Mississippi River Miles 275.2-1.7

Analysis of the Effects of Bendway Weir Construction on Channel Cross-Sectional Geometry

By
Timothy Lauth
David Gordon, P.E.
Katherine Clancey
Adam Rockwell
Brad Krischel
Michael King

ARMY CORPS OF ENGINEERS
ST. LOUIS DISTRICT
HYDROLOGIC AND HYDRAULICS BRANCH
1222 SPRUCE ST.
ST. LOUIS, MISSOURI 63103

Sponsored by and Prepared for:
US. ARMY CORPS OF ENGINEERS – ST. LOUIS DISTRICT

In Cooperation With:
FISH AND WILDLIFE SERVICE
ILLINOIS DEPARTMENT OF NATURAL RESOURCES
MISSOURI DEPARTMENT OF CONSERVATION

Analysis of the Effects of Bendway Weir Construction on Channel Cross-Sectional Geometry

Contents

Figures

Analysis of the Effects of Bendway Weir Construction on Channel Cross-Sectional Geometry

Executive Summary

Bendway weirs are submerged rock river training structures pioneered by the St. Louis District reduce the scouring of exterior bend slopes while simultaneously widening the navigable channel. Since their development, bendway weirs have been installed throughout Corps waterways. Recently, St. Louis's environmental partners have been concerned that the bendway weirs are having an undocumented effect on channel geometry. To investigate the effects of the bendway weirs on cross-sectional bed geometry, a study was undertaken in which area, width, wetted perimeter, and slope were compared pre- to post-weir installation. The inner bend longitudinal slope was of particular interest, as there were concerns that the slopes were increasing, threatening shallow water habitat. Because of this, inner slope was calculated both for the entire cross section and using 10 ft vertical segments. For the study, 22 weir fields were examined over 5 time periods using 197 cross sections. Cross sections were established before the first weir, between each weir, and after the last weir in each weir field. The post-weir periods (2007 and 2005) and pre-weir periods (1986, 1982, and 1976) were chosen because nearly every weir field had been surveyed in each period.

When complete, the study revealed that the width at LWRP increased for 77% of the cross sections with an average increase of ~330 ft. The average slope decreased for 59% of all cross sections, with an average decrease of 1.27 ft. per 100 ft. The 10 ft vertical segment slopes were roughly even between decreases and increases, with ~70% of the slope changes falling with natural variation as defined by the study methodology. These results indicate the bendway weirs are largely achieving their primary goal of widening the navigable portion of the channel without a serious detrimental effect on the inside bar slope.

Scope

The purpose of this study is the analysis of river cross-sections to establish trends in riverbed geometry associated with the installation of bendway weirs. This report presents the findings of the study and the methodologies used in the analysis.

Background

Bendway weirs are river control structures consisting of submerged rock walls installed on the exterior slope of a bend. The weirs are oriented point slightly upstream so they alter the flow dynamics in the river bends to reduce the natural deepening of the river on the exterior of bends and lead instead to a widening of the river. The desired results are a reduction in shoreline erosion, improved navigable conditions for commercial river traffic, and the support of critical wildlife habitats along the river's bank line.

The St. Louis District of the Army Corps of Engineers began constructing bendway weirs on selected river bends along the Mississippi River in 1990. The construction of weirs involved with this study ended in 2000. It is anticipated they altered the riverbed bathymetry as the river established a new equilibrium. Assuming that equilibrium was established so that the effects of the weirs were stable, this study was conducted to determine the effect of bendway weirs on riverbed bathymetry. Particular attention was paid in the analysis of the slopes of the banks opposite the bendway weirs since these slopes are important for point bar development and navigation.

Data Collection

Mississippi River bed topography was measured using single-beam surveys during five different periods, both before and after the installation of the weirs. Survey information from 1976, 1982, and 1986 was selected as representative of the pre-weir bed topography and the available information from 2005 and 2007 was selected as representative of the post-weir topography. The data files from the selected survey years were converted for use with ArcMap software to create 3-dimensional images of the riverbed. Control points were then set at each bend to define the endpoints for the cross-sections analyzed in the study. Using the control points, multiple cross section profiles were measured for each bend for each time period. Cross sections were established before the first weir, after the last weir, and between weirs in each weir field. Depending on the number of weirs in the weir field, as few as 2 and as many as 15 cross sections were defined for each weir field. A cross section was plotted for each year of study to provide an initial idea of the changes that occurred to the section. Because of the width of the cross sections, the scales of the cross sections were distorted. To help prevent any confusion possibly caused by this distortion, one cross-section was plotted at a 1-to-1 scale.

To quantify the changes that occurred across a weir field, the following parameters were calculated for each cross section:

- area
- maximum depth
- inside bar slope (calculated two ways)
- width
- wetted perimeter (calculated as the perimeter of the cross section below a reference elevation)

The area, width, and wetted perimeter were calculated at two elevations: at the Low Water Reference Plane (LWRP) and 10 feet above the LWRP. The LWRP is an imaginary reference plane with known elevations for the entire channel representing the water level the Corps is legally responsible to maintain for a navigable channel. Because LWRP does not represent normal flow conditions and bank stages, a second elevation 10 feet above LWRP was selected. In cases where the elevation from the cross section did not reach LWRP or 10 ft above LWRP, the cross section was assumed to end at a vertical wall. The slope was calculated two ways, as the average inner bar slope (calculated to LWRP) and the inner bar slope divided into 10 ft vertical segments. The second slope method using 10 ft. vertical segments was used as a means to better define the variability of the channel slope that is lost by using the average slope.

The calculations provide a number of ways to measure the physical effect of the bendway weirs. The cross-sectional area serves as a check on the effect the structures are having on the river's geometry, particularly if the cross-section is decreasing in area and becoming channelized, which would present a flood risk. The maximum depth was calculated to see if the decreasing depth predicted by theory was occurring. A lower depth also aids in channel control. The average slope represents an important measure for bank stability and point bar development. The width is a necessity parameter to ensure that there is adequate channel space for barge navigation and environmental habitats. The wetted perimeter acts similarly as the width, while providing a measure of the balance between width and depth necessary for habitat when used in comparison.

Once the physical characteristics were calculated, the pre- and post- weir construction values were averaged within their respective periods to establish two values for comparison between the periods.

Calculation Methodologies and Data Analysis

The calculation of the desired variables required multiple steps:

1. To begin, the raw cross section data was imported into Microsoft Excel. The next step in the process was to filter the data to ensure that the vertical data were referenced to the LWRP elevation. Using an IF statement, the data was filtered by a high value that would fall between a referenced data point and the elevation of the point that had not been referenced to LWRP. If not already referenced to LWRP, the elevation was replaced with the value representing an LWRP-referenced point (the normal elevation minus the elevation at LWRP).
2. The filtered values were then used to calculate the area below LWRP by multiplying a given X1 value by a given Y2 value and vice versa. These values were then summed, added together, and divided by two (essentially, determining one area based on squares too large, one based on squares too small, and then averaging the two to get the best approximation of area).
3. Next, the horizontal values corresponding to the 10 ft elevation segments desired for a magnified slope investigation were determined. Linear interpolation was used where possible. If linear interpolation was not possible, the values were extrapolated from the closest values. With the horizontal references in place, the area below 10 ft above the LWRP was calculated using the same method previously. The widths were also calculated, taken as the horizontal difference between the two points where the desired elevations occurred.
4. The wetted perimeter was calculated next, by determining the distance between two corresponding points. The distances were calculated based on the differences between two corresponding x and y distances. The differences in the x- and y- dimensions were squared, and then the square root of the sum was taken to get a single distance between two points. These distances were summed to get the wetted perimeter for a whole cross section.
5. The last parameter calculated directly from the cross section data was the average slope for the bank opposite the weir installation. This parameter was calculated by dividing the maximum depth (already calculated) by the horizontal distance from the

point of the maximum depth to the bank at LWRP (easily determined from the segment-divided data points).

The relevant parameters were calculated, tabulated, averaged, and compared to establish pre-and post-weir construction conditions. To get a scale of the changes taking place between the values, the percent difference between the two periods was also calculated (See Appendix A).

However, the data tabulated in this step of the process did not necessarily reveal where possible changes in the cross sections were occurring. For example, were the cross sections maintaining their bank geometry while the thalweg widened, or was the weir-opposite channel geometry changing? To determine where changes were occurring, the 1986 and 2005 survey information were plotted together for select cross sections, and the areas representing deposition and erosion were highlighted (See Appendix B).

As mentioned previously, the inner bar slope was also calculated a second way. For a better measure of variation of the inner slope, the horizontal and vertical values of the bankline opposite the bendway weirs were plotted in 10 ft vertical segments and used to develop 10 ft vertical segment slopes. In cases where no measured points fell within a 10 ft segment for a particular year, nothing was plotted for that segment for that year. Once plotted, each year's measured data were fitted with trend lines (plot representations of equations trying to predict trends in the data). The trend lines were studied and R^2 values calculated to measure of the goodness of fit for a trend line (See Appendix C). The slopes of the trend lines were taken as the slopes for each 10 ft segment for the given years. In recognition that linear trend lines do not perfectly describe cross-sectional bed geometry, trend line slopes with an R^2 value below 0.80 were not used. An R^2 of 0.8 was chosen because to accept more variability than the more typical 0.9 (due to the limited sample size) while still removing poor fits. The value was set before analysis as not to prejudice the results. As with the other parameters, accepted values were averaged to determine pre- and post-weir construction values for comparison.

Because of the large amount of data that was collected from the 10 ft slope segments, tables were created to illustrate whether the slope had increased or decreased from the pre-weir period to the post-weir period. A system was developed to determine the scale of these changes and to determine if the changes between pre- to post- weir periods were comparable to the variation of the channel geometry prior to weir installation. The changes in slope were compared to multiples of the standard deviation of the pre-weir slope values. The changes in slope were compared to limits based on an increase or decrease of 1.5x the standard deviation, 3.0x the standard deviation, and 5.0x the standard deviation. Values representing 1.5x the standard deviation were chosen as the lowest setting due to the scarcity of data and the possibility that the weirs are not representative of the full variability. The 10 ft segments for each cross section comparing the slope change to the standard deviation multiples are presented in Appendix D.

Data Considerations

It is important to recognize the extent and limitations of the information captured by the riverbed surveys. Because of the dynamic nature of the riverbed, the bed geometry is constantly shifting, even during a condition that could be considered equilibrium. The continuously shifting bed conditions make the five data sets used in the study to analyze the changes occurring in the channel snapshots of the riverbed bathymetry. The survey data may only be valid for an indeterminate period of time, making the decision to utilize more than one survey per time period important. Although as many surveys as available should be used, the amount of processing required for inclusion of each survey comes at a considerable amount of time and monetary cost. The survey periods used in this study were selected for their near complete survey coverage of the weir fields involved in the study within the period.

It is also important to acknowledge the number of data points used to make up an individual bathymetric survey. In this study, the surveys developed for the earlier time periods were typically defined by dozens of points due to equipment limitations. The more recent surveys, which use more advanced equipment, are defined by thousands of points. For example, an older survey with a cross-section two thousand feet wide might have been defined by only forty-one data points, leaving an average spacing of fifty feet described by each point. It should also be noted that the data points found in the older surveys were not gathered on an average spacing, which potentially left large gaps in the record. These spaces failed to capture the actual variability of the bed geometry, leaving the analysts to work with what was available.

In this study, data was at times scarce above LWRP. The lack of data for the river channel above the LWRP may be attributed to a variety of reasons: the survey boat was operated far from the bank to avoid grounding or equipment damage; the shoreline was not the primary interest of measure; the shoreline was depth-dependent; the surveys were dependent on the date surveyed; etc. Regardless, the lack of data above the LWRP reduces the data's usefulness explaining the weir effects at the 10 ft above LWRP elevation level.

During the development of the 10 ft vertical segments slopes, certain slope values were rejected based on their R^2 value. A minimum R^2value of 0.8 was chosen before analysis to avoid a conflict of interest over choosing a correct value that favors a conclusion. Because of this, 351 of 953 (36.8%) 10 ft vertical segments were not used for pre- to post-weir construction comparison. While this was done to take into account that linear trend lines are not always the ideal fit for channel geometry, at the same time, it may have led to a loss of variability that could have revealed important habitat effects. It is important to acknowledge the link between segment length and variability this issue highlights i.e. smaller vertical segments capture a higher degree of variability but the information captured might not have real meaning for the channel because of data quality.

Analysis of Cross Sections

Pre- and post-weir field construction bathymetric surveys along with a description of the geometric changes to the study parameters pre- to post-weir construction follow. The red lines on the bathymetry images indicate the locations of the weirs; the black lines indicate the placement of the cross sections used in the study. Aerial photography from 2007 was used as the backdrop for the surveys to provide additional location reference. The color scale (Figure I) used for the bathymetry is the common scale used by St. Louis District and is included below. The numbering system implemented for the cross sections (and seen in the images following) was used as a reference for analysts; the numbering does not have a strict relationship to flow direction.

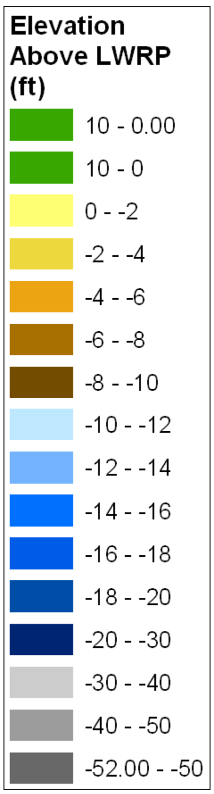

Figure I: Bathymetry Color Scale

1. Lock and Dam 24; *RM 275.2 to RM 274.3*

The weir field at Lock and Dam 24 (Figure 1.1, Figure 1.2) consists of five weirs constructed on the Left Descending Bank (LDB). Four of the five cross sections examined experienced decreasing area under LWRP and 10 ft under LWRP; the two measures of area both increased for the remaining section. All sections displayed decreases in maximum depth ranging from 1.17 ft. to 18.28 ft. The average slopes of the five cross sections did not change or were smaller than 3 ft. per 100 ft. The width and wetted perimeter, measured at both elevations, decreased for all cross sections. There was approximately a 66% negative difference between the pre- and post-weir conditions for all but the middle cross section. Although half of the usable average slopes of the 10 ft vertical segments decreased for the period of study, there was no definite pattern to where the changes occurred. There was one cross-section segment that showed a slope change outside the 1.5x the pre-weir variation, although this large slope increase may be due to a lack of information for the segment.

