less) section of the structure and to a lower elevation (-3 to -5 CRP) than structure lowering which is rock removal usually over the entire exposed portion of the structure. Both have the effect of lowering the effective height of the structure, and for this discussion, notching and lowering will be treated the same.

The negative effects of the perched condition of the structures from 1993 until around 2000 was somewhat masked by the unusually high flow during the period. With the return of normal or low flow after 2001, the accretion induced by the perched structures became exposed and covered with woody vegetation (Figure 18).

Figure 18. Accretion and vegetative encroachment between 1997 and 2003 at rm 364

The accretion process in Figure 18 results in the loss of aquatic habitat as the woody vegetation traps additional sediments and gradually transforms open river into high bank. In 2002 the Corps was constructing shallow water aquatic habitat as part of the Missouri River Mitigation Project (MRMP). The Corps was also obligated to comply with the 2000 Fish and Wildlife Service's Biological Opinion on the Operation and Maintenance of the BSNP (BiOp) which required the preservation of existing shallow water aquatic habitat and the creation of up to 19,565 acres of new aquatic habitat. Since the accretion process in the subject reach and resulting loss of shallow water aquatic habitat was at odds with the objectives of the MRMP and the BiOp, the structures in the subject reach became prime candidates for notching and lowering.

Once or twice a year, ED-H staff conducts low water inspections over the 498 miles of the Missouri River within the District boundaries. During these inspections, structures below the 1973 SDC criteria are prioritized for repair and structures where construction of a notch will benefit aquatic habitat are prioritized for notching.

During field inspections in 2001, due to the perched condition of the structures, staff from ED-H selected structures to lower and notch within the subject reach. Most of the selected structures were located between rm 350 and rm 370 since the perched condition was the most significant, the loss of aquatic habitat due to accretion was greatest, and maximum river cross section area for flow conveyance is important due to the close proximity of the Federal Levees. The lowering was added to the 2002 structure maintenance contract. The details of the completed work were then entered into the IMERO database.

The same selection process was followed in 2004, 2009, and 2013. Figure 19 shows the location, quantity, and year of lowering.

