US Army Corps
of Engineers
Kansas City District

Hydrologic and Geomorphic Changes on the Kansas River

September 2010

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1.0 Introduction

The Kansas River is an important water resource in Kansas. Like most major rivers, the Kansas River has undergone significant changes, both natural and anthropogenic, over the past century, with potential implications for water supply, hydropower, flooding, recreation, and environmental resource management. The purpose of this study is to analyze hydrologic and geomorphic changes on the Kansas River from 1985 – 2009. An analysis of the hydrology, sediment transport, and channel morphology for the period of time prior to 1985 can be found in *Analysis of Channel Degradation and Bank Erosion in the Lower Kansas River* (Simons, Li, and Associates—hereafter SLA 1984). An in-depth look at the geology and economic impact of the Kansas River can be found in Brady et al. (1998).

This study addresses the following questions:

Has the flow volume and flow-duration structure of the Kansas River changed?
What are the hydrologic impacts of the federal reservoirs?
How are the stage-discharge relationships changing?
Did the floods of 1993 and 2007 alter the stage-discharge relationships?
Where is the Kansas River degrading, aggrading, or remaining stable?
Where is the Kansas River widening, narrowing, or unchanging?
Can morphological changes on the Kansas River be correlated to dredging activities?

This report is divided into five sections. Section 1 contains this introduction. Section 2 presents a hydrologic assessment of the Kansas River, including an assessment of flow volumes and the flow-duration structure of the river at five gaged locations. Section 3 presents a geomorphic assessment of the river, including qualitative descriptions based on field reconnaissance, aerial photography, and various published resource, and quantitative analyses based on changes in stage-discharge relationships and measured cross-sections. Section 4 discusses dredging and analyzes influence on current channel changes. Section 5 presents the conclusion.

2.0 Hydrologic Changes

2.1 Kansas River Hydrologic Basin

The Kansas River runs approximately 170 river miles from the confluence of the Republican River and Smoky Hill River to its confluence with the Missouri River. The Kansas River drains 61,440 square miles of mostly agricultural land. Precipitation amounts decrease drastically from east to west in the Kansas River basin. The average rainfall at Kansas City is about 38" per year. About 400 miles west, the average rainfall at Goodland is approximately 18" per year. Irrigation diversions and pumping for agricultural use further decrease the water yield from the upstream area. Table 2.1 demonstrates that the 44,870 square miles of drainage upstream of Fort Riley produce only one-third of the flow at Desoto, while the 14,886 square miles of drainage downstream of Fort Riley produces two-thirds of the flow.

Table 2.1. Average Flow at Kansas River Gages from Water Years 1981-2008

Station	River Mile	Drainage Area (sq miles)	Average Flow (cfs)
Fort Riley	162.2	44,870	2,600
Wamego	126.9	55,280	5,461
Topeka	83.1	56,720	6,210
Lecompton	63.8	58,460	7,407
Desoto	31.0	59,756	8,203

The flow data used in Section 2.2 and 2.3 and the stage-discharge measurements used in Section 3.2 were taken from USGS measurements at five Kansas River gages, shown in Figure 2. 1. The data are available at http://waterdata.usgs.gov/ks/nwis/ .

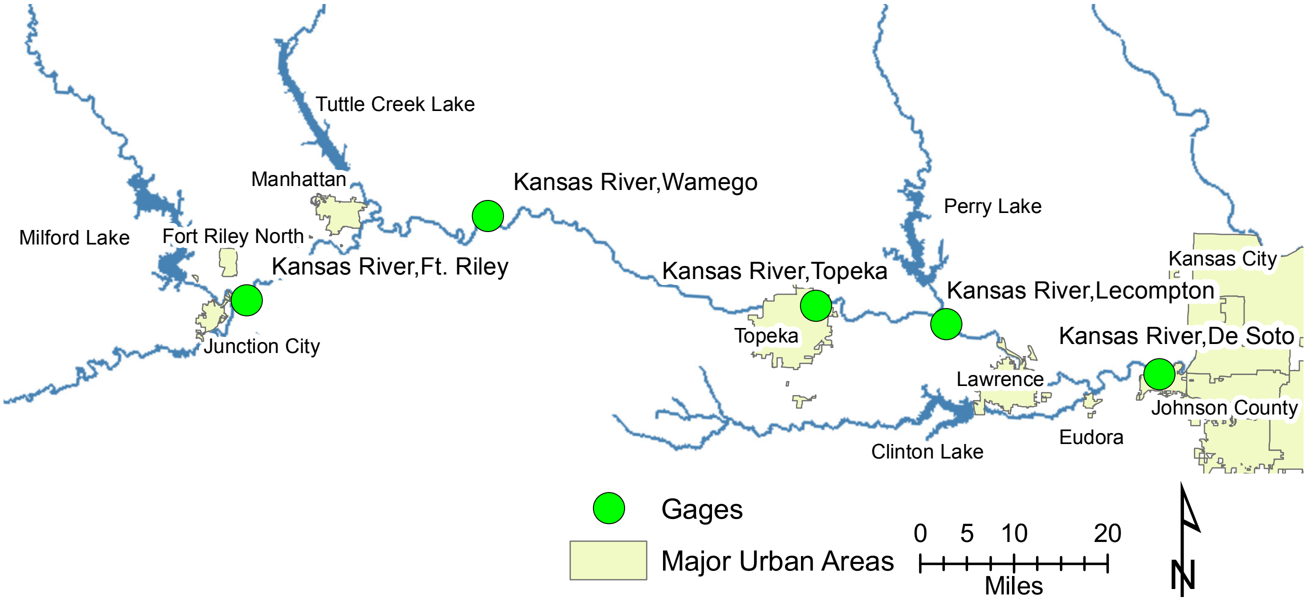

Figure 2. 1 Gage Locations

2.2 Flow Volume

The average annual flow, calculated by averaging daily flow values during a given year, is a measure of the volume of stream flow. In an unchanging watershed, natural variation in annual precipitation leads to large variations in the average annual flow, but the many-year average remains relatively constant. Urbanization and other land use changes may alter the value about which the average annual flow fluctuates. Water withdrawals for irrigation, human consumption, power generation, and industrial use cause the average to decrease. Evaporation from reservoirs may affect flow volumes. Most other natural and human-induced channel changes, including levee construction, bed degradation, and channel migration, do not usually have a major effect on flow volumes.

2.2.1 Kansas River—Fort Riley

The Fort Riley gage (12/19/1963 – current) and the Ogden gage (6/19/1917 – 9/30/1951) describe the flow record of the Kansas River immediately downstream of the junction of the Republican and Smoky Hill Rivers, at river mile 170.5. These data were combined to perform this analysis with no correction made for the slight (< 1%) difference in drainage areas between the gage locations. Flow data was not recorded for the 12 years between 1951 and 1963. Figure 2. 2 shows the average annual flow record at the Ogden and Fort Riley gages. The dashed line is a linear regression line fitted to the time series. The trend line shows that the average flow is essentially steady over the period of record with a slight, likely insignificant, decreasing trend. Milford Lake (closure: 1967) does not seem to affected the average flow volume at this location.

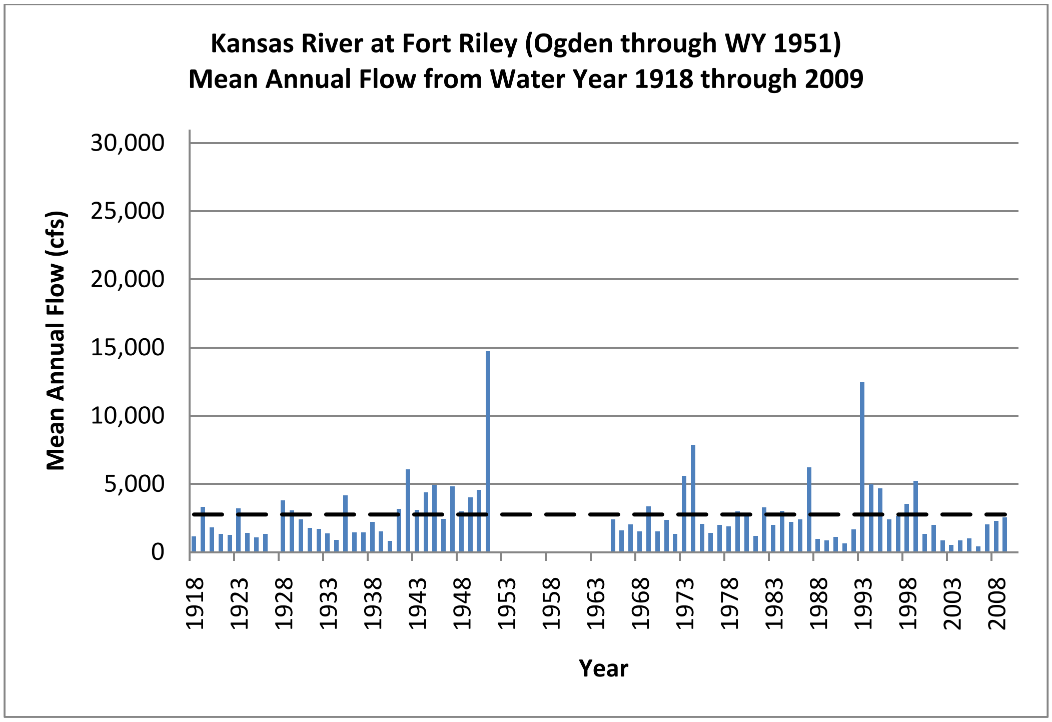

Figure 2. 2. Average annual flow at Fort Riley.

2.2.2 Kansas River—Wamego

The Wamego gage (01/23/1919 – current) describes the flow record of the Kansas River at river mile 126.9, downstream of the entrance of the Big Blue River. Figure 2. 3 shows the annual flow record for water years 1920 through 2009. The slight upward trend may not be significant.

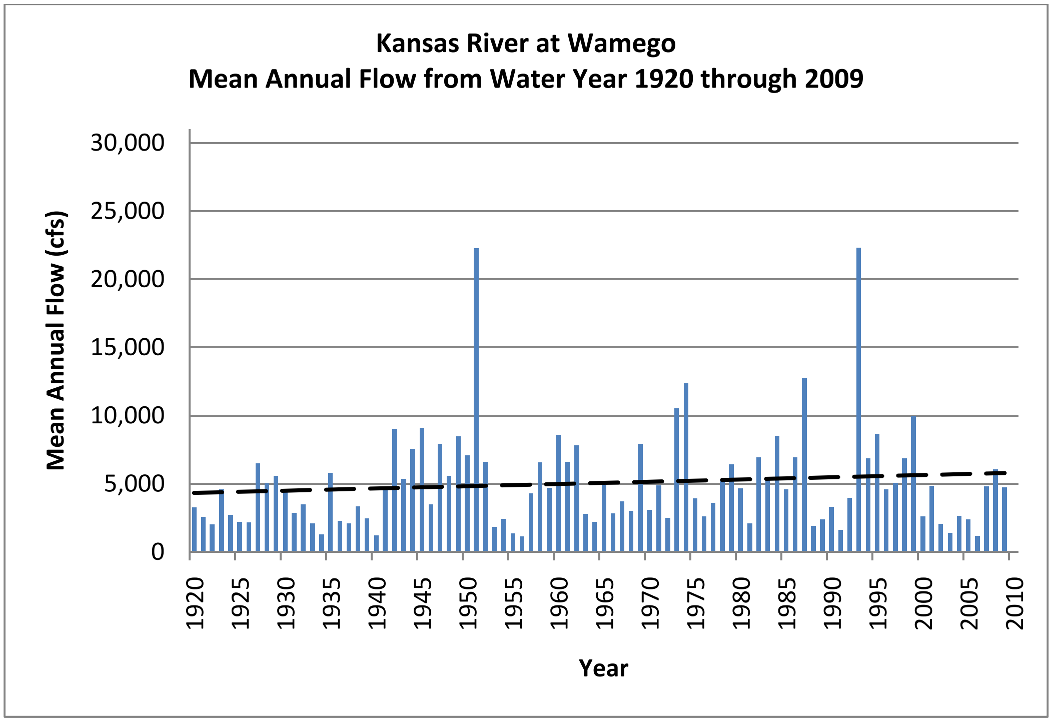

Figure 2. 3. Average annual flow at Wamego.

2.2.3 Kansas River—Topeka

The gage at Topeka (6/12/1917 — current) is located at river mile 83.1. No significant tributaries enter between Wamego and Topeka. Figure 2. 4 shows a slight upward trend in the average annual flow.

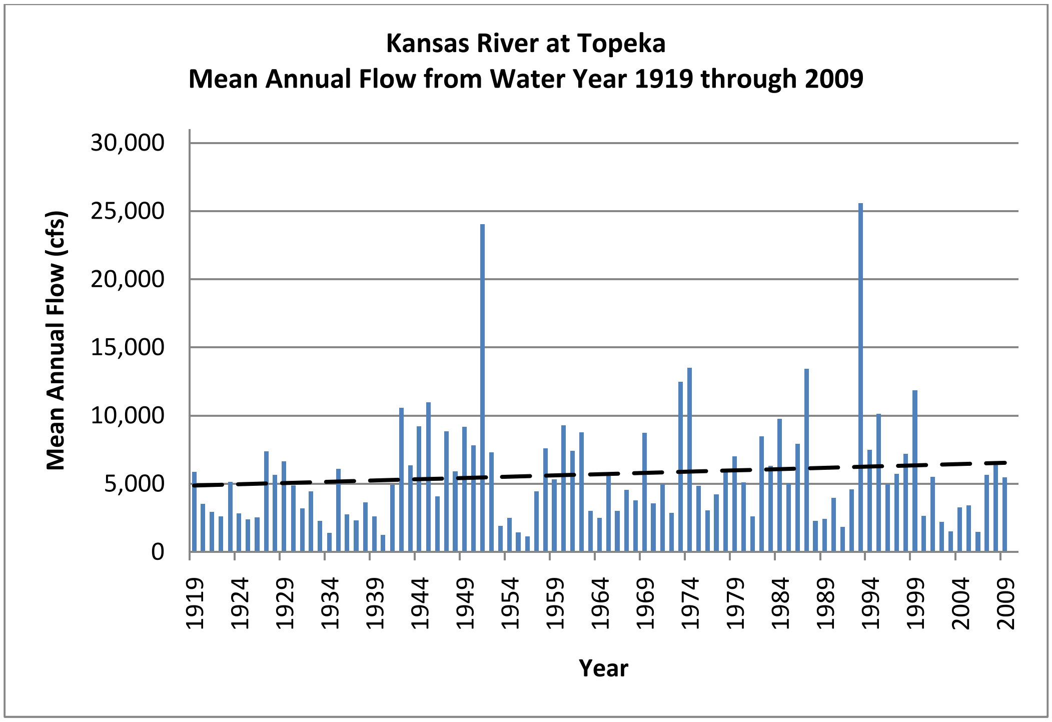

Figure 2. 4. Average annual flow at Topeka.

2.2.4 Kansas River—Lecompton

The Lecompton gage (3/16/1936 — current) is located downstream of the Delaware River at river mile 63.8. Figure 2. 5 shows a slight downward trend over the period of record.

Perry Lake (closure: 1969) regulates flow from the Delaware River. As indicated by Figure 2. 5, the construction and operation of Perry Lake has not significantly affected the flow volumes in the Kansas River.

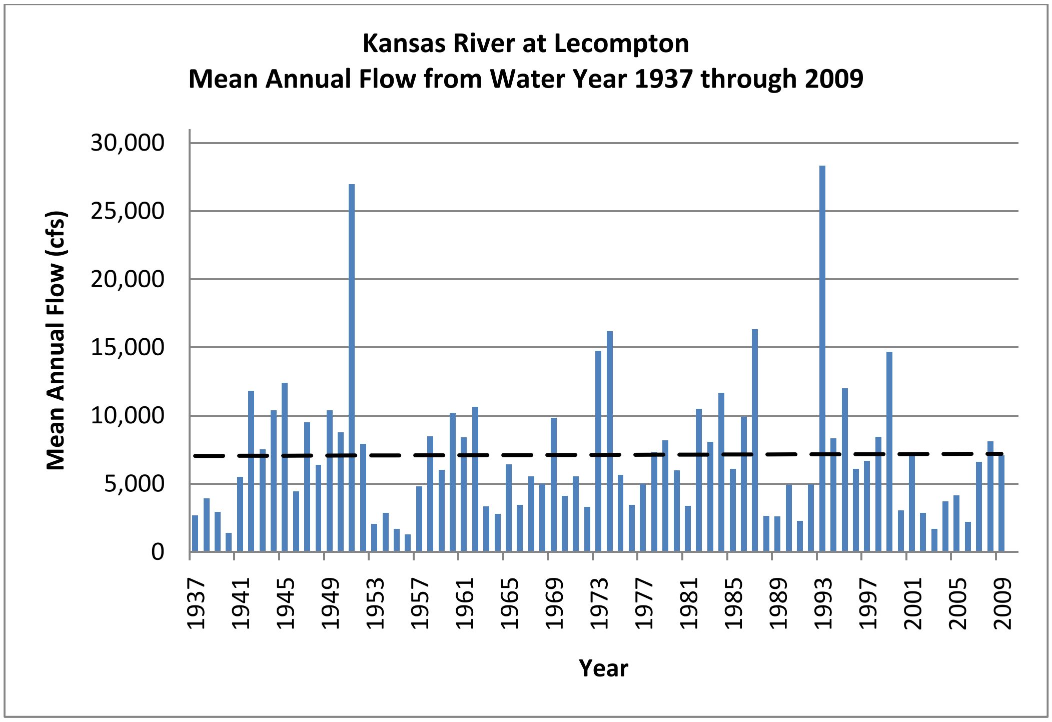

Figure 2. 5. Average annual flow at Lecompton over the period of record

Regression equations between Topeka and Lecompton and between Desoto and Lecompton were used to extend the period of record back to 1919. Figure 2. 6 and Figure 2. 7 show the regression relationship between Topeka and Lecompton and Desoto and Lecompton, respectively. The flow at Lecompton was calculated as the average between the Topeka and Desoto estimates.

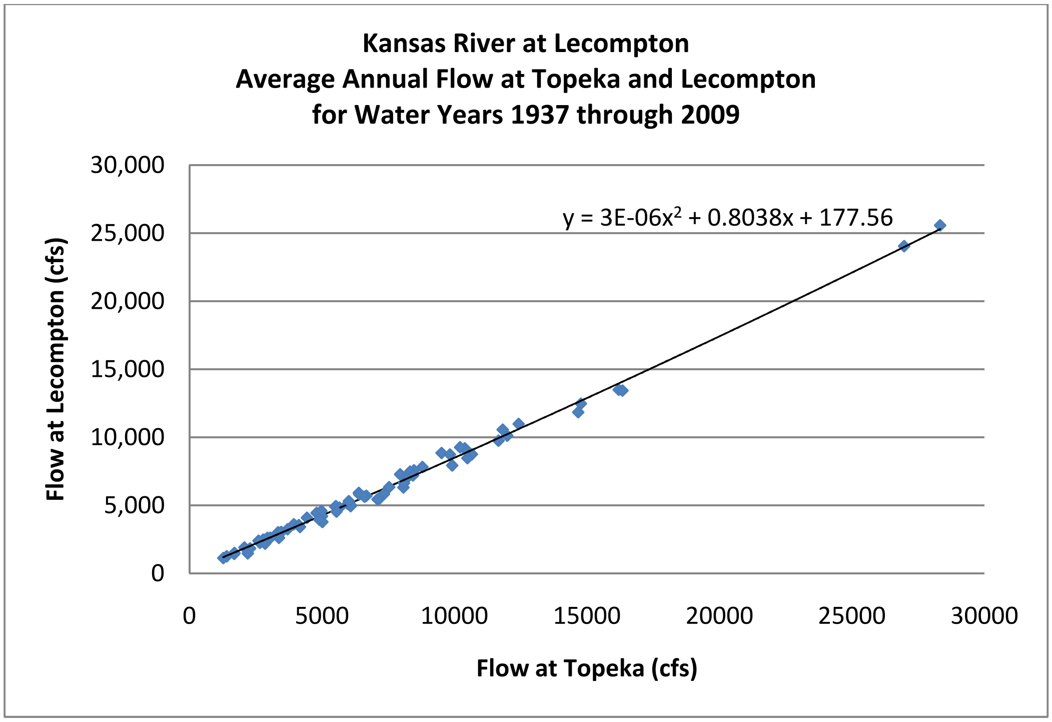

Figure 2. 6. Regression equation relating average flow at Topeka to average flow at Lecompton.

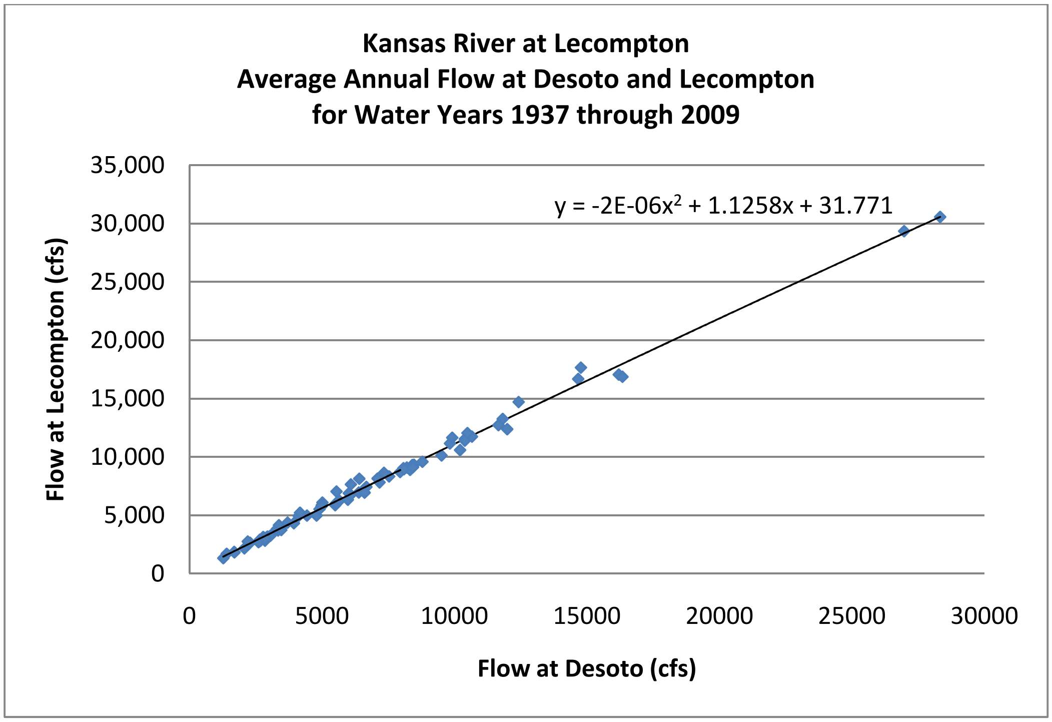

Figure 2. 7. Regression equation relating average flow at Desoto to average flow at Lecompton.

Figure 2. 8 shows the average annual flow at Lecompton for the extended period of record. With these years included, the trend is now upward.

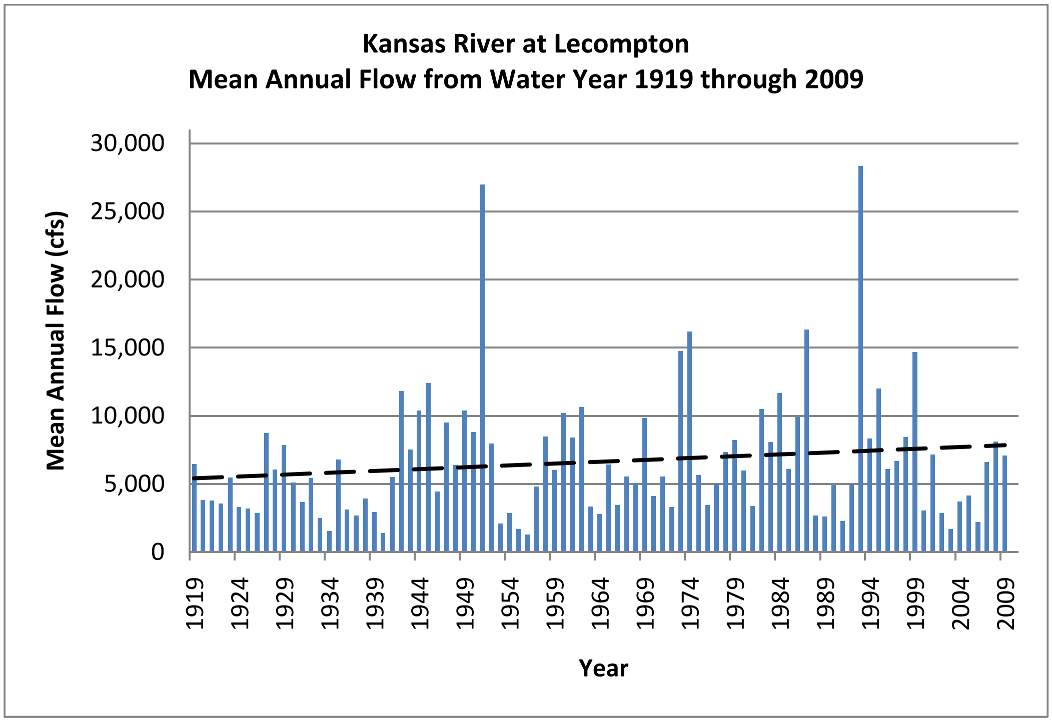

Figure 2. 8. Average annual flow at Lecompton, including the estimated years 1919 - 1936.

2.2.5 Kansas River—Desoto

The Desoto gage (7/8/1917 – current) is the final flow gage on the Kansas River. It is located downstream of the Wakarusa River at river mile 31.0. Figure 2. 9 shows the annual average flow time series from water years 1918 through 2009. Like Wamego and Topeka, the flow trend is upward. Clinton Lake (1977 – current) on the Wakarusa River does not seem to affect the flow volumes in the Kansas River.

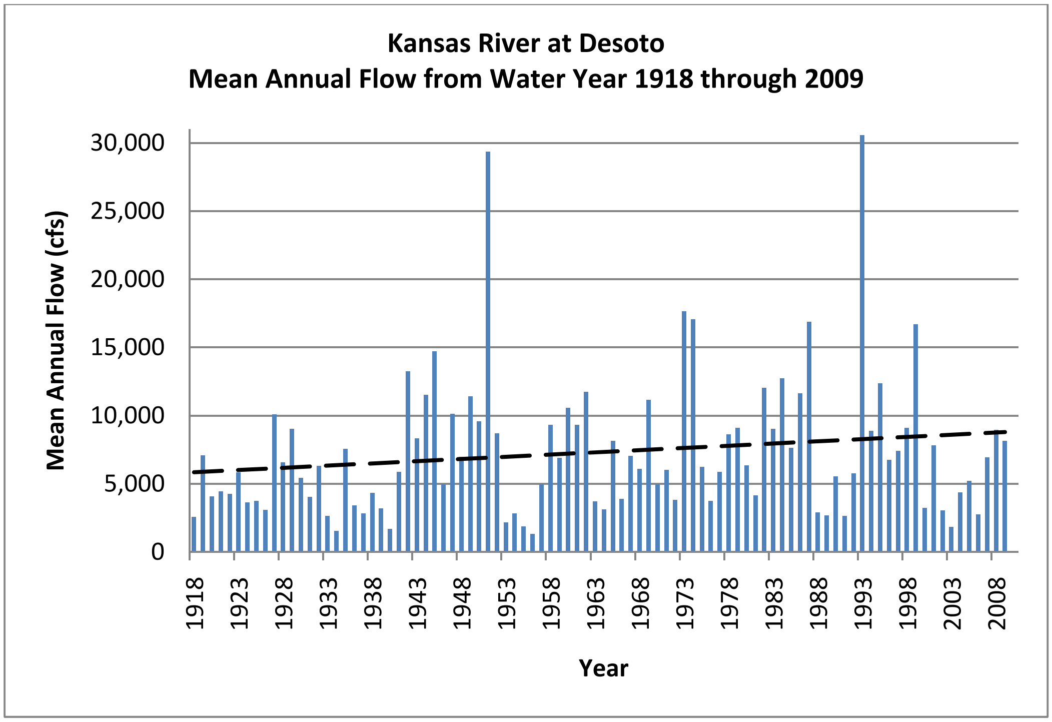

Figure 2. 9. Average annual flow at Desoto.

2.2.6 Flow Volume—Final Thoughts

This analysis shows that the total volume of flow in the Kansas River was lower from 1918 – 1939 than from 1940 – 2009, which yields the upward trending line. There appears to be no increase or decrease in the average annual flow in the Kansas River from 1940 – 2009.

Milford Lake, Tuttle Creek Lake, Perry Lake, and Clinton Lake do not appear to affect the total flow volumes in the Kansas River. This is expected, as the chief purpose of these reservoirs is to alter the timing of the flows, not the total volume of flow.

2.3 Flow Duration

A flow-duration curve reports the percent of the time that a given daily flow is met or exceeded. The 40% flow is the flow which, on the average, is exceeded 146 days per year (0.4*365 days =146 days). The flow-duration structure for a river drives the sediment transport regime and remains relatively independent of the channel morphology. Factors that affect the volume of flow, such as irrigation withdrawals, or the timing of flows, such as detention and releases from reservoirs, can influence the flow-duration curves. The anticipated effect of flow regulation is to decrease the frequency of flood flows and low flows and increase the frequency of intermediate flows. Tuttle, Milford, Perry, and Clinton dams were closed in 1962, 1969, 1969, and 1977 respectively. This analysis divides the flow data into two categories, 1917-1962 (pre-reservoir) and 1963-2009 (post-reservoir). This is not to say that all or even most of the change in the flow-duration structure between the two time periods can be attributed to the reservoirs. Sufficient data is required to accurately reflect the probabilities of floods and low flows, making changes in the flow-duration structure of the river hard to detect.

2.3.1 Kansas River—Fort Riley

As stated in section 3.1.1, the Fort Riley gage (12/19/1963 – current) and the Ogden gage (6/19/1917 – 9/30/1951) describe the flow record at a similar location. Data from these two gages were combined to derive the flow-duration structure of the Kansas River immediately downstream of the junction of the Republican and Smoky Hill Rivers. The flow-duration curves for the two time periods are plotted in Figure 2. 10. Flow data is not available for 1952 to December 1963.

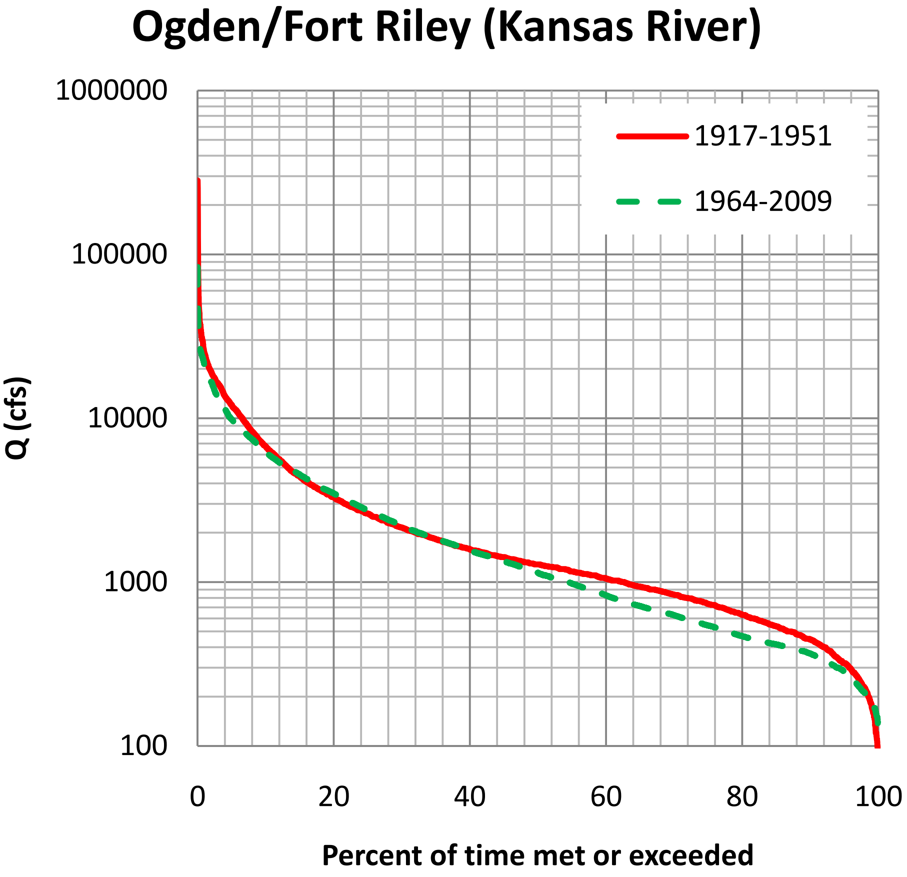

Figure 2. 10. Flow-duration structure for Ogden/Fort Riley

2.3.2 Kansas River—Wamego

Figure 2. 11 presents the flow-duration curves for the Kansas River at Wamego.

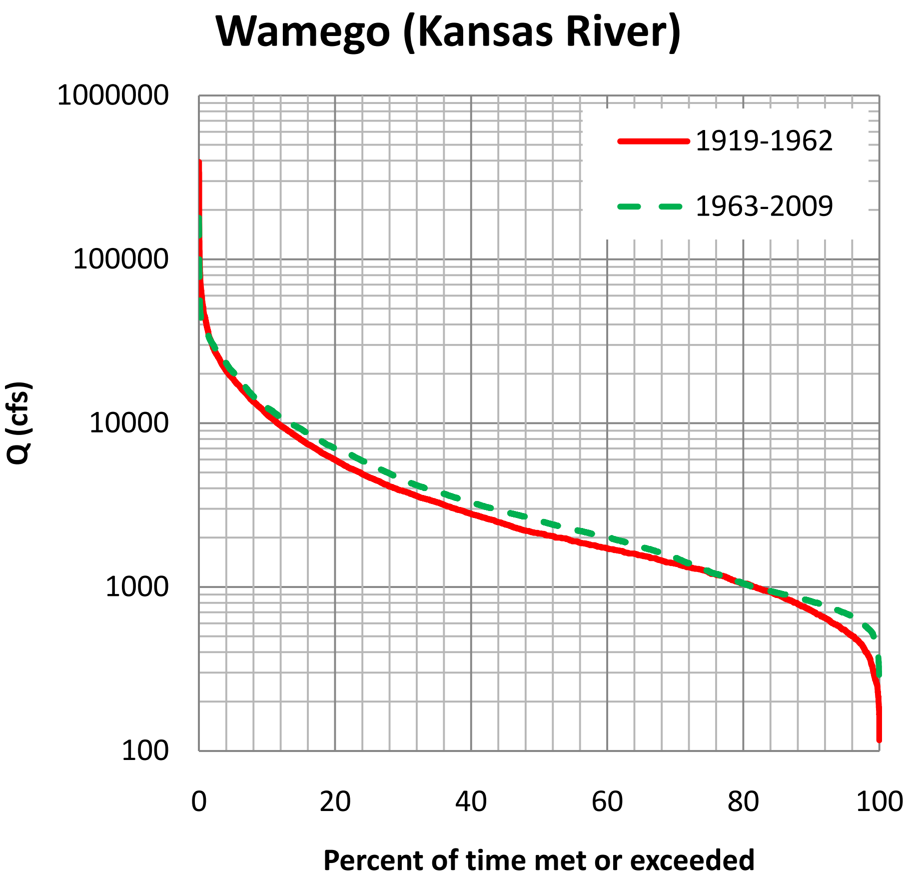

Figure 2. 11. Flow-duration curve for Wamego (Kansas River) 1919 -1967

As seen in Figure 2. 11, the Kansas River at Wamego has less severe floods and droughts but increased discharge for intermediate flows in the recent period. Tuttle Creek Lake and Milford Lake are responsible for the attenuation of the floods and the droughts. However, the period from 1919 – 1966 encompassed the dry 1920s and 1930s, which may be the most significant cause of the increase in intermediate flows from 1967 – 2009. This is demonstrated for the Desoto gage (Figure 2. 13 and Figure 2. 14).