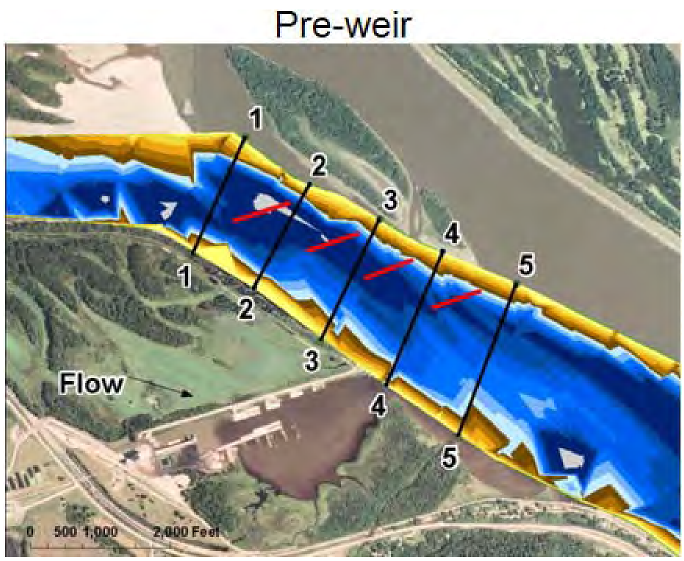

Figure 1.1: Lock and Dam 24 1976 Bathymetry

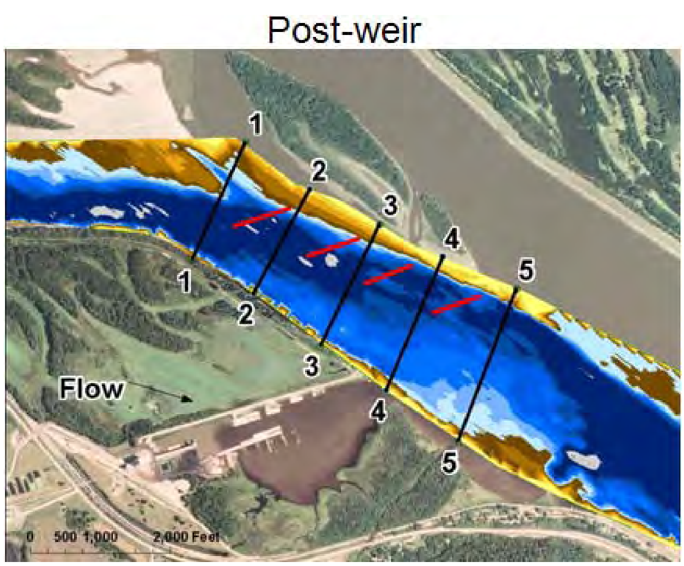

Figure 1.2: Lock and Dam 24 2007 Bathymetry

2. Mosenthien; RM 195.3 to RM 193.9

The Mosenthien weir field (Figure 2.1, Figure 2.12.2) consists of seven weirs on the LDB. Seven cross sections demonstrated increases in area below LWRP and area below 10 ft above LWRP. The two sections demonstrating an area decrease were the two furthest downstream cross sections of the weir field. Six of the cross sections displayed a decrease in maximum depth. The average slope increased or did not change for seven of eight cross sections, with the largest average increase in slope being 1.4 ft per 100 ft. The width and wetted perimeter at LWRP increased for the same seven sections that area did. Only four cross sections increased in width and wetted perimeter at 10 ft above LWRP. Approximately half of the usable average slopes of the individual 10 ft segments show an increasing slope; the -40 ft - -30 ft segments show a trend towards increasing slope. Likewise, the -20ft - -10 ft segment range shows a strong trend towards a decreasing slope. 70% of the slope changes occurring in Mosenthien fell within 1.5x the pre-weir variation; the majority of the remaining slope changes demonstrated an increasing slope.

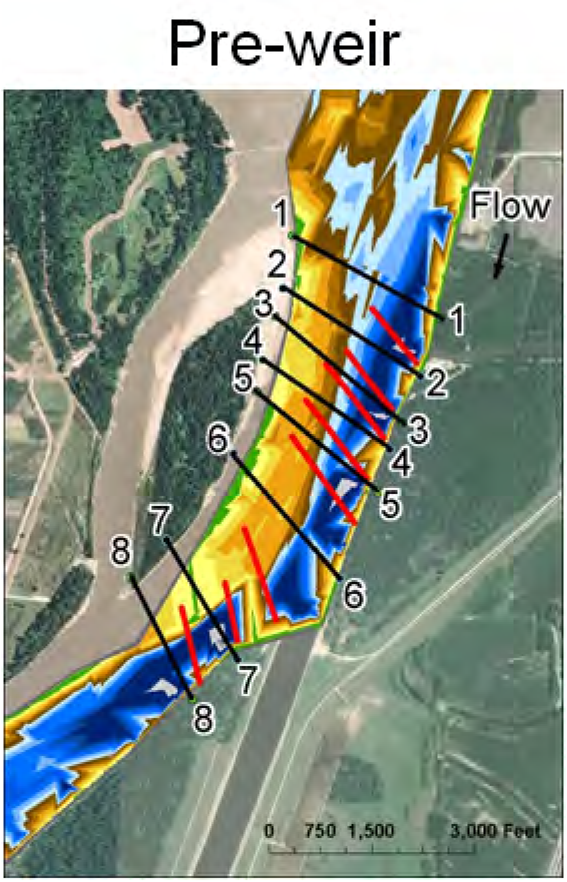

Figure 2.1: Mosenthien 1976 Bathymetry

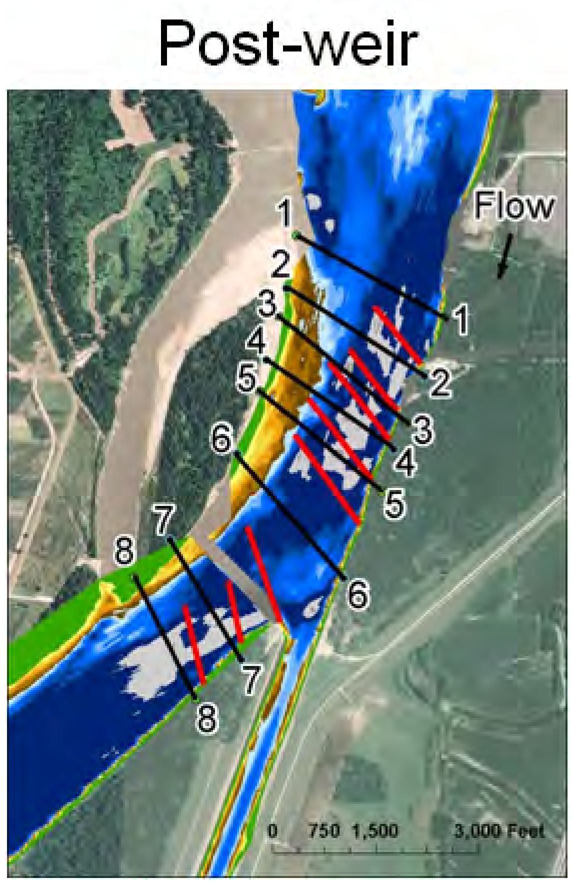

Figure 2.2: Mosenthien 2007 Bathymetry

3. Bellerive*; RM 174.7 to RM 173.8*

The Bellerive weir field (Figure 3.1, Figure 3.2) consists of five weirs constructed on the Right Descending Bank (RDB). The cross sections examined displayed a large increase in area below LWRP (between 44% - 83% difference) and all exhibited an increase in area below 10 ft above LWRP. The maximum depth demonstrated an increase for five of six cross sections, but the average slope decreased for all six cross sections. For all six cross sections, the width and wetted perimeter below LWRP increased, but both parameters decreased when measured up to an elevation of 10 ft above LWRP. The average slopes of the 10 ft vertical segments show a mix of increasing and decreasing, with the majority decreasing. The large majority of slope changes are less than approximately three percent. The -20 ft - -10 ft and -10 ft – 0 ft10 ft foot segments once again largely demonstrate slope decreases. The 0 ft – 10 ft segment experienced a mix of slope increases and indeterminate measurements. All slope changes except two were within 1.5x the pre-weir variation. Of these two, one 10 ft segment slope displayed a slight increase in slope outside of 1.5x the pre-weir variation; the other displayed a moderate decrease in slope.

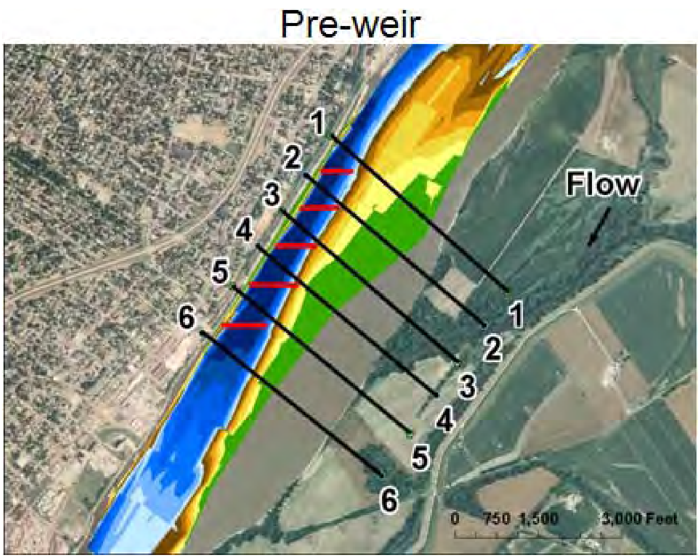

Figure 3.1: Bellerive 1976 Bathymetry

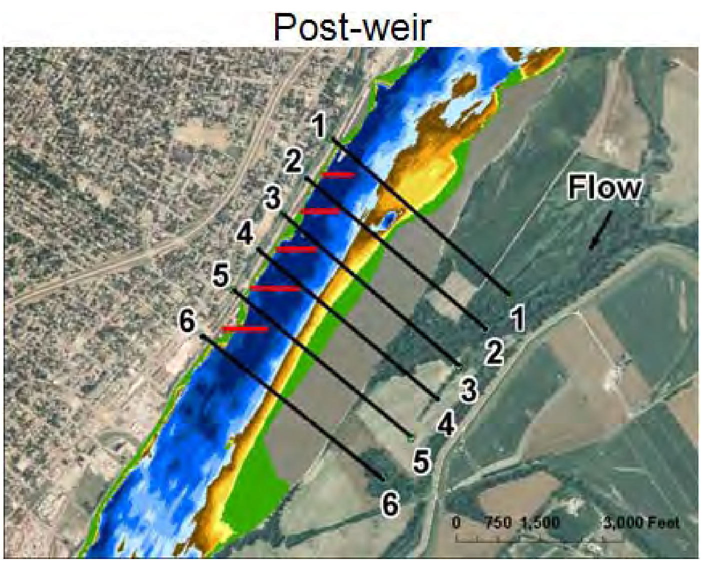

Figure 3.2: Bellerive 2007 Bathymetry

4. Davis*; RM 172.9 to RM 172.2*

The Davis weir field (Figure 4.1:, Figure 4.1:.2) consists of four weirs constructed on the RDB. The area below LWRP and area below 10 ft above LWRP increased across all five cross sections examined, with the increases ranging from approximately 13% to 89%. The maximum depth increased for all sections. The average slope increased for three of the five cross sections; in four of the five cross sections, the change in slope was less than 1 ft per 100 ft. The width and wetted perimeter at LWRP both increased for all sections, with the increases on four of the five sections ranging from approximately 10% to 15%. At 10 ft above LWRP, four out of five cross sections experienced decreases in both width and wetted perimeter; the remaining cross section underwent increases in both parameters. The large majority of the average slopes of the individual 10 ft segments displayed an increase in slope after weir construction. However, due to the filtering process, only 40% of the 10 ft segments yielded data suitable for comparison. Of the eight 10 ft segments with values, three exhibit slope increases outside of 1.5x the pre-weir variation.