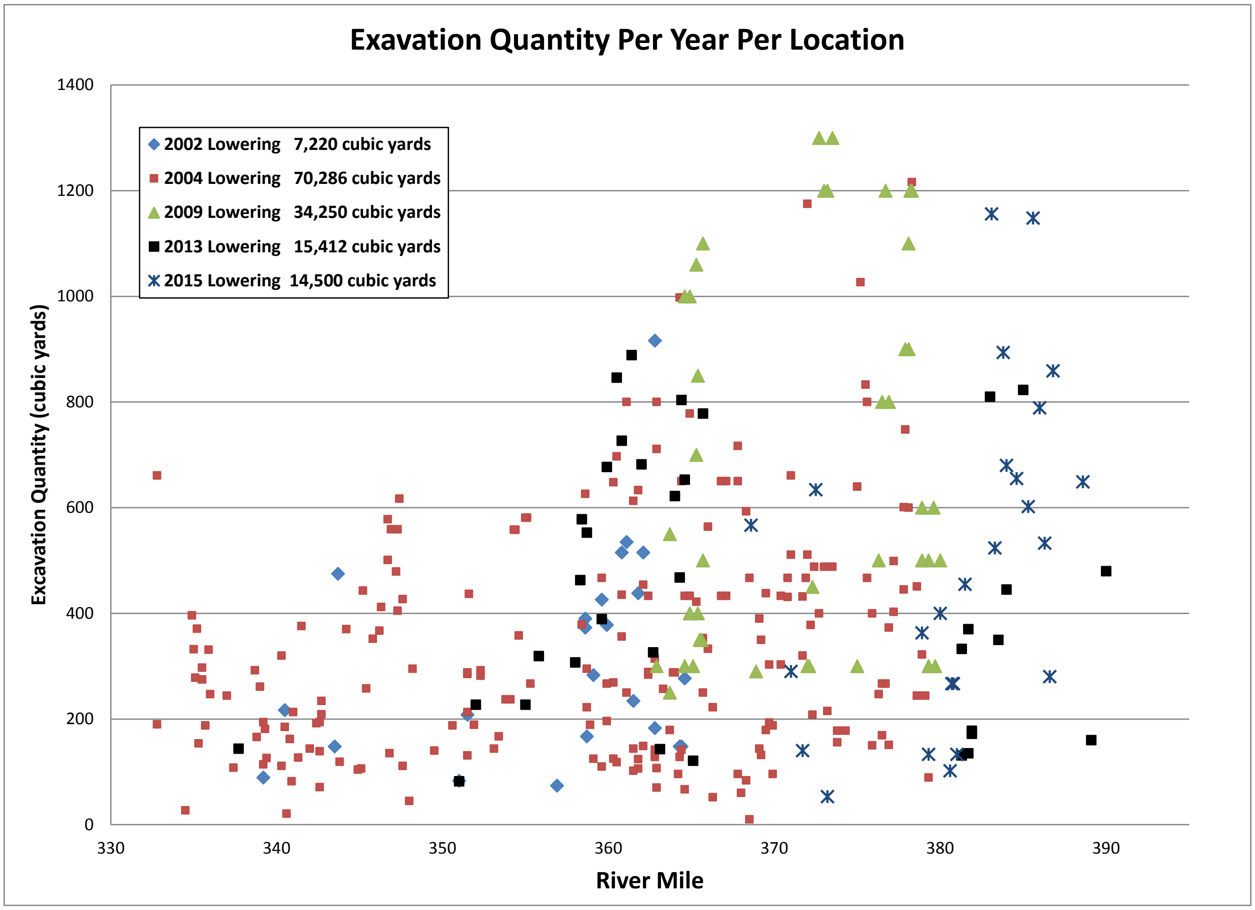

Figure 19. Structure lowering quantities.

Structures lowered in 2002 and 2004 were lowered relative to the 2002 CRP; structures lowered in 2009 were lowered relative to the 2005 CRP; and structures lowered in 2013 were lowered relative to the 2010 CRP. Since the CRP was declining during this period, some of the structures previously lowered were lowered further in 2004, 2009, and 2013. In other cases, additional, usually landward, portions of the same structures were lowered, or previously non-lowered structures were lowered. Due to the multiple iterations of lowering of each structure, and the segmented approach to lowering (selected segments of each structure lowered each time rather than the whole structure lowered) each point on the graph does not represent an entire structure and each structure is not represented by one point.

Since structure heights are measured from the CRP elevation, the height of previously lowered structures change every time the CRP elevations are revised. As the CRP elevation trend in the subject reach is downward, with each CRP elevation revision, the height of previously lowered structures increased. It is therefore useful to plot the height of all lowered structures relative to the current CRP (Figure 20). Since lowering is always to increments of whole numbers, and the CRP elevation did not decrease uniformly across the subject reach, the heights plot in horizontal bands that trend vertically opposite the CRP trend. Thus, for example, structures lowered in 2004 at rm 335 to -3 CRP are still at -3

CRP when evaluated against the 2010 CRP, but structures lowered in 2004 at rm 377 to -3 CRP are now at -0.03 CRP when evaluated against the 2010 CRP. The vertical separation between the bands for each year of lowering is due to rounding to whole numbers and due to the different lowered height for the different types of structures.