2.3.3 Kansas River—Topeka

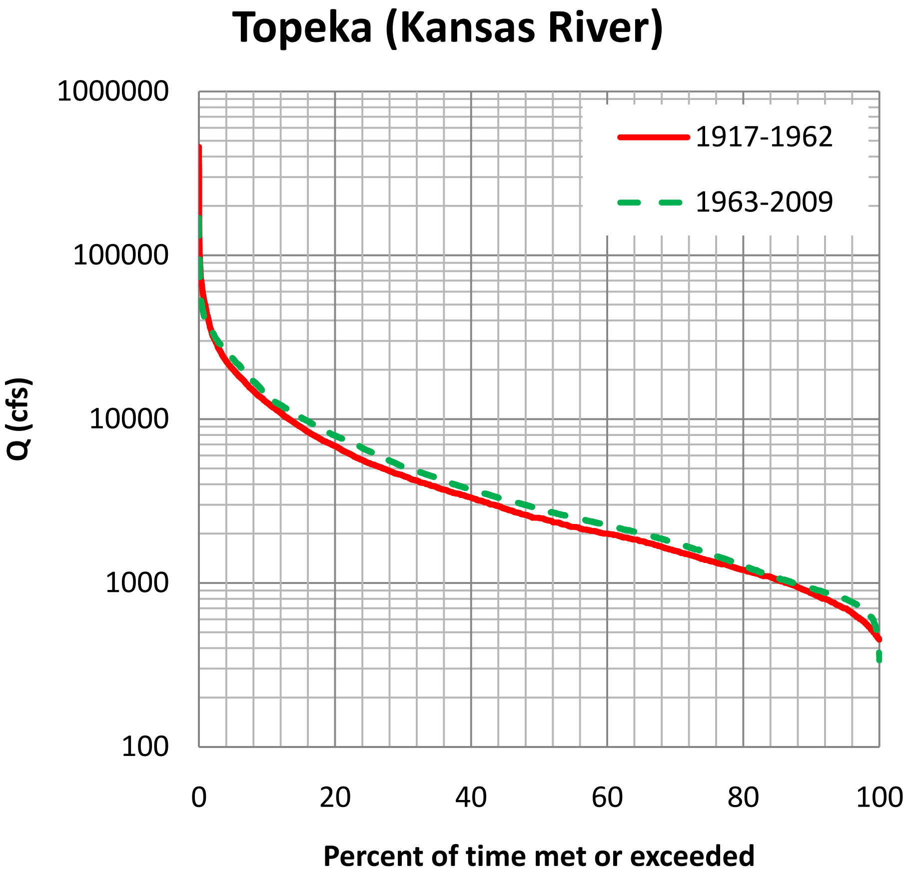

Figure 2. 12. Flow-duration curve for Topeka (Kansas River) 1917-1967

As seen in Figure 2. 12, at Topeka the Kansas River has less severe floods and droughts but increased discharge for intermediate flows in the post-reservoir period. As expected, the flow-duration structure is very similar to that at the Wamego gage. Tuttle Creek Lake and Milford Lake are responsible for the attenuation of the floods and the droughts but the increase in intermediate flows is influenced by the dry 1920s and 1930s.

2.3.4 Kansas River—Desoto

Figure 2. 13 shows a similar result for the Kansas River at Desoto to that seen at Wamego and Topeka. The flood and drought attenuation can be attributed to the action of Tuttle Creek Lake, Milford Lake, Perry Lake, and Clinton Lake.

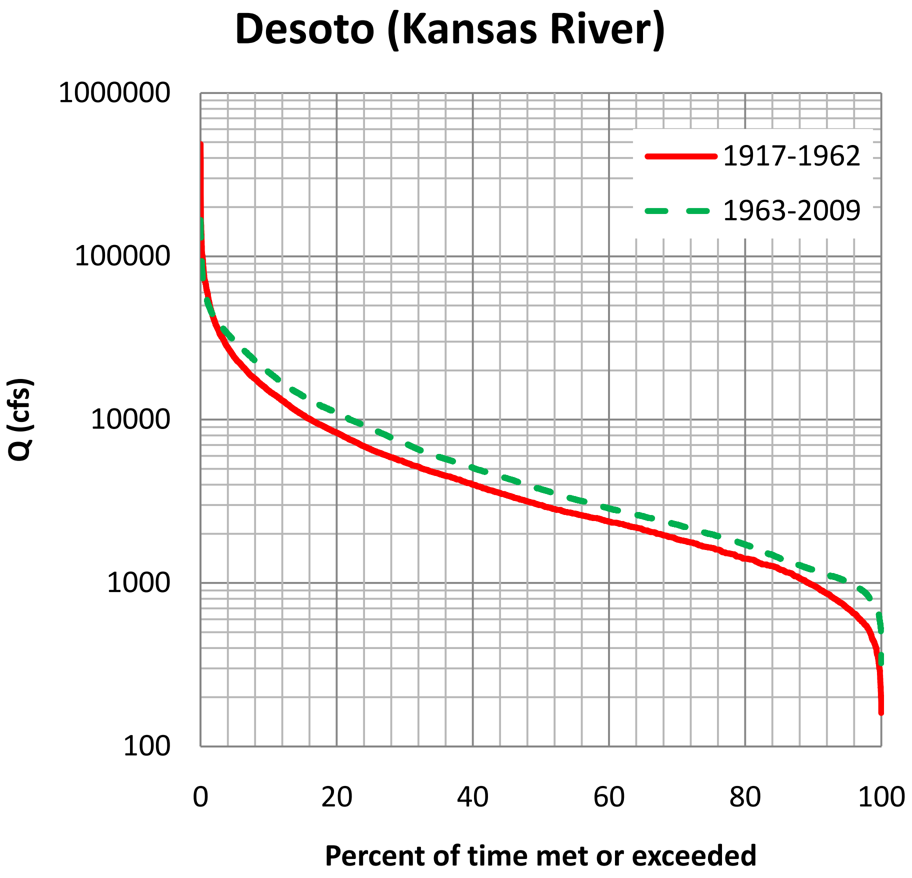

Figure 2. 13. Flow-duration curve for Desoto (Kansas River) 1917-1967

As at earlier gages, the dramatic increase for the intermediate flows shown in Figure 2. 13 is a function of the dry 1920s and 1930s. Figure 2. 14 shows that the intermediate flows have not changed appreciably since 1941.

Figure 2. 15 demonstrates the attenuation in the extreme high and low flows.

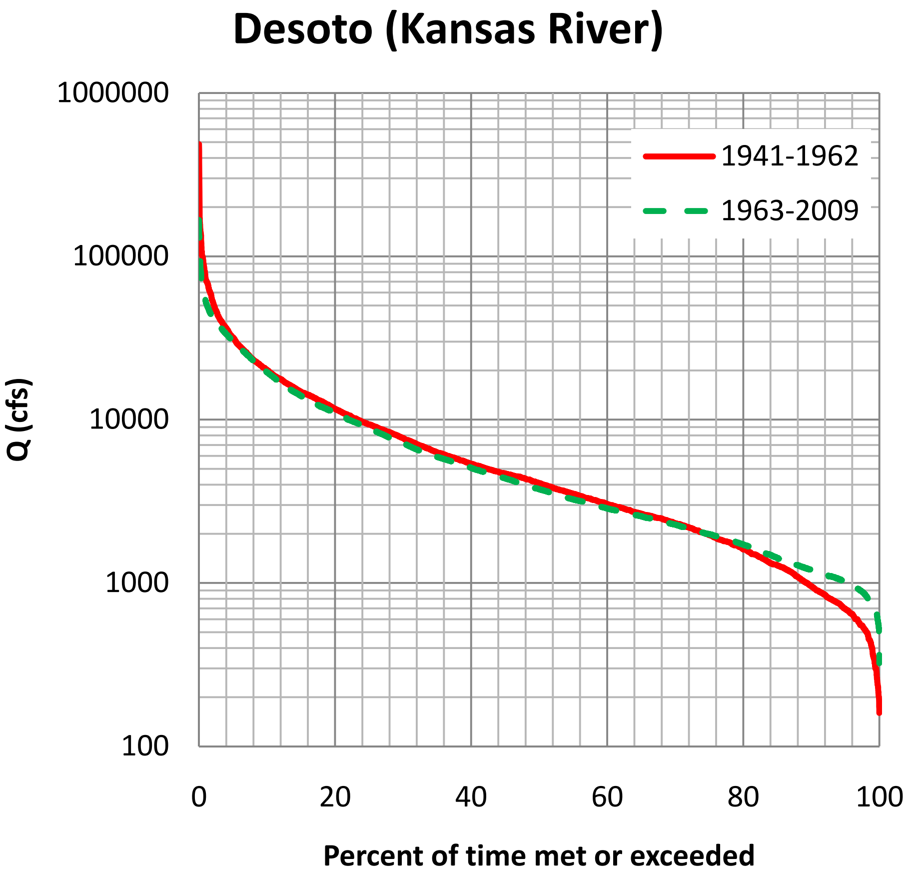

Figure 2. 14. Flow-duration curve for Desoto (Kansas River) 1941-1967

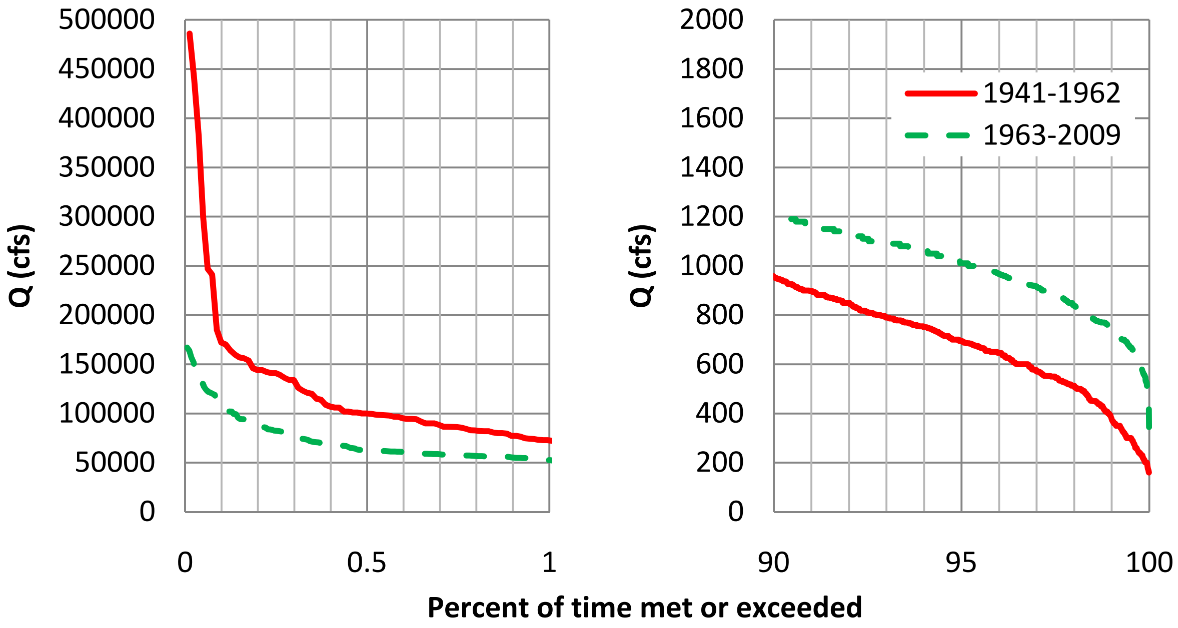

Figure 2. 15. Flow Extremes at Desoto 1941-1967. Note that the scales are arithmetic.

2.3.5 Flow-Duration—Summary

The flow-duration structure of the Kansas River has changed in the past 100 years. The floods and droughts are less severe, but the intermediate flows have increased. The attenuation of the floods and droughts can be attributed to the operation of major federal reservoirs. The increase in the intermediate flows seen in the post-reservoir period is mostly a factor of the drought of the 1920s and 1930s. When these dry years are excluded from the analysis, the changes in intermediate flows are less pronounced.

The flow data at the Ogden/Fort Riley gages show a different pattern than the other gages. At Ogden/Fort Riley, floods and low intermediate flows have decreased in the post-reservoir period, droughts have remained unaffected, and high intermediate flows have increased. Why the hydrology at this site differs from the other sites on the Kansas River is not readily apparent. A possible link between changes in the flow-duration structure and changes in the geomorphology of the Kansas River would require a sediment transport analysis that is beyond the scope of this report.

2.4 Hydrologic Assessment—Summary

The total volume of flow in the Kansas River was lower from 1918 – 1939 than from 1940 – 2009, which yields an upward trending line everywhere except for Fort Riley, where there is no trend.

There is no increase or decrease in the average annual flow at any gage on the Kansas River from 1940 – 2009.

The floods and droughts are currently less severe than in the pre-reservoir period.

Intermediate flows have increased in the post-reservoir period at all gages except for Fort Riley, but this is mostly a factor of the drought of the 1920s and 1930s.

3.0 Geomorphic Assessment

This section presents an analysis of the geomorphology of the Kansas River. It begins with a qualitative description of the Kansas River, based primarily on field reconnaissance that took place July 19, 20, and 21st, 2010—with insight on planform changes taken from Dort (2010) and 2008 aerial photography. Secondly, this section provides an analysis of stage-discharge relationships. Finally, it presents analysis of bed elevation and channel width changes based on measured cross-sections.

3.1 Qualitative Assessment

3.1.1 Kansas River Reaches

SLA (1984) divided the Kansas River into eight reaches based on hydraulic controls and other factors. These reaches are shown in Figure 3. 1. The reader is directed to SLA (1984) section 3.2 for their qualitative description of each reach.

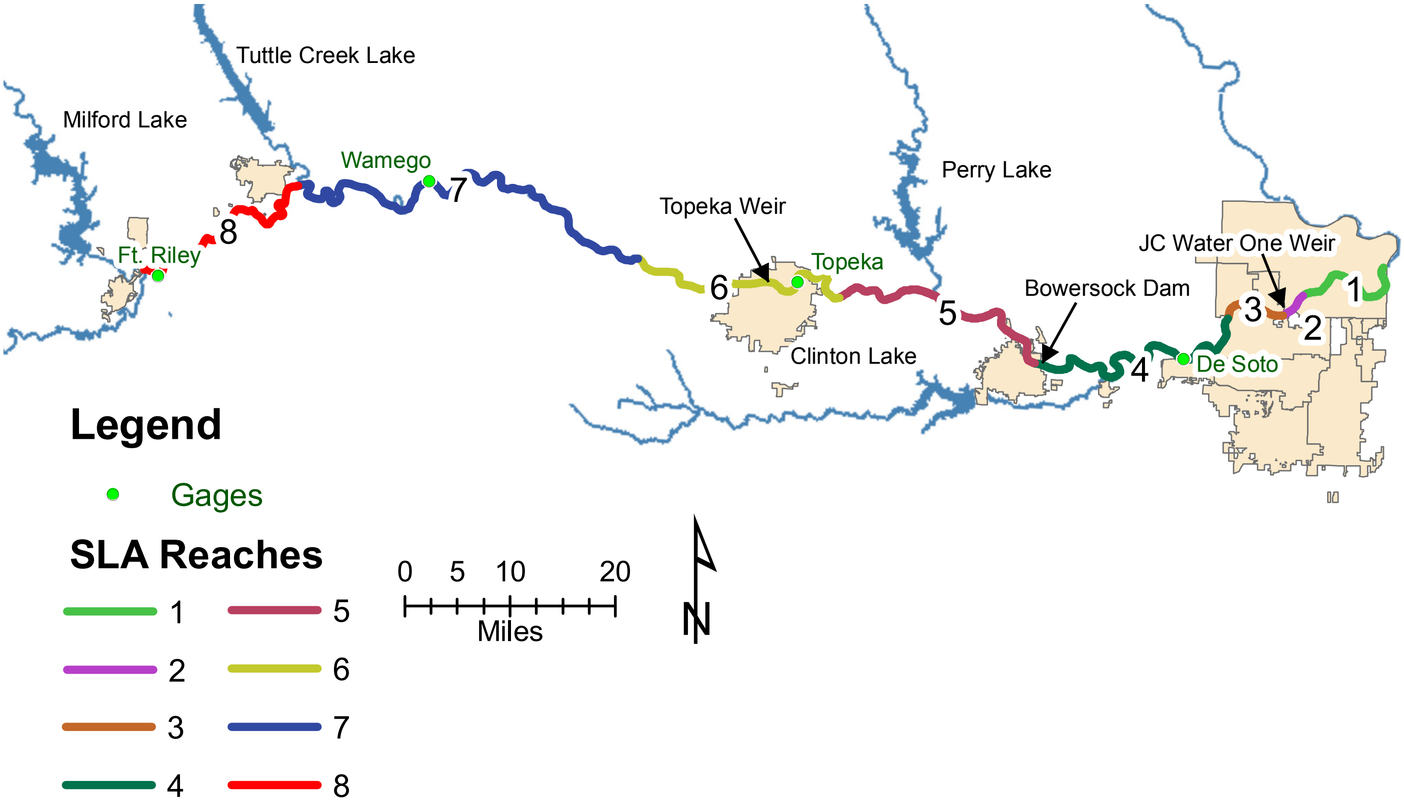

Figure 3. 1. Simons, Li, and Associates (SLA) Reaches

The same eight reaches will be used to qualitatively describe the Kansas River in this report. These reaches, designated as SLA Reach 8, SLA Reach 7, etc., will be discussed starting upstream and working downstream. The following paragraphs present basic, overall trends and pictures from specific locations. This qualitative description is based primarily on field reconnaissance that took place July 19, 20, and 21st, 2010—during which observations, photographs, and a few representative elevations were measured from RM 169 (near Fort Riley) down to the confluence with the Missouri River. High flows during this visit (10,900 – 13,100 cfs at Fort Riley) aided navigation and access to the full length of the river, but submerged many lower elevation features such as sand bars, braided channels, in-stream structures, etc. Accordingly, this assessment concentrates on bank features—erosion, accretion, angle, height, and vegetation.

3.1.2 SLA Reach 8

SLA Reach 8 extends from RM 148 to the confluence of the Smoky Hill and Republican Rivers at RM 170.4. Tall, vertical, eroding banks are common in this reach, as seen in Figure 3. 2 and Figure 3. 3. The erosion typically occurs on outside bends—though not every outside bend erodes and not every eroding bank is on the outside of a bend. Often, farmers have planted corn right up to the edge of the bank.

Figure 3. 2. An eroding, vertical bank. RM 167.8.

Figure 3. 3. An eroding, vertical bank. RM 167.5.

3.1.3 SLA Reach 7

SLA Reach 7 extends from the Willard Bridge at RM 101 to RM 148. Tall, vertical, eroding banks are very common in this reach, as well. While the outside bends tend to erode, the inside bends are depositional, as seen in Figure 3. 4.

Figure 3. 4. Bank erosion at the outside bend (A) and accretion on the inside bend (B) at RM 140.4.

A bedrock outcrop runs parallel to the channel near RM 125.6, as seen in Figure 3. 5. SLA (1984) reports that this bedrock crosses the active channel and forms a vertical control for half the active channel just upstream of Willard Bridge.

Figure 3. 5. Bedrock plane at RM 125.6.

Bank protection measures of many kinds, including hard points, dikes, and stone, slab, and "Detroit" riprap (car bodies) are present in this reach. SLA (1984) reports that most of this bank protection was installed prior to 1958. In most places, the vegetation has grown around and through the riprap, as seen in Figure 3. 6.

Figure 3. 6. Riprap on banks is overgrown with vegetation. RM 102.2.

3.1.4 SLA Reach 6

SLA Reach 6 extends from RM 76 to the Willard Bridge at RM 101. The upstream stretch of Reach 6 does not exhibit the bank erosion present in Reaches 7 and 8. Riprap, overgrown with vegetation, lines the banks (Figure 3. 7). Land accretion is common (Figure 3. 8).

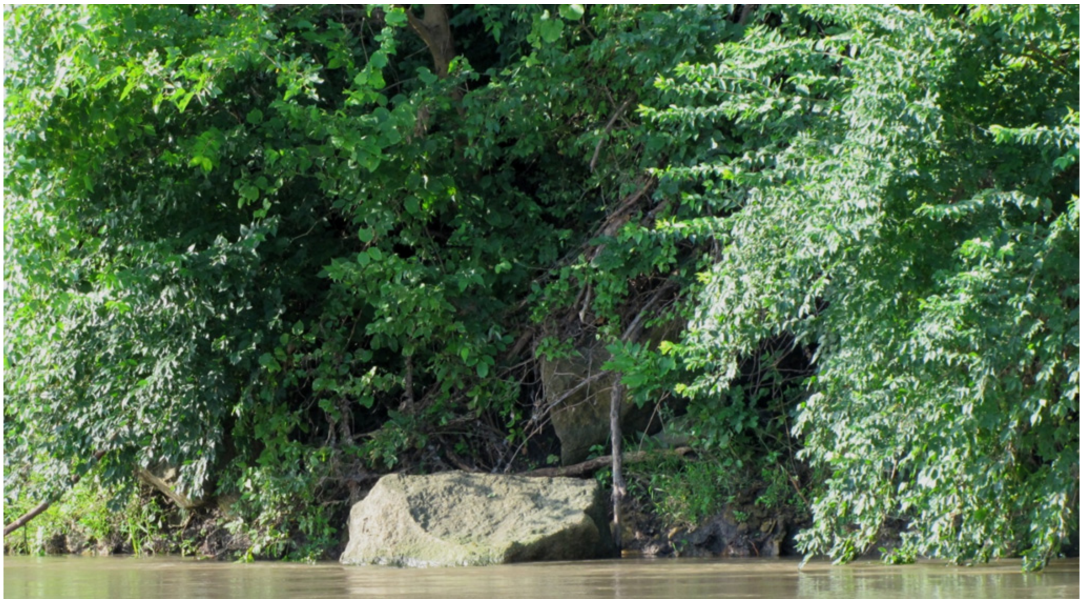

Figure 3. 7. Riprap on banks is overgrown with vegetation. RM 99.6.

Figure 3. 8. Accreted Land. RM 94.8.

The Topeka Weir at RM 87 is a substantial structure on the Kansas River. It provides sufficient depth for the Topeka water intake and serves as a grade control structure. The weir was submerged on the day of the reconnaissance with a flow of approximately 18,400 cfs.   Figure 3. 9 shows the weir with a flow of 2,080 cfs.

Figure 3. 9. The weir downstream of the Topeka water intake. Flow = 2,080 cfs.

Downstream of the weir, the channel narrows considerably, from approximately 830 ft at RM 87.4 to 490 ft at RM 87. From RM 86.5 to 85.3, the levee serves as the left river bank.

Conventional geomorphic theory would assume that an urban stream downstream from a weir with little to no floodplain and a levee for a bank would be degradational with significant bank failures. Surprisingly, this reach is highly depositional in nature. The channel has narrowed considerably from the side opposite of the levee, as seen in Figure 3. 10.

Figure 3. 10. Newly accreted land across from a levee. RM 86.3.

Shortly downstream, there is significant deposition on the levee (Figure 3. 11). This continues for a several miles.

Figure 3. 11. Deposition and land accretion adjacent to a levee. RM 85.8.

A comparison of aerial photographs from 1966 to 2008 shows overall land accretion in this area (Figure 3. 12).

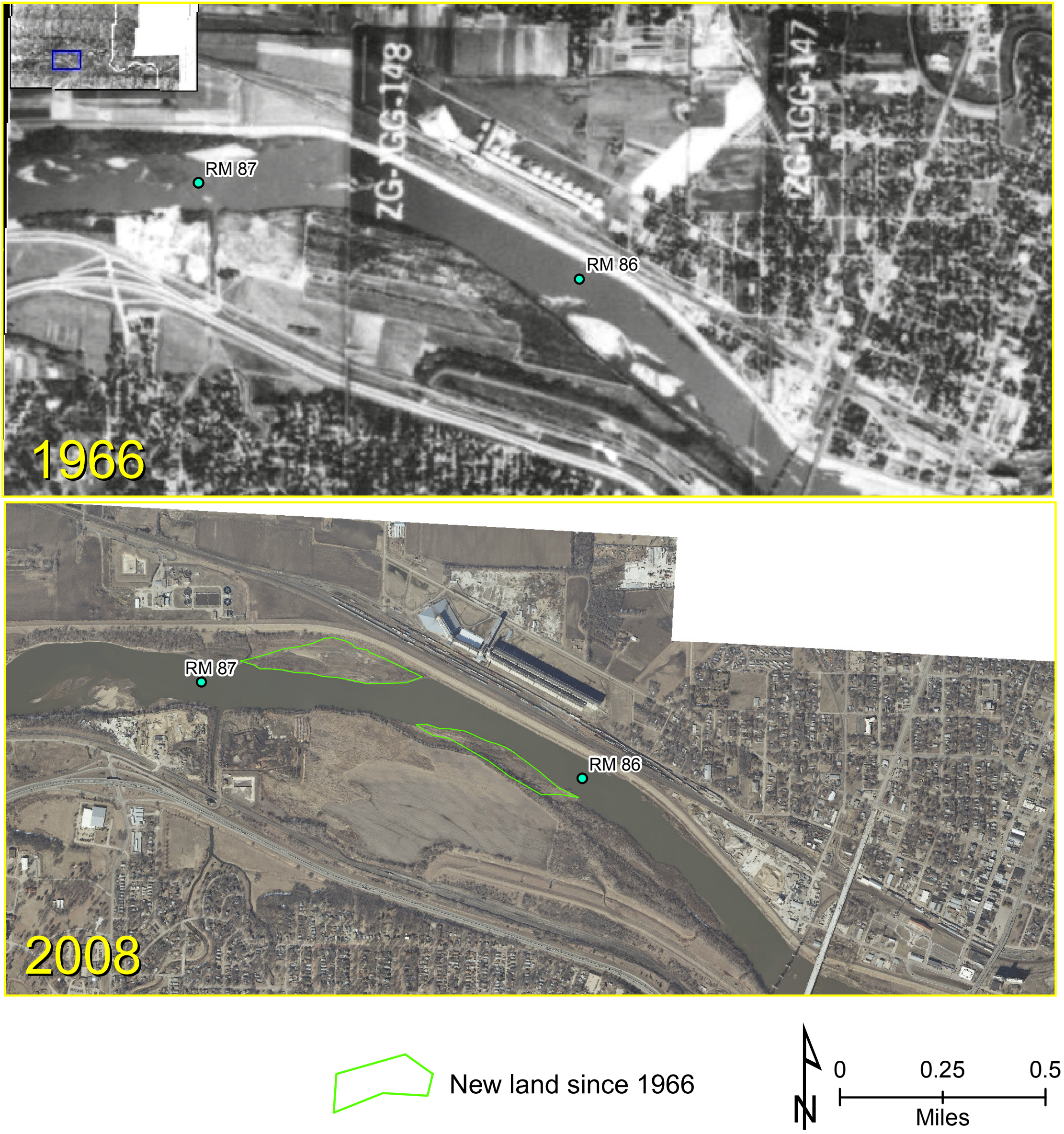

Figure 3. 12. Accretion from 1966 to 2009.

There have been four authorized dredging reaches in SLA Reach 6 during the years 1999 - 2009. As of 2009 three have been discontinued, leaving only one authorized dredging reach near Topeka. One dredge was present on the day of the reconnaissance (Figure 3. 13). There were no visible differences at the dredging site in terms of height of bank, bank erosion, or land accretion compared to adjacent reaches. Differences in bed form could not be assessed because of the high water level.

Figure 3. 13. Active dredging at RM 78.4.

3.1.5 SLA Reach 5

SLA Reach 5 runs from Bowersock Dam at RM 51.7 to RM 76. A small stretch from RM 71 to RM 74 is cutting on the outside banks and depositing on the inside banks (Figure 3. 14). Dort (2009) shows that this cutting and accreting from RM 71 to 74 has caused a slight increase in sinuosity since 1971, as shown in Figure 3. 15.

Figure 3. 14. Cutting outside bank (A) and accreting inside bank (B). RM 74.1.

Figure 3. 15. Planform Changes. RM 70-74.

From Dort (2009). Where the dark red is obscured by the light blue, the 2004 channel follows the 1975 channel.

The rest of this reach is characterized by highly vegetated, sloped banks, most of which have been stabilized by riprap. Apparently the stabilization has been highly successful; Dort (2009) shows that the planform has not changed since 1971. In most places, the rip rap has been overgrown by dense vegetation.

Bowersock Dam is a hydroelectric dam located in Lawrence at RM 51.8. The dam was completed in 1874 and has had its current configuration since 1888. The crest of the dam is 810 feet—about 20 feet above the river bed. The concrete overflow is surmounted by dozens of wicket gates which increase the head by about four feet. At low and moderate flows, this dam creates a significant backwater effect. The stabilizing effect of Bowersock Dam may further explain the stability of the reach upstream.

Bowersock Dam was submerged on the day of the reconnaissance. Figure 3. 16 shows the dam during a lower flow event. The wicket gates are lowered across the center section of the dam. The Obermeyer gates (wicket gates lowered and raised by compressed air) near the powerhouse are raised.

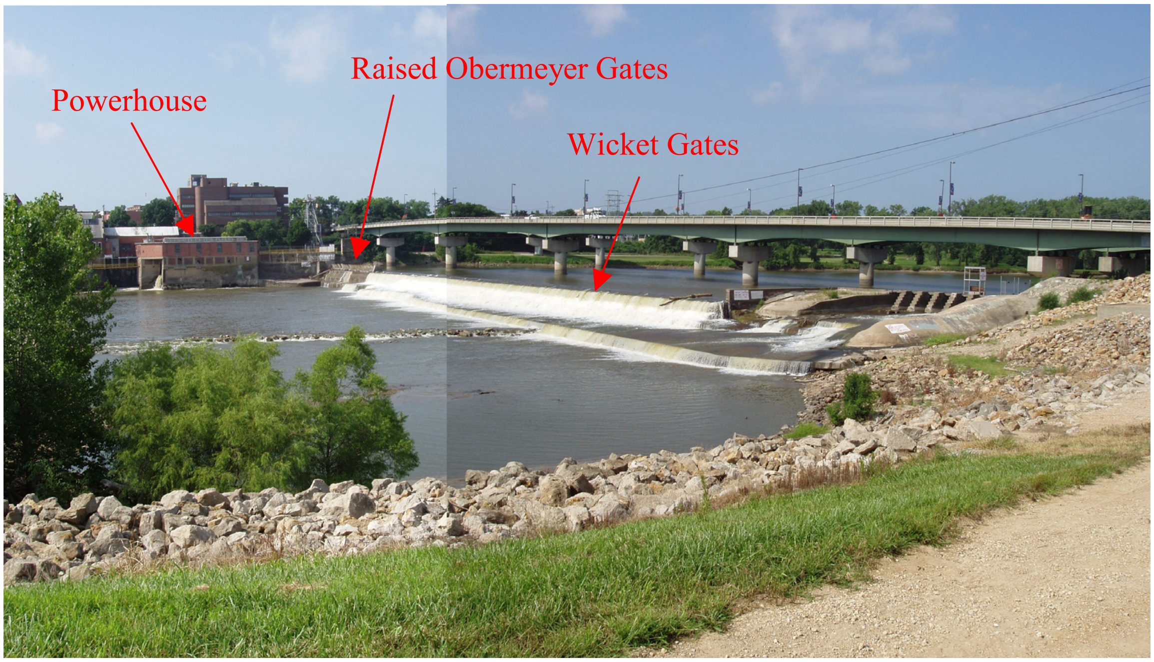

Figure 3. 16. Bowersock Dam

3.1.6 SLA Reach 4

SLA Reach 4 runs from RM 21.5 to RM Bowersock Dam at RM 51.8. Reach 4 includes 8 authorized dredging reaches. While eroding banks do occur in this reach on some outside bends, in most places, the channel is narrowing through accretion, rather than widening through bank failures, as seen in Figure 3. 17.

Figure 3. 17. Accretion on the left bank (A) and right bank (B). RM 47.6.

Bank armoring and different kinds of in-stream structures protect the bank and narrow the channel for much of this reach. A series of in-stream structures has been installed from RM 44 to 43.4, as seen in Figure 3. 18. These structures have effectively stabilized the bank. Vegetation is establishing on accreted land on the right bank.

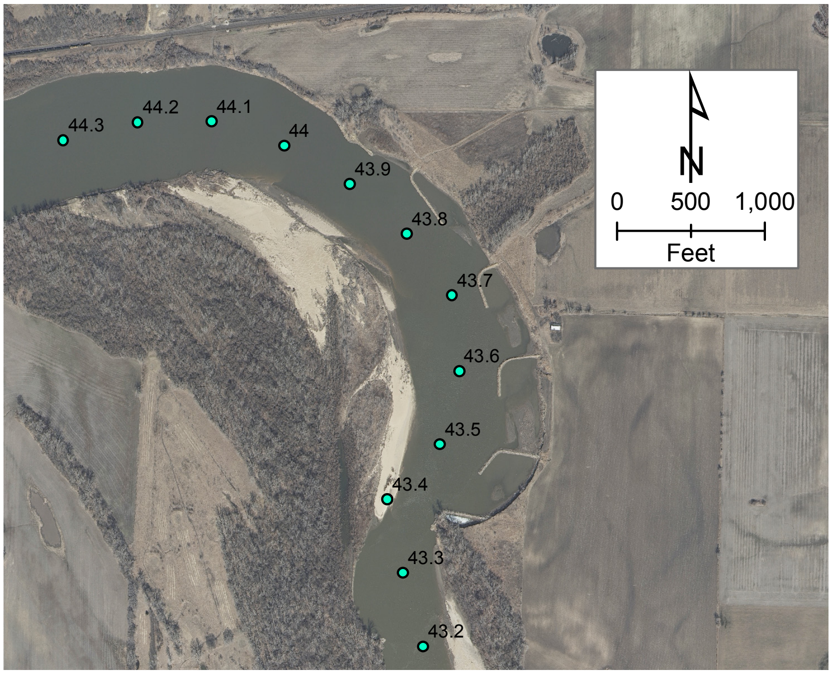

Figure 3. 18. In-stream structures protecting the left bank. The right bank is accreting. RM 43.4 to RM 44.

3.1.7 SLA Reach 3

SLA Reach 3 extends from the Johnson County Water One weir at RM 15 to RM 21.5 and includes four authorized dredging reaches. Like SLA Reach 4, this reach is mostly accretional in nature. The bank (not shown) opposite to the dredge shown in Figure 3. 19 was accreting.

Figure 3. 19. Dredge. RM 15.9.

The Johnson County Water One weir was constructed in 1967 to provide sufficient water depth to the Johnson County Water District No. 1 intake. The weir prevents downstream headcuts from migrating upstream. The weir was submerged on the day of the reconnaissance, as seen in Figure 3. 20.

Figure 3. 20. Johnson County Water One Weir.

3.1.8 SLA Reach 2

SLA Reach 2 extends from RM 12.2 to the Johnson County Water One weir at RM 15 and includes one authorized dredging reach. Shortly downstream from the Johnson County Water One weir is a very high, vertical, eroding bank (Figure 3. 21). The rest of the reach has more gently sloped, non-eroding banks. The channel downstream of the Johnson County Water One weir is noticeably narrower than upstream of the weir.

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Figure 3. 21. Vertical eroding bank just downstream of the Johnson County Water One Weir.

3.1.9 SLA Reach 1

SLA Reach 1 consists of the most downstream 12.2 miles of the Kansas River. The river is very narrow and has no floodplain throughout this reach. In many places, low, vegetated banks have formed on the inside of riprap embankments and floodwalls (Figure 3. 22). Backwater from the Missouri River controls the hydraulics of this reach.

Figure 3. 22. Land accretion inside of a riprap embankment

3.1.10 Qualitative Assessment—Summary

This qualitative assessment of the Kansas River was based primarily on the field reconnaissance performed during a high-flow period. It focused on bank features—erosion, accretion, angle, height, and vegetation. The many sand bars and other bed features of a braided channel were completely submerged on the days of the survey. The extensive rip rap armoring placed over much of the length of the river prior to 1958 (SLA, 1984) has since been overgrown by woody riparian vegetation. The vegetation and the rip rap work in concert to preserve sloping banks and to stabilize the planform along much of the river. Areas with high, vertical banks and obvious erosion lacked such stabilization. Some of these high, vertical banks had riparian vegetation on top that apparently had an insufficient strengthening influence on the toe of the bank to prevent erosion and bank failure. Many of the high, eroding banks occur adjacent to agricultural land, with the crops planted right up to and literally falling off the river's edge. The dredging reaches did not have higher, steeper, or more erosive banks. For the most part, they appeared to be actively accreting land. Changes in bed elevations could not be assessed qualitatively, but will be addressed quantitatively in Section 3.3.

3.2 Stage-Discharge Relationships

Water surface elevations and associated discharges have been measured and recorded at five USGS gages on the Kansas River. Changes in the stage-discharge relationship over time can be indicative of geomorphic changes (Juracek and Fitzpatrick, 2009). A decrease in the stage-discharge relationship indicates that the channel conveys the same discharge at a lower elevation and is often assumed to correspond to a drop in the channel bed. Conversely, an increase in the stage-discharge relationship is assumed to indicate bed aggradation. While the abundance of stage-discharge data makes analyses of this type convenient and useful, the results are limited for two reasons.

First, while a drop in the stage for a given discharge could be caused by bed degradation, it could also be caused by a decrease in the flow depth or increase in velocity (resulting in a decrease in cross-sectional area) with no drop in bed elevation. Additional gage analysis presented in Appendix B shows that the flow area and flow top width rating curves have not changed appreciably since 1960. This suggests that stage degradation on the Kansas River does in fact indicate bed degradation and not a decrease in flow depth.

Second, the long temporal record of USGS gages does not imply spatial applicability. The gage reflects hydraulic conditions (and by inference, geomorphic conditions) at a single location. A stage drop at the gage may indeed indicate a bed drop in the vicinity of the gage, but it does not necessarily reflect conditions ten miles upstream or downstream from the gage. Data from multiple gages should be used in conjunction with other geomorphic measurements.

3.2.1 Fort Riley

Figure 3. 23 presents the stage-discharge measurements for the Kansas River at Fort Riley. As changes in the stage-discharge rating relationship are most easily seen at lower flows, only measurements up to 10,000 cfs have been plotted. As seen, the stage-discharge relationship dropped approximately 3 ft from 1960 – 2005. The downward shift appears to have occurred in response to the 1973 flood, 1987 high water (affects low flows only), and 1993 flood. Outside of these events, no degradational trend is evident. The slight rise in the stage-discharge relationship since 1995 may represent a new aggradational trend or may simply be an oscillation about a new equilibrium established by the 1993 flood. The USGS data from year 1995 to 2001 appeared to be corrupted and was left out of this analysis. The gage was moved to a new location in 2005. There is not enough data at the new location to analyze a possible trend.