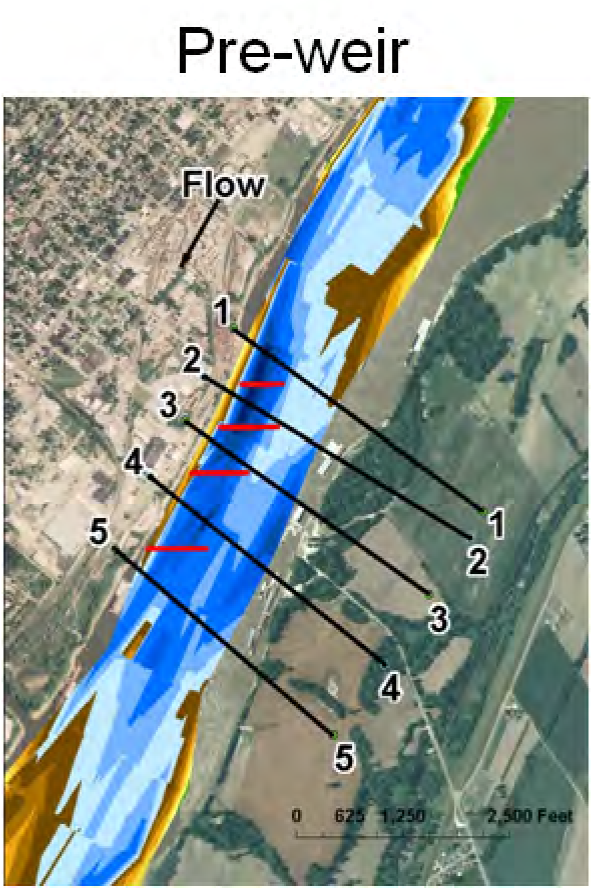

Figure 4.1: Davis 1976 Bathymetry

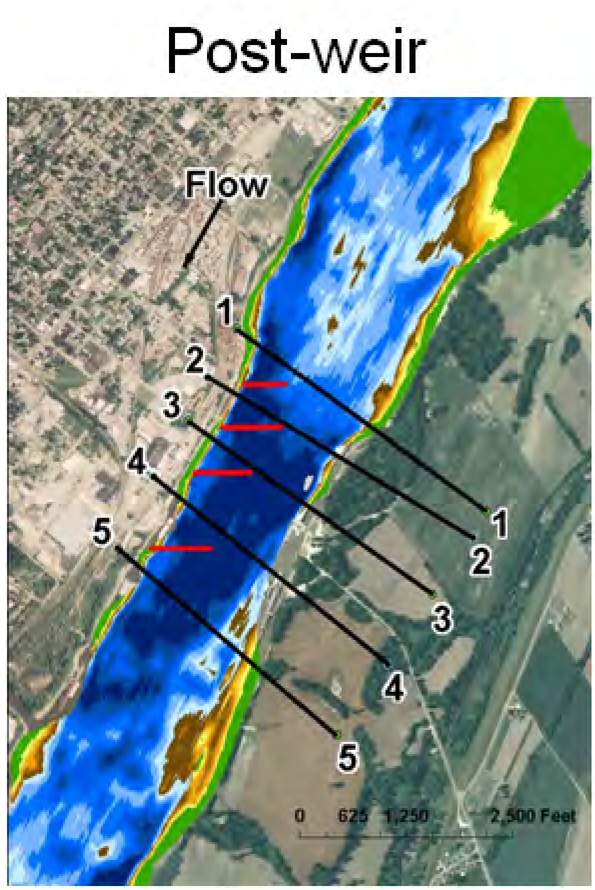

Figure 4.2: Davis 2007 Bathymetry

5. Carl Baer*; RM 164.1 to RM 163.4*

The Carl Baer weir field (Figure 5.1, Figure 5.2) consists of six weirs constructed on the LDB. Five of the seven cross sections examined underwent an increase in both area below LWRP and area below 10 ft above LWRP; the remaining sections decreased in both area measurements. The maximum depth below LWRP increased for four of the seven cross sections. The depth increased between 0.09 ft and 13.54 ft in these cases; the decreasing maximum depths decreased between 1.42 ft and 9.31 ft. The average slope stayed constant or decreased for all cross sections examined. The largest decrease in slope was 1 ft per 100 ft. The width and wetted perimeter at LWRP both increased for six out of seven cross sections; the width and wetted perimeter at 10 ft above LWRP increased for five cross sections and four cross sections, respectively. The average slopes of the individual 10 ft segments revealed that post-weir slopes were typically decreasing, with the decreases averaging between 0.18 ft and 2.51 ft per 100 ft. Carl Baer had a single slope change that was outside of 1.5x the pre-weir variation, and that change appears to be attributable to channel cutting at the lowest elevation of a cross section.

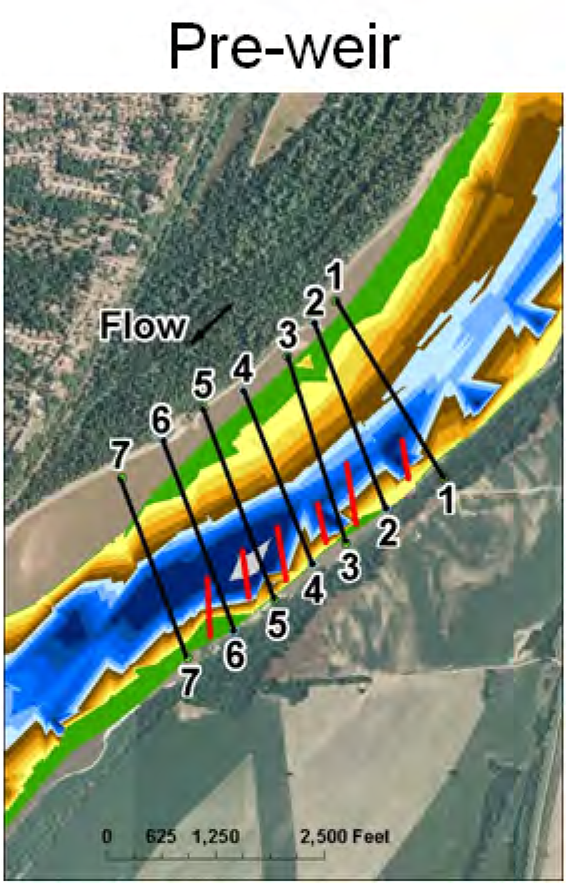

Figure 5.1: Carl Baer 1976 Bathymetry

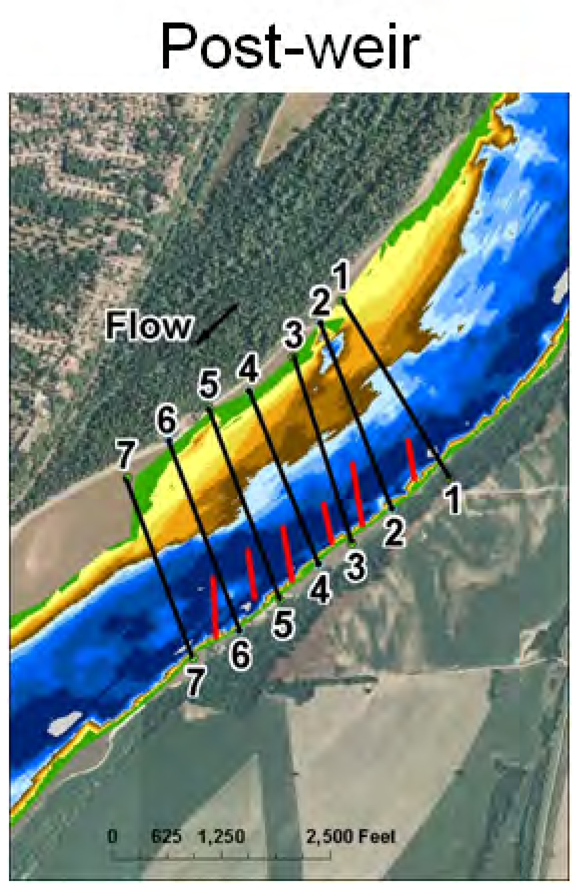

Figure 5.2: Carl Baer 2007 Bathymetry

6. Establishment*; RM 133.2 to RM 132.7*

The Establishment weir field (Figure 6.1, Figure 6.2) consists of four weirs constructed on RDB. The area below LWRP increased for four of the five cross sections examined; the area below 10 ft above LWRP increased for three of five cross sections. The increases ranged from a 5% to 42% above the pre-weir average. The maximum depth decreased for four cross sections, with the increases ranging from 3.92 ft to 14.81 ft. The sole increase in maximum depth was an 8.23 ft decrease at the middle cross section. The average slope decreased for four cross sections; the decreases ranged from 0.8 ft per 100 ft to 2.1 ft per 100 ft. The one increase in slope was less than 1ft per 100 ft. The width at LWRP increased for all cross sections; the wetted perimeter measured at LWRP increased for all but one cross section. The width and wetted perimeter at 10 ft above LWRP increased for three of the five cross sections. The increases were generally below a 26% difference from pre- to post- weir construction. The width and wetted perimeter measured at 10 ft above LWRP increased for the three downstream sections. The large majority of the average slopes of the individual 10 ft segments demonstrate decreasing slopes. In particular, the -20 ft – 10 ft and -10 ft – 0 ft vertical segment slopes exhibited decreasing slopes for all cross sections. All slope changes fall within 1.5x the pre-weir variation.

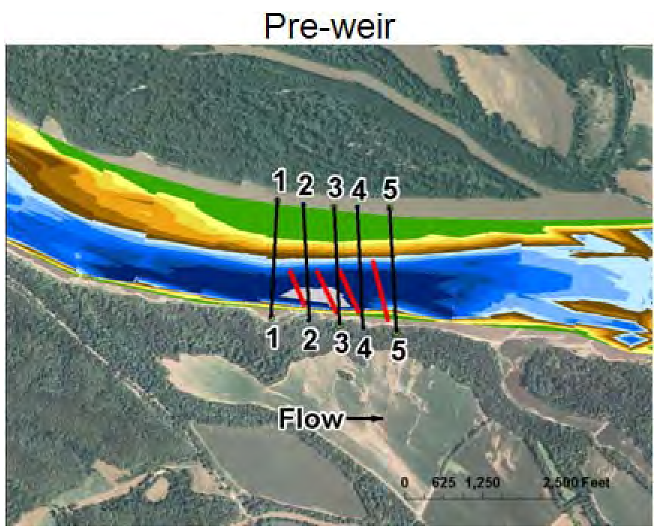

Figure 6.1: Establishment 1976 Bathymetry

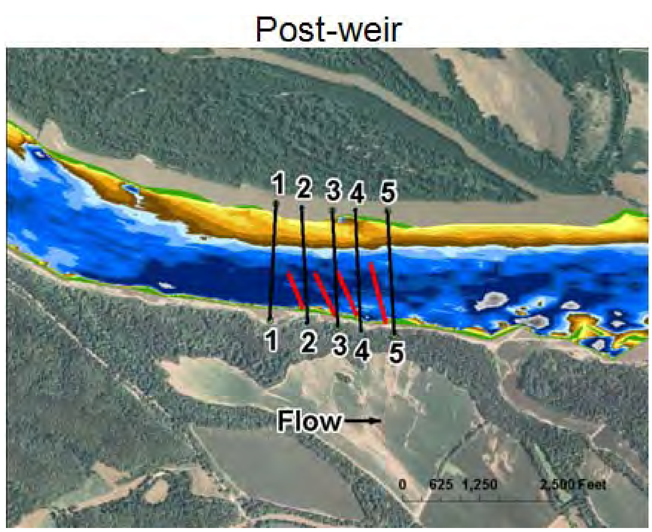

Figure 6.2: Establishment 2007 Bathymetry

7. Ft. Chartres; *RM 131.1 to RM 129.7*

The Ft. Chartres weir field was (Figure 7.1, Figure 7.12) consists of nine weirs constructed along the LDB. The area under LWRP increased for nine of the ten cross sections examined, and the area under 10 ft above LWRP increased for all cross sections. The maximum depth increased for seven cross sections, with the increases ranging from approximately 4 ft to 22 ft. The average slope also increased for seven cross sections, with the largest increase being nearly 8 ft per 100 ft. Nine of the ten cross sections had their widths, measured at LWRP and at 10 ft above LWRP, increase. The wetted perimeter at LWRP increased for only four cross sections, and only for five when measured at 10 ft above LWRP. Almost 80% of the average slopes of the individual 10 ft segments exhibit an increasing slope. In particular, the usable data points for the -40 ft – 30 ft and -30 ft – 20 ft vertical segments demonstrate only increasing slope values. The majority of slope changes were slope increases outside of 1.5x the pre-weir variation, and largely occurred in cross sections 5 through 8.

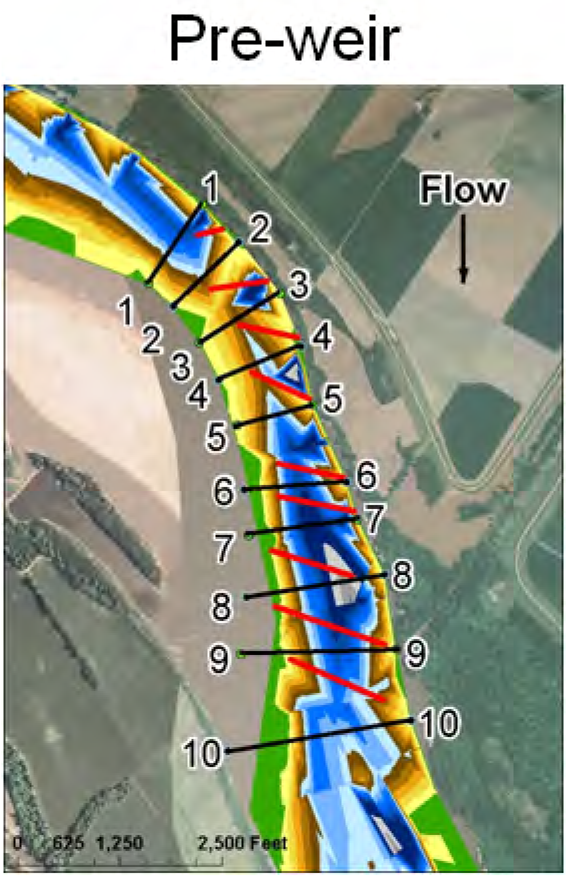

Figure 7.1: Ft. Chartres 1976 Bathymetry

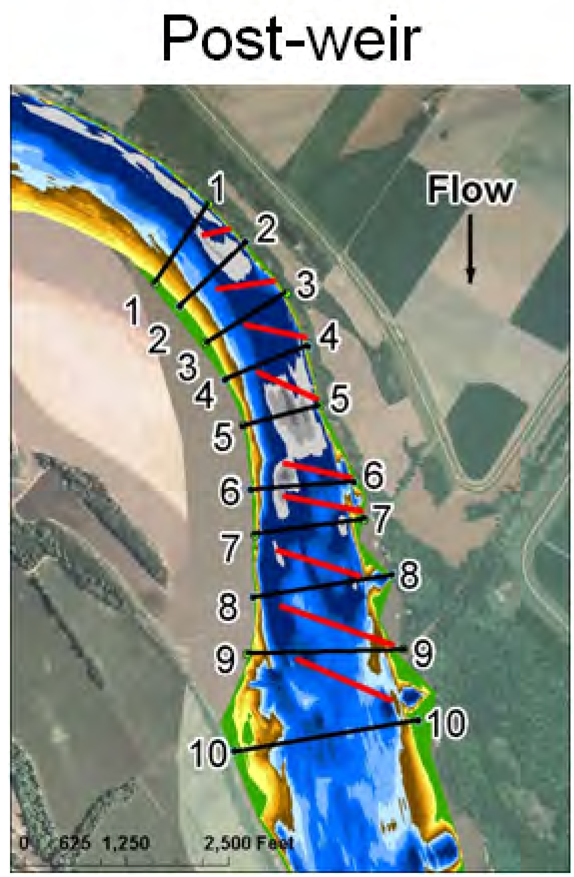

Figure 7.2: Ft. Chartres 2007 Bathymetry

8. St. Genevieve*; RM 120.8 to RM 119.7*

The St. Genevieve weir field (Figure 8.1, Figure 8.2) consists of ten weirs constructed on the RDB. The area under LWRP and area under 10 ft above LWRP increased for all cross sections. The largest increases occurred for the upstream cross sections, with smaller increases down river. The maximum depth increased for eight cross sections, with the increases ranging from 0.01 ft. to 3.3 ft. There was minimal movement in average slope for the weir field; no cross section experienced an average slope change of more than 1 ft. per 100 ft. Ten of the eleven cross sections increased in width at LWRP; the wetted perimeter measured at LWRP increased for all eleven of the cross sections. The width and wetted perimeter measured at 10 ft above LWRP decreased for the same nine of the eleven cross sections. The majority of the average slopes of the 10 ft vertical segments increased. There did not appear to be a pattern to the slope increases and decreases. The large majority of slope changes (86%) fell within 1.5x the pre-weir variation.