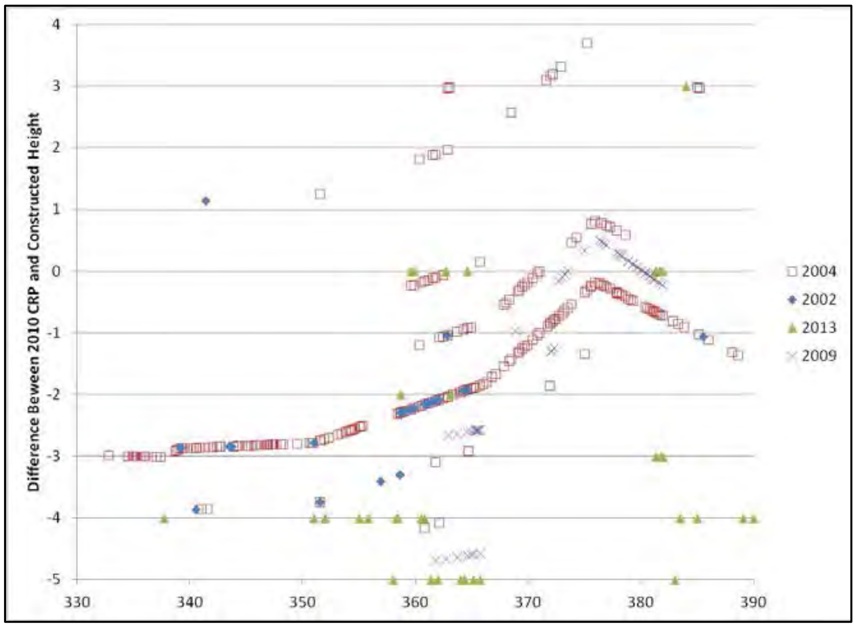

Figure 20. Finished crown height of lowered structures relative to 2010 CRP

4. Current Structure Heights

A field survey of the subject reach was conducted in January 2015 during which time the structure heights relative to the 2010 CRP were recorded. The average height of each structure was recorded. If a structure contained a notch, the width and depth of the notch was not averaged into the height of the structure. Thus, only the height of the un-notched portion of a structure was recorded. Sills have few if any notches and therefore the height recorded represents the average height of the entire sill.

4.1 Sills

Figure 21 plots the height of all sills. As seen in the graph, almost all sills are above criteria.

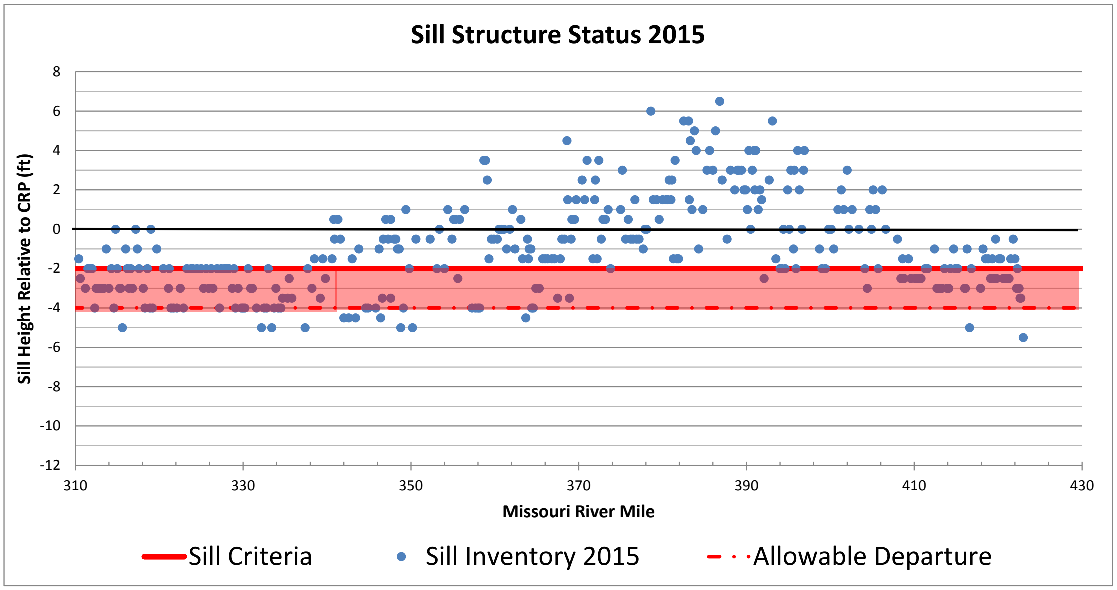

Figure 21. Sill heights in 2015.