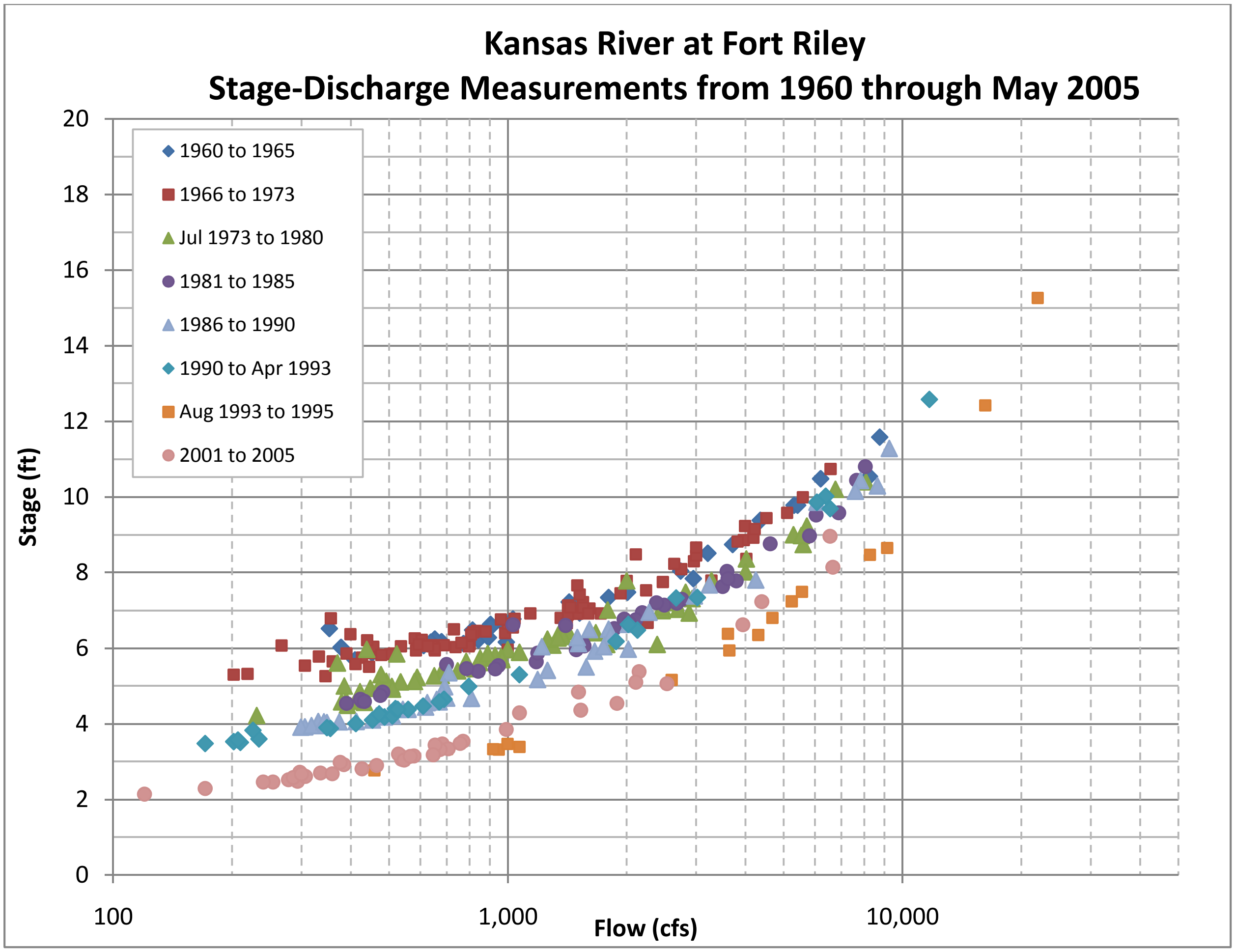


Figure 3. 23 Stage-discharge measurements for the Kansas River at Fort Riley

A third order polynomial trend line was fitted through the data for each time period to produce a single "best-estimate" value for a given flow and time period. Figure 3. 24 uses the "best-estimate" values from the trend lines to show how the stage for various discharges has changed with time. The middle year of each time period is used for the x-axis data point. As seen, the majority of the degradation occurred during the 1993 event.

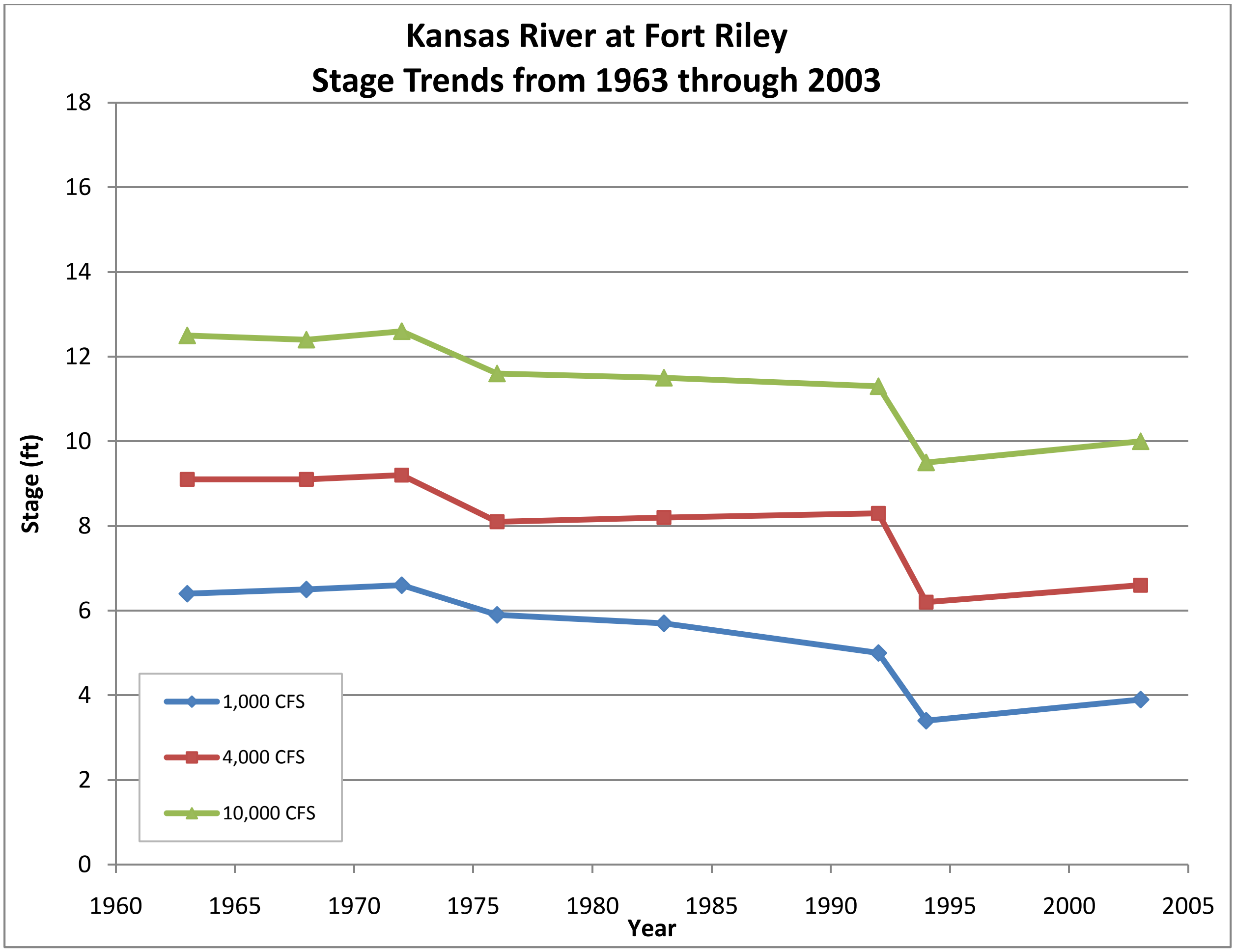


Figure 3. 24 Change in stage with time at Fort Riley

3.2.2 Wamego

Figure 3. 25 presents the stage-discharge measurements for the Kansas River at Wamego, divided into 5-year increments. There is a slight downward trend from 1961 to 1993, resulting in a drop of 0.5 ft. This could also be interpreted as the normal oscillations of a sand-bed river. The flood of 1993 causes a drop of 1 ft, but the stage-discharge relationship rebounds, quickly returning to its pre-1993 flood levels. There is no apparent trend since 2001.

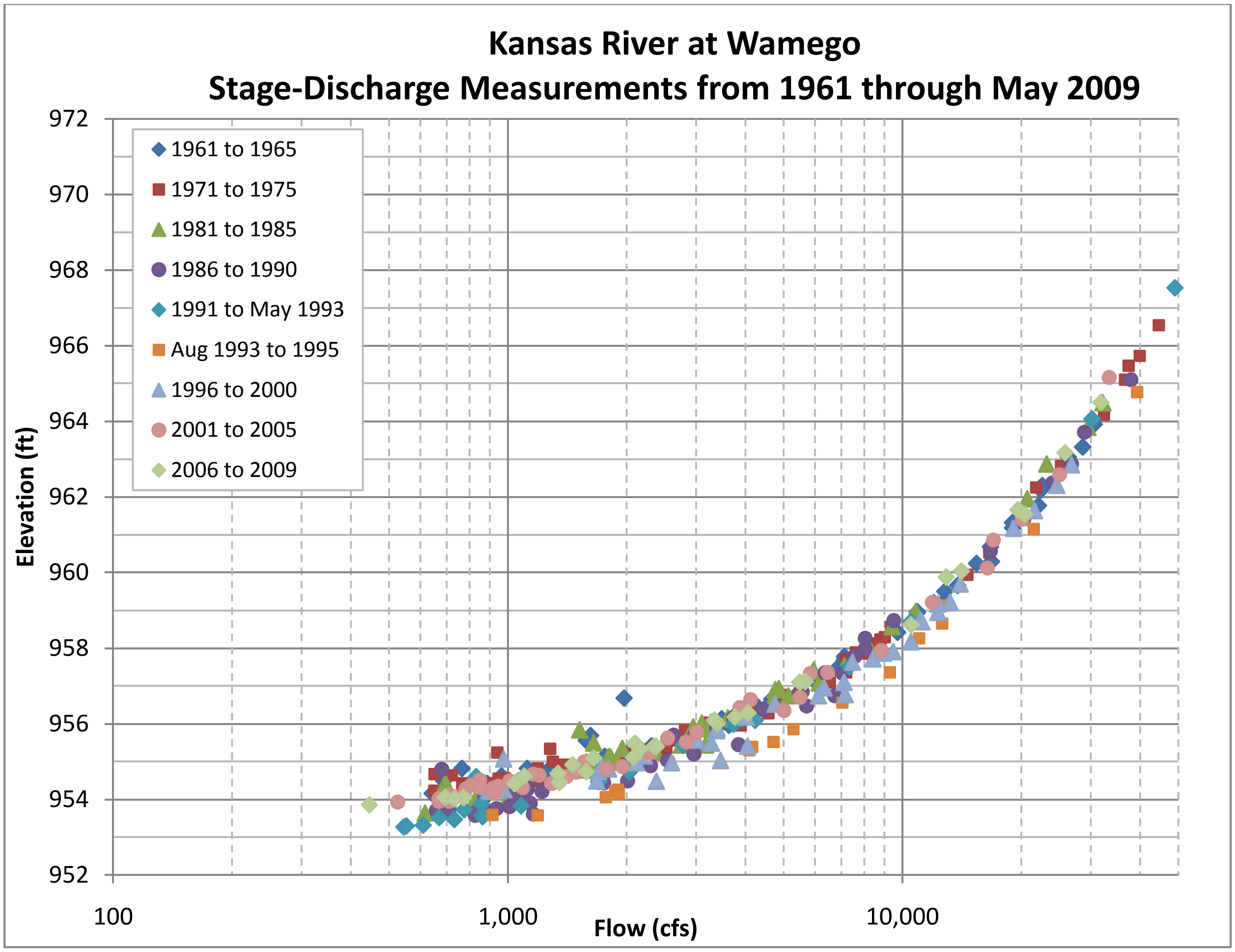


Figure 3. 25. Stage-discharge measurements for the Kansas River at Wamego

Figure 3. 26 shows the change in stage with time from 1921 to the present. As seen, the stage has completely recovered to pre-1993 levels, but has not rebounded to pre-1951 levels.

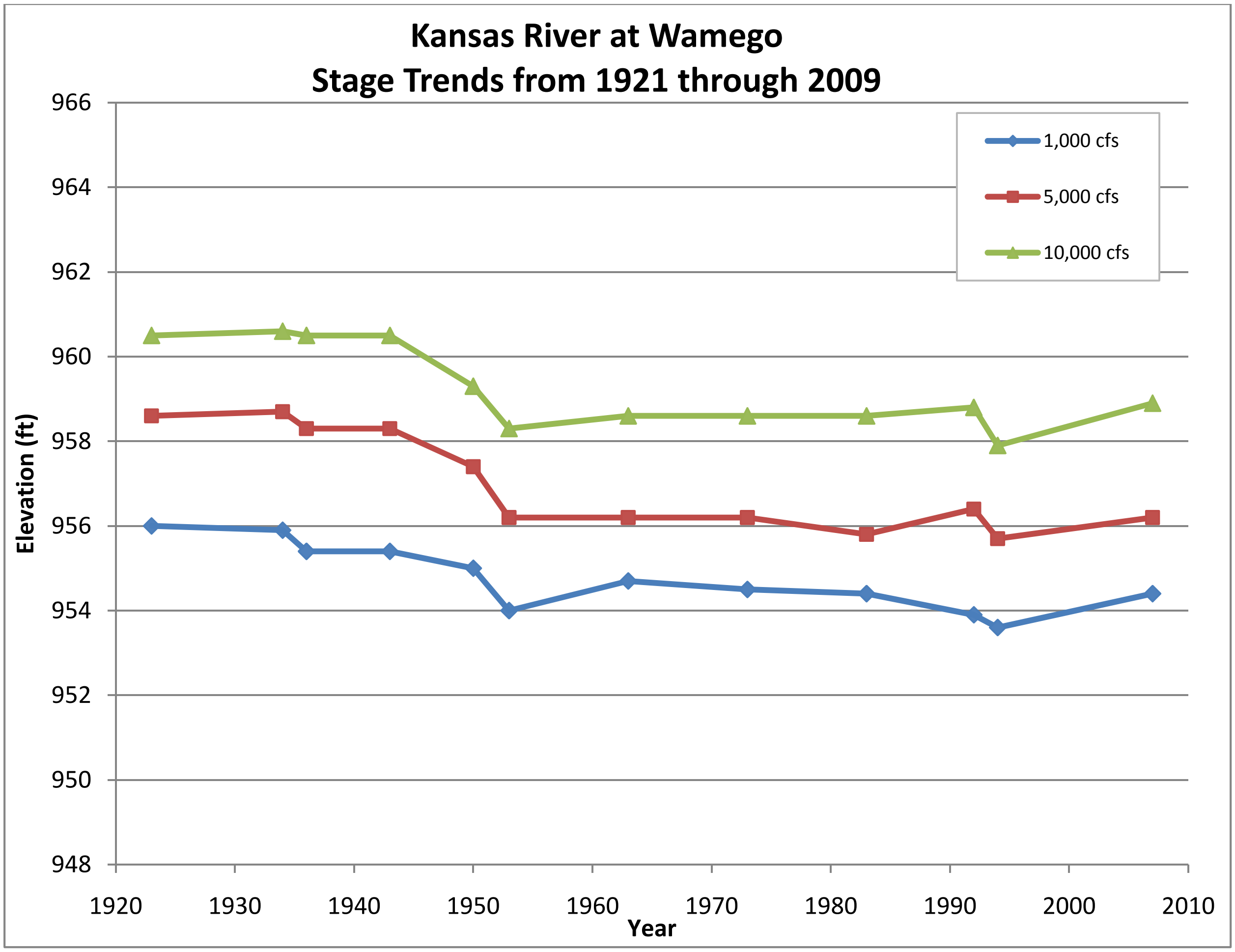


Figure 3. 26. Change in stage with time at Wamego

3.2.3 Topeka

Figure 3. 27 presents the stage-discharge measurements for the Kansas River at Topeka. Because of the abundance of data, 3-year increments were possible. As seen in Figure 3. 28, the stage has steadily decreased approximately 3 ft since 1961. The 1993 and 2007 floods do not appear to have influenced the stage-discharge relationship at Topeka.

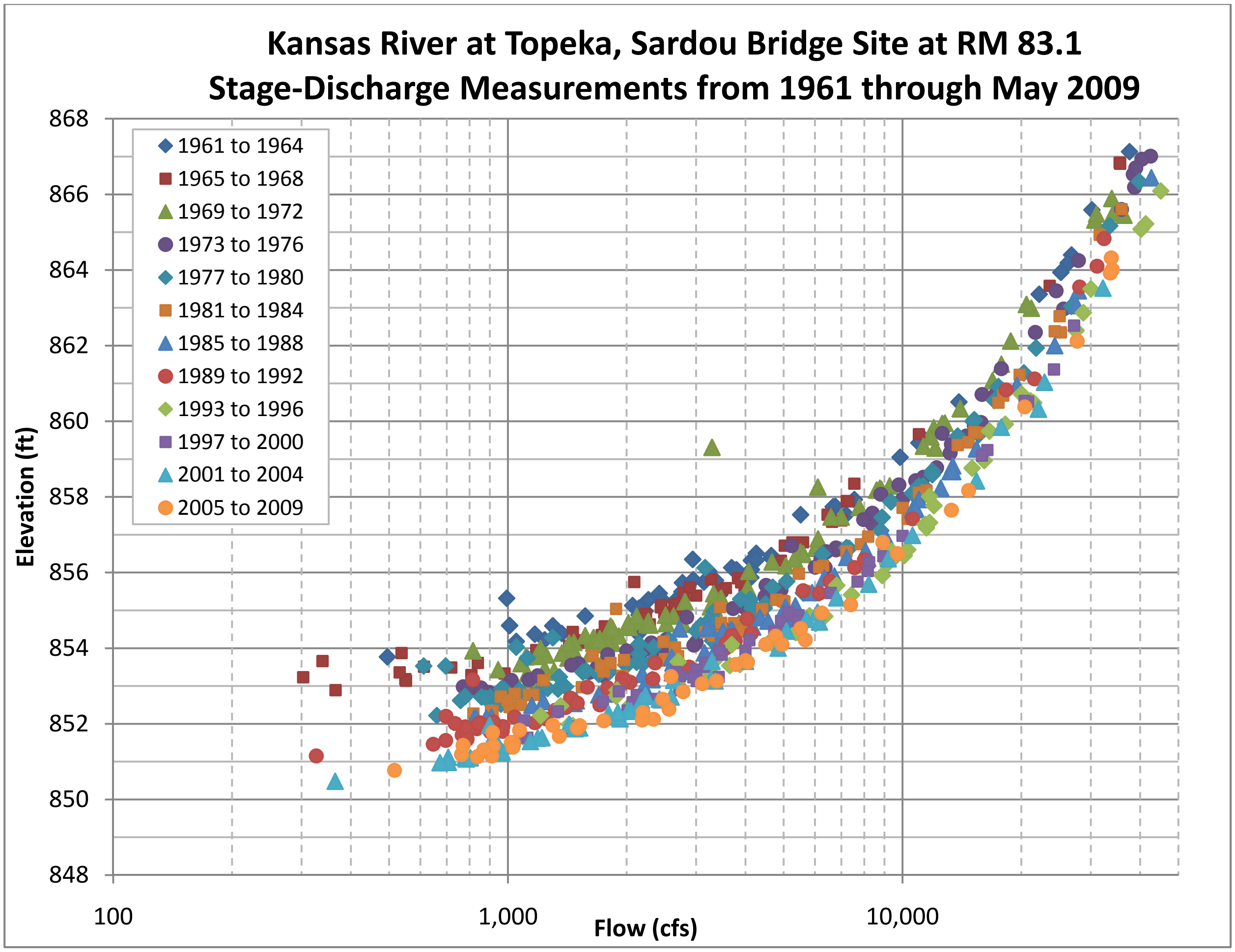


Figure 3. 27. Stage-discharge measurements for the Kansas River at Topeka

Figure 3. 28 shows the change in stage with time from 1961 to the present. The decrease in stage is gradual, making it is difficult to determine whether the stage is still dropping or has stabilized.

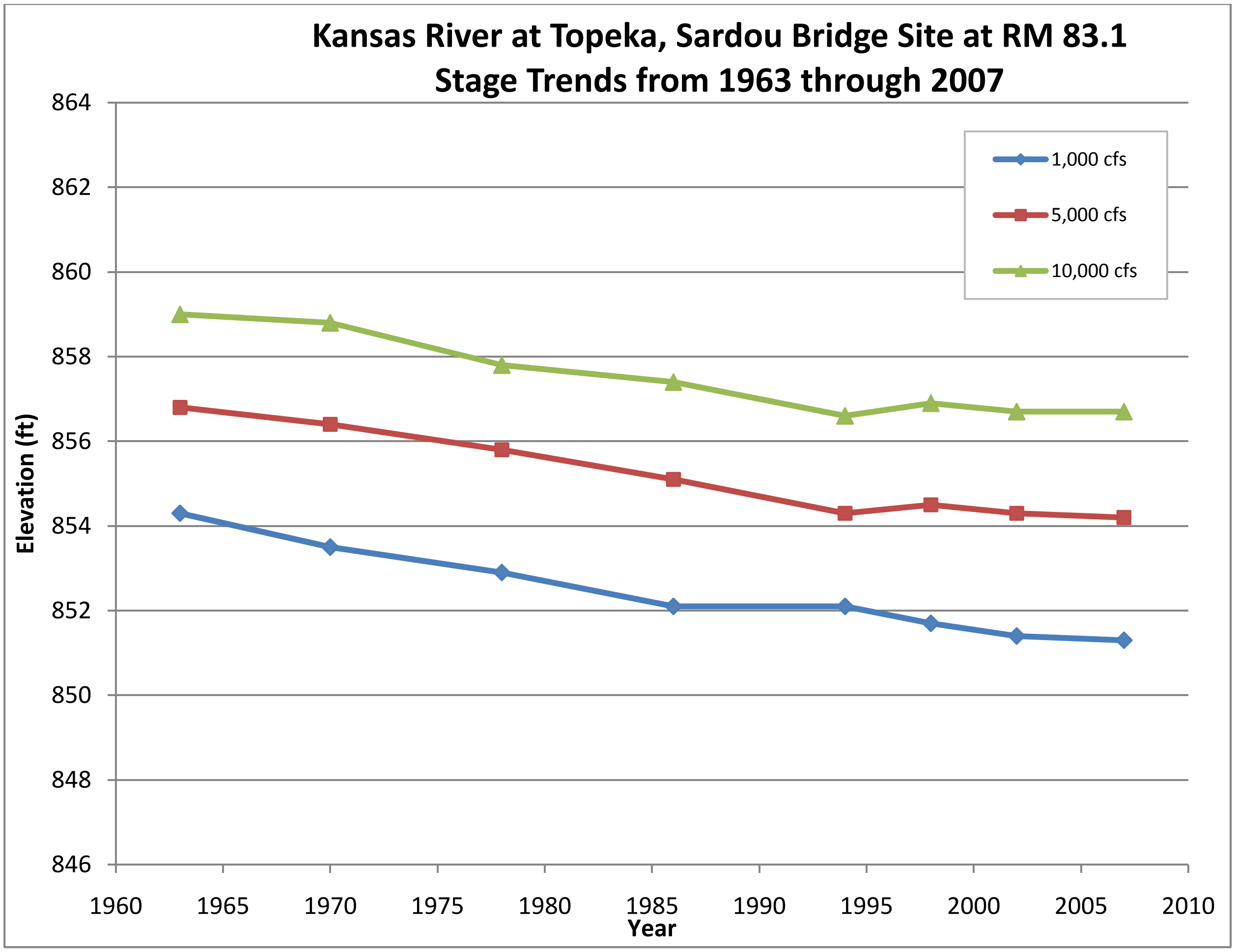


Figure 3. 28. Change in stage with time at Topeka

3.2.4 Lecompton

Figure 3. 29 presents the stage-discharge measurements for the Kansas River at Lecompton. The plot shows random oscillations, but no stage trend and no effect from the floods of 1993 or 2007. Similarly, Figure 3. 30 shows no trend in stage with time.

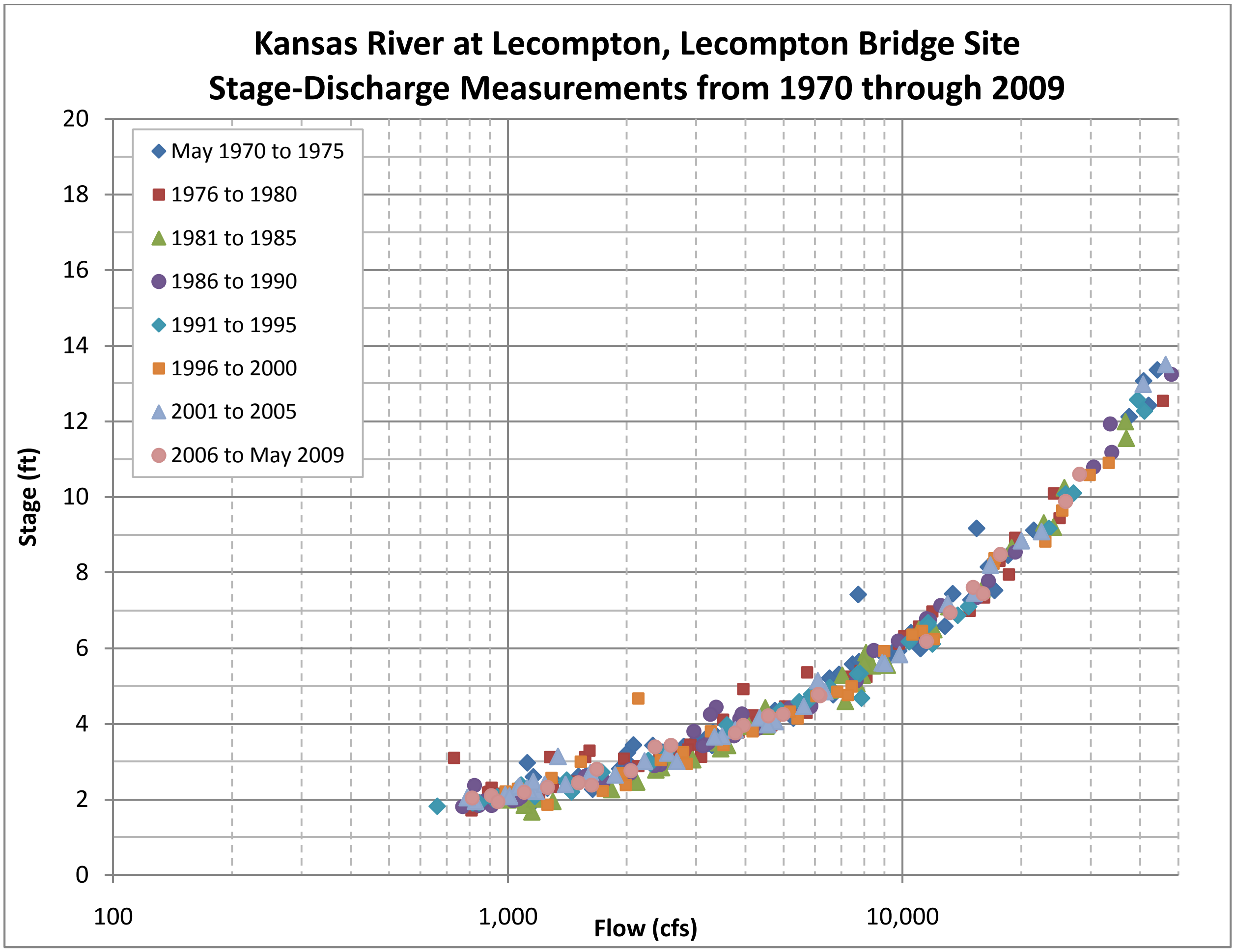


Figure 3. 29.Stage-discharge measurements for the Kansas River at Lecompton

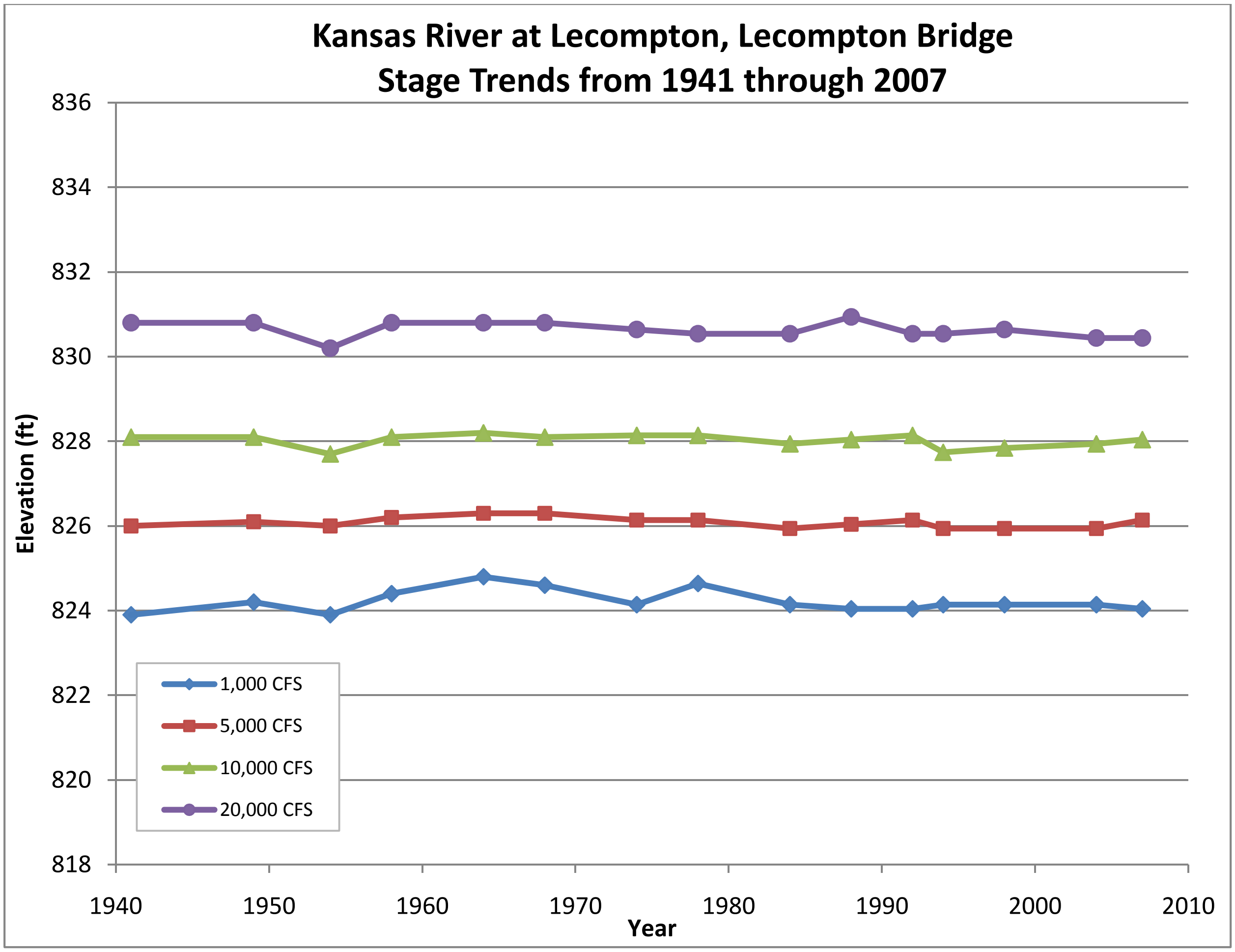


Figure 3. 30. Change in stage with time at Lecompton

3.2.5 Desoto

Figure 3. 31 presents the stage-discharge measurements for the Kansas River at Desoto. The plot shows a steady decrease in stage from 1972-1993 (pre-flood) totaling 2 ft. The flood of 1993 resulted in a rapid 1 – 1.5 ft drop in stage. An additional 1 ft decrease occurs from 1993 to 2000. There has been no significant change in stage since 2000. Figure 3. 32 shows how the stage has changed with time.

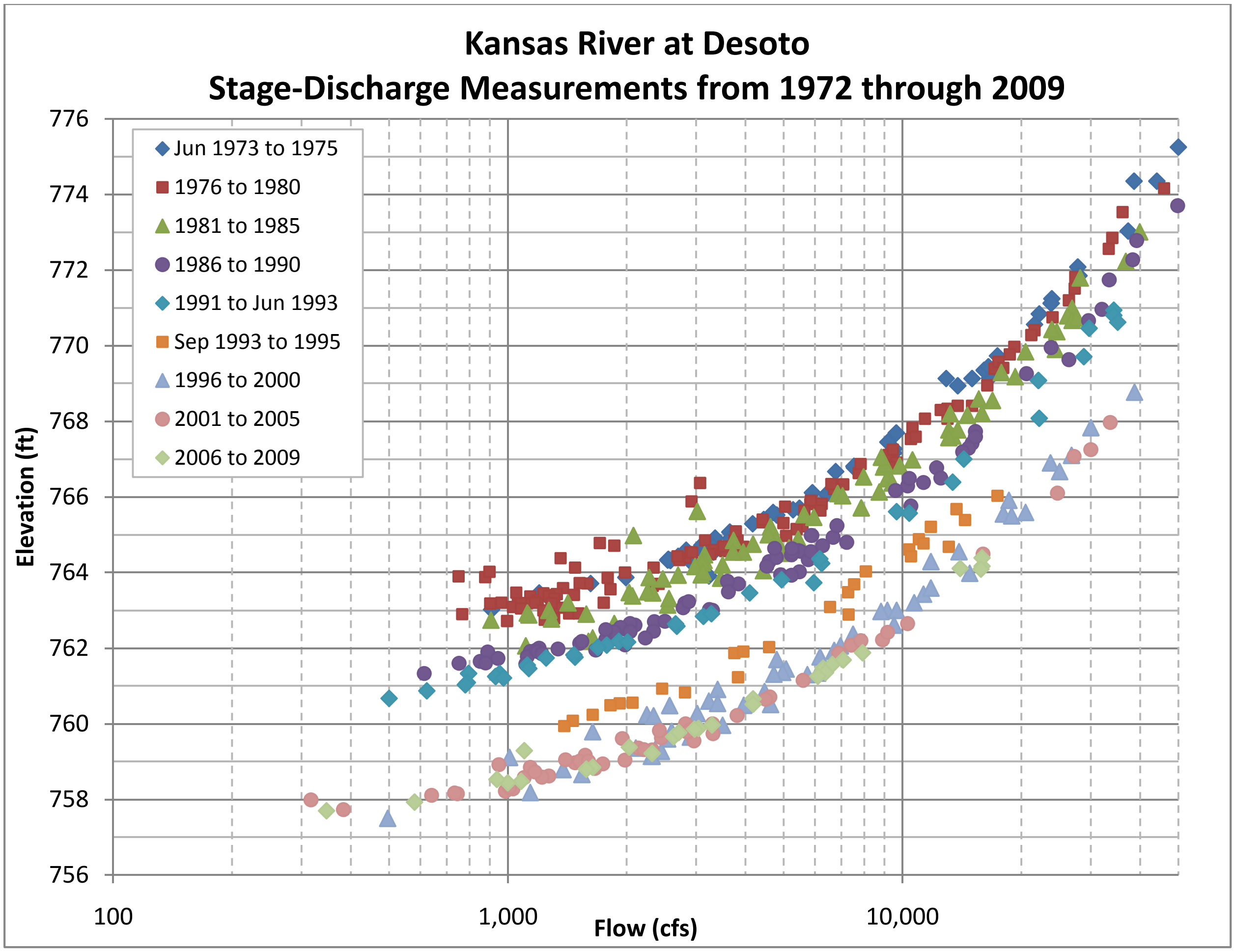


Figure 3. 31. Stage-discharge measurements for the Kansas River at Desoto

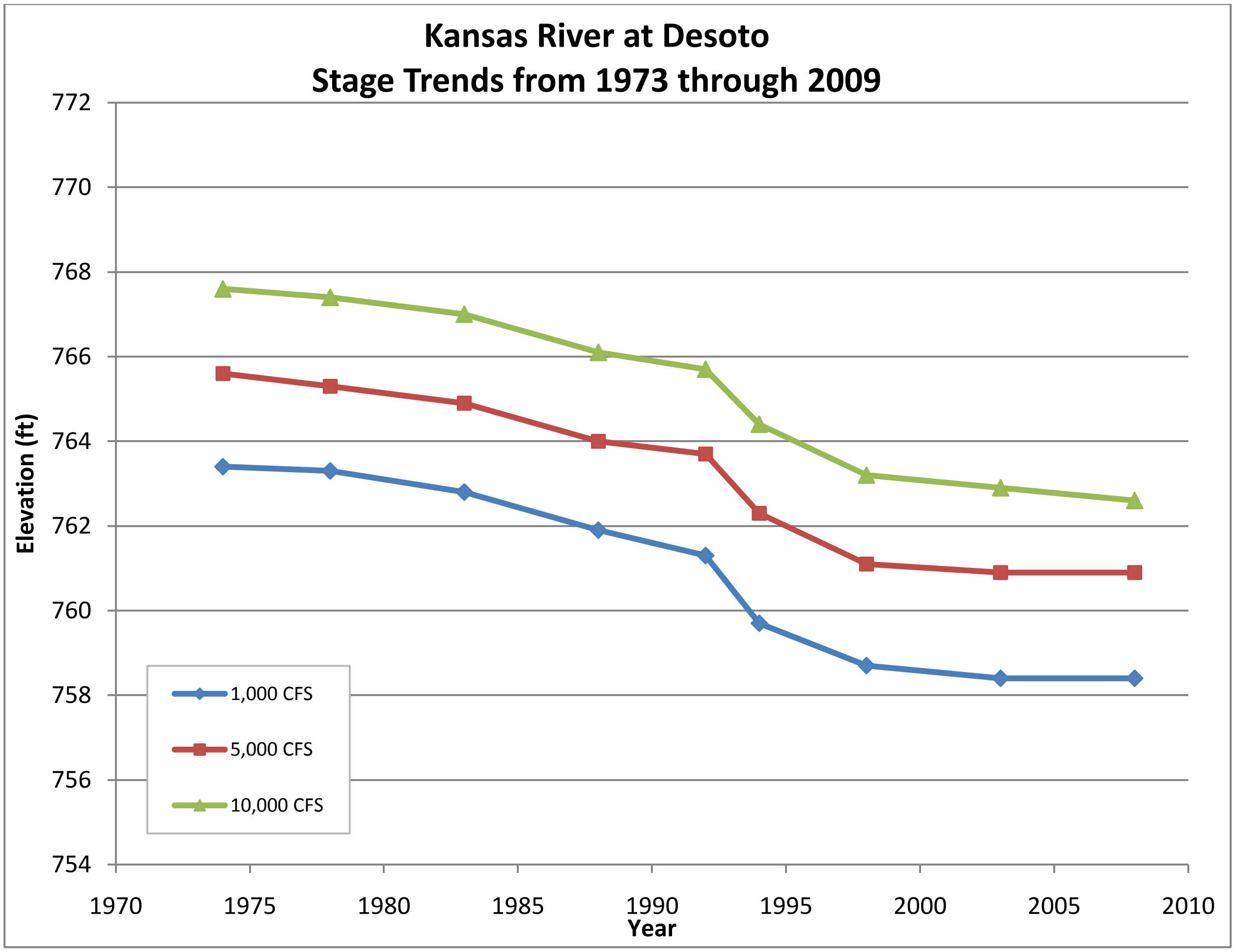


Figure 3. 32. Change in stage with time at Desoto

3.2.6 Tributary Analysis

Appendix A provides flow volume and stage-discharge analysis for several tributaries to the Kansas River.