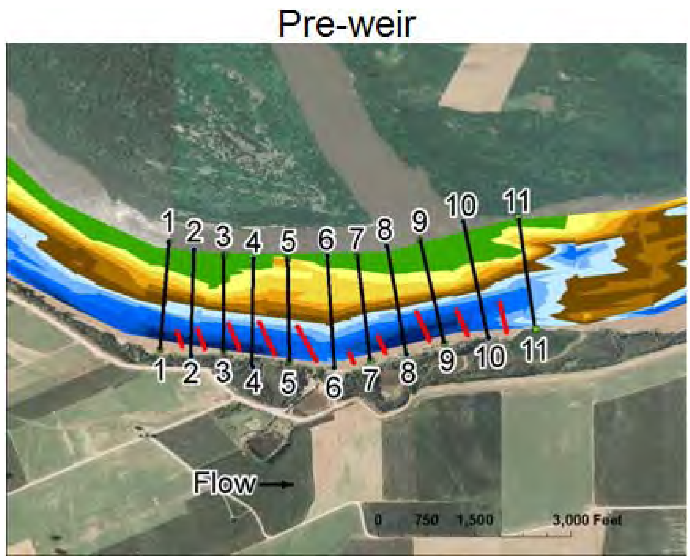

Figure 8.1: St. Genevieve 1976 Bathymetry

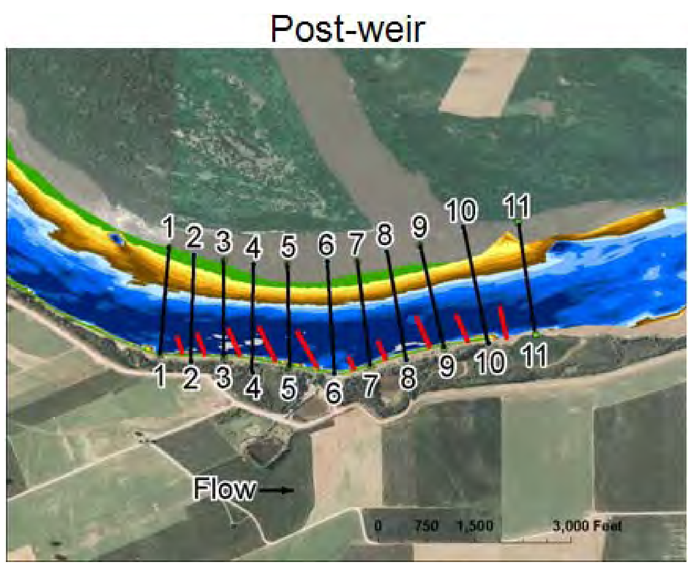

Figure 8.2: St. Genevieve 2007 Bathymetry

9. Kaskaskia Bend*; RM 117.4 to RM 115.9*

The Kaskaskia Bend weir field (Figure 9.1, Figure 9.1) consists of twelve weirs constructed along the LDB. All of the thirteen cross sections demonstrated increases in area under LWRP and area under 10 ft above LWRP. The differences pre- to post weir ranged from 12.2% to 85.3%. Seven cross sections increased in maximum depth after the weirs were constructed. Seven slopes (not the same slopes as the depth) underwent decreases; the decreases were less than 3 ft per 100 ft. Twelve of the thirteen cross sections increased width and wetted perimeter at LWRP. In contrast, only two of thirteen cross sections increased at 10 ft above LRWP. The majority of the average slopes of the individual 10 ft vertical segments demonstrated increasing slopes. The -30 ft - -20 ft segment slopes in particular experienced a strong trend of increasing; the other segments were generally mixed. The slope changes for Kaskaskia Bend were largely (79%) within 1.5x the pre-weir variation, and slopes changes outside 1.5x pre-weir variation tended to favor slope increases.

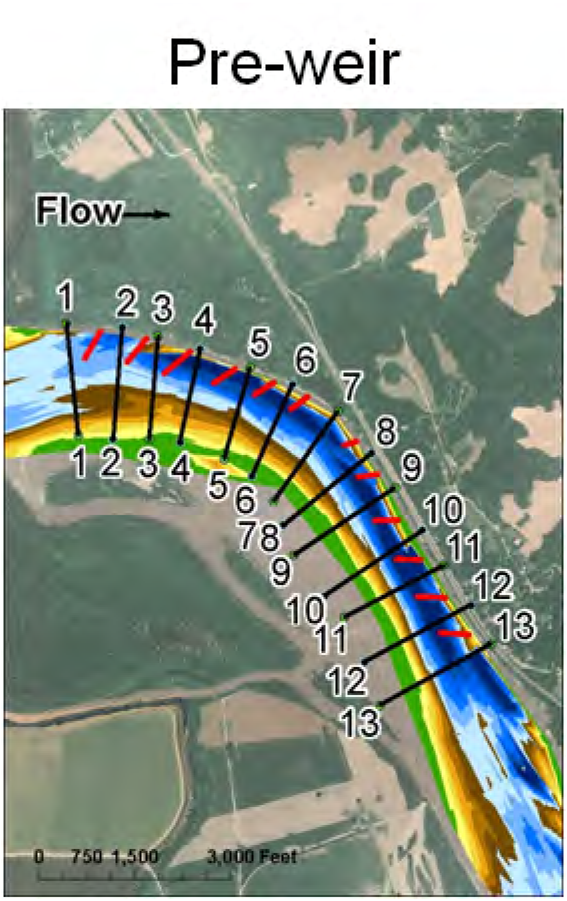

Figure 9.1: Kaskaskia Bend 1976 Bathymetry

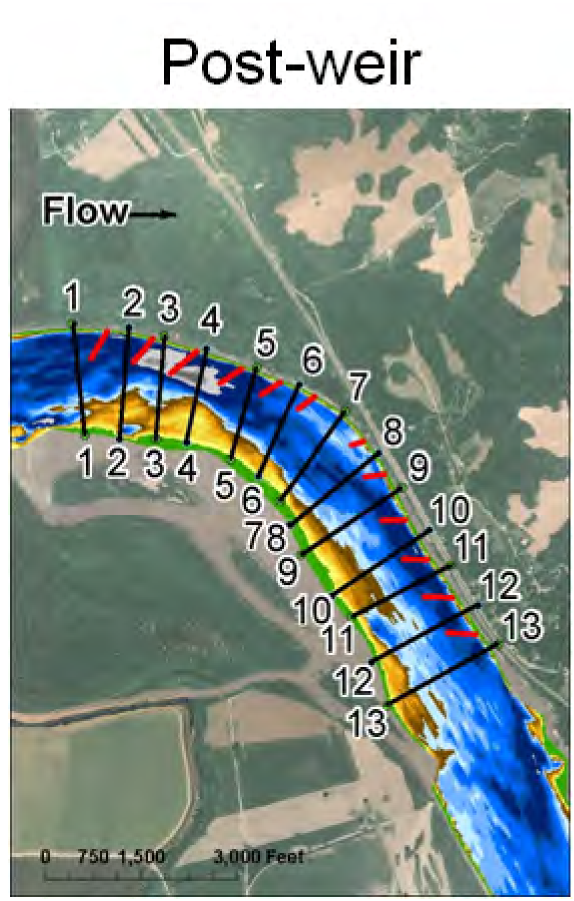

Figure 9.2: Kaskaskia Bend 2007 Bathymetry

10. River Mile 103.25

The weir at river mile 103.25 (Figure 10.1, Figure 10.1) consists of one weir on the LDB. The cross sections underwent a moderate decreases in area below LWRP and area below 10 ft above LWRP. The maximum depth decreased for both cross sections, decreasing over 12 ft at the first section and almost 3 ft at the second section. The average slope decreased approximately 0.1 ft per 100 ft at each cross section. For both cross sections, the width and wetted perimeter at both LWRP and 10 ft above LWRP decreased. The average slopes of the individual 10 ft vertical segments almost all reflect a drop in slope after the weir was installed. Both the -20 ft - -10 ft and -10 ft – 0 ft segments saw decreases on both cross sections. All slope changes were within 1.5x the pre-weir variation except one, which recorded a slight decrease in slope.

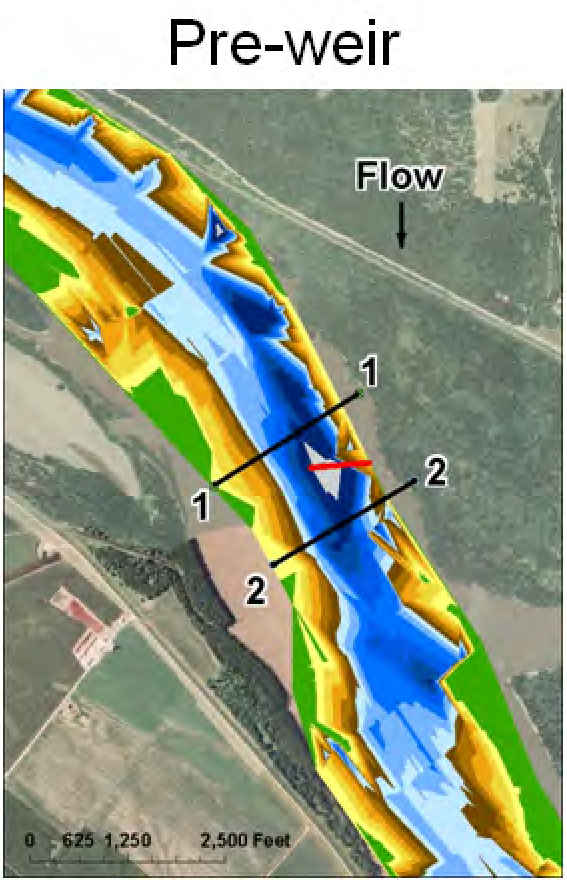

Figure 10.1: River Mile 103.25 1976 Bathymetry

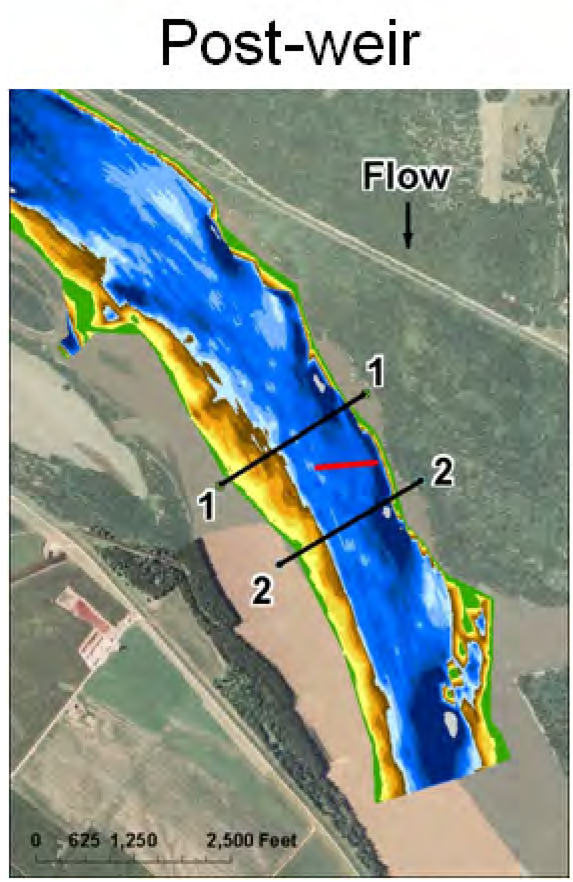

Figure 10.2: River Mile 103.25 2007 Bathymetry

11. Red Rock; *RM 95.0 to RM 93.6*

The Red Rock weir field (Figure 11.1, Figure 11.1) consists of nine weirs constructed on the RDB. The area below LWRP increased for six cross sections, with the largest increase leading to a 35.6% difference pre-to post- weir. The area below 10 ft above LWRP increased for eight cross sections, with a 30.5% difference caused by the largest increase. Half of the cross sections had their maximum depth decrease; the decreases ranged from 0.92 ft. to 26.5 ft. Six cross sections underwent an average slope decrease, with the decreases ranging from 0.8 ft. to 4.8 ft per 100 ft. All sections increased their width at LWRP and at 10 ft above LWRP. The wetted perimeter measured at LWRP and at 10 ft above LWRP increased for the same eight cross sections. A majority of the average slopes of the 10 ft vertical segments underwent decreases during the pre- to post- weir period. Once again, no 10 ft segment underwent changes for all sections. Cross sections 8 and 10 contributed half (8) of the average 10 ft segment slopes demonstrating an increase in slope. Less than 60% of the slope changes in the Red Rock weir field fell within 1.5x the pre-weir variation; the slope changes outside of 1.5x pre-weir variation roughly split between slope decreases and increases.