4.2 Inside and Outside Bend Dikes

Figure 22 and Figure 23 plot the height of inside bend dikes and outside bend dikes. Dike heights are generally above criteria.

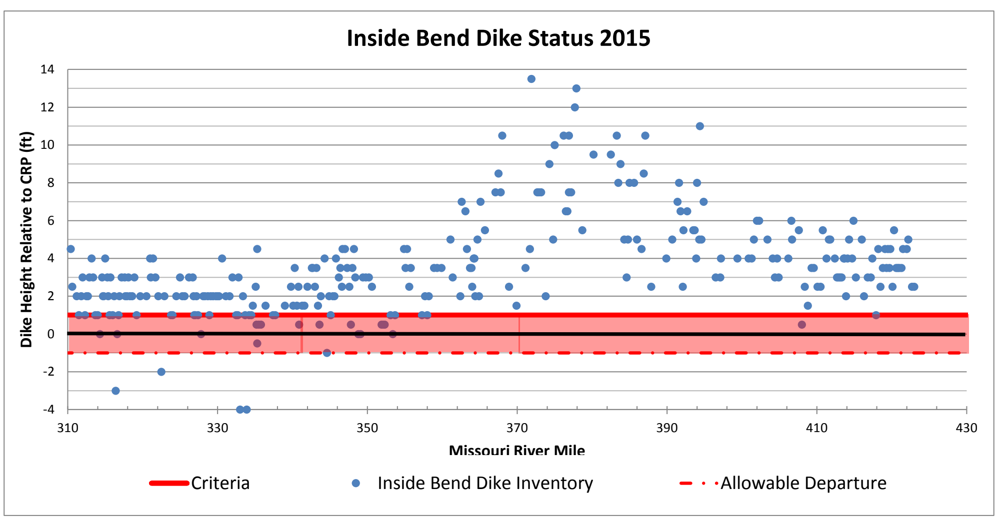

Figure 22. Inside Bend dike heights in 2015.

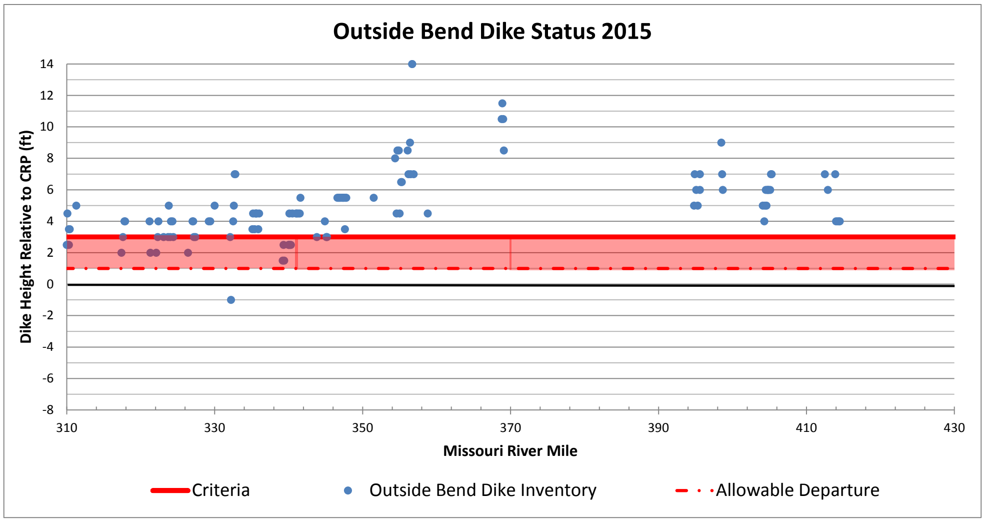

Figure 23: Outside Bend Dike Heights in 2015

4.3 Crossing Control Structures

Figure 23 plots the height of crossing control structures (CCS). CCS heights are on average above or within criteria over the entire study reach.