3.2.7 Stage-discharge Analysis Summary

Table 3. 1 summarizes the results of this analysis. Notably, the decreasing trend which had been apparent in at many of the gages has not continued from 2000 – 2009.

Table 3. 1. Summary of stage-discharge analysis

River Mile	SLA Reach	Gage	Stage discharge rating curve since 1984	Effect of 1993 flood	Effect of 2007 flood
169	8	Fort Riley	Decrease in stage resulting from floods. No trend during non-flood events.	1.5-2 ft decrease in stage.	Insufficient data. (Gage relocated in 2005.)
127	7	Wamego	Slight stage decrease following 1993 flood has been regained. No current trend.	Temporary decrease in stage of approximately 0.5 ft.	No effect
83.1	7	Topeka	1 ft drop in stage since 1984. Possible continued degradation.	No appreciable change	No effect
63.8	6	Lecompton	No trend	No effect	No effect
31.1	4	Desoto	Decreasing trend has apparently stopped. 3.5-4 ft drop from 1985 - 2000. No change from 2000-2009.	1-1.5 ft decrease in stage	No effect

3.3 Cross-Sectional Changes

For many years, the Kansas Water Office and the Army Corps of Engineers have collected cross-sections at strategic locations along the Kansas River. In 1992, 1995, and every two years thereafter until 2009, a consistent set of 100 - 130 cross-sections have been re-surveyed for the primary purpose of monitoring dredging impacts. The cross-sections span river miles 9 – 51 (SLA Reaches 2,3, and 4), and 72 – 96 (SLA Reach 6). No cross-sections are available for RM 51 – 72 (SLA Reach 5) or upstream of RM 96 (SLA Reaches 7 and 8). This provides an excellent dataset for analysis of recent changes in cross-sectional parameters and bed profiles for SLA Reaches 2, 3, 4, and 6. By comparing subsequent years, the changes in width and average bed depth can be calculated at the location of each cross-section.

These parameters are reported with respect to a baseline water surface elevation at each cross-section. The baseline elevations were somewhat arbitrarily chosen, but are in the general range of the 2-year flow water surface elevation. Several consecutive cross-sections will share the same baseline water surface elevation, and the elevations are not based on geomorphic features. *Changes* in bed elevation and width are therefore more important than absolute depth or width values.

The sections that follow report changes in bed elevation and width. Appendix C provides cross-sectional plots for multiple years at specific locations.

3.3.1 Average Bed Elevation

The bed in a sand-bed river is constantly fluctuating. Bed forms such as dunes may be present at a given river mile one year and absent the following year, giving the appearance of significant bed degradation. For this reason, multiple years must be examined to determine if bed-elevation changes represent actual trends or simply reflect the temporal and spatial variability inherent in sand-bed streams.

These cross-sections yield two readily available options for channel depth. The first option is based on the average bed elevation, calculated as the baseline elevation minus the hydraulic depth (cross-sectional area / top width). This provides a measure of what the entire bed is doing and is perhaps more appropriate when a limited number of cross-sections are available. The second option is based on the channel thalweg. These measurements reflect the formation of low-flow channels and are usually more variable than average bed measurements. An example of these measurements is shown in Figure 3. 33. In this report, the average bed elevation is used.

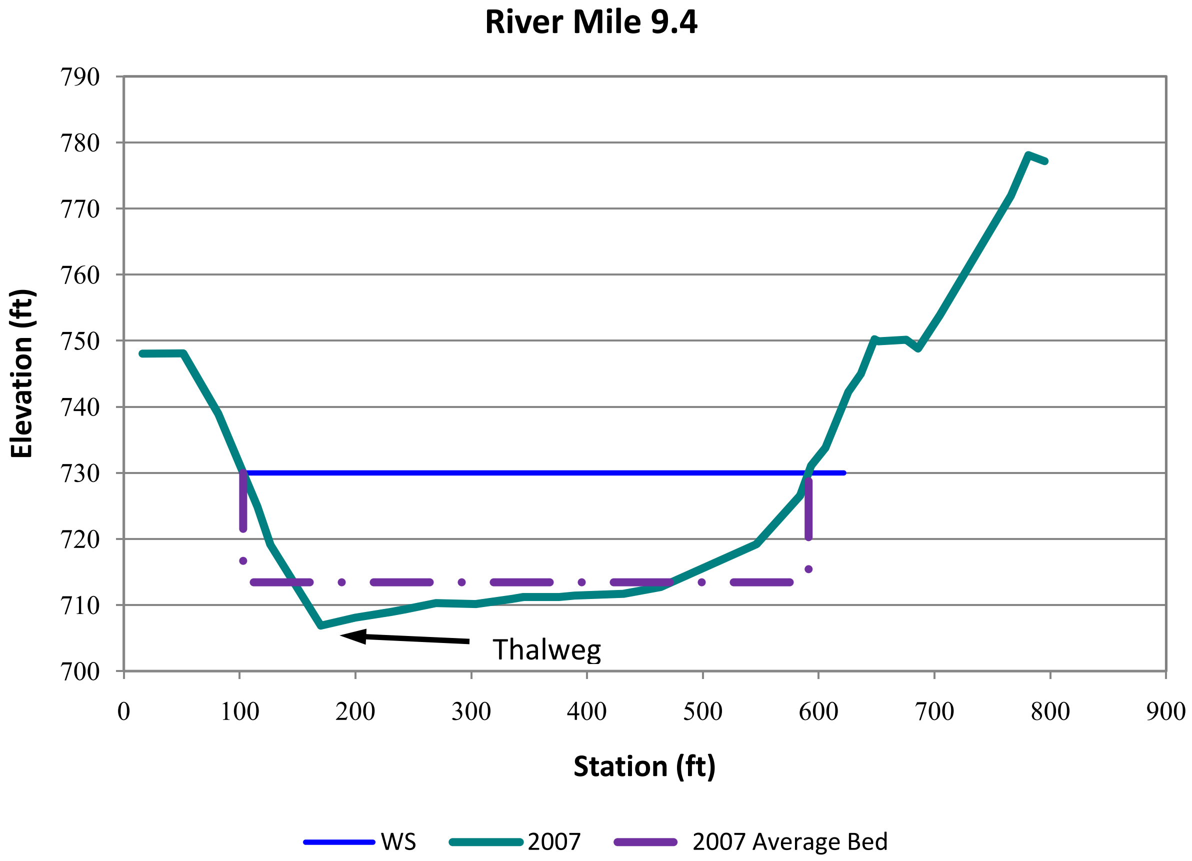


Figure 3. 33. Average bed elevation at river mile 9.4

Figure 3. 34 shows the change in average bed elevation from survey to survey. At many cross-sections, the river oscillates between aggradation and degradation. This could be due to a passing sand dune that is present one year but absent a subsequent year. Figure 3. 34 also suggests that the more extreme changes in elevation have become less pronounced with time. For consistency Figure 3. 34 only includes cross-sections that were surveyed every survey year (1992, 1995, 1997, 1999, 2001, 2003, 2005, 2007, and 2009). The maximum degradation oscillates, but is lessening in magnitude with time.

To assess overall degradation or aggradation, average elevation changes over 1 mile segments were calculated. (Example: The bed change at the two cross-sections between RM 12 and 13 are 1.63 ft (RM 12.1) and 0.42 ft (12.6). The bed change for RM 12 to 13 is (1.63 + 0.42)/2 = 1.03 ft.) These one-mile reaches were grouped into SLA reaches and plotted in Figure 3. 35.

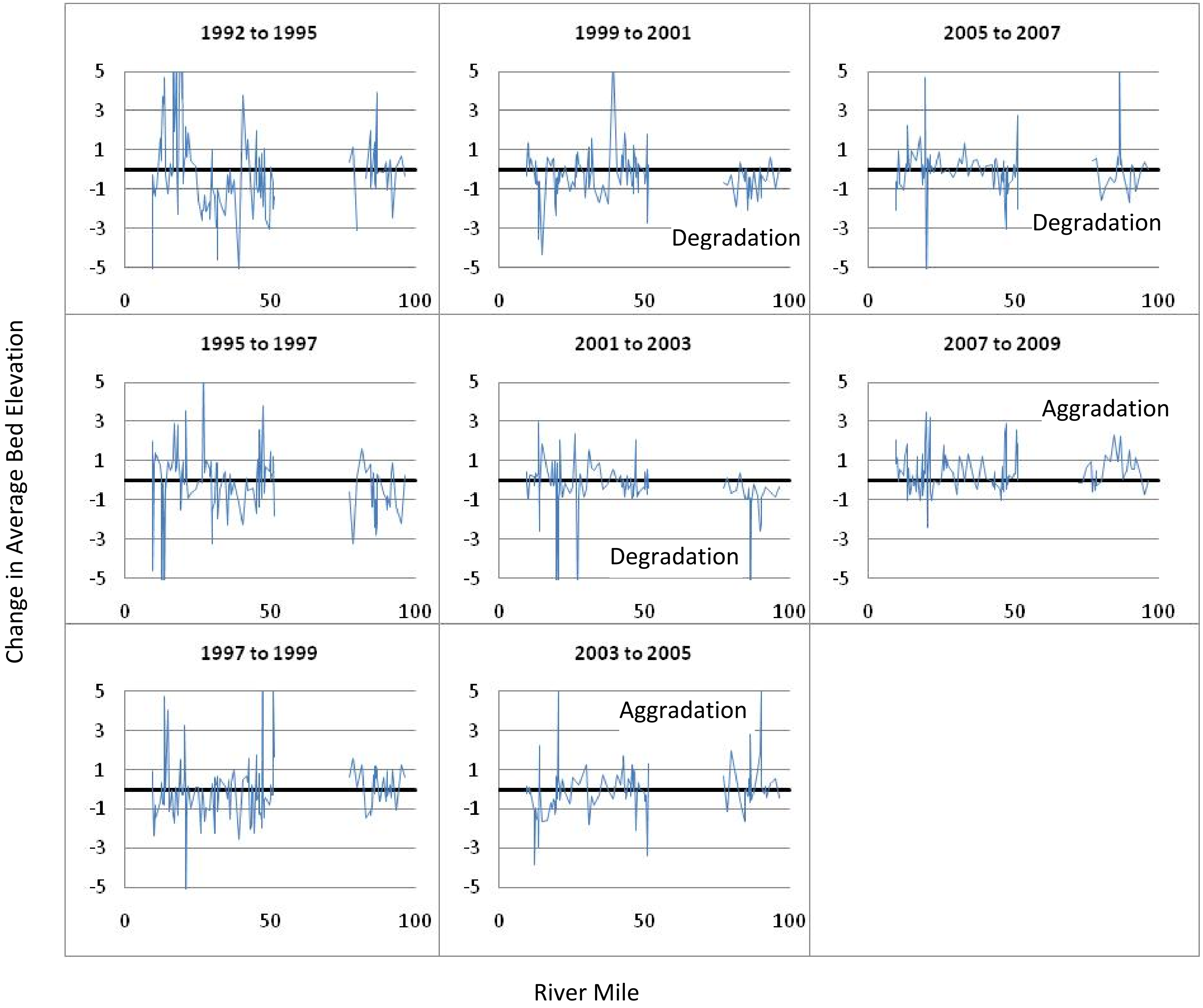


Figure 3. 34. Regular changes in average bed elevation. The periodic nature of aggradation and degradation is easily seen in the cross-sections at River Miles 77 to 97.

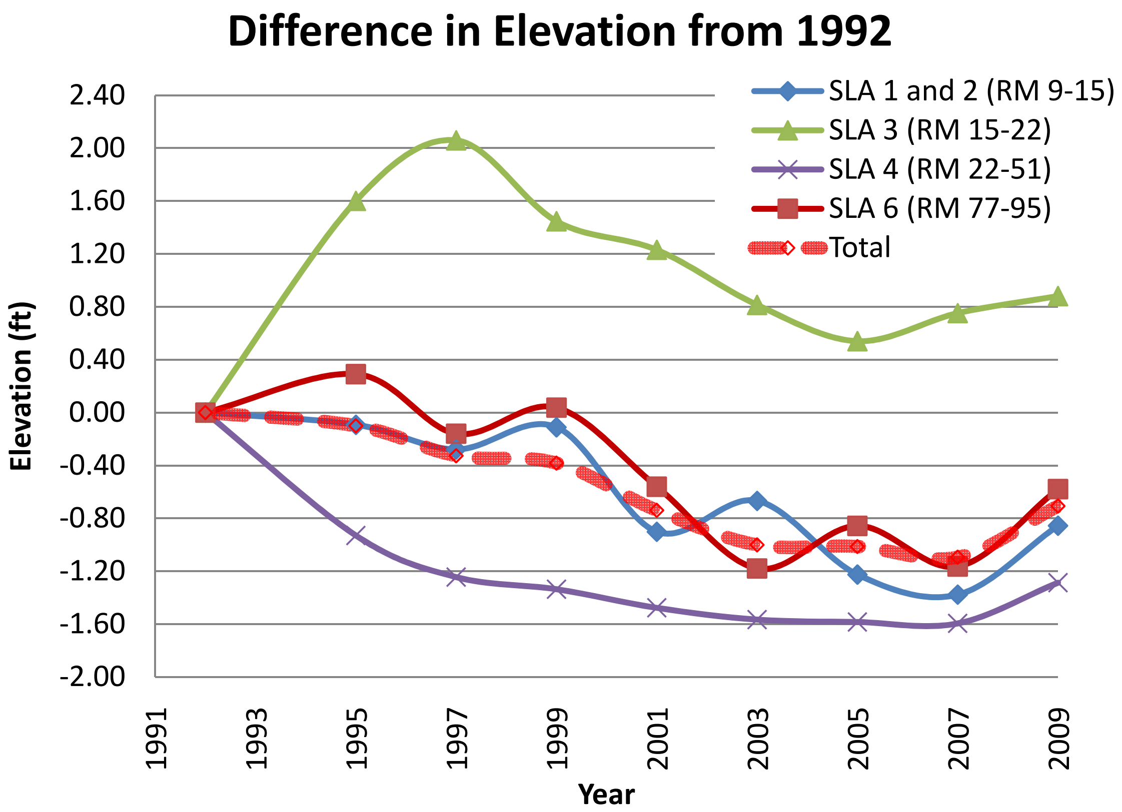
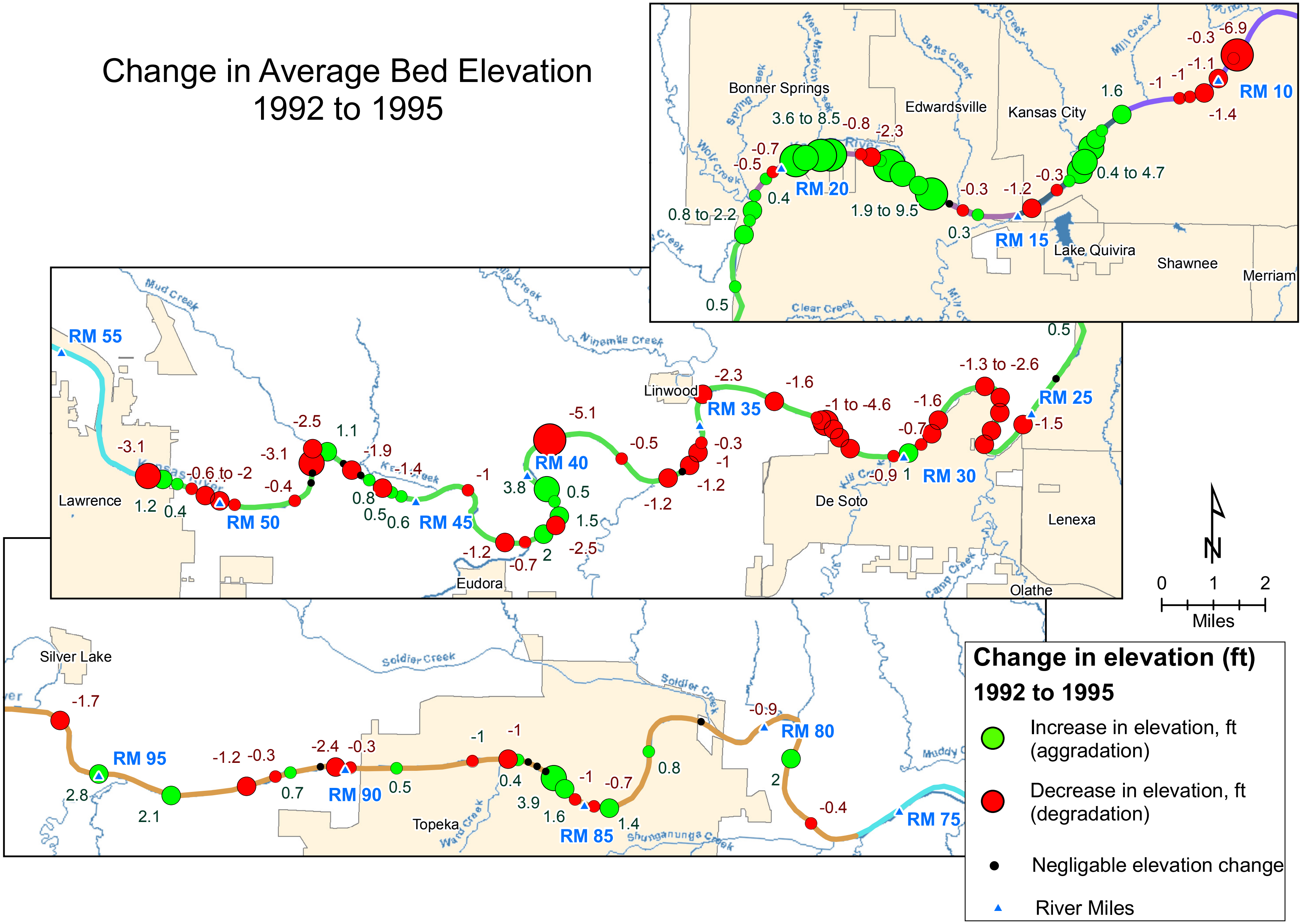


Figure 3. 35. Elevation changes with time

SLA Reaches 1 and 2 experienced very slight degradation as a result of the 1993 flood and continued degrading until 2001. After 2001, the bed has been oscillating between aggradation and degradation. SLA Reach 3 experienced significant aggradation during the 1993 flood. Reach 3 continued to aggrade until 1997, when it began to degrade. It degraded until 2005, when it began to rebound. As of 2009, the elevations in Reach 3 had returned to 2003 levels. SLA Reach 4 experienced 1 ft of degradation as a result of the 1993 flood. The degradation rate slowed significantly after the flood. Reach 4 saw no appreciable bed change (on average) 2003 – 2007, and rebounded in 2009 to 1997 levels. SLA Reach 6 aggraded slightly as a result of the 1993 flood, then degraded until 2003, when it began oscillating between degradation and aggradation. When all 1-miles segments are averaged together, there was no immediate effect from the 1993 flood, steady degradation until 2003, then oscillations and a rebound to 2001 levels.

At individual locations, degradation and aggradation are more pronounced and sustained. Figure 3. 36 shows the locations and magnitude of change in average bed elevation from 1992 to 1995, which includes the effect of the 1993 flood. Figure 3. 37 shows the change in elevation from 1995-2009. These figures include all cross-sections that were surveyed in both the starting and ending year (1992 and 1995 or 1995 and 2009, respectively).


Change in Average Bed Elevation
1992 to 1995

Change in elevation (ft)
1992 to 1995

🟩	Increase in elevation, ft (aggradation)
🟥	Decrease in elevation, ft (degradation)
●	Negligable elevation change
▲	River Miles

Figure 3. 36. Change in average bed elevation 1992 to 1995

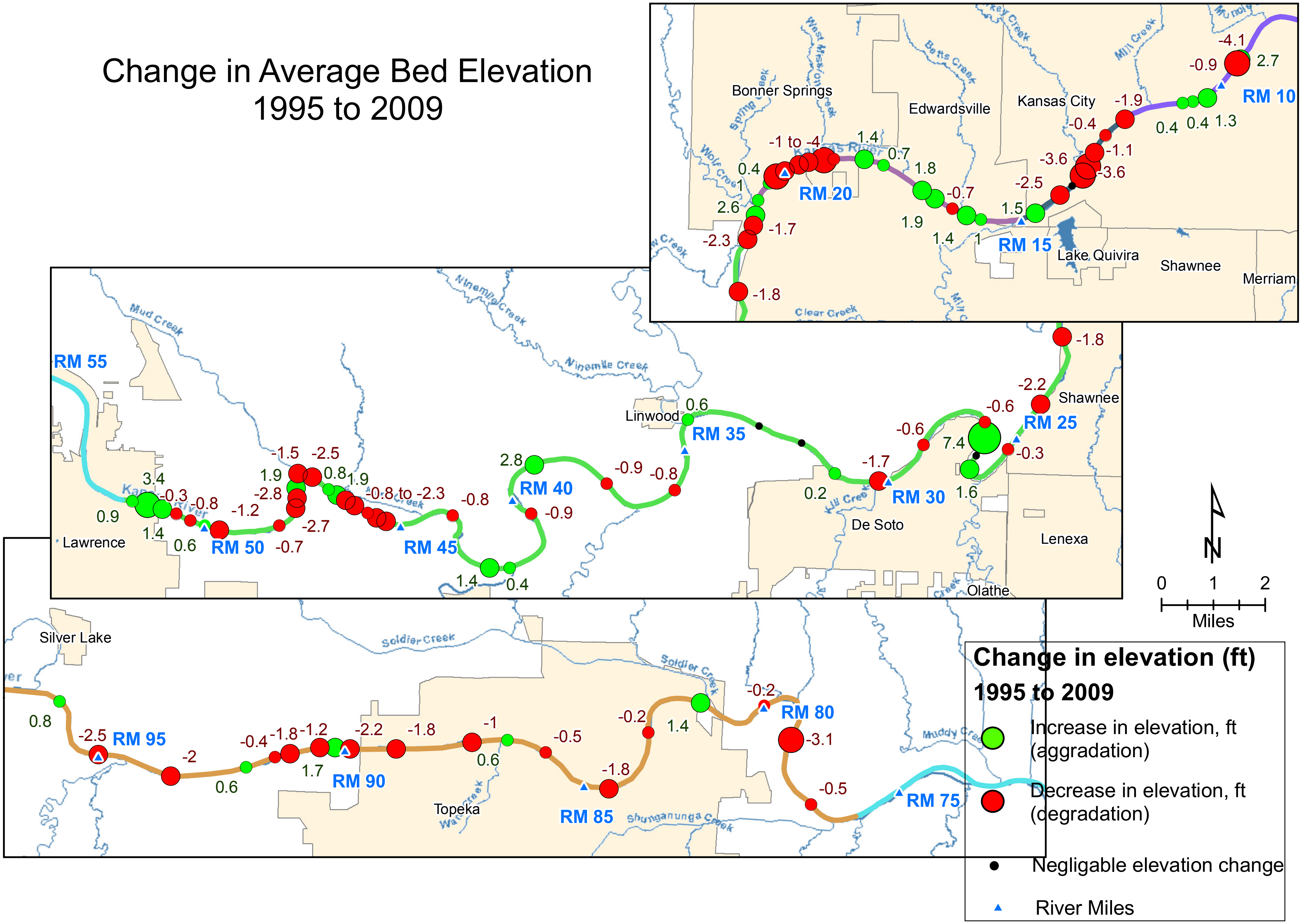


Figure 3. 37. Change in average bed elevation 1995-2009

Figure 3. 36 indicates that RM 12 to 23 experienced significant aggradation during the 1993 flood. A possible source of this aggraded sediment could be from RM 25 to 40, which experienced significant degradation during the flood. Figure 3. 37 shows that RM 12 to 14 and RM 19 to 20 degraded from 1995 to 2009. Whether or not the degradation from 1995 to 2009 exceeds the deposition from the 1993 flood varies from cross-section to cross-section.

3.3.2 Channel Width

A river channel may widen or narrow in any given year. Channels typically widen through mass-wasting processes. This often occurs following a flood, when banks are saturated and the water level in the channel has dropped. Channels narrow through the process of bar formation, trapping and deposition of sediments, and re-vegetation. The relationship between bed degradation and channel width changes is complex. In some reaches, degrading beds create high, unstable banks that are prone to mass wasting. However, bed degradation also reduces the frequency of inundation of point bars, which accelerates the establishment of stabilizing vegetation.

Changes in channel widths are shown in Figure 3. 38 and Figure 3. 39. These are not changes in the top width of the active channel, but rather the width of the channel at the baseline water surface elevation. Figure 3. 38 shows the width changes from 1992 – 1995, which includes the effect of the 1993 flood. Figure 3. 39 presents the width changes from 1995 to 2009.

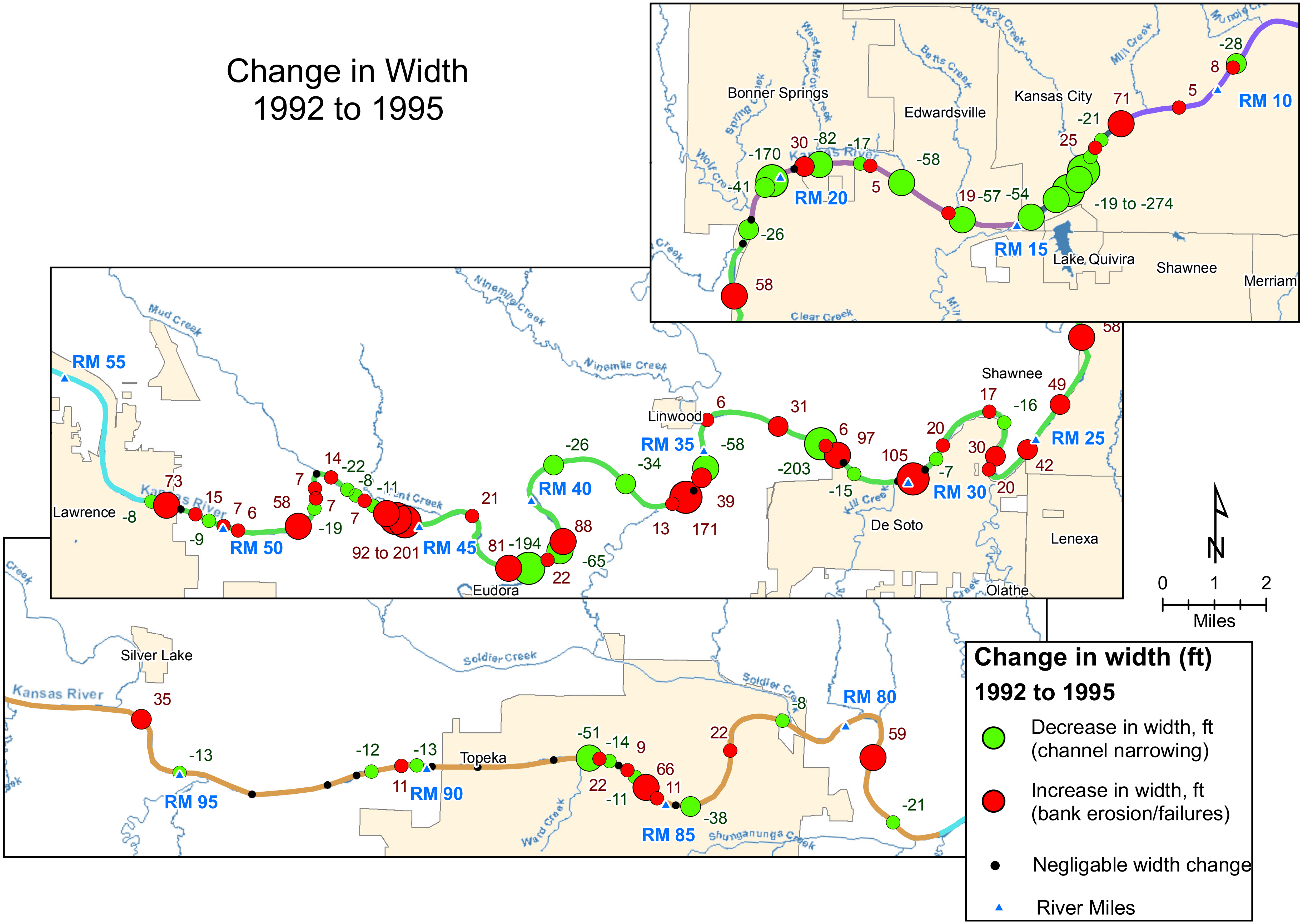


Figure 3. 38. Channel width response to the 1993 flood

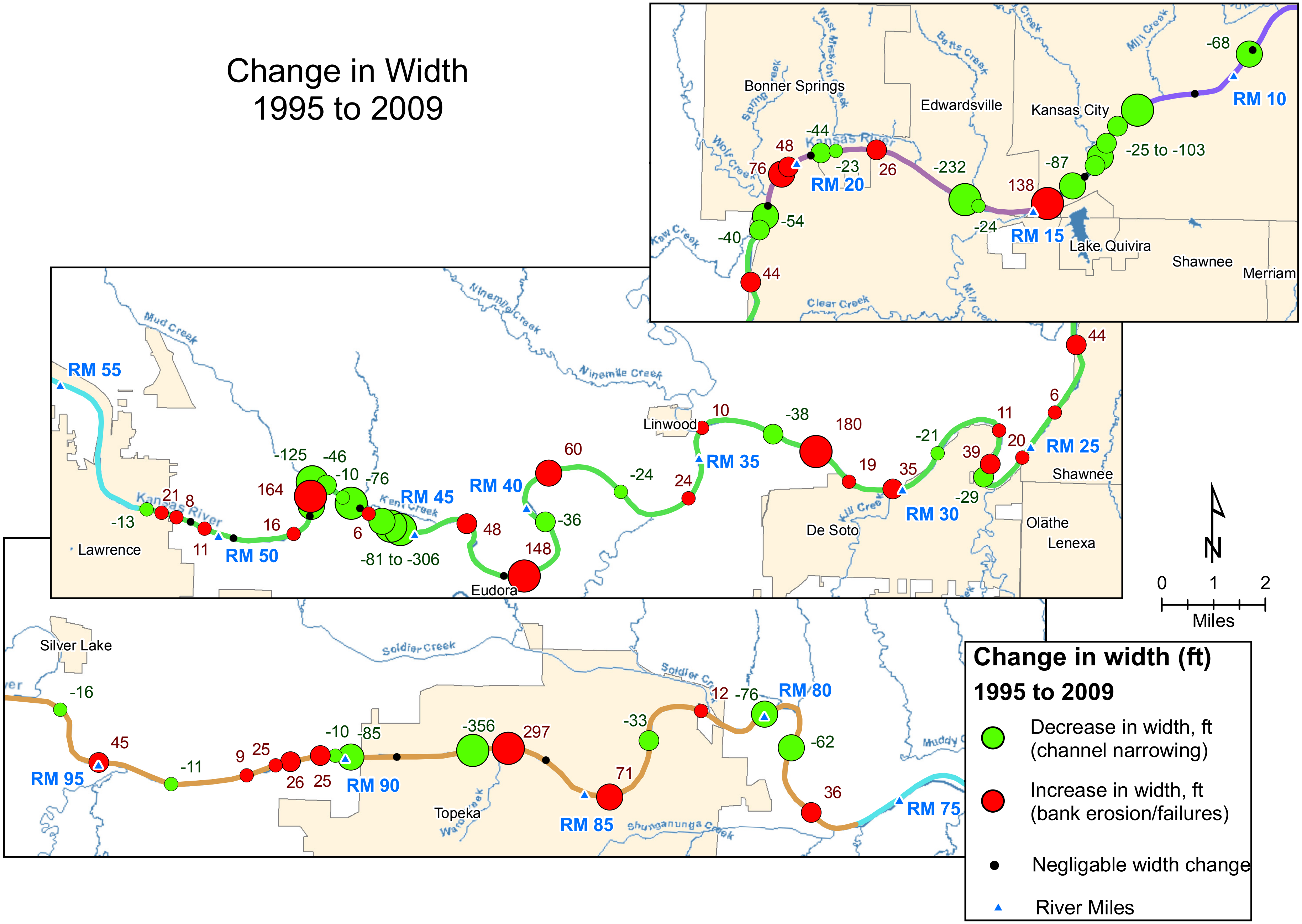


Figure 3. 39. Channel width change 1995 - 2009

As seen in Figure 3. 38, from RM 13 to RM 21 the channel narrowed as a result of the 1993 flood. Overall, the river widened from RM 22 to RM 51, though channel narrowing did occur at some locations. No cross-sections are available from RM 52 to RM 77. From RM 77 to RM 99, some locations experienced mild narrowing or widening while others did not appreciably change.

From 1995 to 2009, channel narrowing continued from RM 12 to 14, and channel widening continued at many locations from 20 to 22. From RM 32 to RM 48 the river is narrowing at the meander inflections and widening at the meander bends—a characteristic response of a river reforming its structure following a disturbance. RM 45 to 48 experienced significant channel narrowing. As before, bank erosion may be present in otherwise narrowing reaches and channel narrowing may be present in otherwise widening reaches. No cross-sections are available from RM 52 to RM 77 (SLA Reach 5) or upstream of RM 97 (SLA Reaches 7 and 8).

3.4 Geomorphic Assessment—Summary

1. The stage-discharge relationships at Fort Riley, Topeka, and Desoto have dropped since 1984, but have slowed or stopped dropping since 2001.
2. The stage-discharge relationships have not dropped at Wamego or Lecompton since 1984.
3. The 1993 flood caused stage degradation at Fort Riley (permanent), Wamego (temporary), Topeka (permanent), and Desoto (permanent).
4. The 2007 flood had no noticeable effect on the stage-discharge relationships at any Kansas River gage.
5. Bed elevations shift noticeably over any two-year period.
6. Cross-sections indicate that SLA Reaches 1, 2, 4, and 6 have degraded since 1992. No data is available for SLA Reaches 5, 7, and 8.
7. SLA Reach 3 aggraded significantly as a result of the 1993 flood. The effect lasted until 1997.
8. SLA Reaches 1, 2, 3, 4, and 6 have experienced bed elevation fluctuations, but no degradational trend, since 2003.
9. SLA Reaches 2 and 3 experienced significant channel narrowing as a result of the 1993 flood. SLA Reach 2 has continued to narrow, while SLA Reach 3 has experienced both narrowing and widening.
10. SLA Reaches 4 and 6 mostly widened during the 1993 flood and have localized widening and narrowing since.