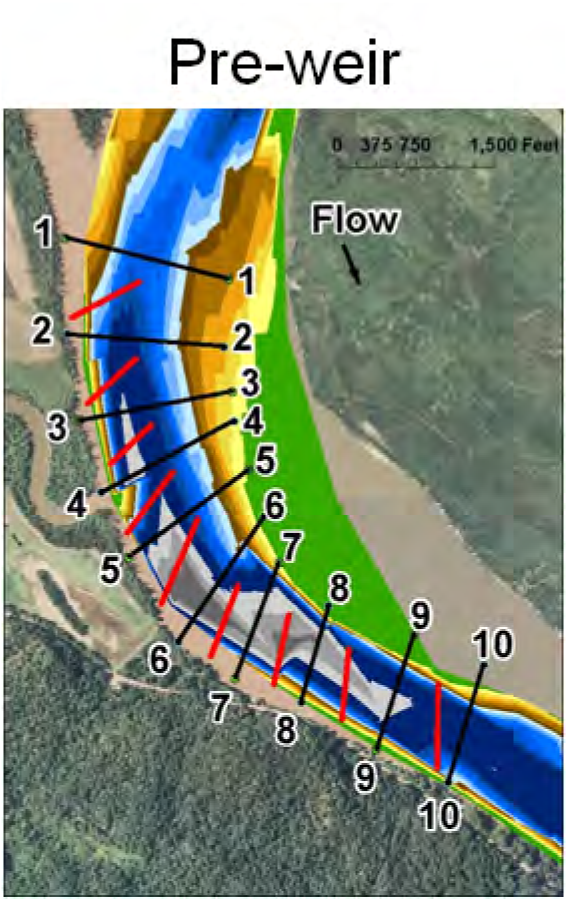

Figure 11.1: Red Rock 1976 Bathymetry

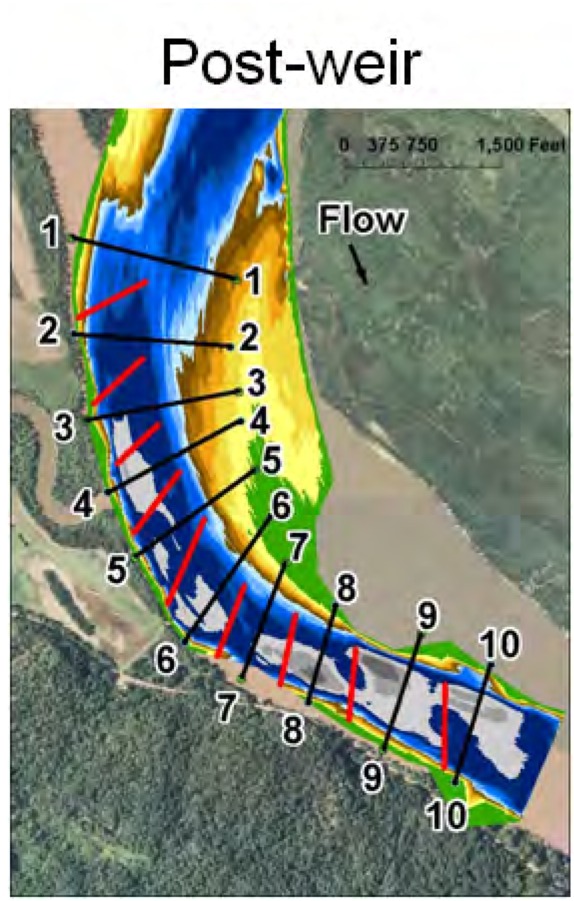

Figure 11.2: Red Rock 2007 Bathymetry

12. Fountain Bluff*; RM 84.2 to RM 82.9*

The Fountain Bluff weir field (Figure 12.1,   Figure 12.12) consists of ten weirs constructed on the LDB. All eleven of the cross sections underwent an increase both in area below LWRP and area below 10 ft above LWRP; the difference in pre- and post- construction values varied from 17% to 92.5%. Six of the eleven cross sections had their maximum depth increase after weir construction. The increases in depth ranged from 2.65 ft. to 19.97 ft. Seven of the eleven cross sections experienced a decrease in average slope, with the decreases ranging from 0.1 ft. 3.4 ft. per 100 ft. All of the cross sections demonstrate increasing widths and wetted perimeters measured at LWRP. The width and wetted perimeter at 10 ft LWRP demonstrate a similar trend, except for the seventh cross section. The largest increases occurred at cross section three, and led to approximately 47% differences. The average slopes of the 10 ft vertical segments demonstrate a slight majority experienced decreasing slopes. The -10 ft – 0 ft segments demonstrate a strong trend of decreasing slopes. Less than half of the slope changes fall within 1.5x the pre-weir variation, and those outside are roughly split between increasing and decreasing slopes. The slope changes outside 1.5x the pre-weir variation largely fall in cross sections 6 through 11.

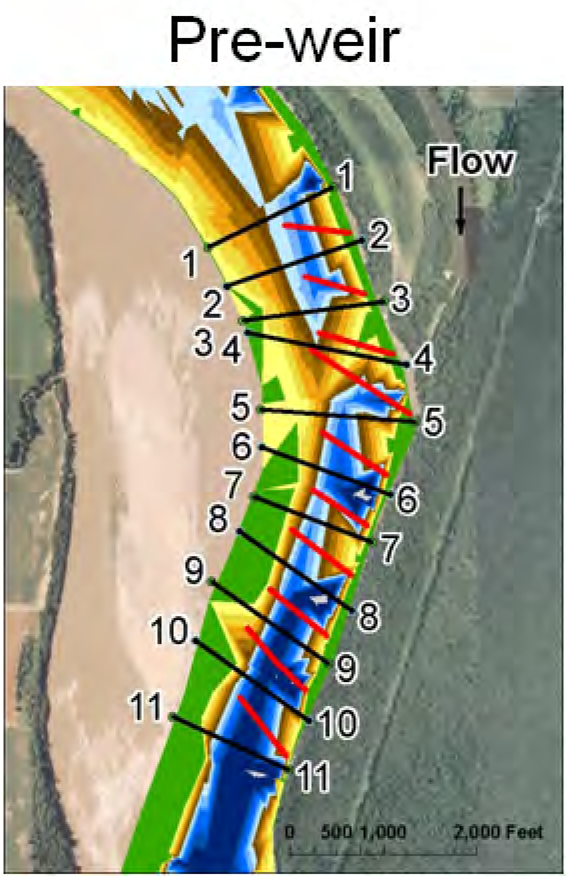

Figure 12.1: Fountain Bluff 1976 Bathymetry

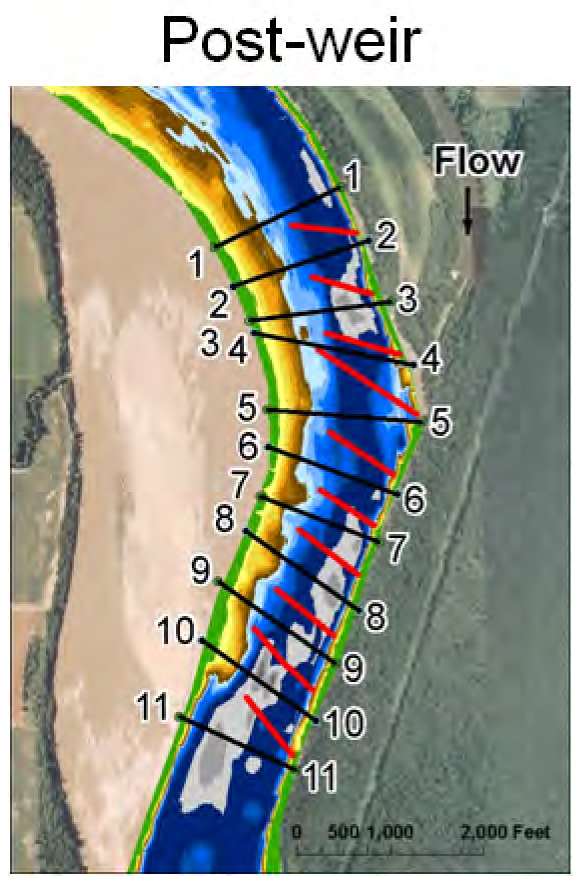

Figure 12.2: Fountain Bluff 2007 Bathymetry

13. Hanging Dog; *RM 70.5 to RM 69.8*

The Hanging Dog weir field (Figure 13.1, Figure 13.12) consists of five weirs constructed on the LDB. The area below LWRP increased for four cross sections; the area below 10 ft above LWRP increased for three of the sections. The maximum depth decreased for four cross sections, with all decreases ranging from approximately 4ft to 6ft. The average slopes for the cross section decreased for five of the cross sections; the decreases were never more that 1ft per 100 ft. The width and wetted perimeter, measured at both locations, increased for half of the cross sections and decreased for the remaining half. Over three-fourths of the average slopes of the 10 ft vertical segments demonstrated decreasing slopes for post-weir conditions. The -30 ft - -20 ft and -20 ft – 10 ft segments uniformly experienced decreasing slopes. Only one segment out of 32 underwent a slope change outside of 1.5x the pre-weir variation; that segment was a decreasing slope in the -30 ft - -20 ft segment in cross section 6.

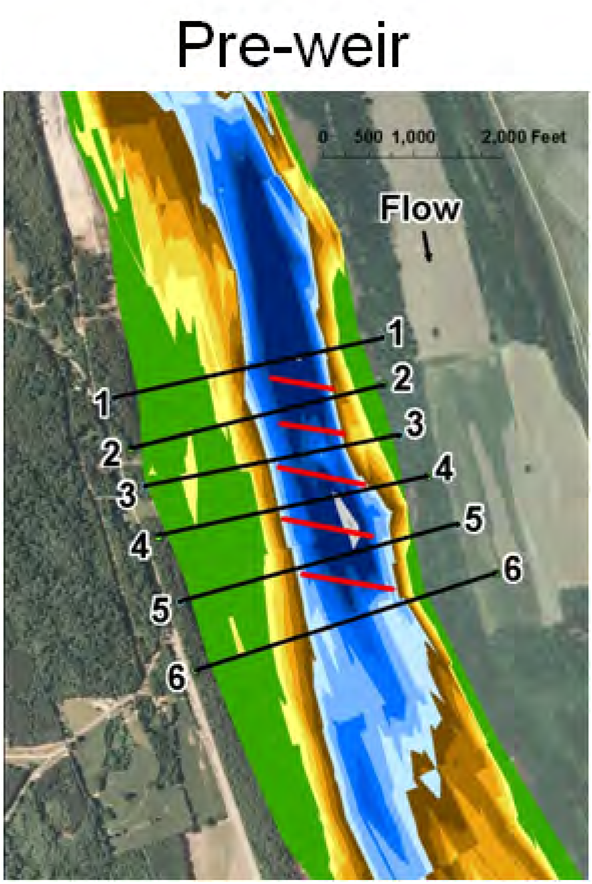

Figure 13.1: Hanging Dog 1976 Bathymetry

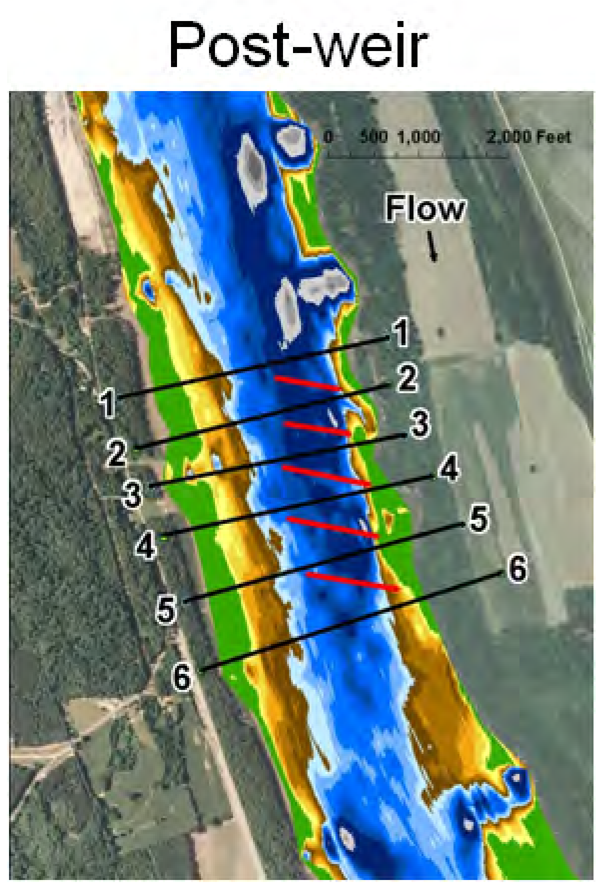

Figure 13.2: Hanging Dog 2007 Bathymetry

14. Picayune; *RM 77.9 to RM 55.7*

The Picayune weir field (Figure 14.1, Figure 14.2) consists of fourteen weirs constructed along the LDB. The area below LWRP and below 10 ft above LWRP both increased for eleven of the fifteen cross sections, but the increases did not always occur at the same cross sections. The maximum depth increased for eight sections, with the increases ranging from 1.05 ft to 13.28 ft. Ten cross sections experienced a decreasing or constant average slope. The largest slope decrease was 1.2 ft per 100 ft; the largest increase 1.5 ft per 100 ft. The width at LWRP increased for ten sections; at 10 ft above LWRP, the width increased for eleven cross sections. Nine cross sections underwent an increase of wetted perimeter at LWRP; twelve underwent increases at 10 ft above LWRP. The increases led to at most an approximate 40% difference from the pre- to post- weir averages. More than half of the average slopes of the individual 10 ft vertical segments underwent increases, but there was no apparent pattern to the increases. The slope increases outside of 1.5x the pre-weir variation outnumbered the slope decreases over 4 to 1 (22% to 5%), with the slope decreases present only in two places in the highest segment.