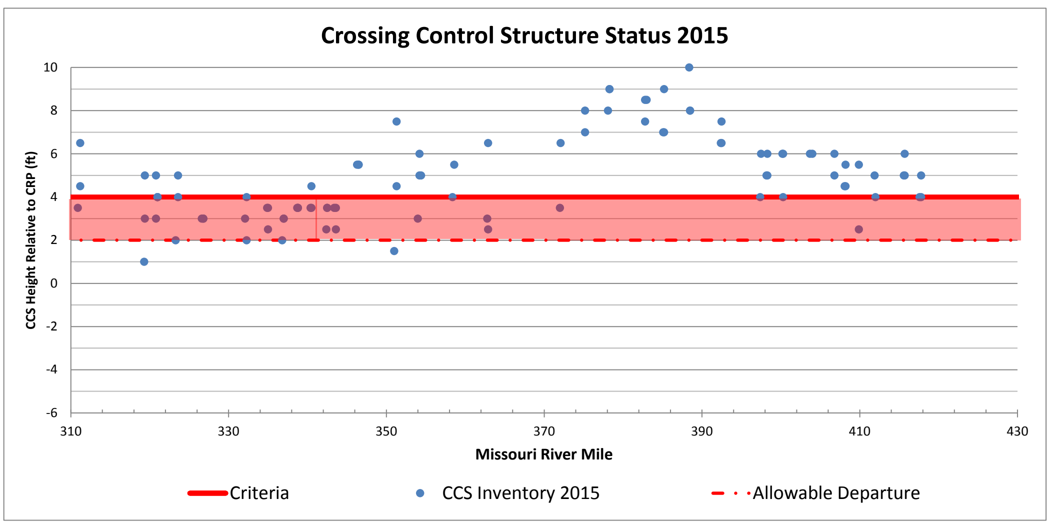

Figure 24. Crossing control structure heights in 2015

4.4 L-Head Revetments

Figure 24 plots the height of L-Head revetments. L-Head revetment heights are on above criteria over the entire study reach.

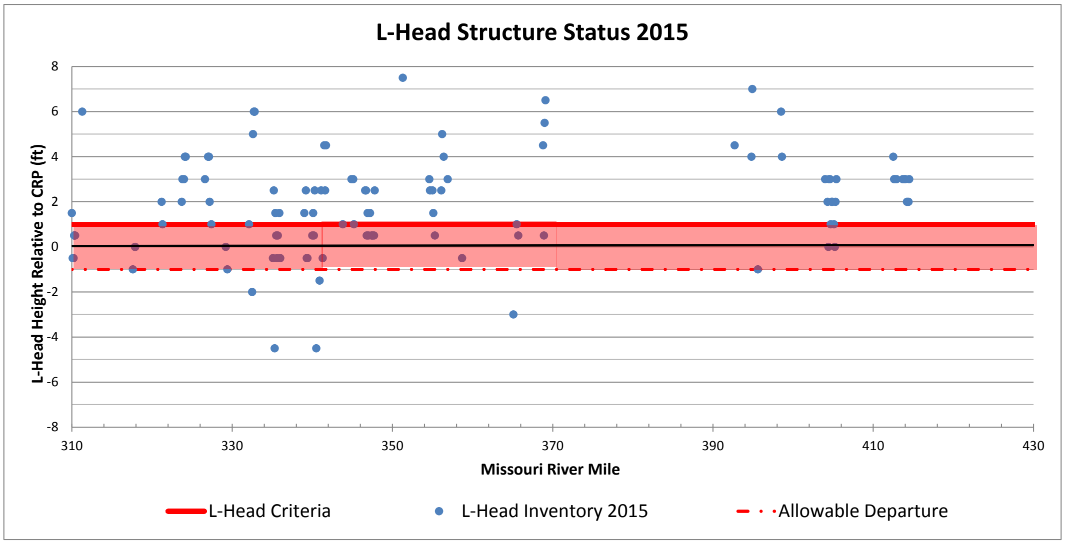

Figure 25. L-head revetment heights in 2015.