4.0 Dredging

4.1 Dredging Rates and Locations

Dredging has occurred in various reaches of the Kansas River for decades. Unfortunately, reports of historic dredging quantities are inconsistent among sources. SLA (1984) reports dredging extraction quantities from 1926 to 1983 from many sources with overlapping time periods and spatial extents. The earliest dredging data, from years 1926 to 1931, has an unknown location. From 1939 to 1977, data is only available for RM 9.5 to 22; no data is available for dredging near Topeka (USACE 1977). Hibpshman (1971) offers extraction amounts from the entire Kansas River (RM 0 to 169) for the years 1961 to 1968. From 1979 to 1983, SLA (1984) presents quantities reported by the Kansas Department of Revenue.

Figure 4. 1 presents a reasonable estimate for dredging quantities developed from USACE and Kansas Department of Revenue data. From 1939 to 1963, only extraction amounts for the lower Kansas River, RM 9.5 to 22, are available. Starting in 1964, data is available for the full river. Reach-specific dredging quantities from the USACE regulatory program are available since 1999. These more specific dredging records will be used in subsequent analysis. As seen in Figure 4. 1, dredging rates have been decreasing over the past decade.

Commercial dredging operations were authorized in 19 reaches on the Kansas River at some point from 1999 – 2009. These reaches, shown in Figure 4. 2, cover a total of about 18 miles between river miles 9.4 and 96.5. As of 2009, 10 of the 19 had been discontinued. As seen in Figure 4. 2, recent dredging occurred in two disconnected stretches of the river, near Topeka (77.1 to 91.6) and from Lawrence to Kansas City (RM 9.1 – 51.3).

Figure 4. 3 and Figure 4. 4 show the yearly dredged quantities from 1999 to 2009 for each dredging reach. Regulatory limits on dredging rates and locations, set forth in *Regulatory Plan for Commercial Dredging Activities on the Kansas River* (USACE 1990), automatically prohibit dredging in any 5-mile reach when degradation since 1992 reaches 2 ft. When a reach is closed to dredging, the dredging operations often re-locate to new reaches. This explains the sudden start or end of dredging activities seen in many of the dredging reaches in Figure 4. 3 and Figure 4. 4.

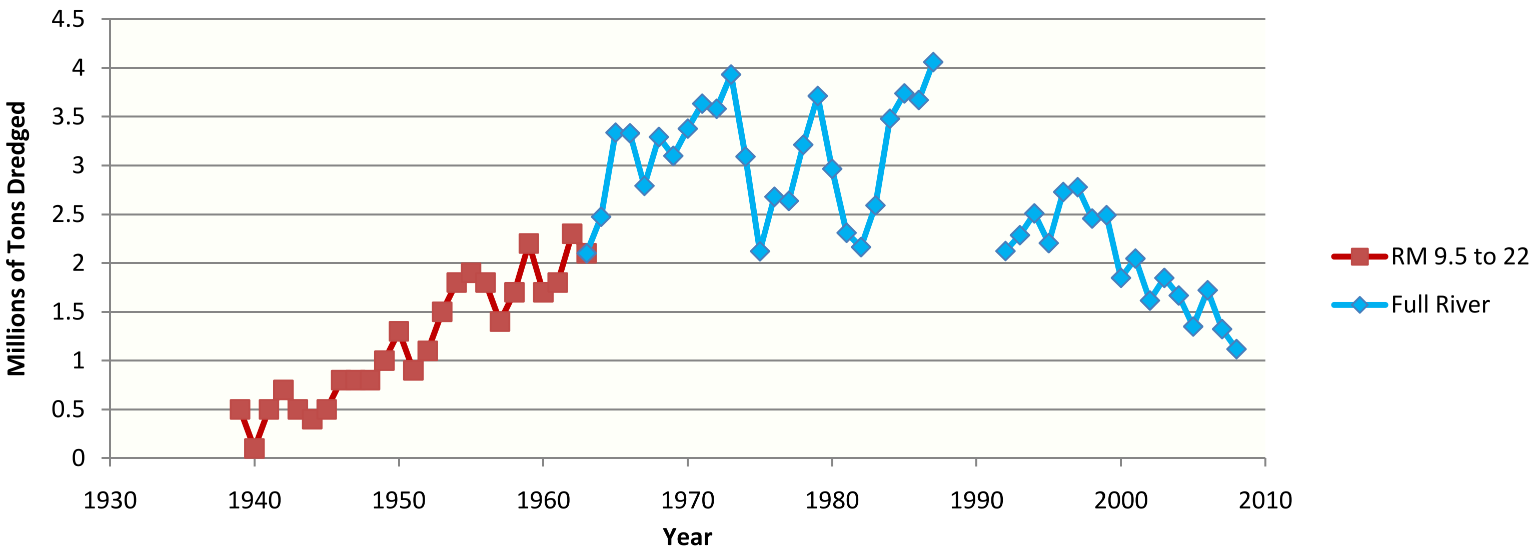


Figure 4. 1. Estimated Dredging Rates

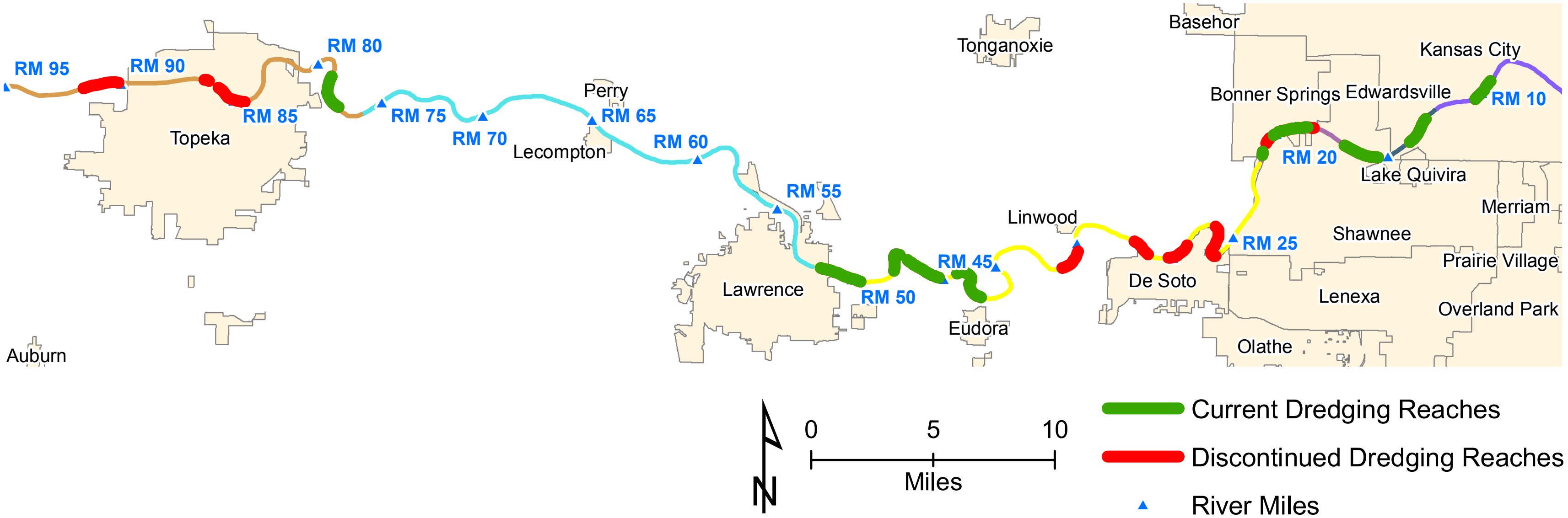


Figure 4. 2. Dredging Reaches on the Kansas River

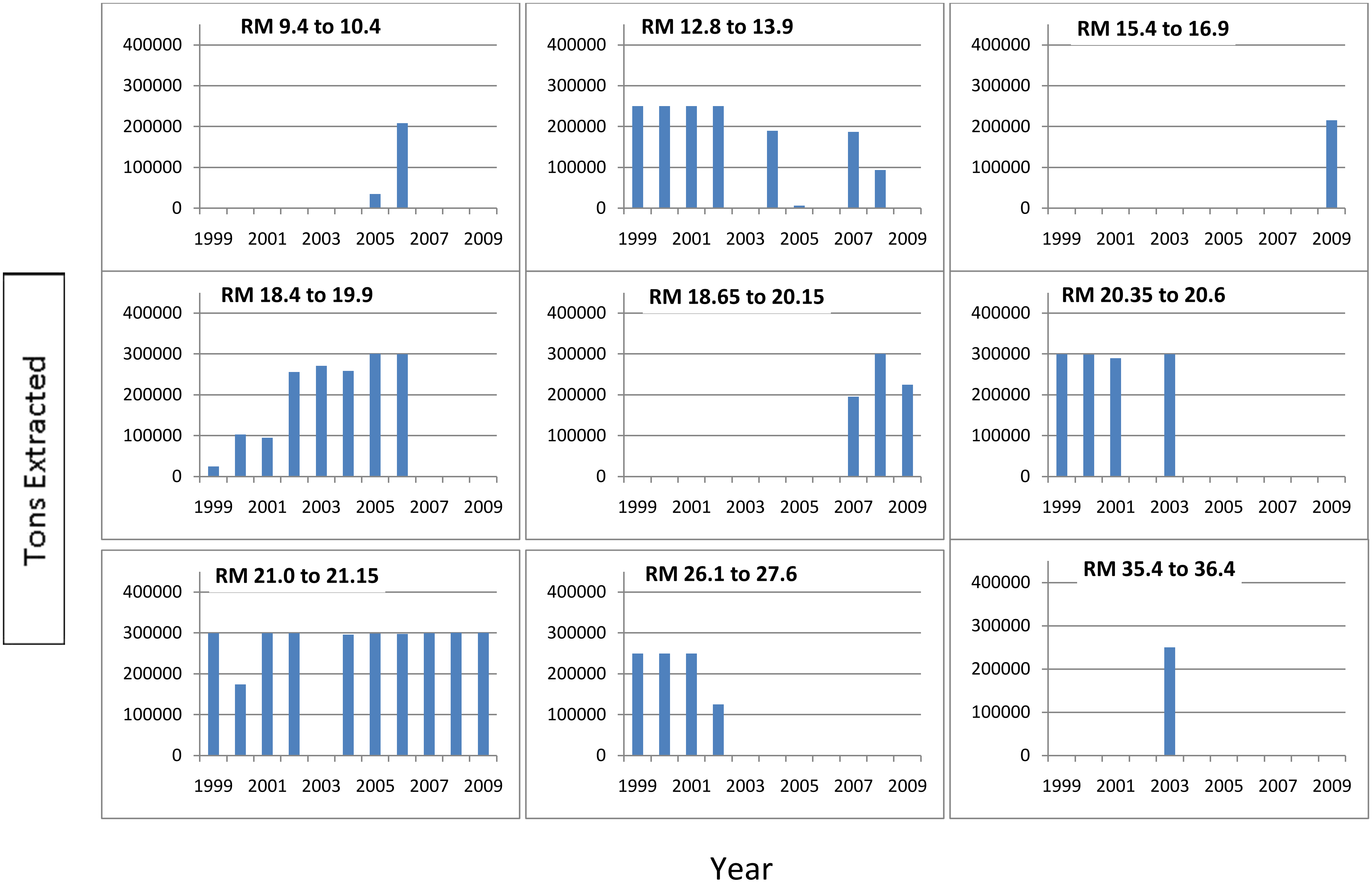


Figure 4. 3. Extraction Rate by Dredging Reach.

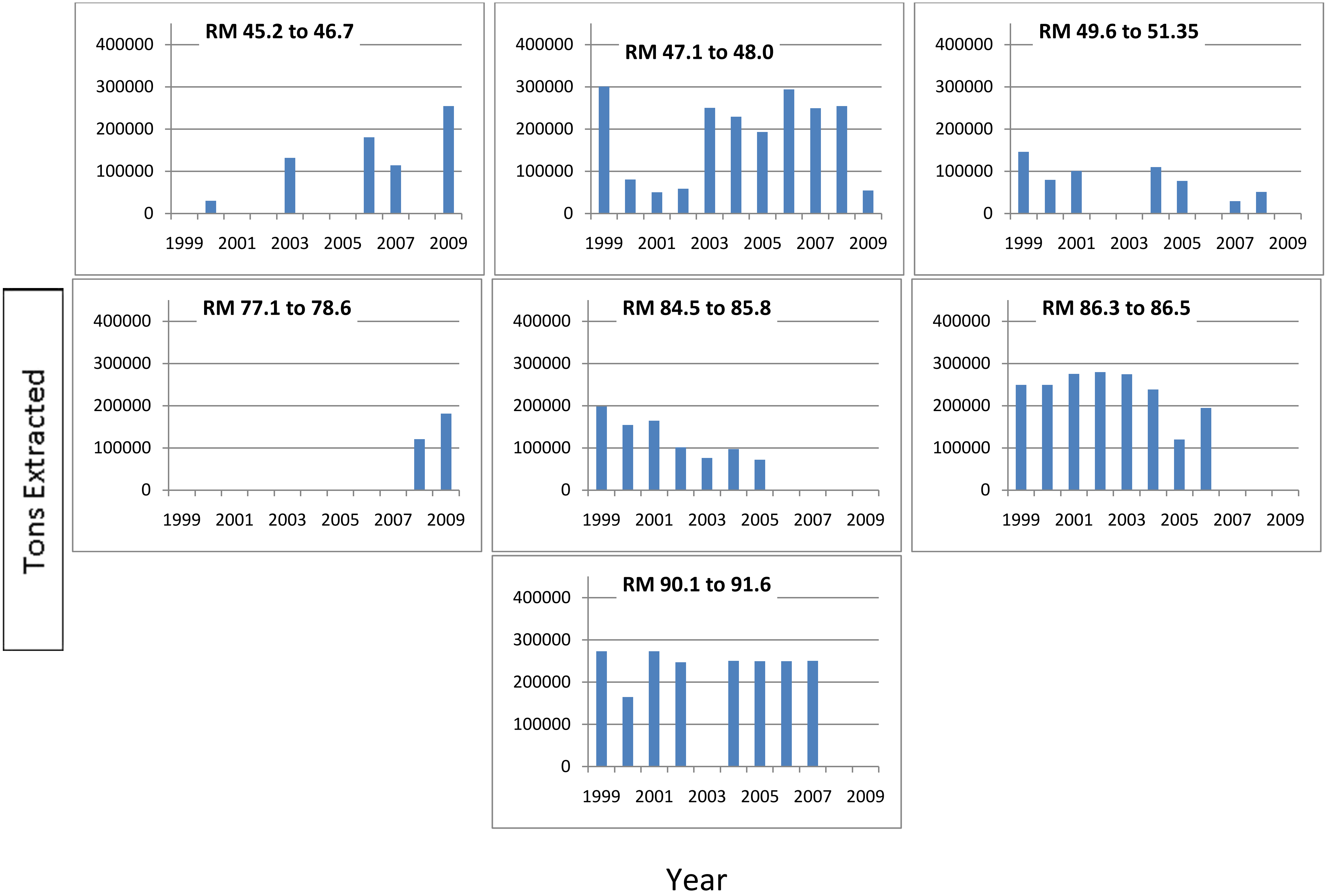


Figure 4. 4. Extraction Rate by Dredging Reach.

Figure 4. 5 shows the total extracted amount from 1999 to 2009 for each dredging reach.

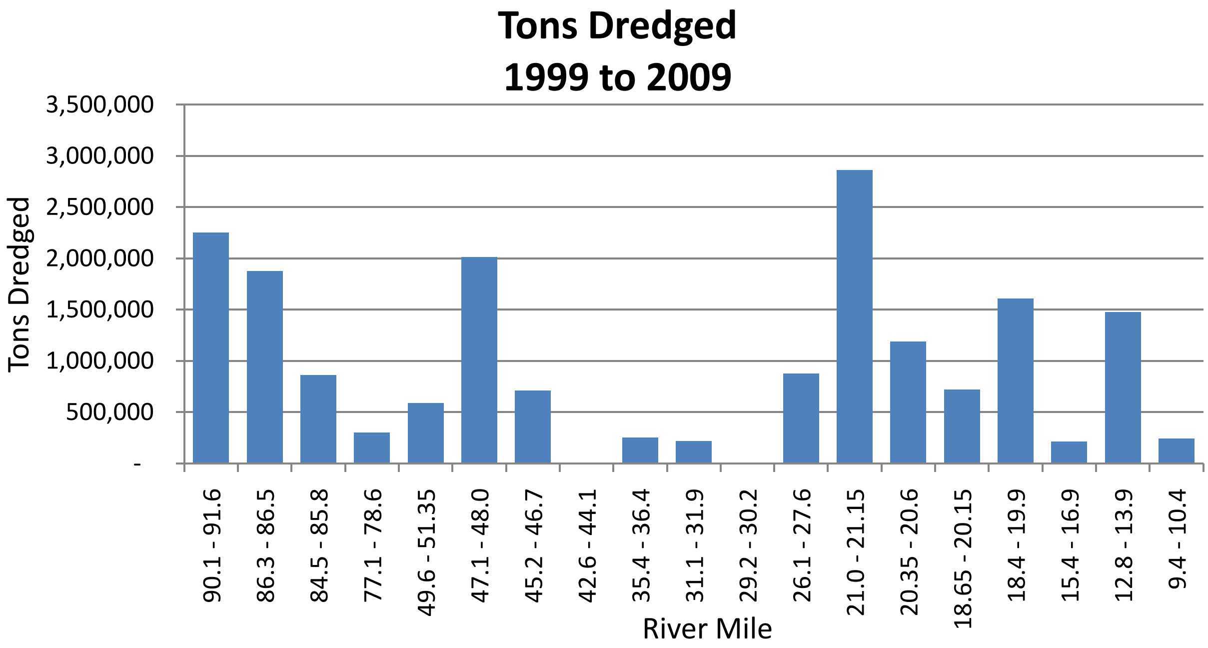


Figure 4. 5. Total Dredged Quantities 1999 to 2009

4.2 Dredging Rates and Stage Degradation

The Topeka gage and the Desoto gage are located near dredging reaches. Changes in the stage/discharge relationship over time were presented in Section 3.2. This section demonstrates changes in dredged quantities and the stage of 5,000 cfs with time.

Figure 4. 6 depicts dredging quantities at RM 9.4 to 22 (1977-1983) and RM 9.5 to 22 (1999-2009) and the elevation of 5,000 cfs at the Desoto gage (RM 31.1). The dredging quantities from 1973 to 1983 fluctuated between 1.5 and 4 million tons per year. In the same time period, the stage of 5,000 cfs steadily decreased. From 1999 to 2009, dredging quantities decreased from 2 million tons per year to 1 million tons per year and the stage of 5,000 cfs remained essentially constant.

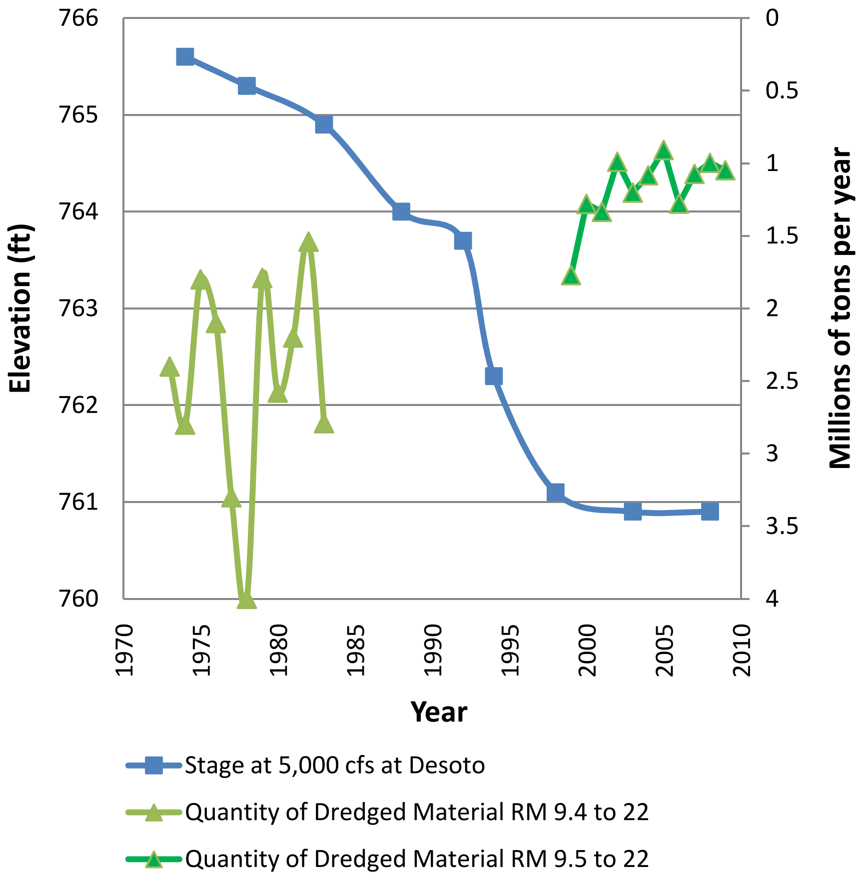


Figure 4. 6. Stage at Desoto and dredging quantities over time

The recent rates and locations of dredging have not caused stage degradation at the Desoto gage. Figure 4. 5 indicates that the dredging reaches directly upstream and downstream of the gage underwent very little and no dredging (respectively) from 1999 to 2009, which may explain the recent stabilization of the stage. Whether or not the increased dredging from 1973 to 1983 significantly contributed to the degradation seen in that time period cannot be concluded from this analysis.

Figure 4. 7 presents dredging amounts at RM 81 to 86 (1978 – 1983) and RM 77.1 to 91.6 (1999 – 2009) and the elevation of 5,000 cfs at the Topeka gage (RM 81.2). Dredged amounts near Topeka have varied from 0.1 to 0.8 million tons per year—significantly less than dredged amounts from Lawrence to Kansas City.

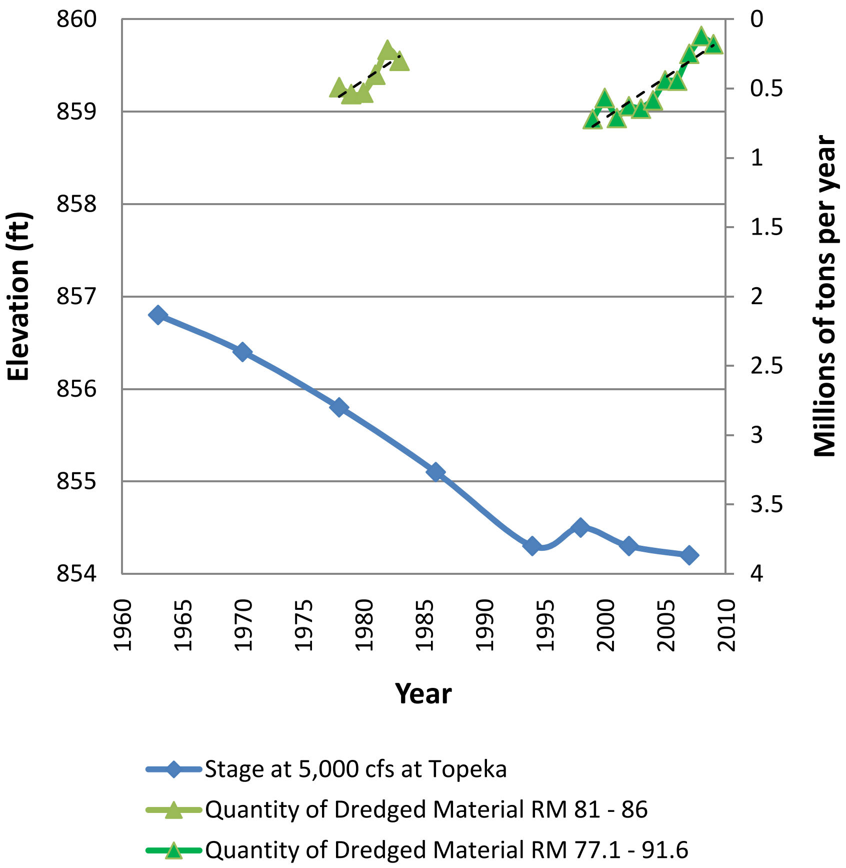


Figure 4. 7. Stage at Topeka and dredging quantities over time

The rate of stage degradation at Topeka has slowed from previous decades. The dredging rates near Topeka are less than 1 million tons/year, which are not that different than previous years. Figure 4. 7 yields two plausible predictions. First, stage degradation at Topeka may continue at a very gradual rate, which suggests that current levels of dredging may be a contributing factor. Second, the degradation may have stopped, suggesting that dredging at the current rates may be sufficiently small not to noticeably effect the stage at Topeka.

4.3 Coincident Locations of Degradation and Dredging

Dredging causes a localized decrease in bed elevation at the dredging site immediately following the sediment extraction. This scour hole can have important consequences depending on its depth and proximity to critical infrastructure. In a high-sediment system like the Kansas River, the hole refills if dredging is stopped. Continuously dredged reaches of the Missouri River with significant dredging have shown a persistent depression in bed elevation compared to non-dredged reaches upstream and downstream (Entrix, 2010).

Simons, Li, and Associates (1984) postulated that dredging was the primary cause of bed degradation on the Kansas River from River Mile 9.6 to 22 and was likely a contributing cause of degradation at Topeka. One of their supporting arguments is that the worst degradation and channel widening occurred in dredged reaches and did not occur in non-dredged reaches. This statement was made based on their qualitative assessment.

This assertion can be tested for the recent decade using the measured cross-sections from 1999-2009 and the location of authorized dredging reaches. The effects of dredging decrease with distance from the dredging site (SLA, 1984). Accordingly, cross-sections within a dredging reach would be expected to show degradation more often than cross-sections that are not in the dredging reach.

This analysis pertains to the time period with detailed dredging quantities: 1998 to 2009. Table 4. 1 presents the results of the probability assessment that answers the question *Are cross-sections in authorized dredging reaches more likely to be degrading than nearby cross-sections not in dredging reaches?* For this analysis, authorized dredging reaches that were dredged during at least one year between 1999 to 2009 were considered dredged reaches.

Table 4. 1. Degradation Probability Matrix for Reaches Dredged at Least One Year

	Totals	48	34
Totals		Dredged	Not dredged
58	Degraded	34	24
24	Not degraded	14	10

Out of all degraded reaches	59%	are dredged
	41%	are not dredged
Out of all non degraded reaches	58%	are dredged
	42%	are not dredged
Out of all dredged reaches	71%	are degraded
	29%	are not degraded
Out of all non dredged reaches	71%	are degraded
	29%	are not degraded

Table 4. 1 indicates that a cross-section has the same probability of being degraded (71%) whether or not it is in a dredged reach. The definition of a "dredged reach" for Table 4. 1 was "an authorized dredging reach that was dredged during at least one year from 1999 to 2009."

Table 4. 2 shows the results of a similar analysis that defines "dredged reach" as "an authorized dredging reach that was dredged during at least three years from 1999 to 2009."

Table 4. 2. Degradation Probability Matrix for Reaches Dredged at Least Three Years

	Totals	37	45
Totals		Dredged 3 years	Not Dredged 3 years
58	Degraded	29	29
24	Not degraded	8	16

Out of all degraded reaches	50%	are in dredged reaches (3 or more years)
	50%	are not in dredged reaches (3 or more years)
Out of all non degraded reaches	33%	are in dredged reaches (3 or more years)
	67%	are not in dredged reaches (3 or more years)
Out of dredged reaches (3 or more years)	78%	are degraded
	22%	are not degraded
Out of non-dredged reaches (3 or more years)	64%	are degraded
	36%	are not degraded

Table 4. 2 indicates that 78% of cross-sections in reaches dredged three or more years are degraded, while only 64% of cross-sections that are not in reaches with at least three years of dredging are degraded. This suggests that in the more heavily dredged reaches are slightly more degradational than nearby lightly dredged or non-dredged reaches. Cross-sections further downstream of Topeka or upstream of Bowersock dam—further away from the dredging reaches—would allow a more robust comparison between reaches affected and not affected by dredging.

4.4 Volume Changes in Dredging Reaches

The second analysis quantifies the total volume of sediment lost or gained in each dredging reach. The change in volume of bed material was calculated as the change in cross-sectional area from one time period to another, multiplied by the stream length over which that cross-section applies (half the distance to the previous cross-section plus half the distance to the next cross-section, not extending past the limits of the dredging reach). Thus, each dredging reach is defined by a weighted average of all the cross-sections in the reach. Analyzed this way, 13/18 (72%) dredging reaches experienced an overall loss in volume from 1998 to 2009, while 5/18

(28%) experienced a gain. An analysis of only the most recent years, 2004 – 2009, shows that only 6/13 (46%) dredging reaches experienced degradation, while 7/13 (54%) experienced aggradation. This is further evidence that the overall degradational trend of the river has slowed or stopped.

Plotting the quantity of material dredged versus the change in volume of the bed (Figure 4. 8) reveals negligible to non-existent correlation between dredging and degradation in the dredging reaches. This is true when the time period is broken into two time periods (1998 to 2003 and 2004 to 2009) or when the entire time period is analyzed together. If dredging were indeed the primary cause of degradation in the Kansas River from 1999 to 2009, a stronger correlation would be evident.

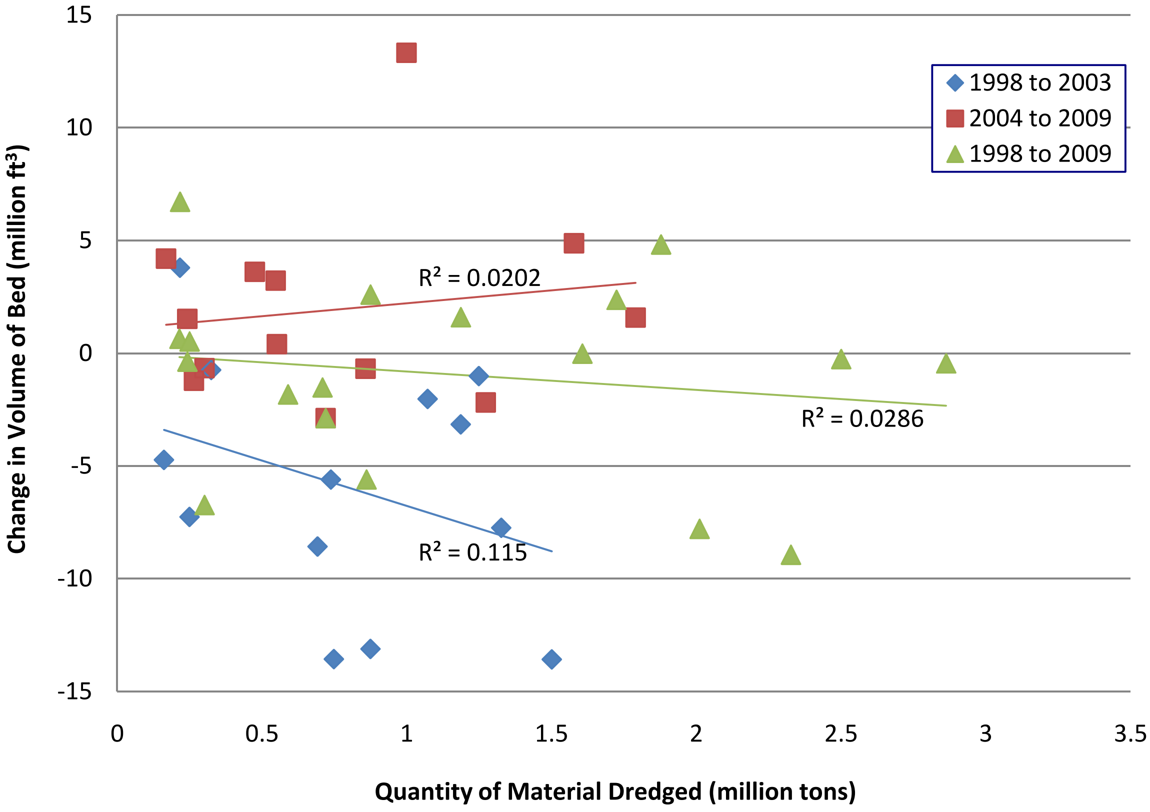


Figure 4. 8. Correlation between dredging and volume lost

Figure 4. 9 converts the volume lost to a weight. This does not change the relationship, but it illustrates that the dredged amount is much higher than the sediment lost from the dredging reaches. Sediment from upstream is replacing the dredged sediments.

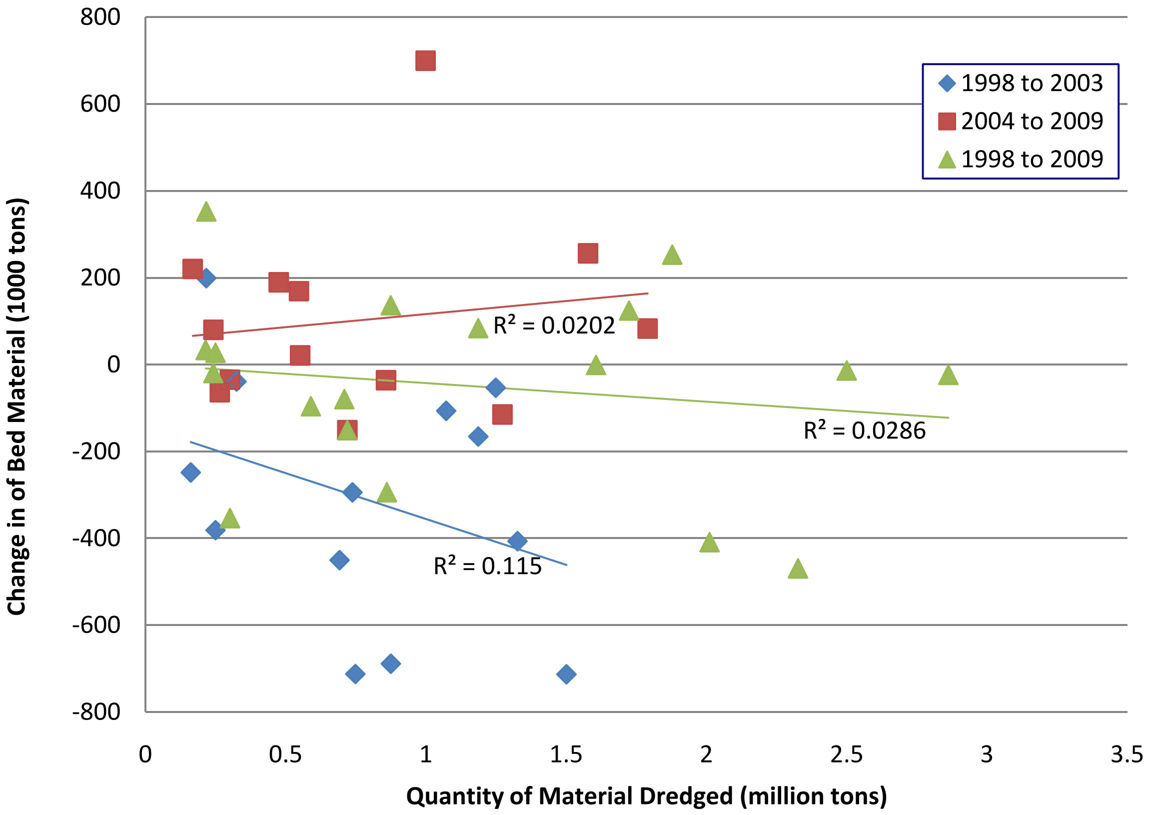


Figure 4. 9. Correlation between dredging and weight of sediment lost

4.5 Dredging—Additional Thoughts

Simons, Li, and Associates (1984) found that dredging on the Kansas River extracted a significant quantity of sediment compared to an overall sediment budget. Sedimentation modeling is beyond the scope of this report; however, it is clear that the dredged material must come from somewhere. As observed during the field reconnaissance, continued bank failures in upstream reaches could be supplying the sediment that replaces dredged sediment in downstream reaches. In addition, degrading tributaries may be contributing sediment to offset the extracted amounts. The dredging may be offsetting what would otherwise be an aggradational trend in the lower Kansas River. Another possibility is that a threshold dredging level exists below which dredging reduces the total sediment yield to the Missouri River without causing significant changes to the Kansas River. These are possibilities that could be supported or negated by future research.

4.6 Dredging—Summary

1. Dredging amounts are significantly less than they have been in the past.
2. Current rates and locations of dredging have not caused significant stage degradation at the Desoto or Topeka gages since 1999.
3. Cross-sections in dredged reaches (at least one year of dredging) are no more likely to have degraded than nearby cross-sections not in dredged reaches.
4. Cross-sections in actively dredged reaches (3 or more years of dredging) are slightly more likely to have degraded than nearby cross-sections not in actively dredged reaches.
5. Most of the authorized dredging reaches have lost volume since 1998, but not since 2004.
6. The volume of sediment lost from the dredging reaches is not correlated to the quantity of dredged material.

5.0 Conclusion

This report analyzed changes in the Kansas River with a particular focus on the years from 1985 to 2009. This report specifically addressed changes in the hydrology and geomorphology of the Kansas River and the issue of in-stream sand and gravel dredging. The analyses presented in this report conclude the following:

1. The total volume of flow in the Kansas River was lower from 1918 – 1939 than from 1940 – 2009, which yields an upward trending line everywhere except for Fort Riley, where there is no trend.

2. There is no increase or decrease in the average annual flow at any gage on the Kansas River from 1940 – 2009.

3. The floods and low-flows are currently less severe than in the pre-reservoir period.

4. Intermediate flows have increased in the post-reservoir period at all gages except for Fort Riley, but this is mostly a factor of the drought of the 1920s and 1930s.

5. The stage-discharge relationships at Fort Riley, Topeka, and Desoto have dropped since 1984, but have slowed or stopped dropping since 2001.