Pre-weir

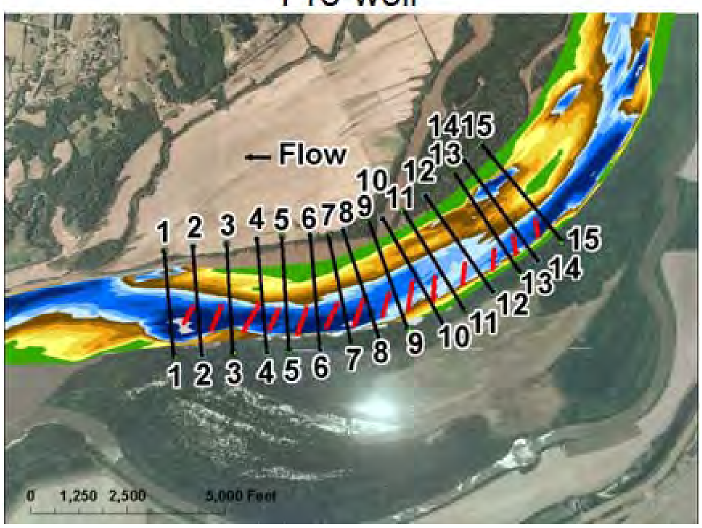

Figure 14.1: Picayune 1976 Bathymetry

Post-weir

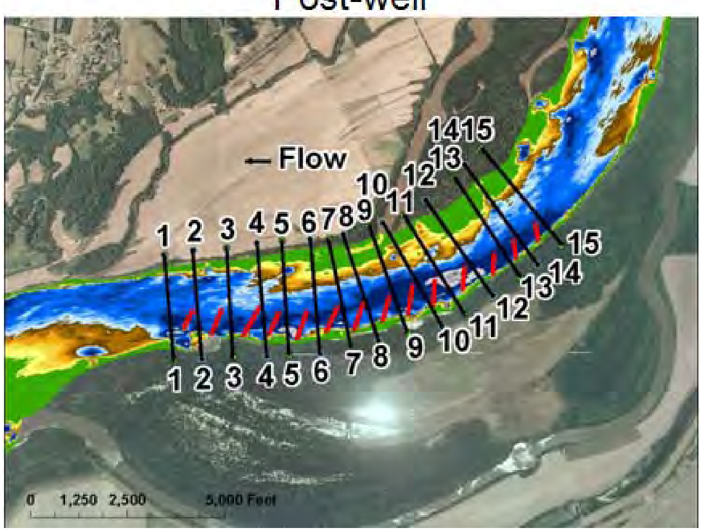

Figure 14.2: Picayune 2007 Bathymetry

15. Cape Rock*; RM 55.0 to RM 53.7*

The Cape Rock weir field (Figure 15.1, Figure 15.1) consists of nine weirs constructed along the RDB. Half of the cross sections examined exhibited an increase in area below LWRP, but all exhibit an increase in area below 10 ft above LWRP, with the increases 10% to 29% above the pre-weir geometry. The maximum depth increased for six of ten cross sections, with the increases generally occurring in the downstream cross sections. The average slopes typically increased, with the increases ranging from 0.3 ft per 100 ft to 4.2 ft per 100 ft. The width at LWRP increased for six of ten cross sections; the wetted perimeter for all ten cross sections. The width at 10 ft above LWRP increased for seven of ten cross sections, with the wetted perimeter again increasing for all cross sections. The average slope of the 10 ft vertical segments increased for a small majority of the segments. The 10 ft segments indicate a trend of increasing slope at the deepest segments moving to a decreasing slope at the highest segments. The slope changes that were outside 1.5x the pre-weir variation were all slope increases occurring in the beginning and end of the weir field.

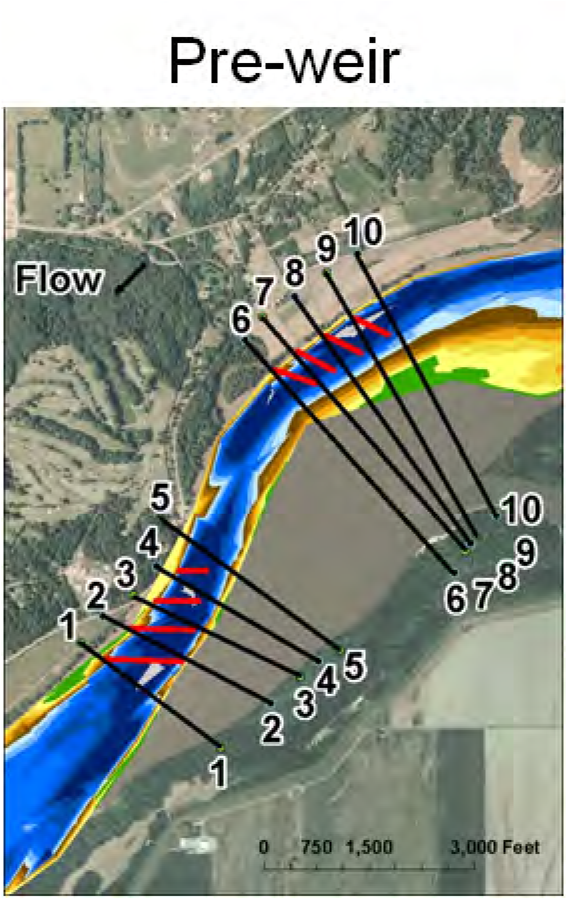

Figure 15.1: Cape Rock 1976 Bathymetry

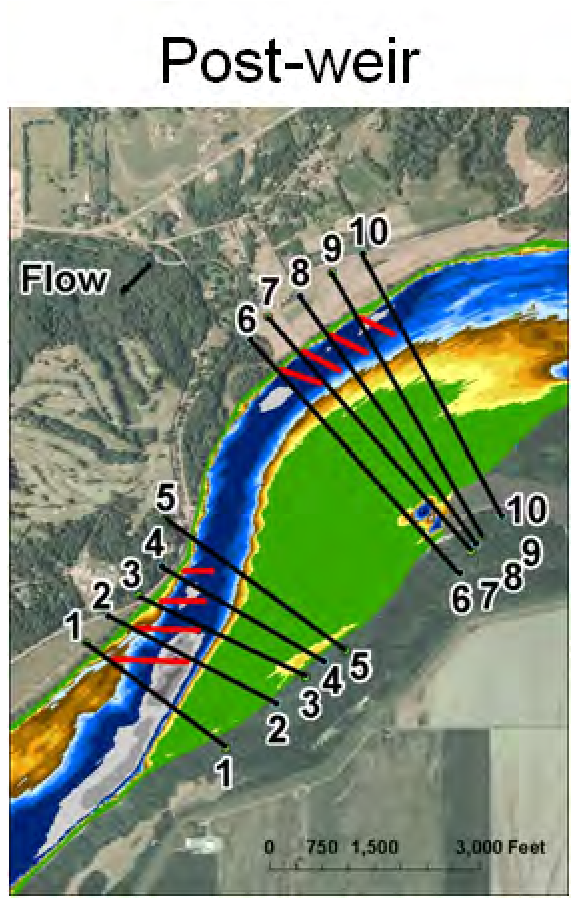

Figure 15.2: Cape Rock 2007 Bathymetry

16. Cape Bend*; RM 49.4 to RM 48.3*

The Cape Bend weir field (Figure 16.1, Figure 16.1) consists of thirteen weirs constructed along the RDB. The cross sections exhibited a modest increase in area below LWRP and below 10 ft above LWRP (between 3% - 30% difference). Eleven of fourteen cross sections experienced a decrease in maximum depth below LWRP. The average slope decreased for nine out of the fourteen cross sections, with the slopes decreasing between 0.1 and 1.8 ft per 100 ft. The increases ranged from 0.4 to 1.1 ft per 100 ft. The width at LWRP increased for ten of fourteen cross sections and the wetted perimeter at LWRP increased for 11 of the 14 cross sections. The width and wetted perimeter at 10 ft above LWRP both increased for 13 of 14 cross sections. Sixty percent of the average slopes for the 10 ft vertical segments decreased in slope after the construction of the bendway weirs. Despite the majority of slopes decreasing, only the -20 ft - -10 ft segments demonstrated a definitive trend of decreasing slope. The large majority (82%) of slope changes for this cross section fell within 1.5x the pre-weir variation.

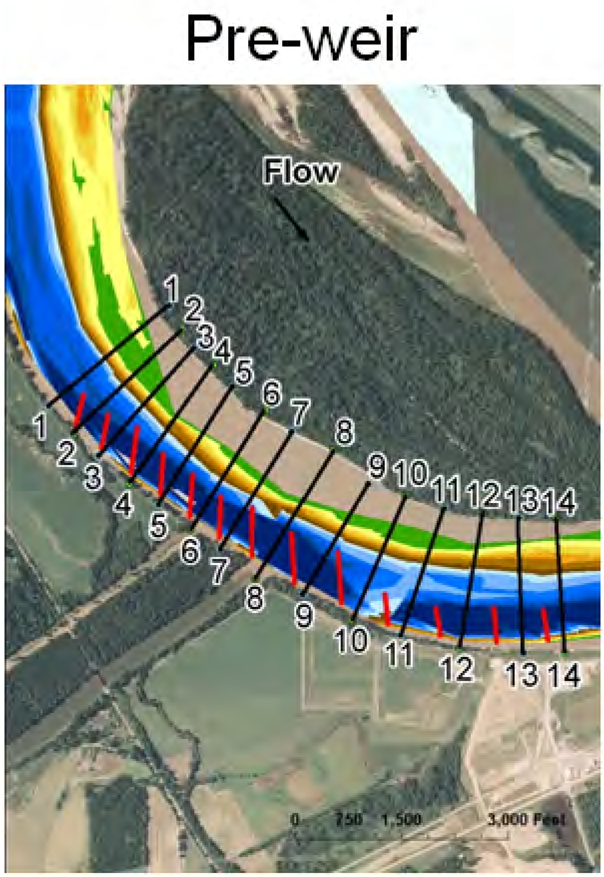

Figure 16.1: Cape Bend 1976 Bathymetry

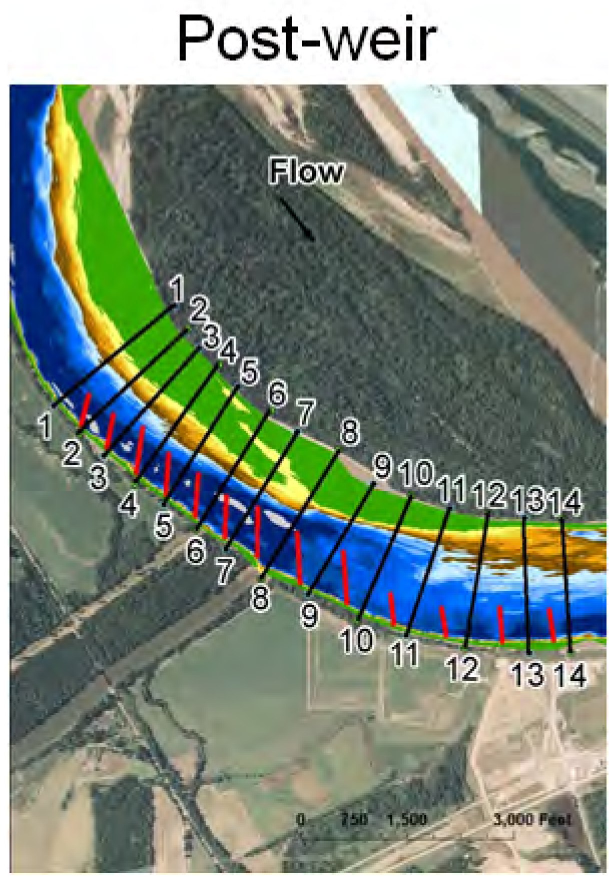

Figure 16.2: Cape Bend 2007 Bathymetry

17. Prices Bend*; RM 30.8 to RM 29.5*

The Prices Bend weir field (Figure 17.1, Figure 17.12) consists of nine weirs constructed along the RDB. All ten cross sections increased in area, measured both at LWRP and at 10 ft above LWRP. The increases ranged from a 0.9% to 40% difference pre- to post- bendway weir installation. The maximum depth decreased for half of the sections. Seven cross sections had their average slope either increase or remain constant. Of the slopes that increased, only two sections experienced a slope increase of more than 3 ft. per 100 ft. The width at LWRP and at 10 ft above LWRP increased for the same eight channel cross sections. The wetted perimeter measured at LWRP and at 10 ft above LWRP increased for the same six sections. The average slopes of the 10 ft vertical segments increased for approximately 65% of the usable measurements. No 10 ft segments underwent increases for all ten cross sections; instead, most vertical segments of the same elevation range experienced increases for the majority of the cross sections, with 1-3 sections decreasing. Sixty-three percent of the slope changes were within the range of 1.5x the pre-weir variation; the large majority of the slope changes outside 1.5x the pre-weir variation demonstrated an increasing slope.