5. BSNP and Adjacent Levees

While the BSNP was built for the purpose of providing a self scouring navigation channel, the project had the ancillary benefit of eliminating meander of the Missouri River allowing development to take place on the floodplain. Most of this development is protected by an extensive system of levees running from Omaha, Nebraska to the mouth of the river north of St. Louis, Missouri. The levee system is diverse; levees are located in rural and agricultural settings as well as in heavily populated urban settings such as Omaha, Nebraska, Council Bluffs, Iowa, St Joseph, Missouri, and Kansas City, Missouri. The inventory includes federally authorized and federally constructed levees (federal levees) operated by non-federal sponsors, and levees constructed and operated by non-federal sponsors (non-federal). The levees were mostly constructed between the mid-1940's and the early 1980's, with the most recent federal levee constructed in 2003.

The federally constructed levees are in general more robust and were designed and constructed to Corps standards in place at the time of construction. Conversely, the non-federal levees were rarely constructed to Corps standards and lack detailed subsurface investigation or detailed engineering analysis. The frequency at which the existing Missouri River levees overtop also varies widely. In general, the federal levees were designed based upon an authorized discharge and currently overtop at a 100-year (1% annual chance of exceedance) frequency or greater event. The non-federal levees are significantly lower in profile than the federal levees and most overtop at a 50-year (2% annual chance of exceedance) frequency or less event.

Specific to the subject reach, non-federal levees protect a wide river valley downstream of the Kansas City Metropolitan Area and overtop at or above a 10-percent annual exceedance probability (AEP). These levee heights allow the flow widths to increase from approximately 2,900 ft for a 10-year event to over 50,000 ft, or the valley width, during the largest flood events. In the highly urbanized Kansas City metropolitan area with all federal levees, rm 360 to 375, the 100-year flow width of 1900 ft is only slightly greater than the 10-year flow width of approximately 1650 ft. Upstream of Kansas City, there is a mix of federal levees and non-federal levees, with most non-federal levees providing less than a 20-year (5% AEP) level of protection. Figure 25 presents river top width for the 5-yr (20% AEP), 10-yr (10% AEP), 50-yr (2 % AEP), and 100-yr (1% AEP) floods compared to the natural valley width.