6. The stage-discharge relationships have not dropped at Wamego or Lecompton since 1984.

7. The 1993 flood caused stage degradation at Fort Riley (permanent), Wamego (temporary), Topeka (permanent), and Desoto (permanent).

8. The 2007 flood had no noticeable effect on the stage-discharge relationships at any Kansas River gage.

9. Bed elevations shift noticeably over any two-year period.

10. Cross-sections indicate that SLA Reaches 1, 2, 4, and 6 have degraded since 1992. No data is available for SLA Reaches 5, 7, and 8.

11. SLA Reach 3 aggraded significantly as a result of the 1993 flood. The effect lasted until 1997.

12. SLA Reaches 1, 2, 3, 4, and 6 have experienced bed elevation fluctuations, but no degradational trend, since 2003.

13. SLA Reaches 2 and 3 experienced significant channel narrowing as a result of the 1993 flood. SLA Reach 2 has continued to narrow, while SLA Reach 3 has experienced both narrowing and widening.

14. SLA Reaches 4 and 6 mostly widened during the 1993 flood and have localized widening and narrowing since.

15. Dredging amounts are significantly less than they have been in the past from Bowersock dam to Kansas City. Dredging rates near Topeka are similar to those in the past.

16. Current rates and locations of dredging have not caused significant stage degradation at the Desoto or Topeka gages since 1999.

17. Cross-sections in dredged reaches (at least one year of dredging) are no more likely to have degraded than nearby cross-sections not in dredged reaches.

18. Cross-sections in actively dredged reaches (3 or more years of dredging) are slightly more likely to have degraded than nearby cross-sections not in actively dredged reaches.

19. Most of the authorized dredging reaches have lost volume since 1998, but not since 2004.

20. The volume of sediment lost from the dredging reaches (1999 – 2009) is not correlated to the quantity of dredged material (1998 – 2009).

While many issues have been addressed, many questions remain unanswered, including the following: What are potential geomorphic effects of another major flood event? What are the expected downstream effects of upstream bank stabilization? What is the return period of in-bank flows, and how does that compare to the characteristic “bankfull flow” of less modified Kansas streams and rivers? What is the effective discharge for different segments of the Kansas River? How “natural” is the geometry of the Kansas River compared to Kansas reference reaches? What is the equilibrium configuration of the Kansas River? Future research and continued monitoring are suggested for this important water resource.

References

Brady, Lawrence L. (1998), David A. Grisafe, James R. McCauley, Gregory C. Ohlmacher, Hernán A. M. Quinodoz, and Kenneth A. Nelson. *The Kansas River Corridor--Its Geologic Setting, Land Use, Economic Geology, and Hydrology.* Kansas Geological Survey Open-file Report 98-2. January 1998. http://www.kgs.ku.edu/Publications/KR/index.html

Dort, Wakefield Jr. (2009). *Historical Channel Changes of the Kansas River and Its Major Tributaries.* American Geographical Society. Special Publication Number 5.

Entrix (2010). *Missouri River Dredging Draft Environmental Impact Statement.* Available at http://www.nwk.usace.army.mil/regulatory/Dredging/MO/MOdredging.htm .

Hibpshman, M. H. (1971) Availability of Sand and Gravel Along the Kansas River between Junction City, Kansas, and Kansas City, Missouri. Preliminary report 184, United States Department of the Interior, Bureau of Mines.

Juracek and Fitzpatrick (2009). *Geomorphic applications of stream-gage information. River Research and Applications.* Vol. 25 (329-347).

Simons, Li, and Associates (1984). *Analysis of Channel Degradation and Bank Erosion in the Lower Kansas River.* U.S. Army Engineer District, Kansas City Corps of Engineers. MRD Sediment Series No 35. September 1984.

Stark, Ken (2009). *Notes on Kansas River Dredging Data.* U.S. Army Corps of Engineers, Kansas City District. Internal Memo, March 2009.

Tool, Allen (2009). *Missouri River Degradation.* Greater Kansas City Post Industry Day Education & Training Workshop. http://www.nwk.usace.army.mil/projects/MoRiverDegradation/Documents/SAME_28_Jan_2009.pdf

USACE (1977). *Impact of Commercial Sand Dredging in the Lower Kansas River.* U.S. Army Corps of Engineers, Kansas City District.

USACE (1990). *Regulatory Plan for Commercial Dredging Activities on the Kansas River.* U.S. Army Corps of Engineers, Kansas City District. An online version is available at http://www.kgs.ku.edu/Publications/KR/appA.html .

Appendix B- Additional Gage Analysis

The water surface elevations and associated discharges have been measured and recorded at five USGS gages on the Kansas River. Changes in the stage–discharge relationship over time can be indicative of geomorphic changes, especially of bed degradation and aggradation (Juracek and Fitzpatrick, 2009). A decrease in the stage-discharge relationship indicates that the channel conveys the same discharge at a lower elevation and often corresponds to a drop in the channel bed. Conversely, an increase in the stage–discharge relationship may indicate bed aggradation. However, while a drop in the stage for a given discharge could be caused by bed degradation, it could also be caused by a decrease in the flow depth with no drop in bed elevation.

Changes in channel slope (avulsions, channelizations, meander cutoffs), changes in cross-sectional area (bank erosion and failure, bar formation) and changes in roughness (sediment fining or coarsening, changes in bankside vegetation) can change the stage–discharge relationship. A large flood may increase the channel slope by cutting off meanders and may increase the total cross-sectional area through bank failures with the combined effect of lowering the stage for a given discharge without lowering the bed elevation.

This appendix provides additional gage analysis that shows that for a given flow, the flow cross-sectional area and top width have not changed appreciably since the 1960s. A constant area and top width for a given flow implies that the depth of that flow has not changed. Thus, any observed change in stage is in fact due to bed degradation.

B1 Flow Area and Top Width

Prior to the mid 2000s, USGS reported cross-sectional area and top width for each measured stage and discharge. The purpose of this width and area data is to allow the computation of flow. USGS did not originally intend for these measurements to be meaningful in and of themselves, though they have been used in various research and design applications (Juracek and Fitzpatrick, 2009). The scatter in the data is large, especially at low flows, because of the high variability in braided channel rivers and because the wading location is not consistent.

In the mid 2000’s, the USGS started measuring flow using Acoustic Doppler Current Profiler (ADCP) equipped boats, which measure flow at random locations. Data measured in this way is in the vicinity of the gage, but not at a defined, consistent cross-section. For this reason, cross-section analysis at gages cannot be used for recent data and will not be useful for future data.

For a given location, a rating curve can be created that casts cross-sectional flow area and top width as functions of discharge. These types of relation are known as at-a-station hydraulic geometry equations (Leopold and Maddock, 1953).

B1.1 Fort Riley

Figure B. 1 and Figure B. 2 show the discharge – flow area and top width relationships at the Fort Riley gage. As seen, the relationships did not change appreciably 1960 – 2005. Over the same time period, the stage–discharge relationship dropped approximately 3 ft (see report section 3.2.1).

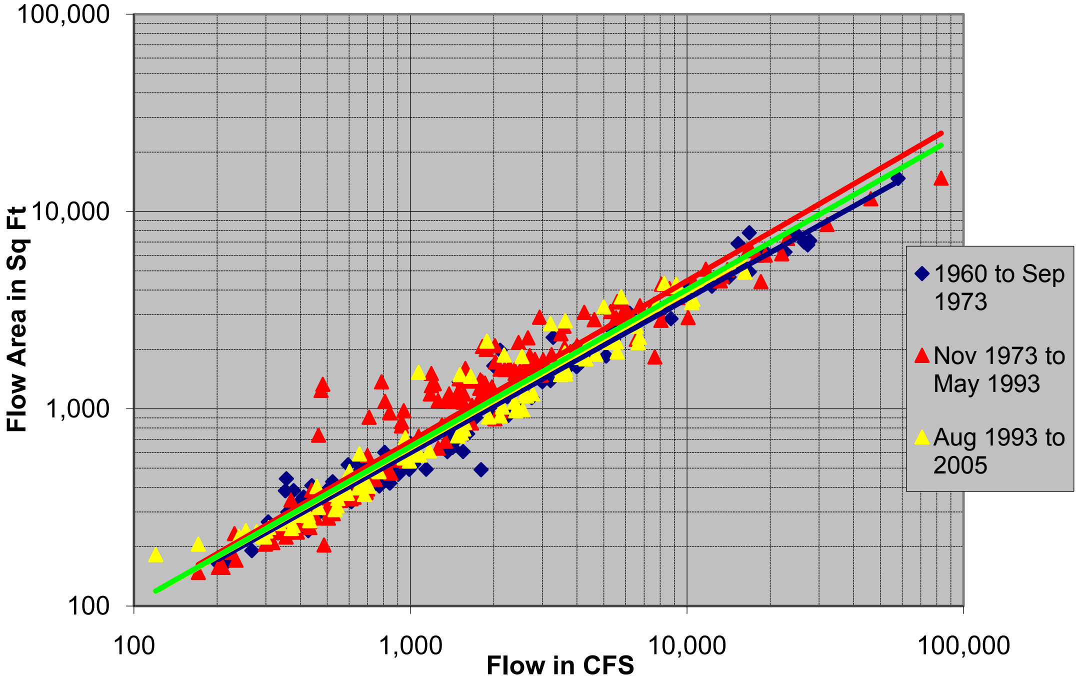


Figure B. 1. Discharge–area relationship at Fort Riley. RM 168.9. 1960 – 2005.

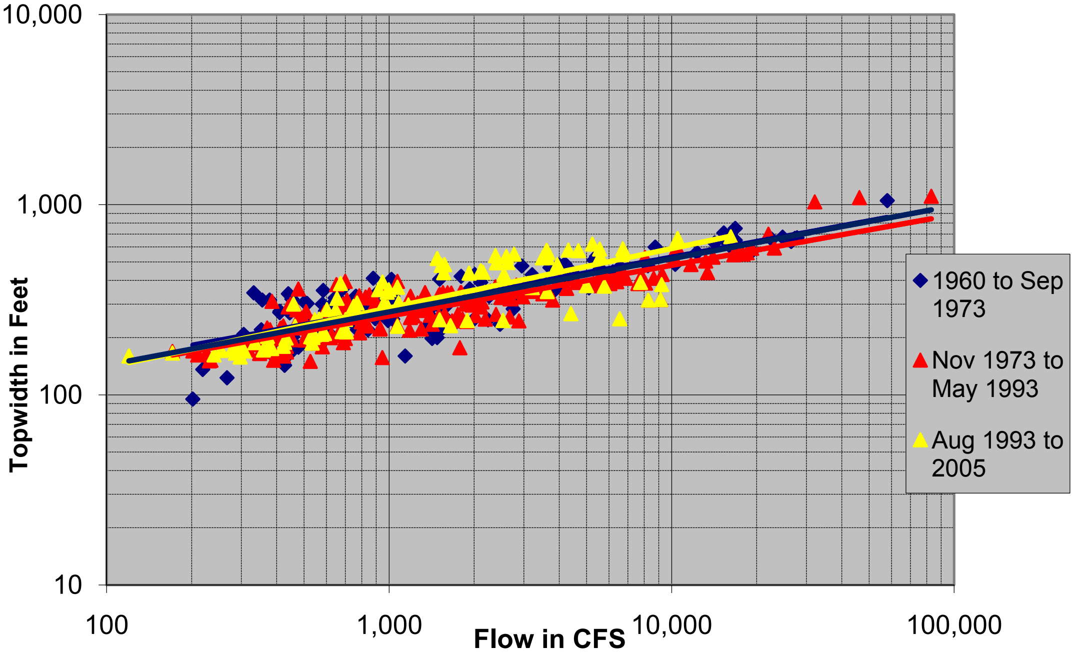


Figure B. 2. Discharge–width relationship at Fort Riley. RM 168.9. 1960–2005.

B1.2 Wamego

Figure B. 3 and Figure B. 4 show the discharge–area and discharge–width relationships at the Wamego gage. As seen, the discharge–area relationship exhibited random fluctuations, but did not change appreciably 1961 – 2005. Although no clear trend is evident in the discharge– width relationship, it appears that the channel is approximately 50 ft wider in 2009 than in 1961. The tremendous scatter in the discharge – width relationship makes trends difficult to establish. Over the same time period, the stage–discharge relationship showed no trend (see report section 3.2.2).

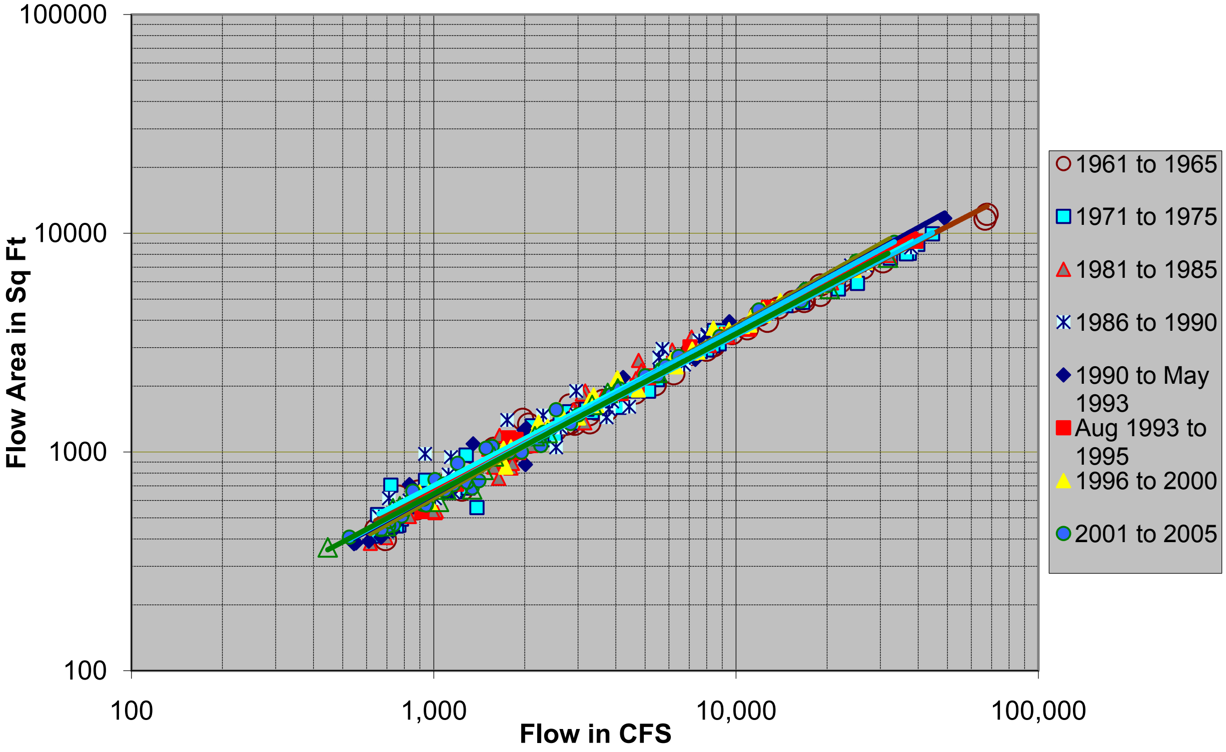


Figure B. 3. Discharge–area relationship at Wamego. RM 126.9. 1961 – 2005.

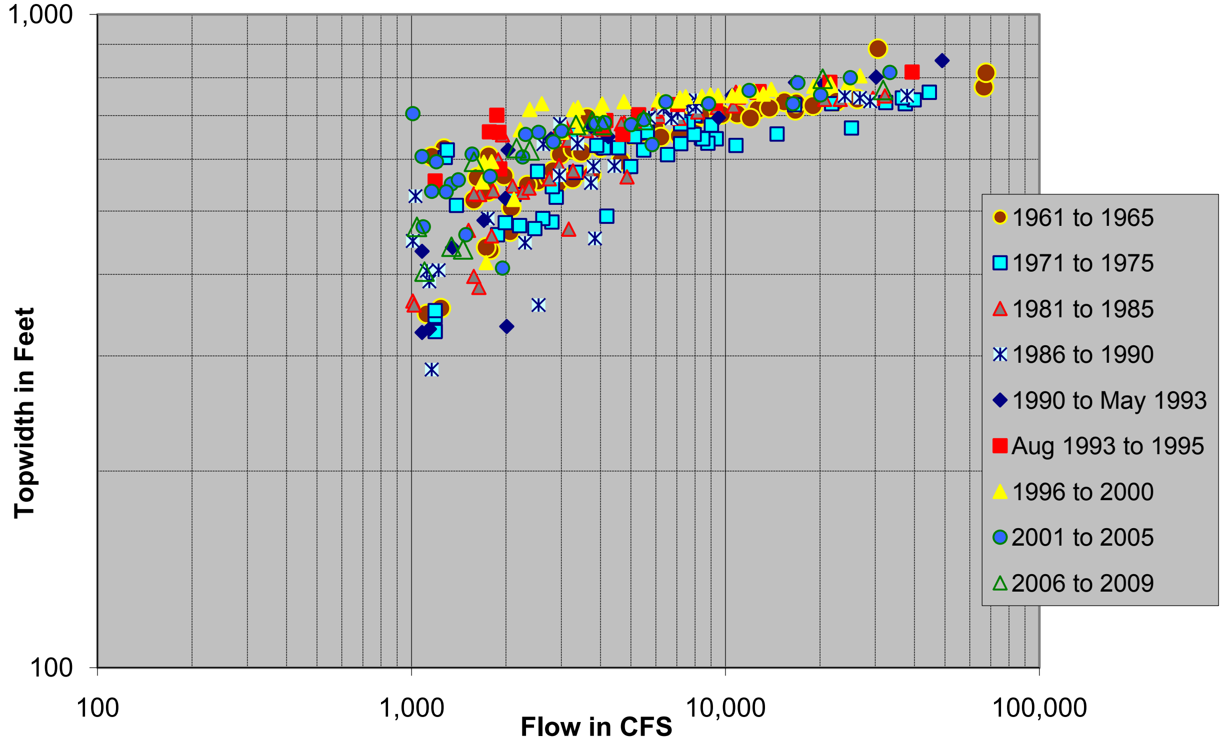


Figure B. 4. Discharge–width relationship at Wamego. RM 126.9. 1961 – 2005.

B1.3 Topeka

Figure B. 5 and Figure B. 6 show the discharge–area and discharge–width relationship at the Topeka gage. Flows below 1,000 cfs have been excluded from this analysis to remove skew from the trend lines. As seen, the discharge – area relationship rose slightly between 1961 and 1971, but has remained unchanged since. The width did not change. Over the same time period, the stage–discharge relationship dropped approximately 3 ft (see report section 3.2.3).

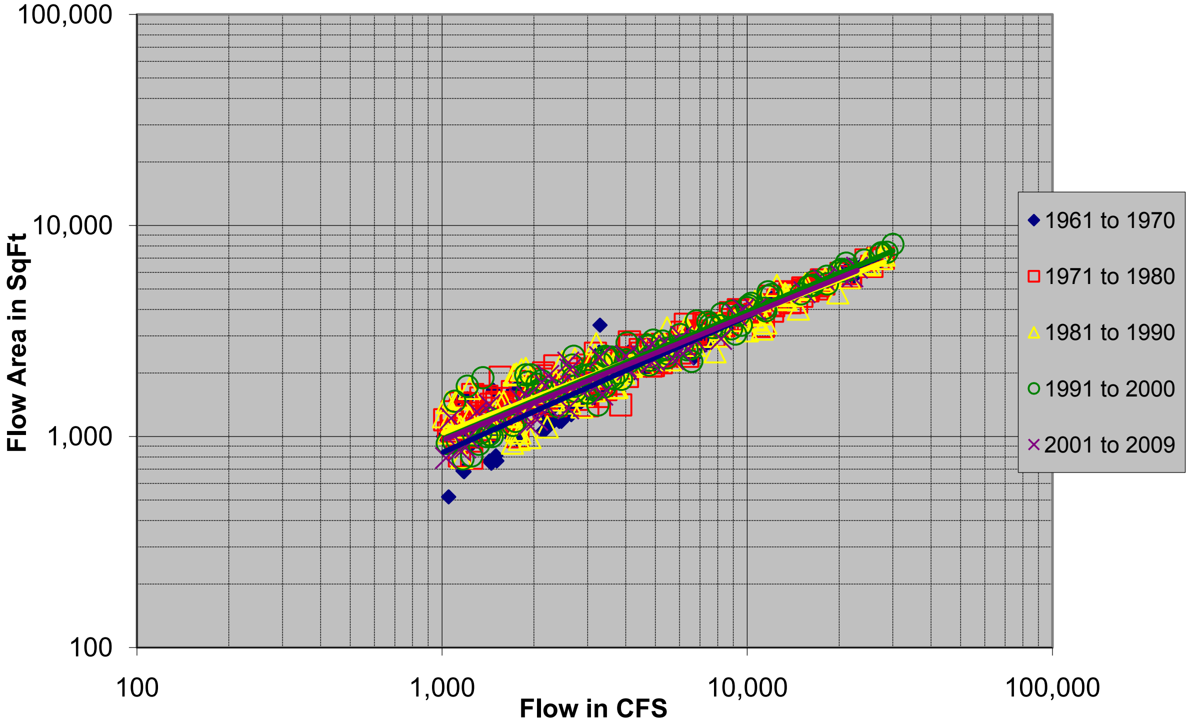


Figure B. 5. Discharge–area relationship at Topeka. RM 83.1. 1961 – 2009.

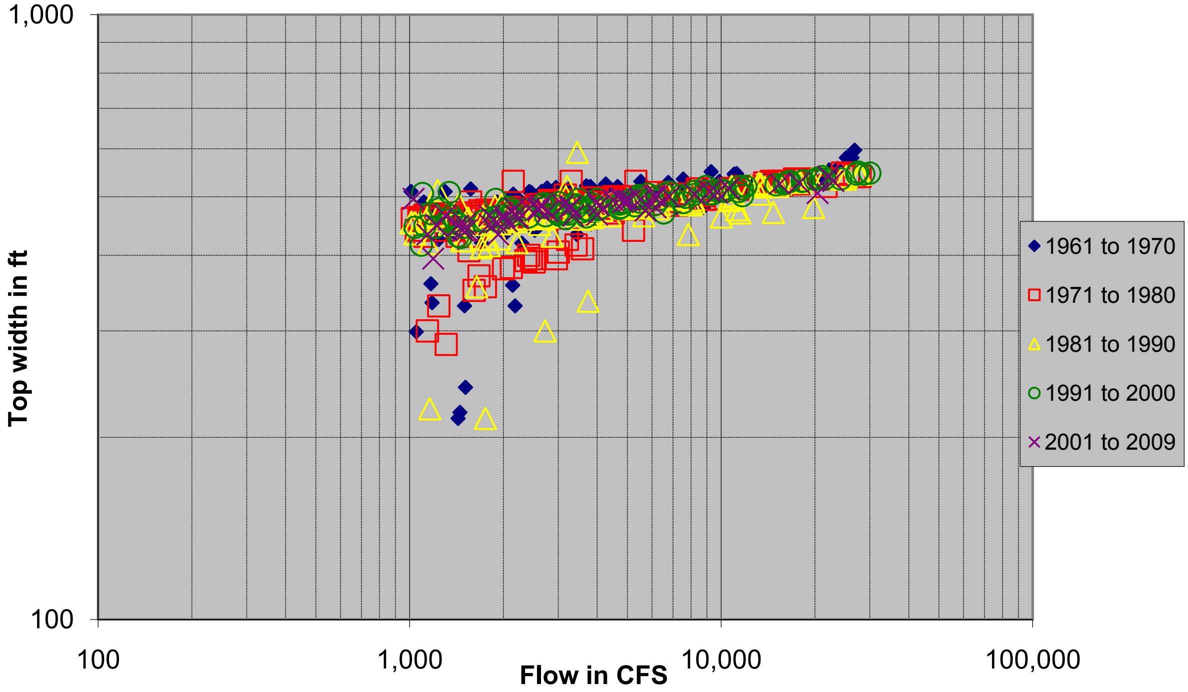


Figure B. 6. Discharge–width relationship at Topeka. RM 83.1. 1961–2009.

B1.4 Lecompton

Figure B. 7 and Figure B. 8 show the discharge–area and discharge–width relationship at the Lecompton gage. No trend is evident 1970—2005. Over the same time period, the stage–discharge showed no trend (see report section 3.2.4).

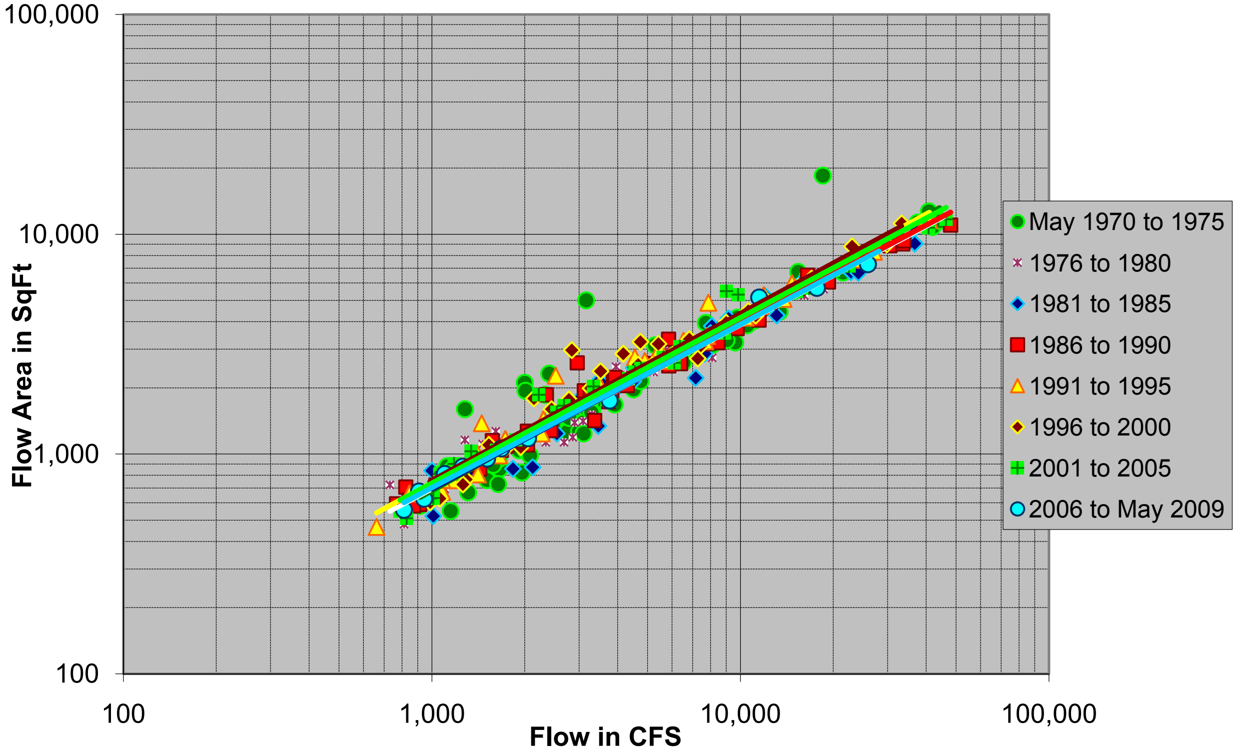


Figure B. 7. Discharge–area relationship at Lecompton. RM 63.8. 1970—2005.

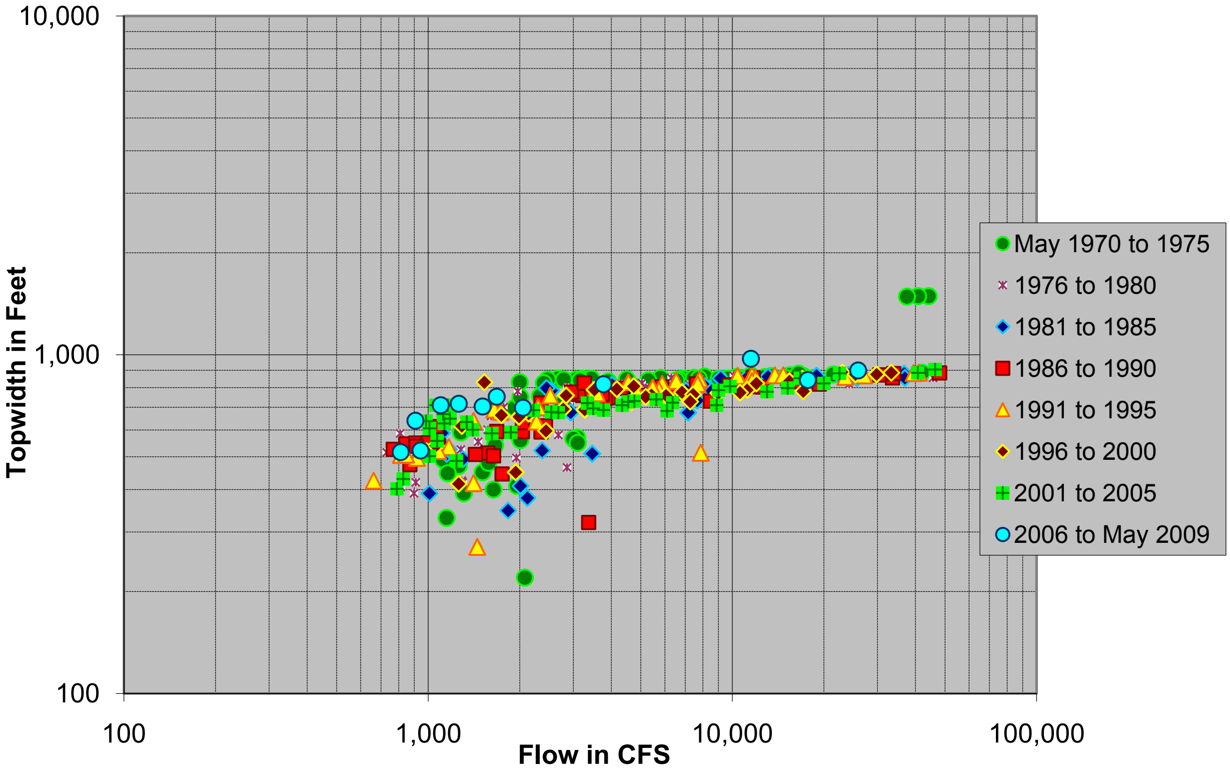


Figure B. 8. Discharge–width relationship at Lecompton. RM 63.8. 1970–2005.

B1.5 Desoto

Figure B. 9 and Figure B. 10 show the discharge–area and discharge–width relationships at the Desoto gage. An oscillatory pattern is evident in the area 1973—2005, but no trend. The scatter is so large on the width graph, that trends or the lack of trends are obscured. It is easier to see that the data exhibit no trend by analyzing a subset of the flow (2,000 to 10,000 cfs) shown in Figure B. 11. Over the same time period, the stage–discharge relationship showed 4-5 ft of degradation (see report section 3.2.5).

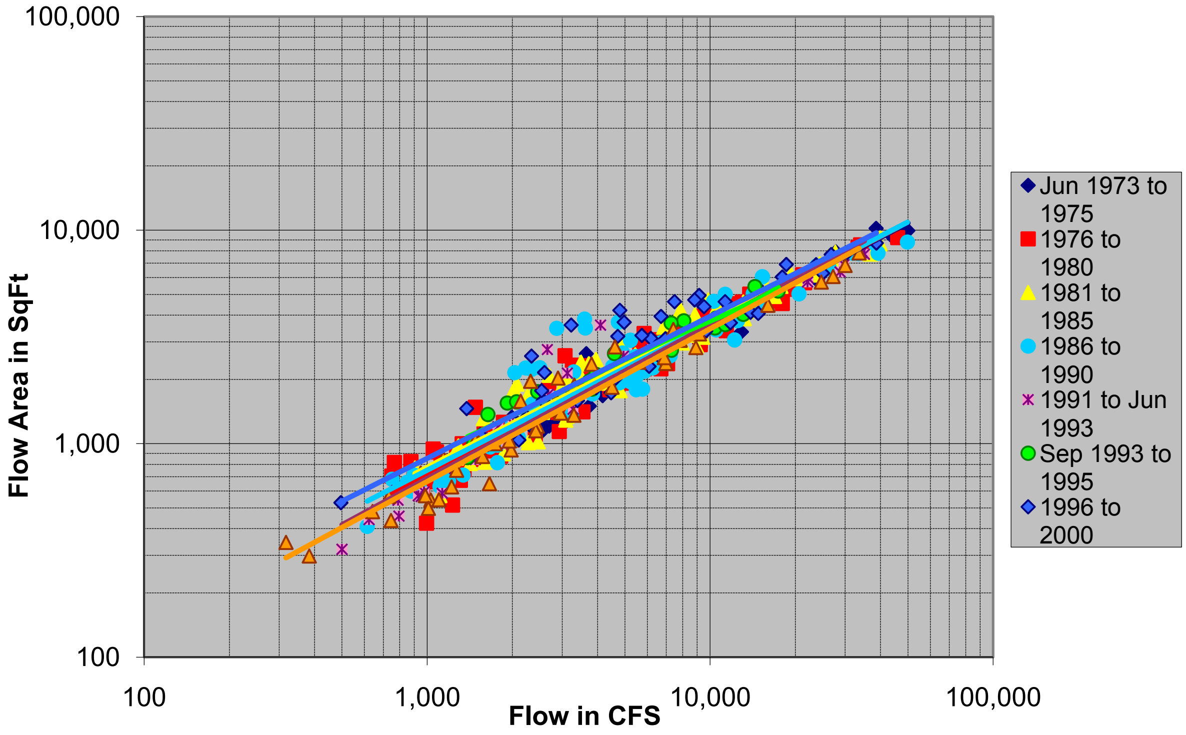


Figure B. 9. Discharge–area relationship at Desoto. RM 31.1. 1973—2005.

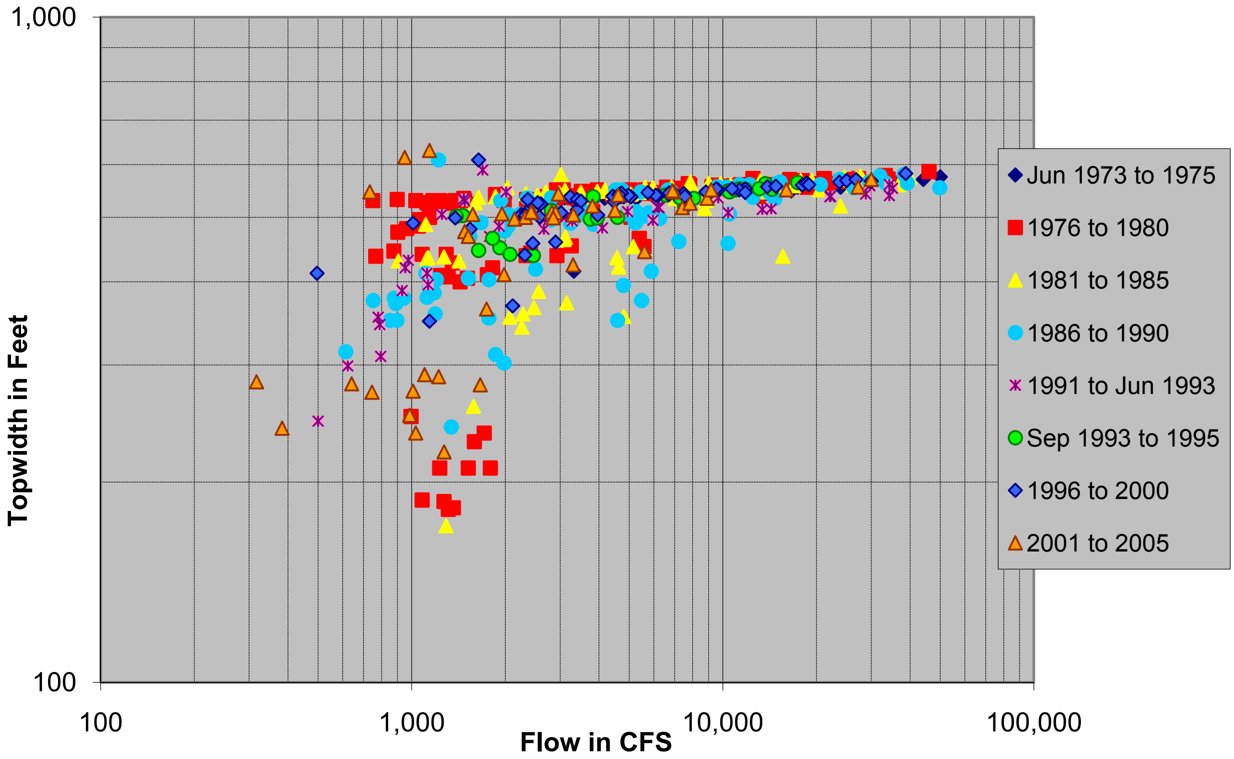


Figure B. 10. Discharge–width relationship at Desoto. RM 31.1. 1973 –2005.