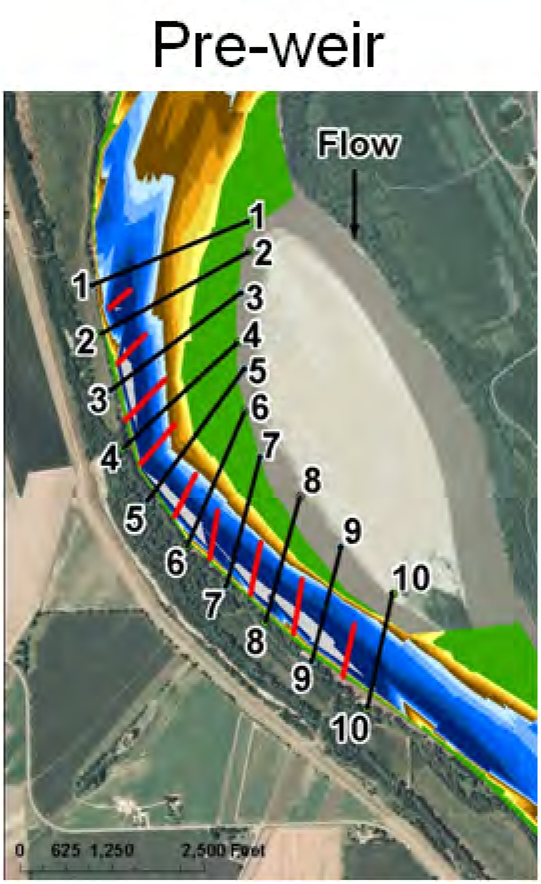

Figure 17.1: Prices Bend 1976 Bathymetry

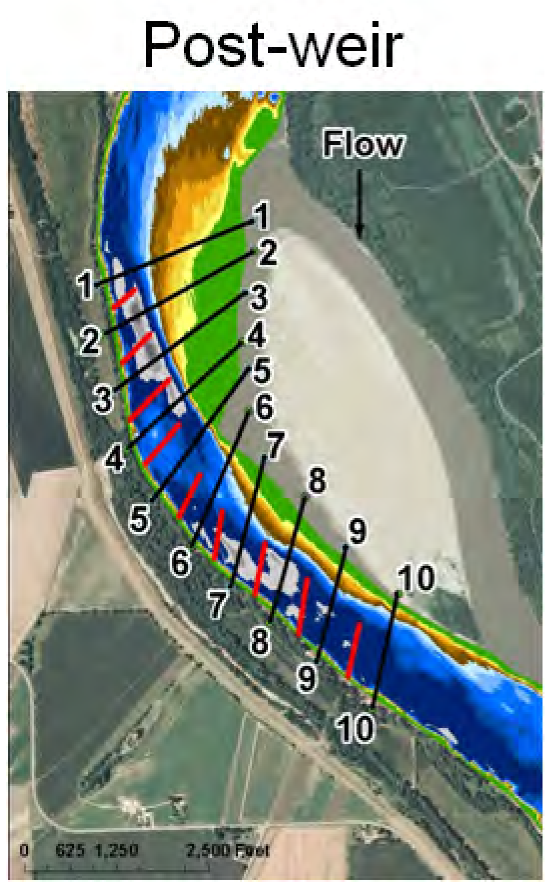

Figure 17.2: Prices Bend 2007 Bathymetry

18. Dogtooth*; RM 24.5 to RM 22.2*

The Dogtooth weir field (Figure 18.1, Figure 18.2) consists of thirteen weirs constructed along the RDB. The area below LWRP increased for eight cross sections, with the increases pre- to post-weir ranging between 4.7% and 23.1%. Half of the sections had their areas below 10 ft above the LWRP increase. The maximum depth decreased for ten of fourteen cross sections, with the depths decreasing by 0.74 ft to 23.67 ft. The average slopes of the cross sections decreased for eleven sections, with the decreases ranging from 0.4 ft to 3.1 ft per 100 ft. For the width and wetted perimeter at LWRP, ten of the fourteen cross sections increased, with the increases occurring after the first four cross sections. The increases ranged from a 0.5% to 33.4% difference above the pre-weir construction. The width and wetted perimeter at 10 ft above LWRP increased for six cross sections, with the increases occurring at the cross sections at the upstream and downstream ends of the weir field. The average slopes of the 10 ft vertical segments decreased for nearly 75% of the cross sections. The -10 ft – 0 ft segment exhibited a definitive downward trend in the slope; the rest of the segments demonstrated a mix of increasing and decreasing slopes. The slope changes of the weir field are largely (78%) within 1.5x the pre-weir variation. The slope changes outside of 1.5x the pre-weir variation favored slope decreases 2 to 1, and were scattered throughout the cross sections.

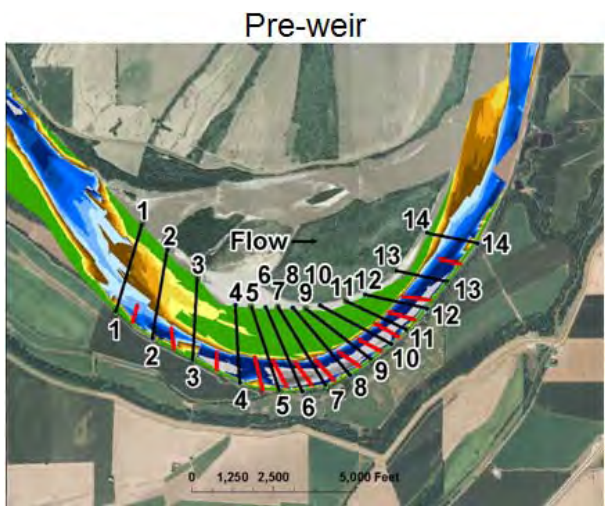

Figure 18.1: Dogtooth 1976 Bathymetry

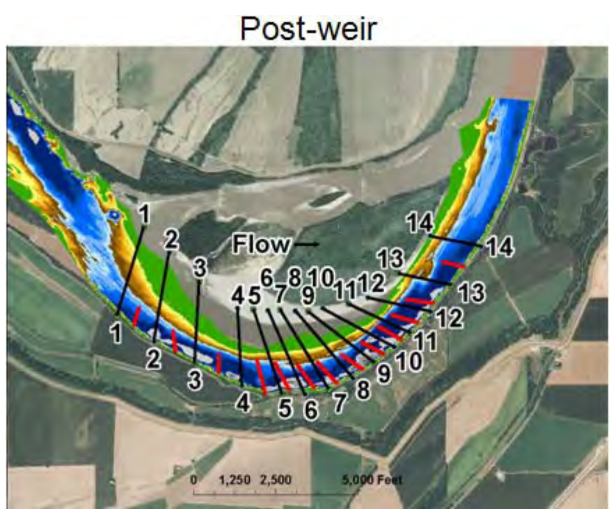

Figure 18.2: Dogtooth 2007 Bathymetry

19. Scudders Bend*; RM 17.4 to RM 16.5*

The Scudders weir field (Figure 19.1, Figure 19.12) consists of nine weirs constructed along the LDB. All sections underwent increases in both area under LWRP and area under 10 ft above LWRP. Half of the sections experienced a decrease in maximum depth; the decreases were at most 14.69 ft., the increases 20.74 ft. The average slope decreased for half of the cross sections, with the decreases ranging from 0.3 ft per 100 ft to 3.3 f. per 100 ft. The width at LWRP increased for nine of the ten sections. The width at 10 ft above LWRP, the wetted perimeter at LWRP, and the wetted perimeter at 10 ft above LWRP all increased for all cross sections. Approximately half of the average slopes of the 10 ft vertical segments decreased for the ten cross sections. When examining the 10 ft segment slopes, no elevation segment exhibited only increases or decreases. However, there was a trend of increasing slopes dominating at the lower 10 ft segment elevations moving to a majority of decreasing slopes at the topmost 10 ft segment elevations. Two-thirds of the slope changes in the weir field were within 1.5x the pre-weir variation. The remaining third of the changes were dominated by slope increases.

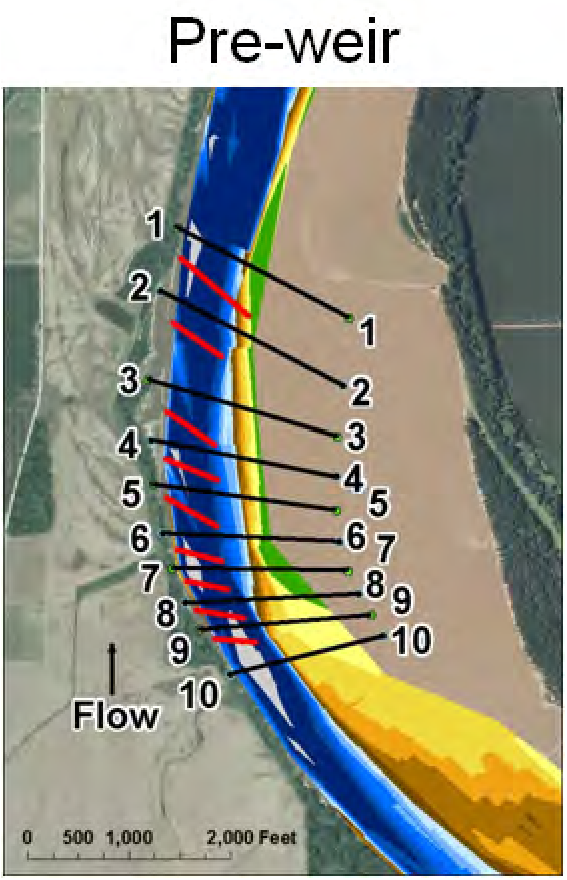

Figure 19.1: Scudders 1976 Bathymetry

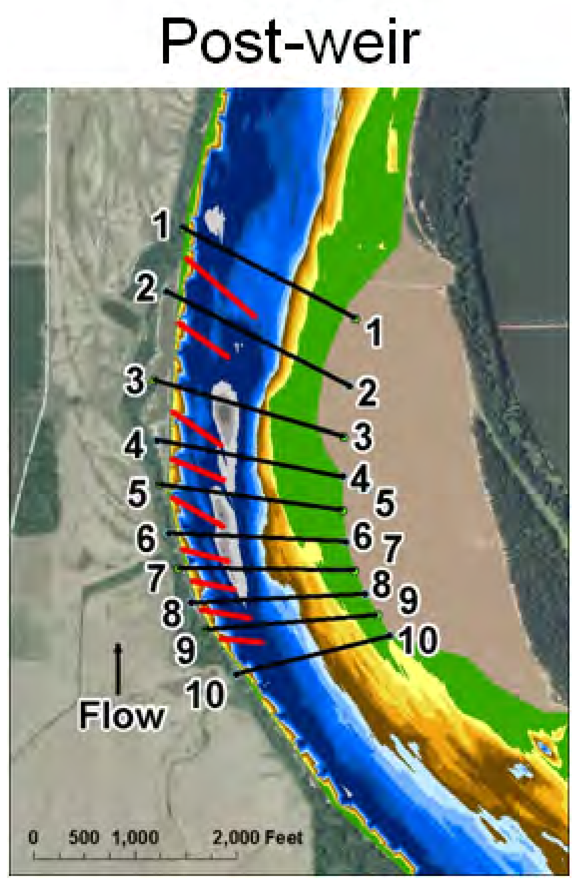

Figure 19.2: Scudders 2007 Bathymetry

20. Eliza Point*; RM 6.8 to RM 5.6*

The Eliza Point weir field (Figure 20.1, Figure 20.1) consists of ten weirs constructed along the LDB. Nine out of the eleven cross increased in both area below LWRP and area below 10 ft above LWRP, with the increases ranging largely between a 5% and a 50% difference post-bendway weir construction. The remaining two cross sections decreased for both areas, with the differences falling between 2.1% to 5.3%. The maximum depth decreased for six of the eleven cross sections; the decreases ranged from 0.15 ft to 6.81 ft. Three of the five depth increases that occurred were approximately 10 ft to 11 ft. The average slope increased for eight of the eleven cross sections, with the increases at most being 2.1 ft per 100 ft. The three decreasing average slopes occurred in the most downstream cross sections of the weir field. Eight of eleven cross sections increased in width and wetted perimeter at LWRP, with the increases typically occurring in the downstream section of the weir field. The area and wetted perimeter at 10 ft above LWRP increased for only one of the eleven cross sections; the decreases ranged from a 0.2% to 3.1% difference. The majority of the average slopes of the 10 ft vertical segments increased after weir construction. The middle segment elevations (-30 ft - -20 ft and -20 ft – 10 ft) demonstrated solid trends for increasing slopes. The slope changes were mainly within 1.5x the pre-weir variation, but when they were not, slope increases are favored almost 4 to 1.

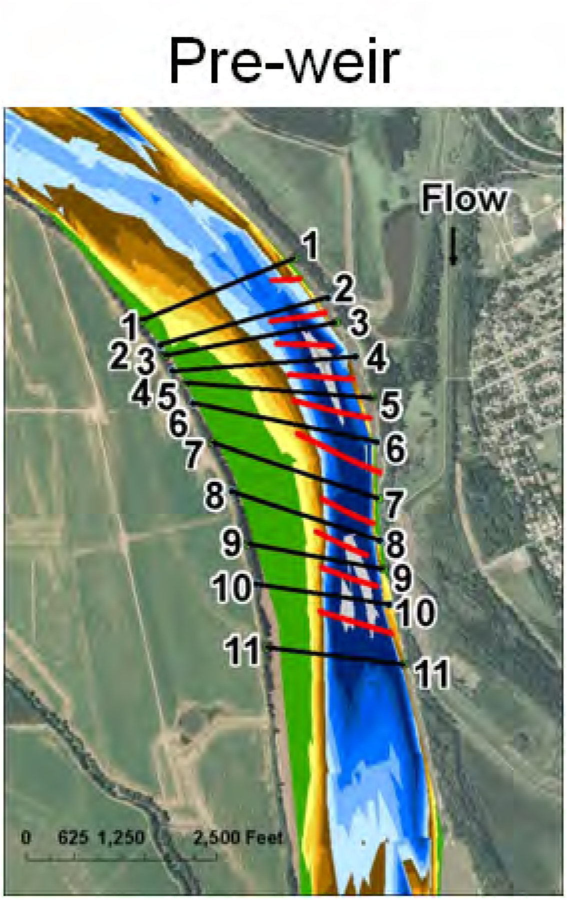

Figure 20.1: Eliza Point 1976 Bathymetry

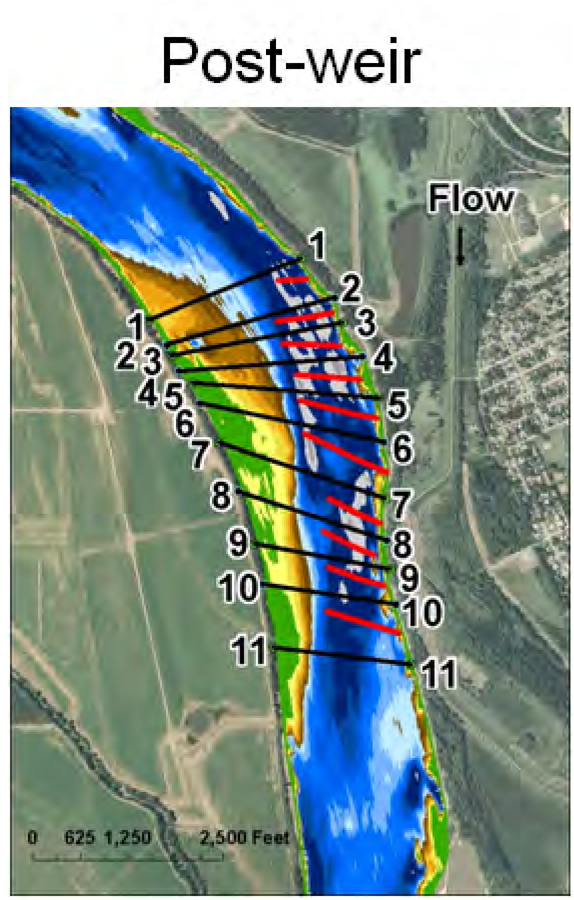

Figure 20.2: Eliza Point 2007 Bathymetry

21. Greenfield Bend*; RM 4.2 to RM 3.0*

The Greenfield Bend weir field (Figure 21.1, Figure 21.1) consists of nine weirs constructed along the RDB. The area under LWRP and area under 10 ft above LWRP both increased for all cross sections. Six cross sections experienced a decrease in their maximum depth, with the decreases ranging from 0.79 ft to 7.85 ft. The average slope decreased for all sections; the decreases ranged from 0.2 ft to 3.7 ft per 100 ft. The cross sections underwent increases in width at LWRP and at 10 ft above LWRP for all sections. The wetted perimeter at LWRP increased for eight of the cross sections, and the wetted perimeter at 10 ft above LWRP increased for nine cross sections. Approximately two-thirds of the average slopes of the 10 ft vertical segments decreased for the cross sections. In particular, the -30 ft - -20 ft and -20 ft – 10 ft segment elevations demonstrated slope decreases for almost all cross sections. The slope changes decreased beyond 1.5x the pre-weir variation for over 40% of the segments.