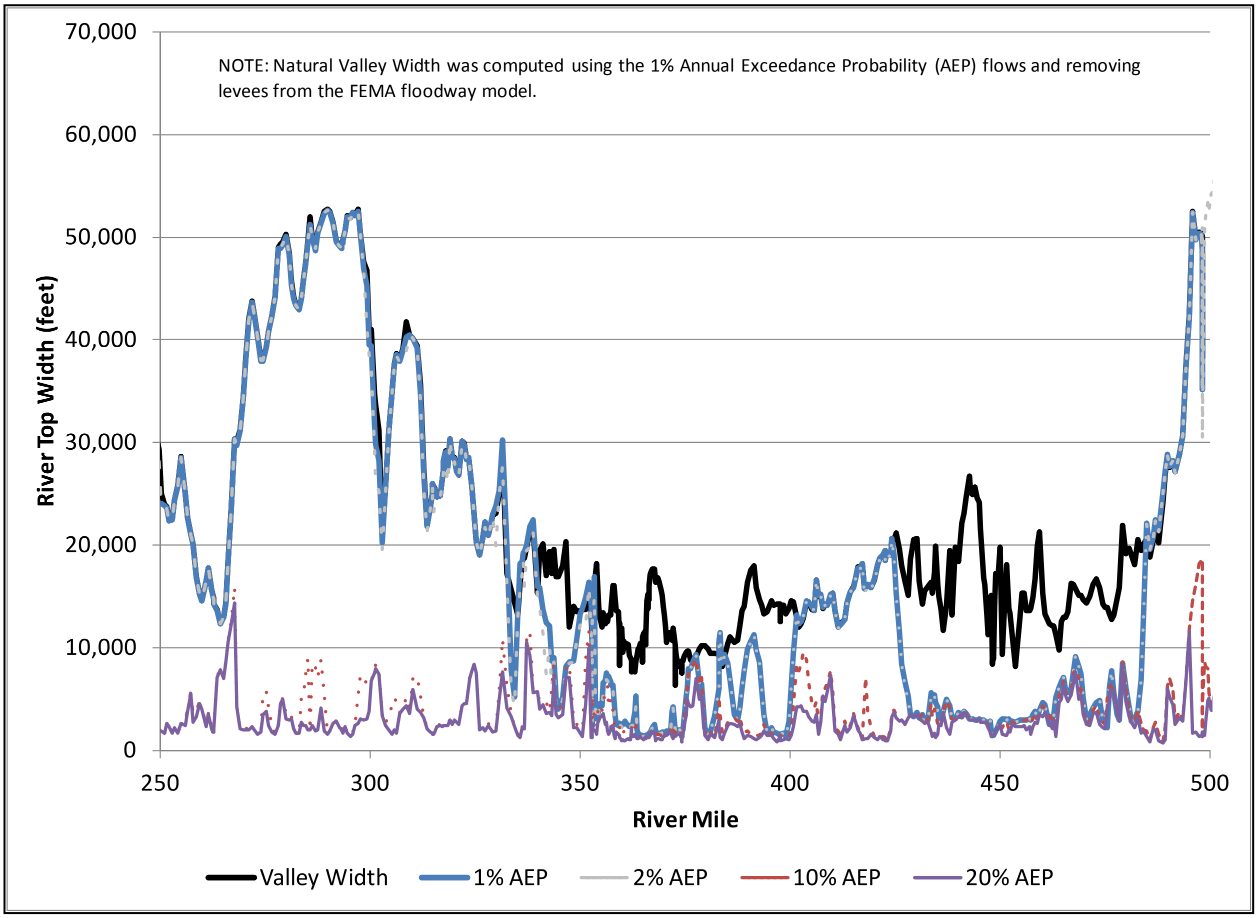

Figure 26. Approximate river widths for various annual flow frequency floods compared to the natural valley width (rm 250-500).

6. Summary and Conclusions

- The CRP elevation of the subject reach was relatively stable between 1973 and 1990 and began declining after 1990.

- Greater than 90% of the existing BSNP structures were built prior to 1960 and almost 100% were constructed prior to 1980. It would be expected that adjustment of the river to BSNP construction activities would have occurred prior to 1990.
- Between 1974 and 1990, a percentage of structure repairs intentionally deviated from the SDC. Most of the high elevation sill repairs were in 1980 and 1981, and almost all high elevation inside bend dike repairs were prior to 1988.
- By 1990, with the exception of the sills repaired in 1980 and 1981, all sills were at or below criteria.
- Between 1990 and 2002, with the exception of some outside bend dikes located at 1993 flood scour holes, most structures were repaired to elevations at or below the 1973 SDC.
- By 2002, due to falling CRP elevations, almost all sills between rm 350 and rm 410 became perched when referenced to the 2002 CRP. The perched condition was due to falling CRP elevations. Not due to intentional SDC deviations.
- By 2002 the amount of intentional SDC deviation was minor compared to the perched condition of the sills that resulted from falling CRP elevations.
- To minimize the adverse impact of the perched condition of the structures, selected structures were mechanically lowered starting in 2002.
- As the CRP continued to drop after 2002, multiple iterations of lowering were necessary to keep the same structures within criteria. Almost all lowering was downstream of rm 380. Total quantity of rock removed is 127,168 cubic yards removed over four iterations of lowering between rm 350 and 390.
- In December 2013, the average effective height of the structures from rm 310 to rm 380 was at or below SDC criteria and above SDC criteria from rm 380 to rm 430.

7. Appendix Plates 1-18, Maps of Lowered Structures