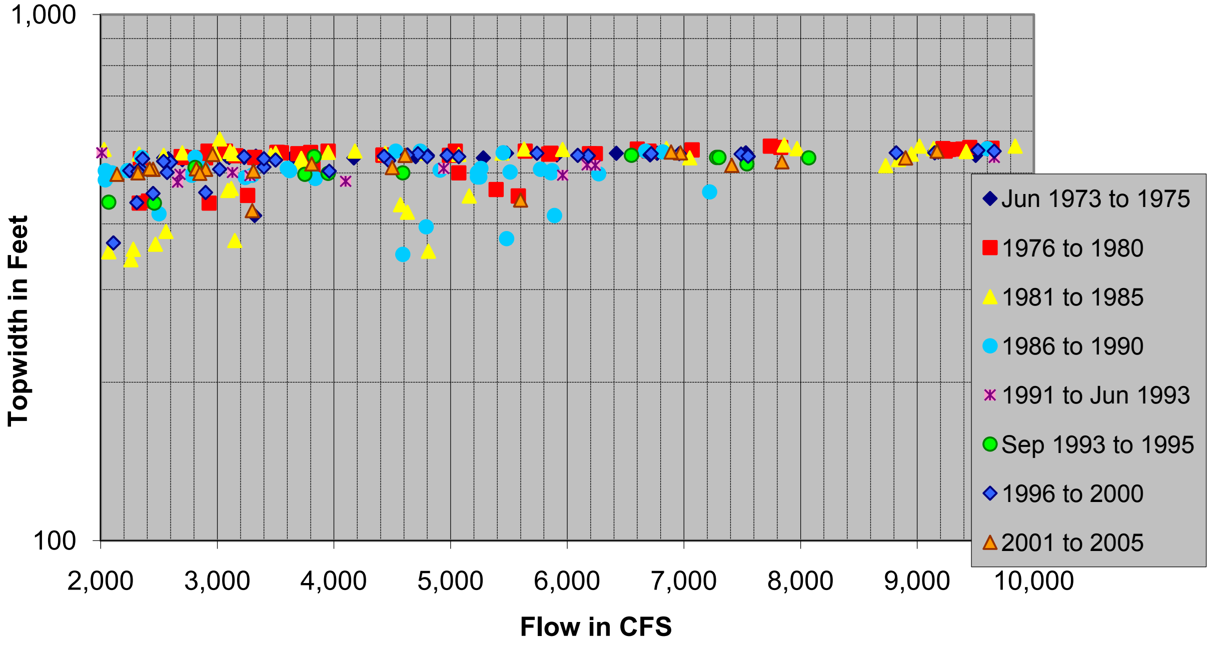


Figure B. 11. Discharge–width relationship at Desoto. 5,000 cfs to 50,000 cfs.

B1.6 Discharge–Flow Area — Summary

The discharge – area and discharge – width relationships for all the gages on the Kansas River have been remarkably constant, notwithstanding significant bed degradation. This supports the assumption that the stage degradation evident at the Kansas River gages is due to bed degradation and not a decrease in flow depth.

Appendix C- Cross-sections

For many years, the Kansas Water Office and the Army Corps of Engineers have collected cross-sections at strategic locations along the Kansas River. In 1977 35 cross-sections were surveyed. In 1992, 1995, 1999, 2001, 2003, 2005, 2007, and 2009 a consistent set of 100 - 130 cross-sections were surveyed and re-surveyed for the primary purpose of monitoring dredging impacts. These cross-sections are located in and between authorized dredging reaches in river miles 9 – 51 and 72 – 96. These cross-sections provide an excellent dataset for analysis of recent changes in cross-sectional parameters such as average bed elevation and width for the covered stretches of the Kansas River. By comparing subsequent years, the changes in width and average bed elevation can be calculated at the location of each cross-section. These cross-sections were used in the analysis presented in the body of the report.

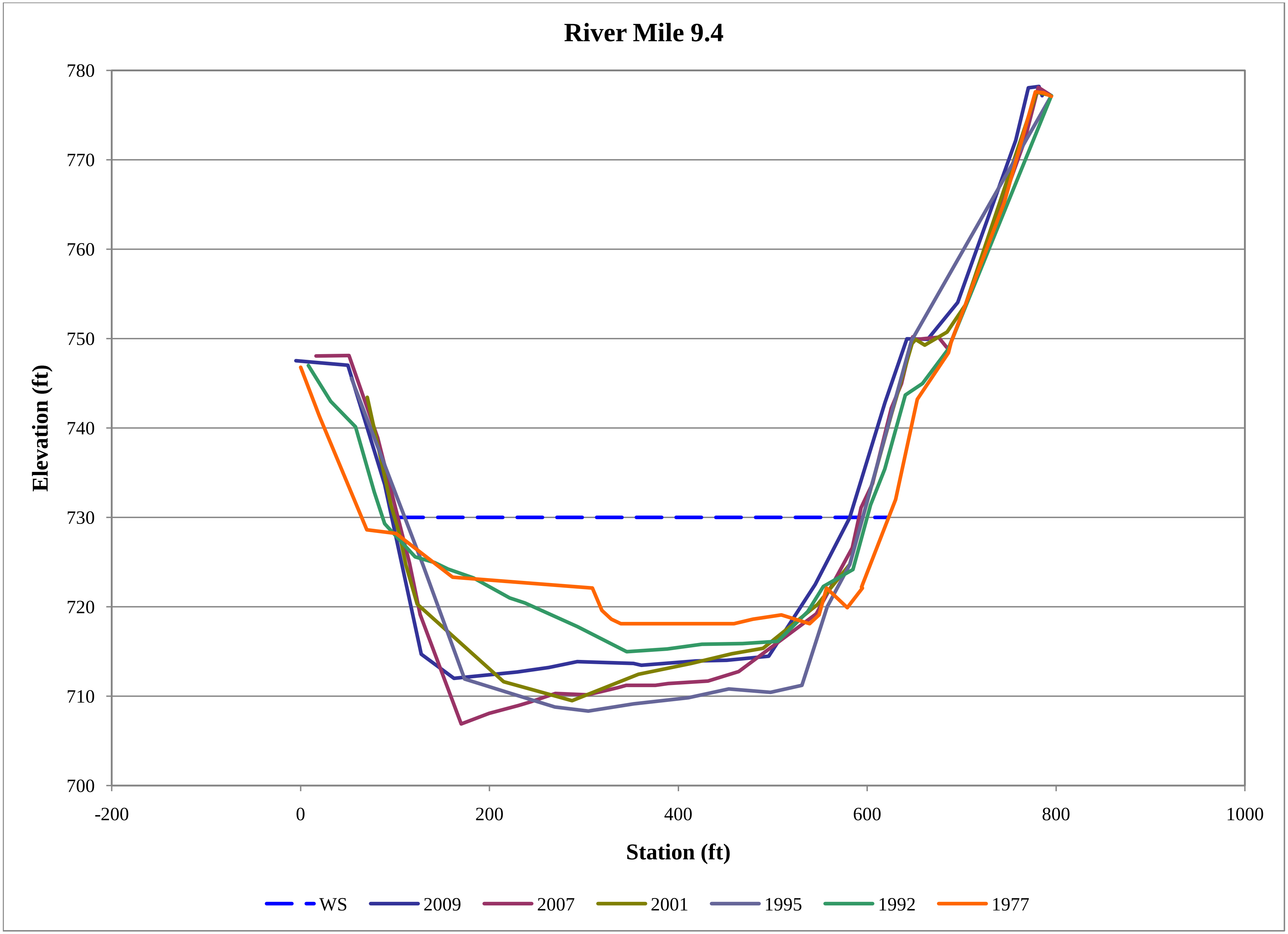
In 2007 and 2009, the Kansas Water Office (KWO) funded the collection of additional cross-sections in stretches of the river not covered by the dredging cross-sections. The KWO cross-sections will serve as a valuable baseline for future analysis.

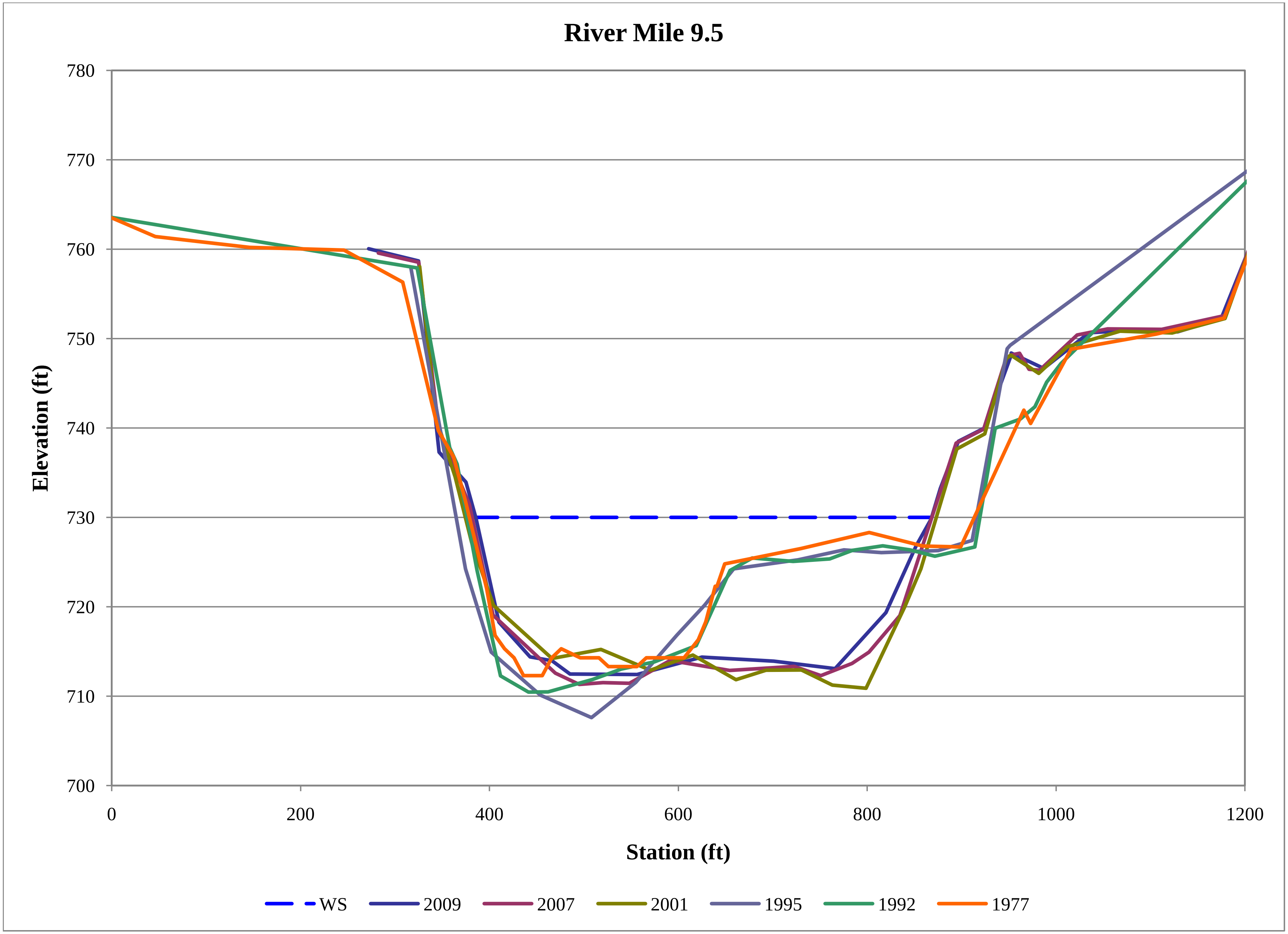
This appendix provides 1) Cross-sectional plots for selected locations on the Kansas River, and 2) An Excel-based cross-section plotting program.

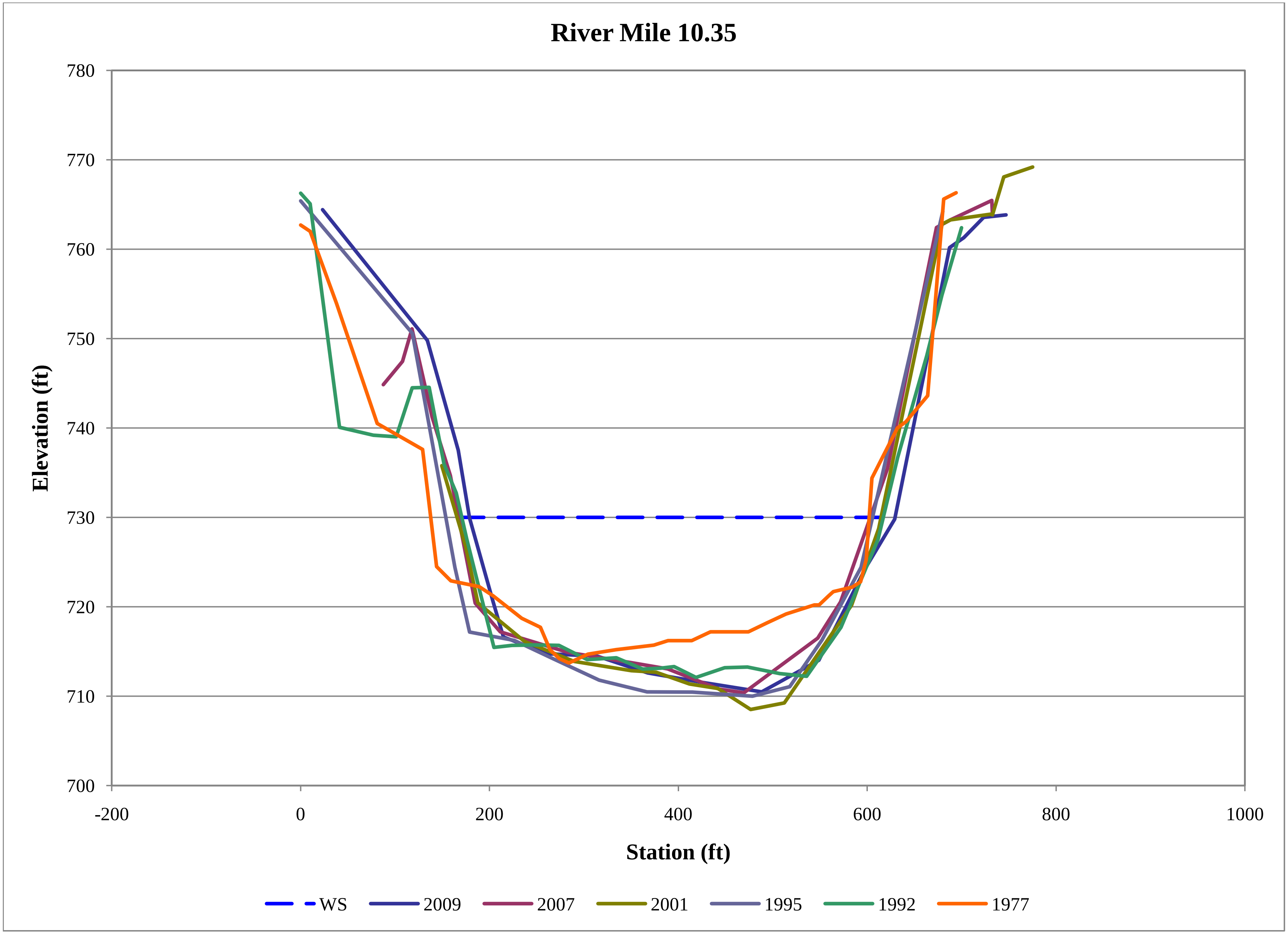
This appendix provides cross-sectional plots from specific locations. These cross-sections were chosen because (1) they were surveyed in 1977 as well as more recently and/or (2) they represented general trends seen in adjacent cross-sections. To make the following plots more readable, only the surveys from 1977, 1992, 1995, 2001, 2007, and 2009 are shown.

The water surface shown on the cross-sectional plots represents the baseline water surface used to compute average depth and channel width parameters. The water surface elevations for the dredging cross-sections were somewhat arbitrarily chosen, but are in the general range of the water surface for the 2-year flow. Several consecutive cross-sections will share the same baseline water surface elevation, and the elevations are not based on geomorphic features. It is unknown how the water surface elevations for the KWO cross-sections were chosen.

An Excel-based cross-section plotting program is included with this appendix. This program was developed by Dr. Bob Barcau to allow easy visualization and plotting of cross-sections at specific locations. The program has not been thoroughly reviewed for completeness or accuracy and is provided “as-is” to be used without USACE warranty or support. The dredging cross-sections and the 2009 KWO cross-sections are included in the plotting program.


River Mile 9.4
Elevation (ft)
780
770
760
750
740
730
720
710
700
Station (ft)
-200
0
200
400
600
800
1000
WS
2009
2007
2001
1995
1992
1977


River Mile 9.5
Elevation (ft)
780
770
760
750
740
730
720
710
700
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992
1977

River Mile 10.35
Elevation (ft)
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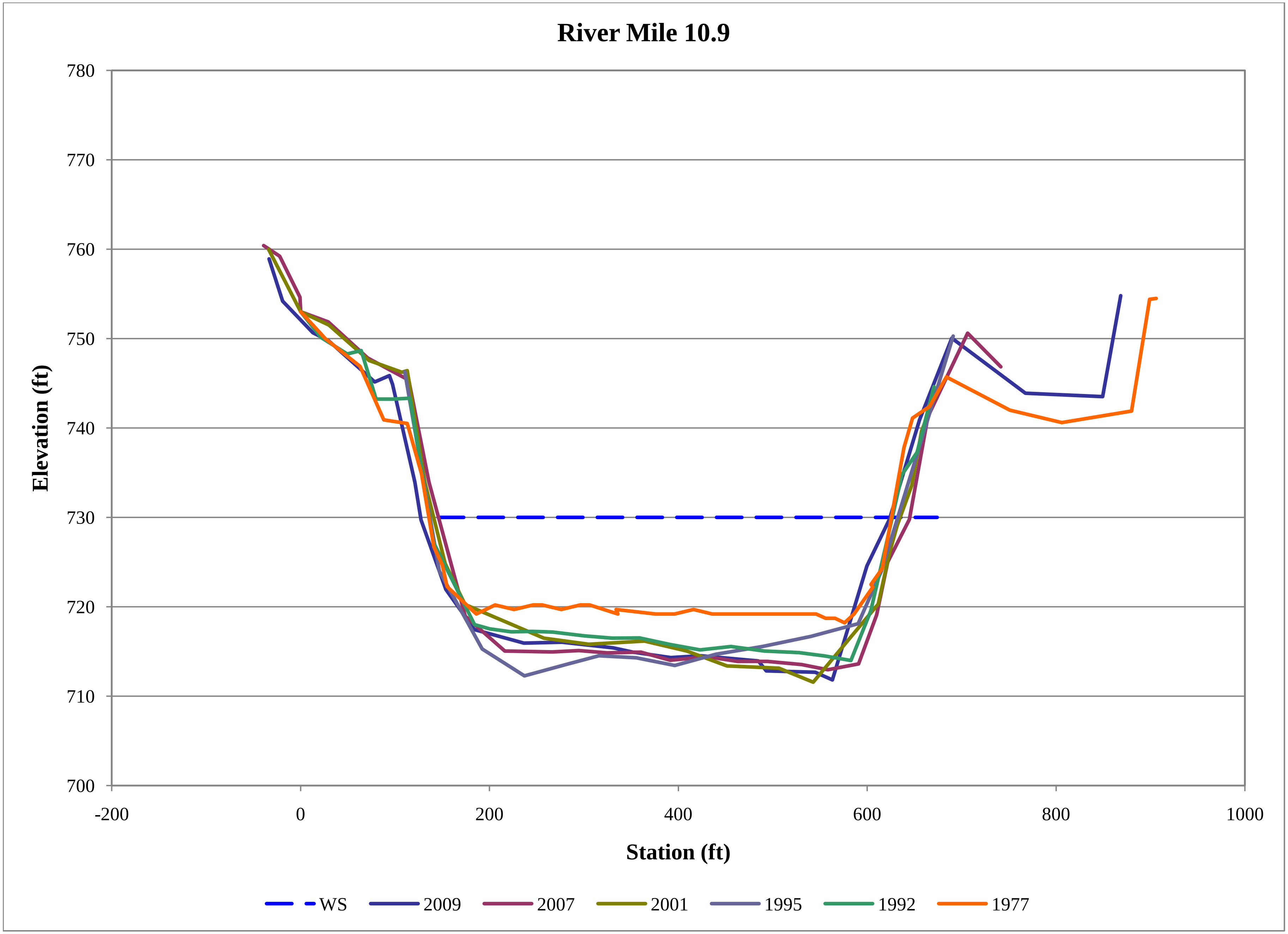
770
760
750
740
730
720
710
700
-200
0
200
400
600
800
1000
Station (ft)
WS
2009
2007
2001
1995
1992
1977


River Mile 10.9
Elevation (ft)
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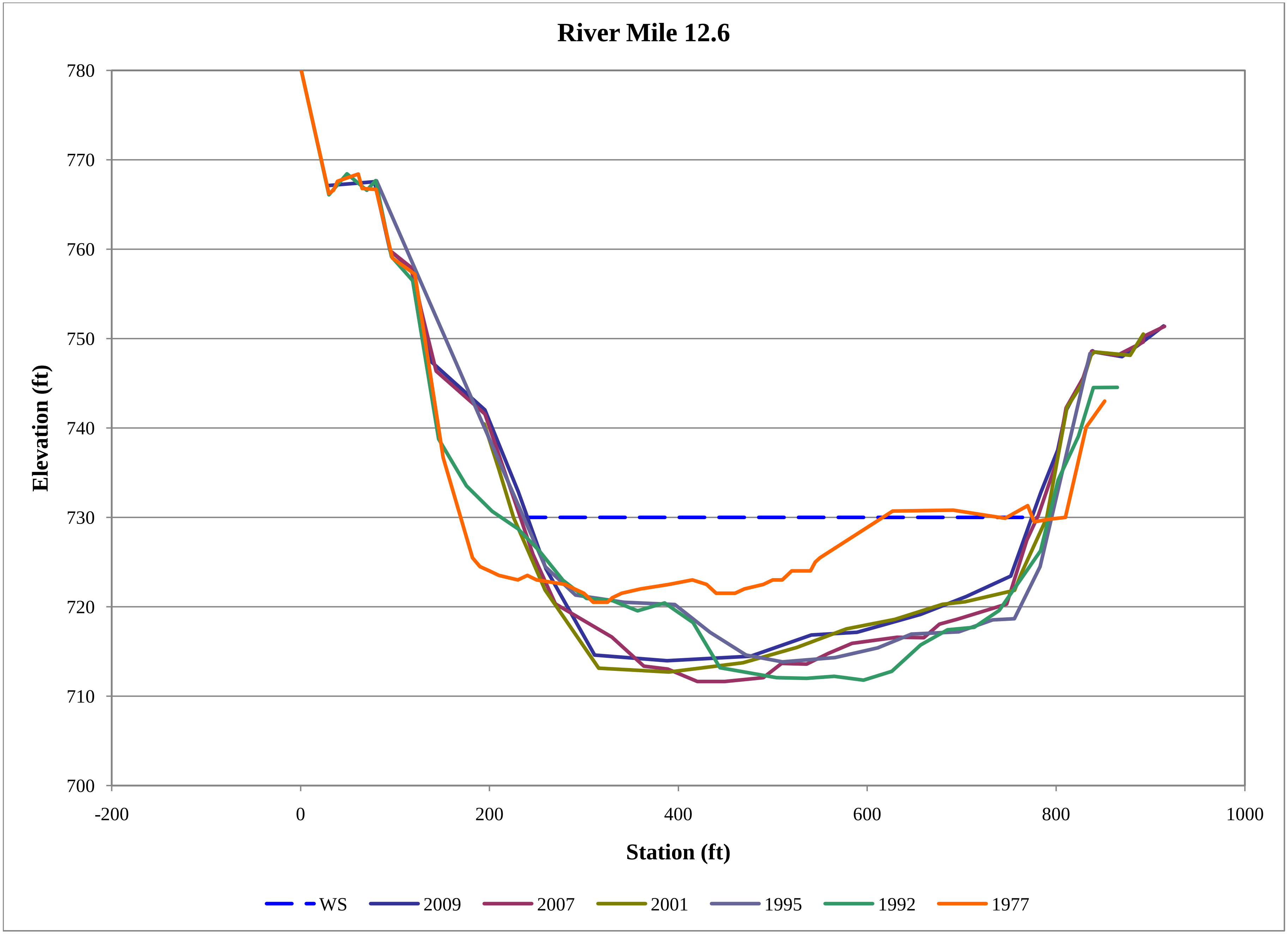
770
760
750
740
730
720
710
700
-200
0
200
400
600
800
1000
Station (ft)
WS
2009
2007
2001
1995
1992
1977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Elevation (ft)
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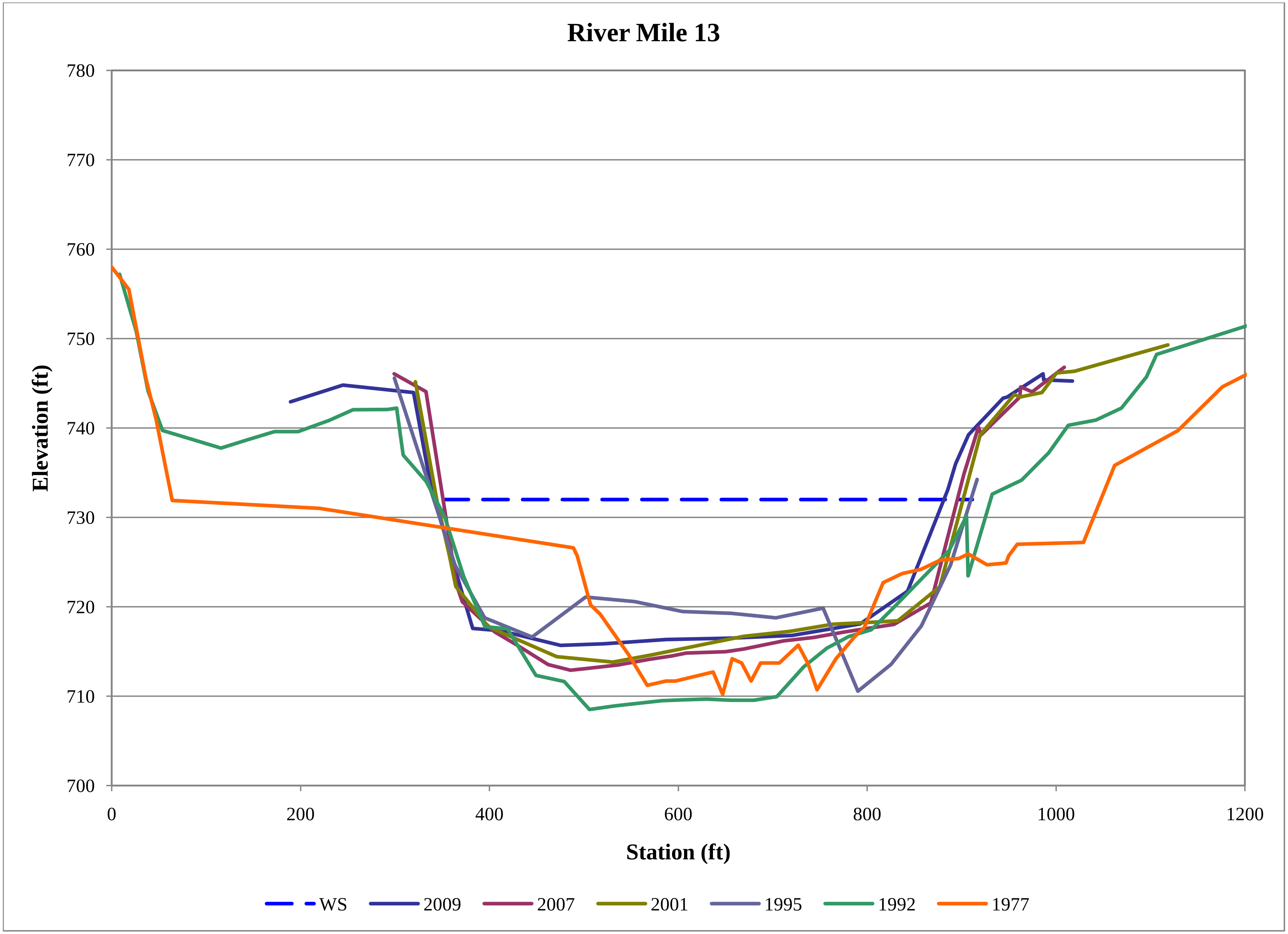
770
760
750
740
730
720
710
700
-200
0
200
400
600
800
1000
Station (ft)
WS
2009
2007
2001
1995
1992
1977


River Mile 13
Elevation (ft)
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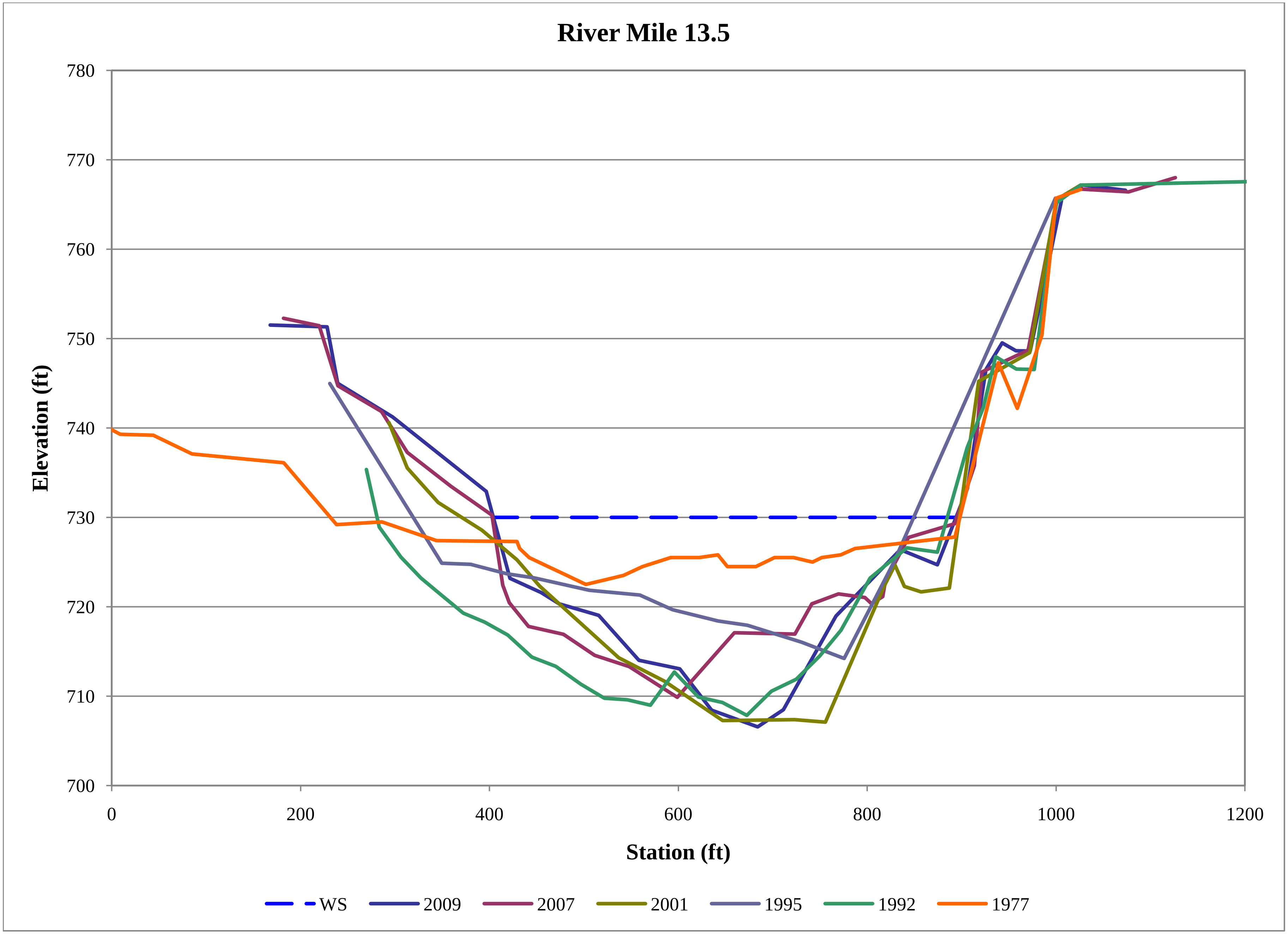
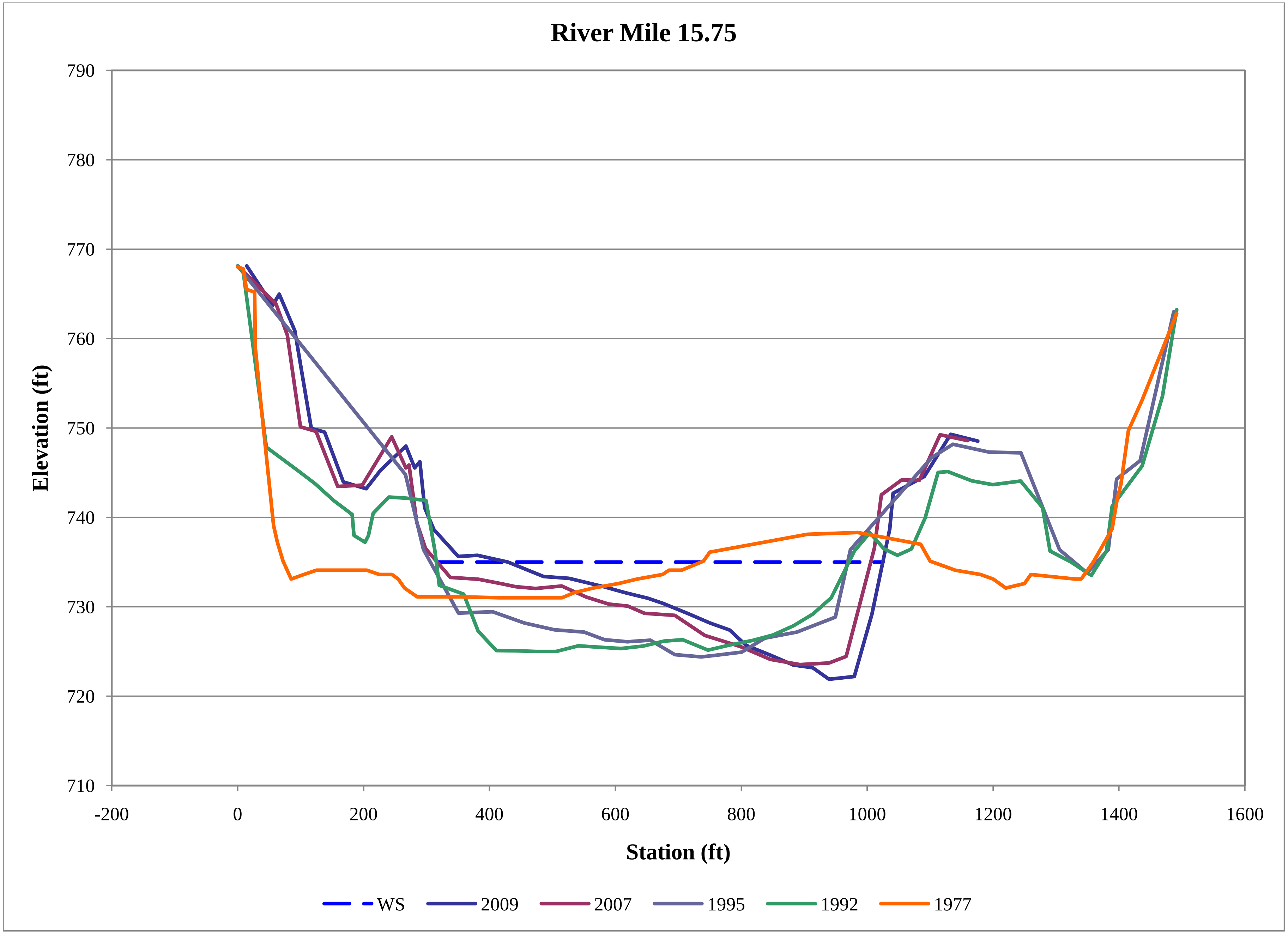
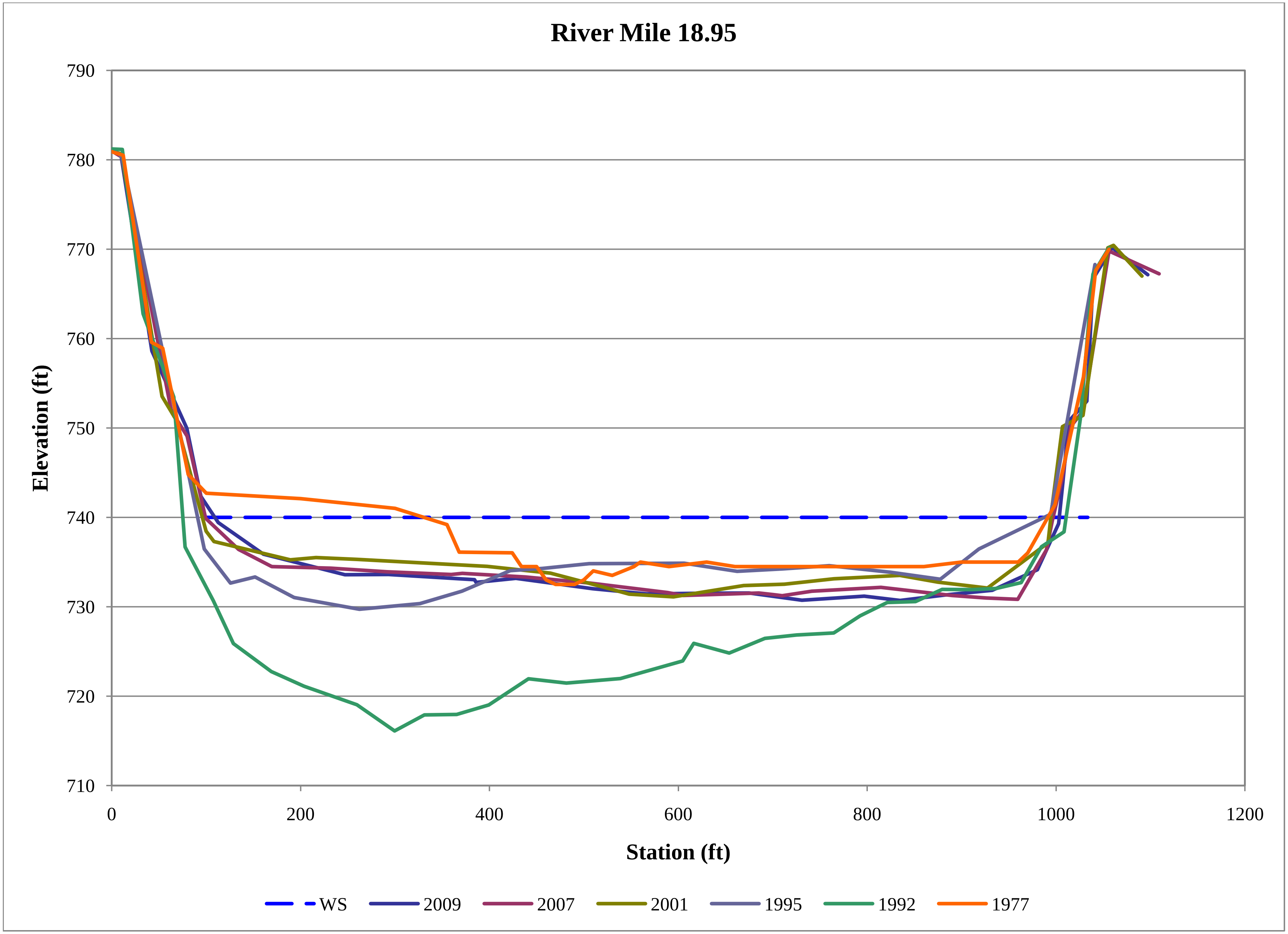
770
760
750
740
730
720
710
700
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992
1977