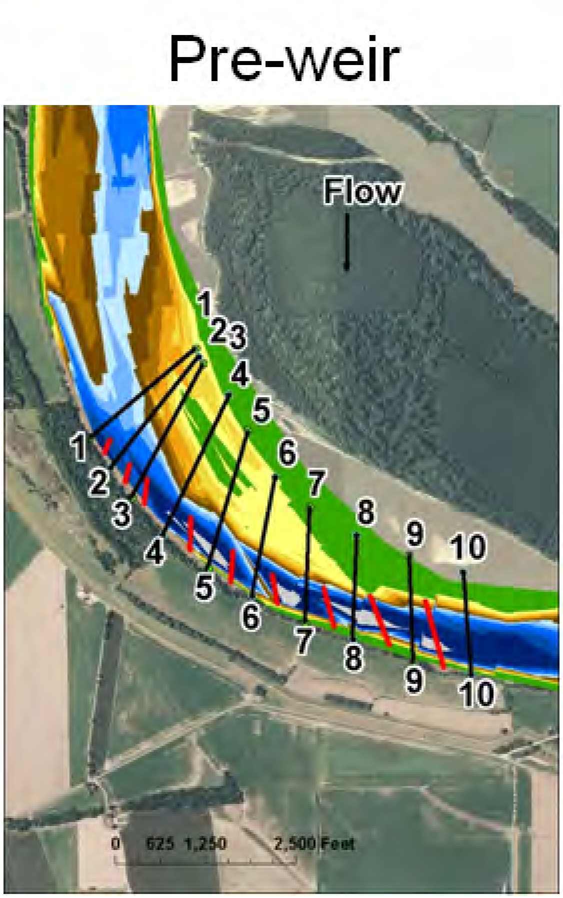

Figure 21.1: Greenfield Bend 1976 Bathymetry

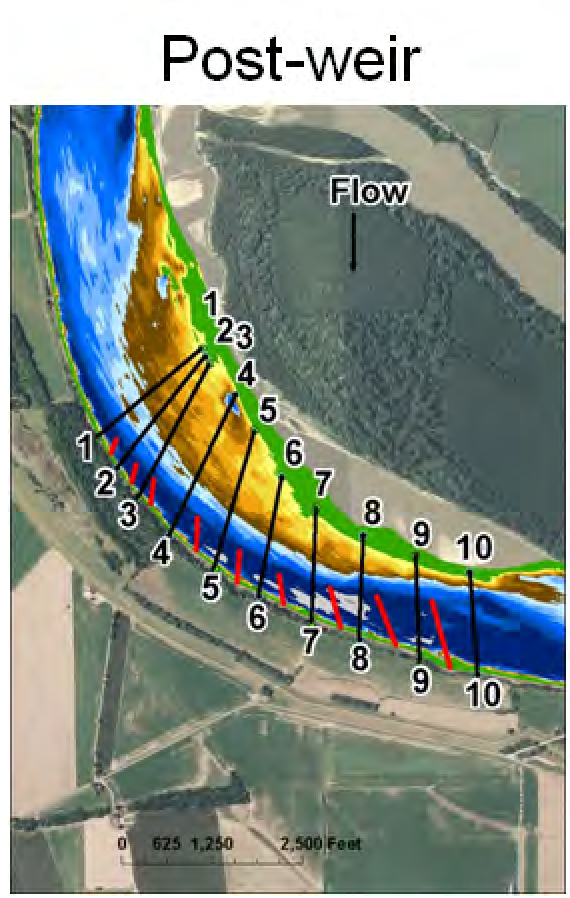

Figure 21.2: Greenfield Bend 2007 Bathymetry

22. Bird's Point; *RM 2.3 to RM 1.7*

The Bird's Point weir field (Figure 22.1, Figure 22.2) consists of three weirs constructed along the RDB. The cross sections exhibited increases in the area below LWRP for all four sections and below 10 ft above LWRP for three of four sections. The maximum depth decreased for three of the four cross sections, with the decreases ranging from 3 ft to nearly 6 ft. The average slope decreased for all four cross sections, decreasing between 0.1 ft per 100 ft and 2.0 ft per 100 ft. The width and wetted perimeter at LWRP increased for all cross sections. At 10 ft above the LWRP, the width decreased for three of four sections and the wetted perimeter decreased for two of the four cross sections. The majority of the average slopes of the 10 ft vertical segments decreased in slope, with the decreases ranging from 1.65 ft per 100 ft to 5.32 ft per 100 ft. Half of the increases that occurred were in the 0 ft – 10 ft segment elevation range. The slope changes in the weir field were mixed. The 0 ft – 10 ft elevation range exhibited an area of rapidly increasing slopes, with an area of decreasing slopes in the immediately lower elevation range. This was due perhaps to the scarcity of data in the top range.

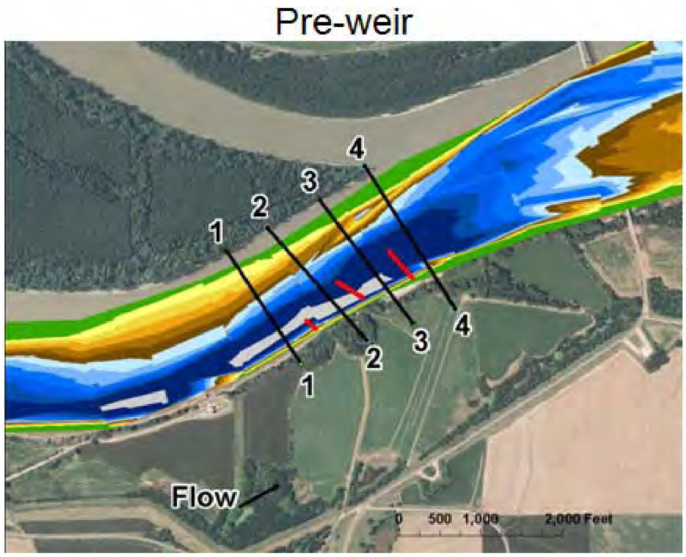

Figure 22.1: Birds Point 1976 Bathymetry

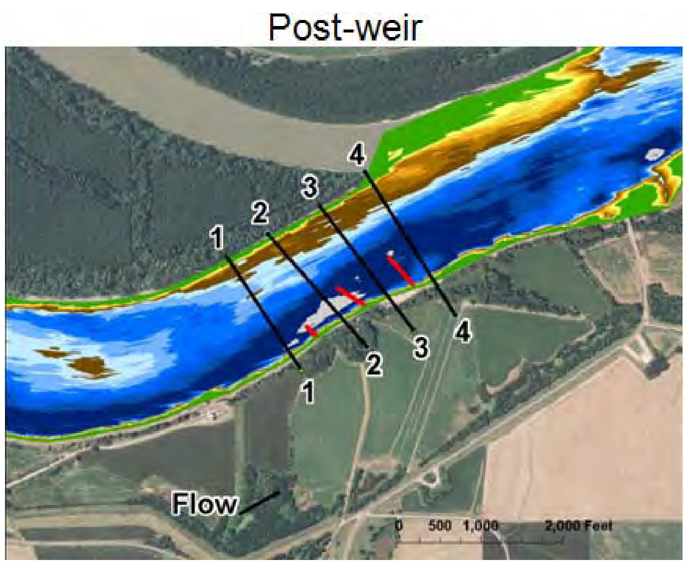

Figure 22.2: Birds Point 2007 Bathymetry

Summary of Results

The following Table 1 summarizes the findings of the eight analyzed parameters for the 22 weir fields studied. Table 1 also summarizes the 15 weir fields specifically installed at locations with point bars developed on the inside of bends. These fields do not include: 103.25; Bellerive; Birds Point; Davis; Establishment; Hanging Dog; and L&D 24.

Table 1: Results Compilation for Study Parameters

Cross-Sectional Geometry Parameter Results - All Fields and Point Bar/Bend Fields only	All Weir Fields (197 Cross Sections)		Bend - Point Bar Fields (164 Cross Sections)		
	Value	Percent of Value	Value	Percent of Value	Percent Difference
# Area Increases at LWRP	163	82.7%	140	85.4%	
Average Area Increase at LWRP (ft^2)	5473		5430		0.8%
Average Pre-Weir Area at LWRP (ft^2)	19240		18737		2.6%
# Area Increases at 10 ft above LWRP	166	84.3%	146	89.0%	
Average Area Increase at 10 ft above LWRP (ft^2)	6904		6711		2.8%
Average Pre-Weir Area at 10 ft above LWRP (ft^2)	34797		34099		2.0%
# Maximum Depth Increases	104	52.8%	93	56.7%	
Average Maximum Depth Increase (ft)	7.5		7.7		3.2%
Average Pre-Weir Maximum Depth (ft)	-31.2		-31.8		-1.8%
# Width Increases at LWRP	151	76.6%	128	78.0%	
Average Width Increase at LWRP (ft)	328		263		22.0%
Average Pre-Weir Width at LWRP (ft)	1277		1236		3.3%
# Width Increases at 10 ft above LWRP	112	56.9%	98	59.8%	
Average Width Increase at 10 ft above LWRP (ft)	368		265		32.5%
Average Pre-Weir Width at 10 ft above LWRP (ft)	1772		1670		5.9%
# Wetted Perimeter Increases at LWRP	157	79.7%	135	82.3%	
Average Wetted Perimeter Increase at LWRP (ft)	310		262		16.8%
Average Pre-Weir Wetted Perimeter at LWRP (ft)	1298		1255		3.4%
# Wetted Perimeter Increases at 10 ft above LWRP	109	55.3%	99	60.4%	
Average Wetted Perimeter Increase at 10 ft above LWRP (ft)	296		286		3.4%
Average Pre-Weir Wetted Perimeter at 10 ft above LWRP (ft)	1906		1818		4.7%
# Average Slope Decreases	117	59.4%	89	54.3%	
Average Slope Decrease (ft per 100 ft)	1.27		1.30		2.3%

The results show a similar occurrence rate for all eight parameters, with the locations at a bend with an inside point bar at most occurring ±5.1% from the all weir fields included condition. There is a difference in the magnitude of in the average increase between the two datasets for width at LWRP, width at 10 ft above LWRP, and wetted perimeter at LWRP. The comparisons reveal that the bendway weirs are having a smaller effect at increasing width (one of their primary intended functions) at bend locations. There does not appear to be an easily identifiable pattern in the values of individual cross sections explaining this trend.

The 10 ft vertical segment slopes for all fields decreased for 51.8% of the segments. The slopes decreased for 48.8% of the vertical segments, with the remaining 0.4% showing no change to a hundredth of a percent. Each 10 ft segment for each cross section of the weir fields was analyzed to determine if the segment had an increasing or decreasing behavior with the goal of recognizing patterns. Frequently but by no means definitively, the -20 ft - -10 ft segment indicated a decreasing behavior for the slope, and the -40 ft - -30 ft segment indicated an increasing behavior. The degree of change occurring in the 10 ft segments was compared to the pre-weir variation. Overall, approximately 68% of the slope changes fell within the 1.5x the pre-weir variation as defined above; of the 32% of slope changes remaining that could be calculated, the slope increased for 22% of the segments and decreased for the remaining segments.

Considering only the bend-inside point bar fields, the 10 ft vertical segment slopes decreased for 49.8% of the segments; slopes increased for 49.7% of segments and exhibited no change at beyond a hundredth of a foot per 100 ft for 0.5% of segments. Approximately 69% of the segment slopes fell within 1.5x the pre-weir variation. The slope outside of 1.5x the pre-weir variation increased for ~22% of the slopes, with the remaining slopes decreasing outside of 1.5x the pre-weir variation.

Conclusions

The goal of this study was to evaluate changes in riverbed geometry associated with the installation of bendway weirs. To accomplish this, cross sections of the riverbed were established, surveyed, and examined for set time periods. Different parameters of the cross sections were defined, measured, and calculated for each period, and the results of the pre-weir and post-weir construction conditions compared.

The dominant demonstration (~77%) of width increases at LWRP strongly suggests that the bendway weirs are accomplishing one of their primary goals: to widen and improve the navigable river channel at the level the Corps is legally responsible for maintaining. This finding is reinforced when considering the increases in cross-sectional area that many weir fields saw for all or a controlling majority of their cross sections.

The similarity in changes to width and wetted perimeter suggests that wetted perimeter serves as a secondary indicator that the findings for the width above are valid; the cross sections were heavily width-dominated, so the wetted perimeter at LWRP functions almost as another measurement of width. The deviation between the width and wetted perimeter may be explained by the variation in maximum depth, which factors into the wetted perimeter calculation.

The average maximum depth underwent a near-even split between increases and decreases. This can be explained with the consideration that the river is a natural system constantly undergoing changes. For equilibrium to exist in a constantly changing system, the deviations in either direction from a norm must be roughly equivalent, which is what appears to be happening. The dominance of area and width increases and the near-even split in maximum depth changes suggests that the cross-sectional area increases are attributable to the widening of the channel.

The average slope revealed a slight majority of decreasing pre- to post-weir, and the average 10 ft segment slopes split between increases and decreases pre- to post-weir construction. This contradicts fears that bendway weir construction is leading to the rapid increasing of inside point bar slope and the loss of shallow water habitat. The strong majority of average 10 ft segment slopes demonstrated a change within 1.5x the pre-weir construction variation, further refuting the worry over increased slopes. The increases in average slope outside of 1.5x the pre-weir construction variation that did are partially explainable because of their location. The average slope increases above 1.5x the pre-weir variation occur have a minor tendency to occur in lower cross sections, which would be the case if the channel is incising and cutting to a deeper depth.