River Mile 13.5
Elevation (ft)
780
770
760
750
740
730
720
710
700
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992
1977


River Mile 15.75
Elevation (ft)
790
780
770
760
750
740
730
720
710
-200
0
200
400
600
800
1000
1200
1400
1600
Station (ft)
WS
2009
2007
1995
1992
1977


River Mile 18.95
Elevation (ft)
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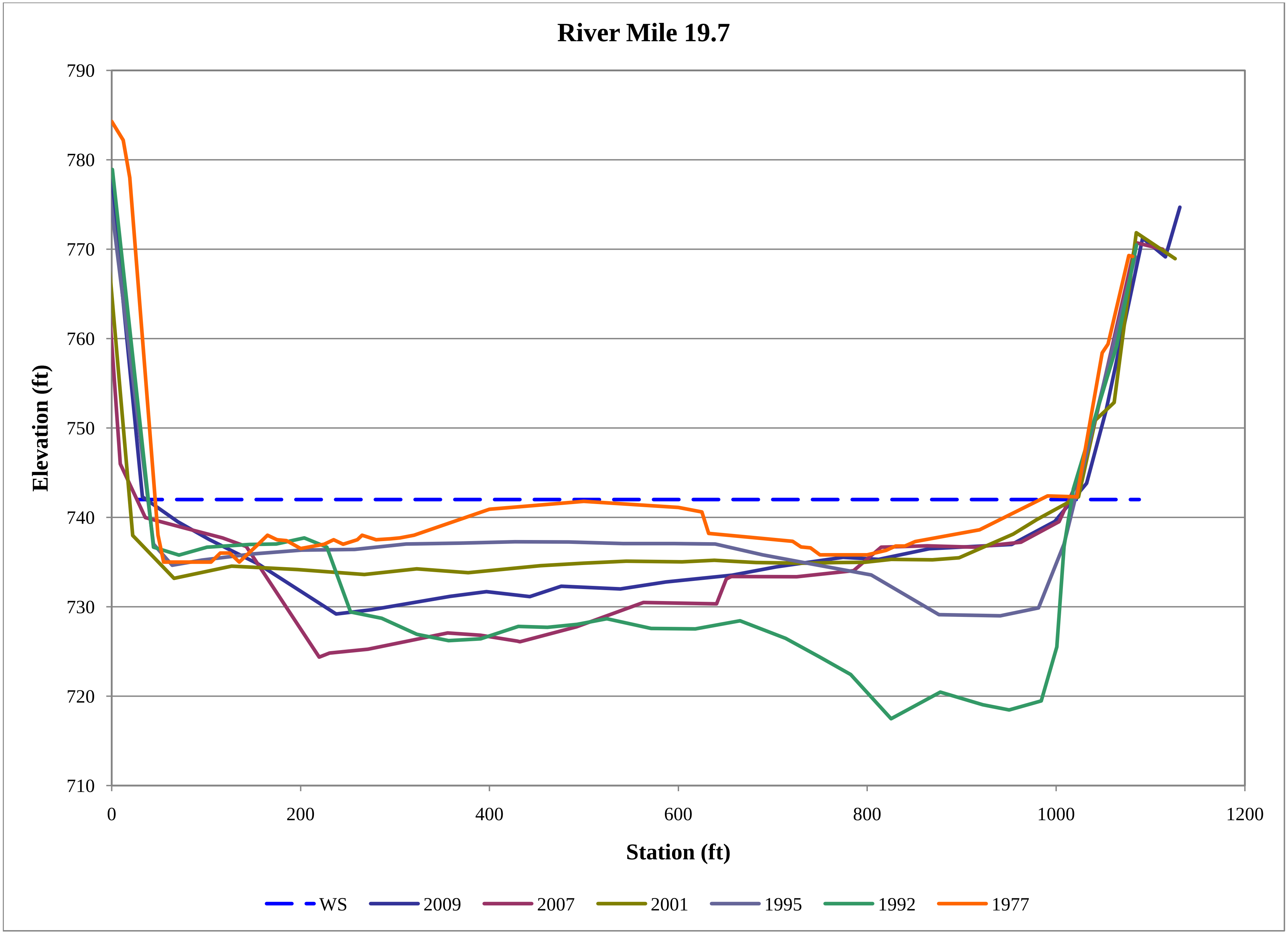
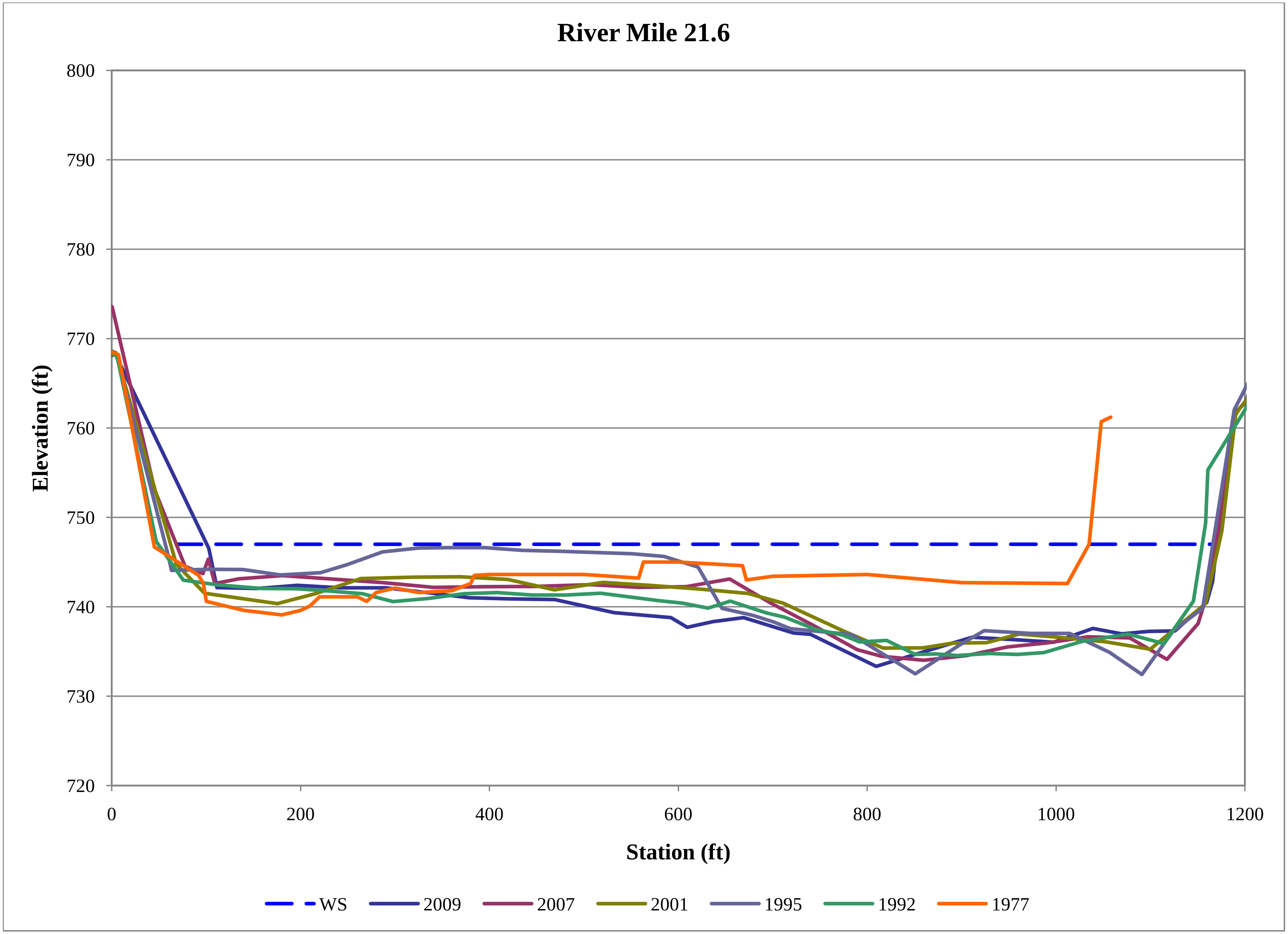
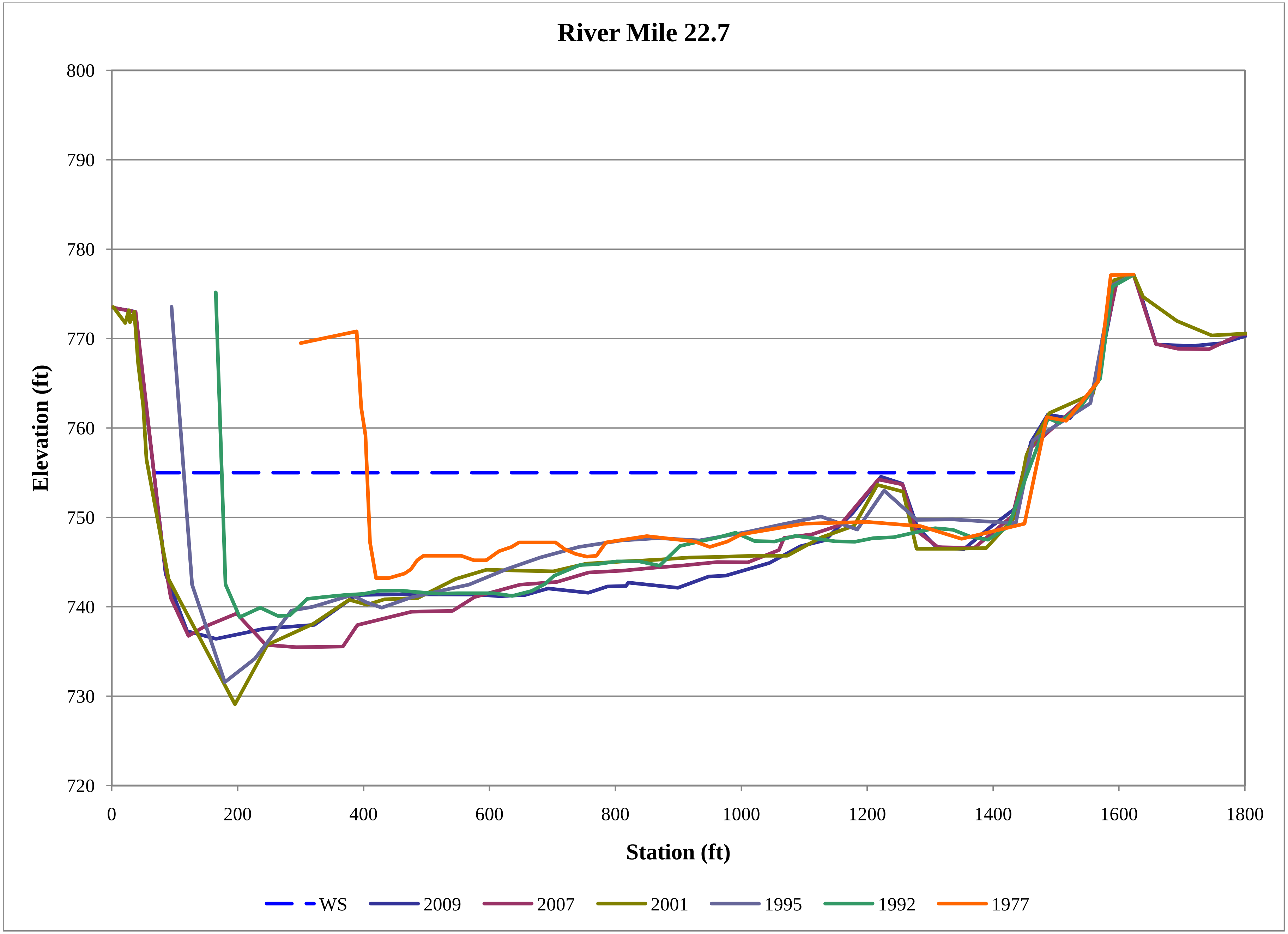
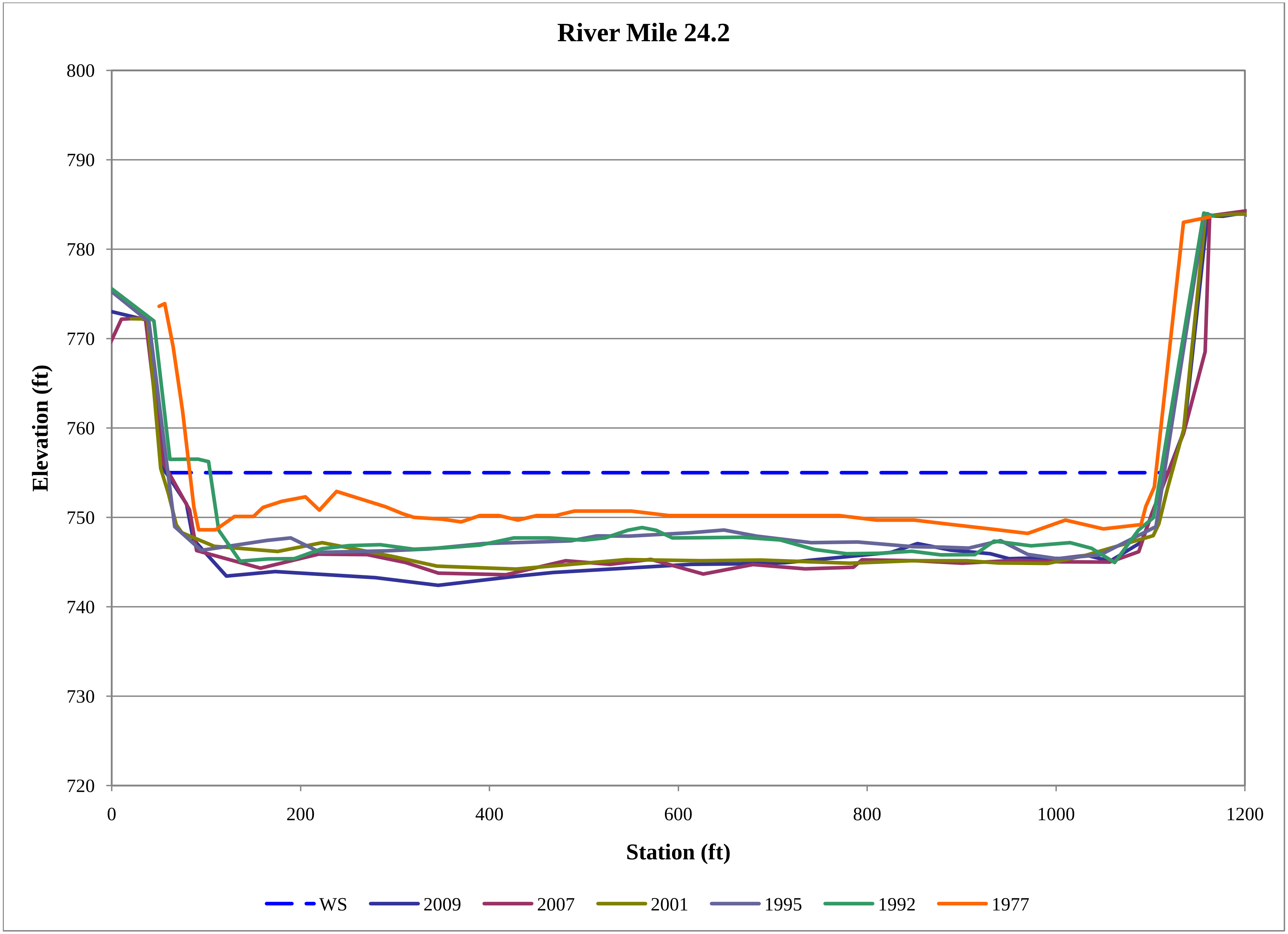
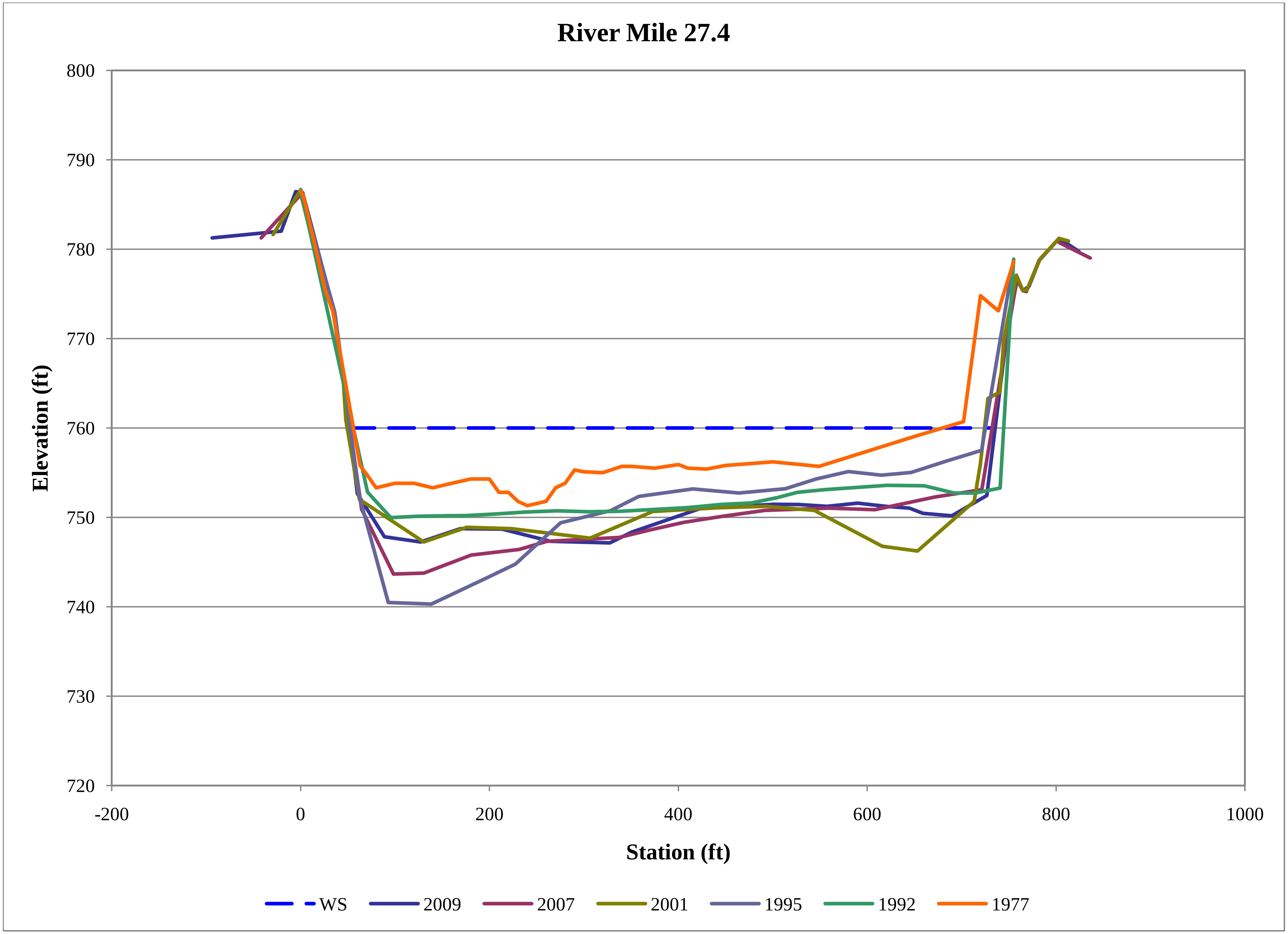
780
770
760
750
740
730
720
710
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992
1977

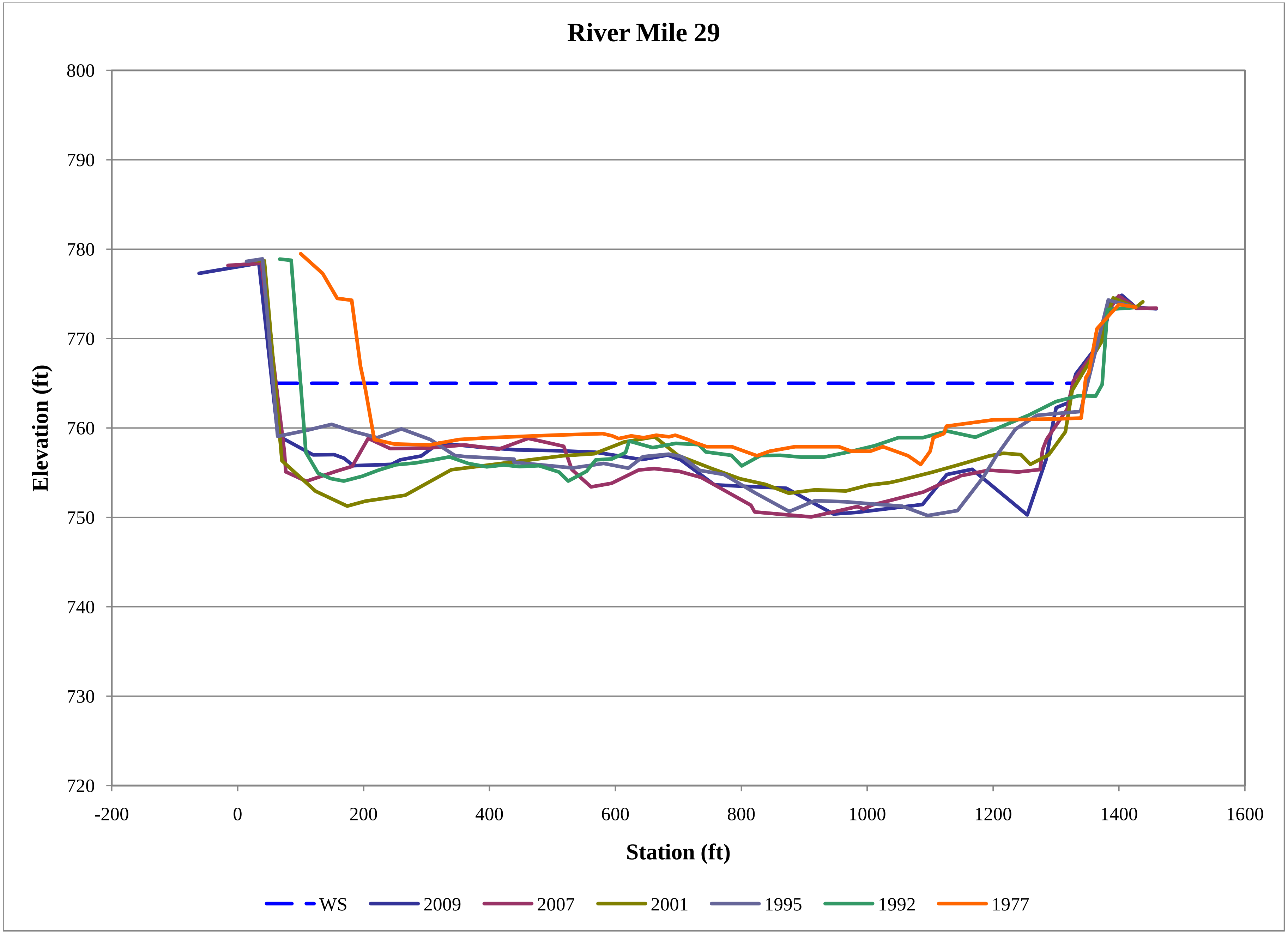

River Mile 19.7
Elevation (ft)
790
780
770
760
750
740
730
720
710
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992
1977

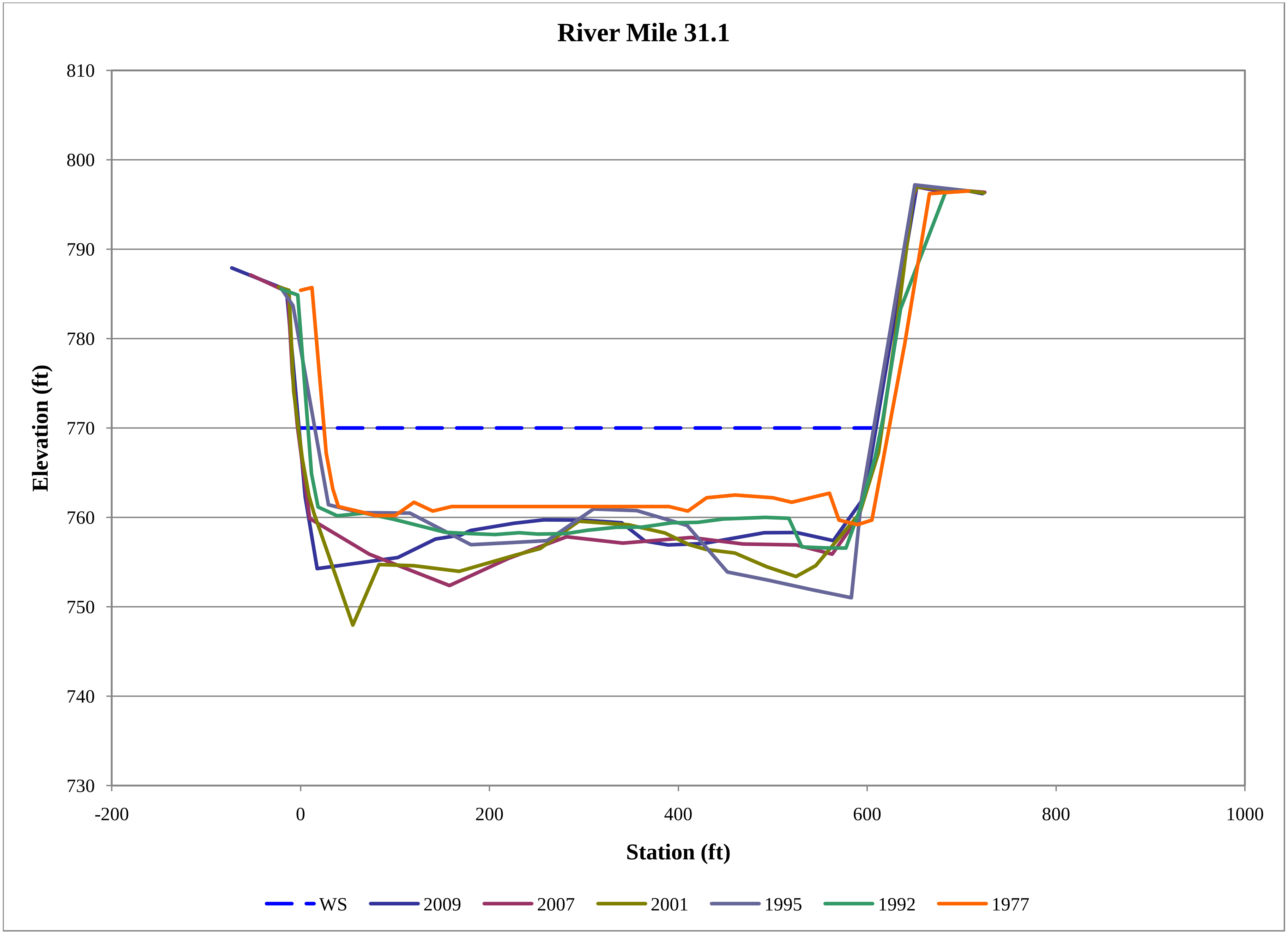

River Mile 21.6
Elevation (ft)
800
790
780
770
760
750
740
730
720
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992
1977

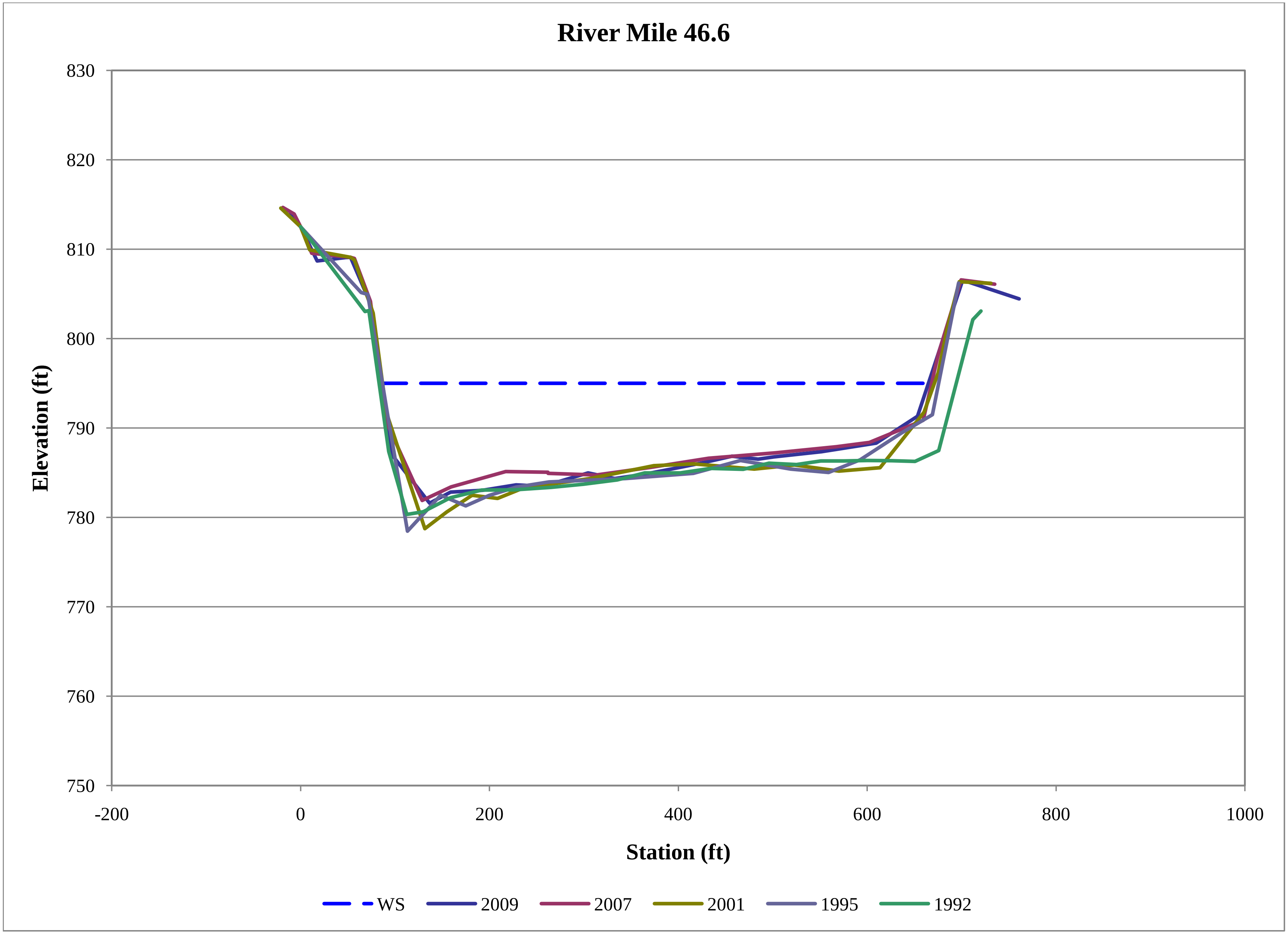

River Mile 22.7
Elevation (ft)
800
790
780
770
760
750
740
730
720
0
200
400
600
800
1000
1200
1400
1600
1800
Station (ft)
WS
2009
2007
2001
1995
1992
1977

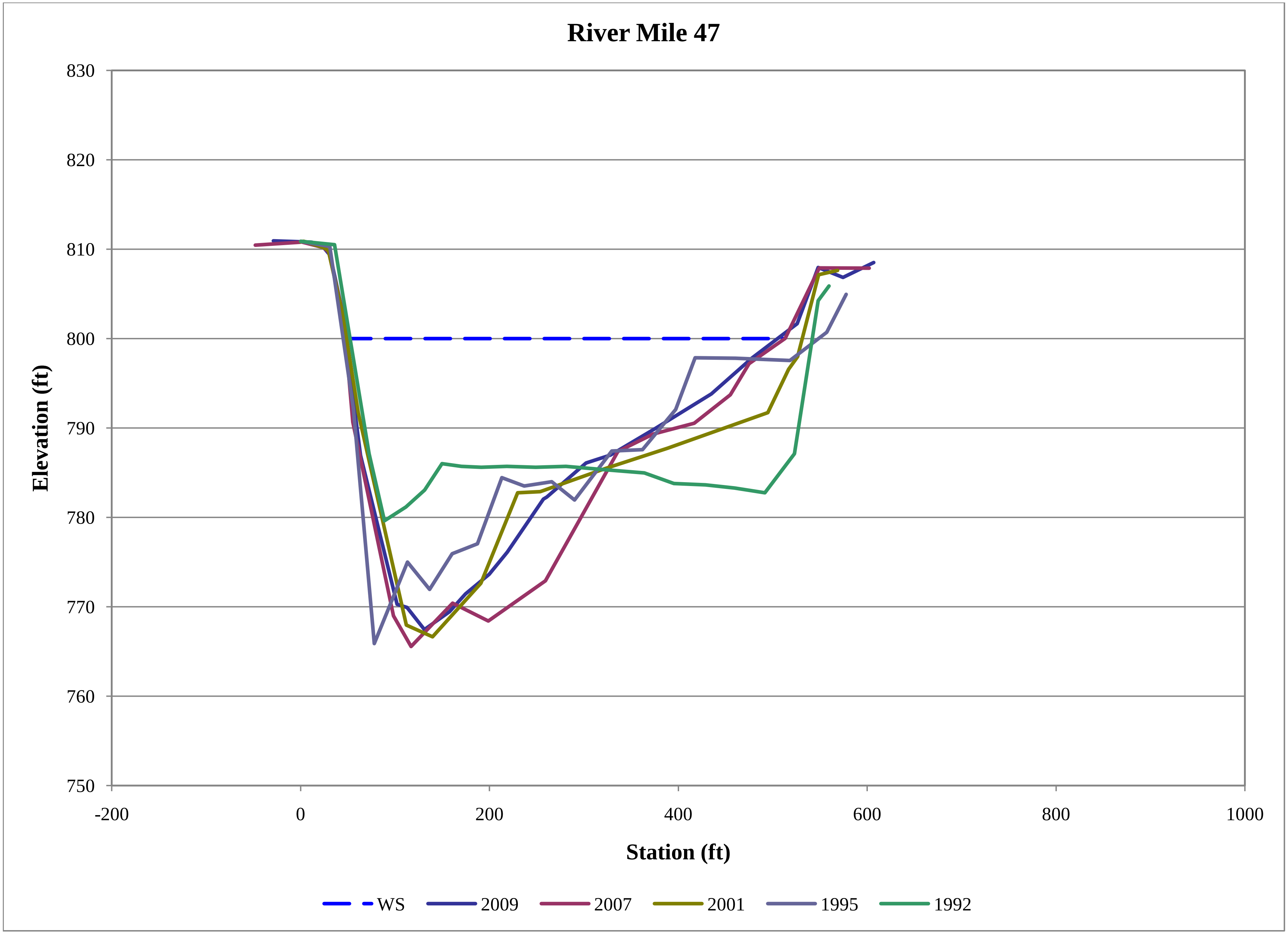

River Mile 24.2
Elevation (ft)
800
790
780
770
760
750
740
730
720
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992
1977

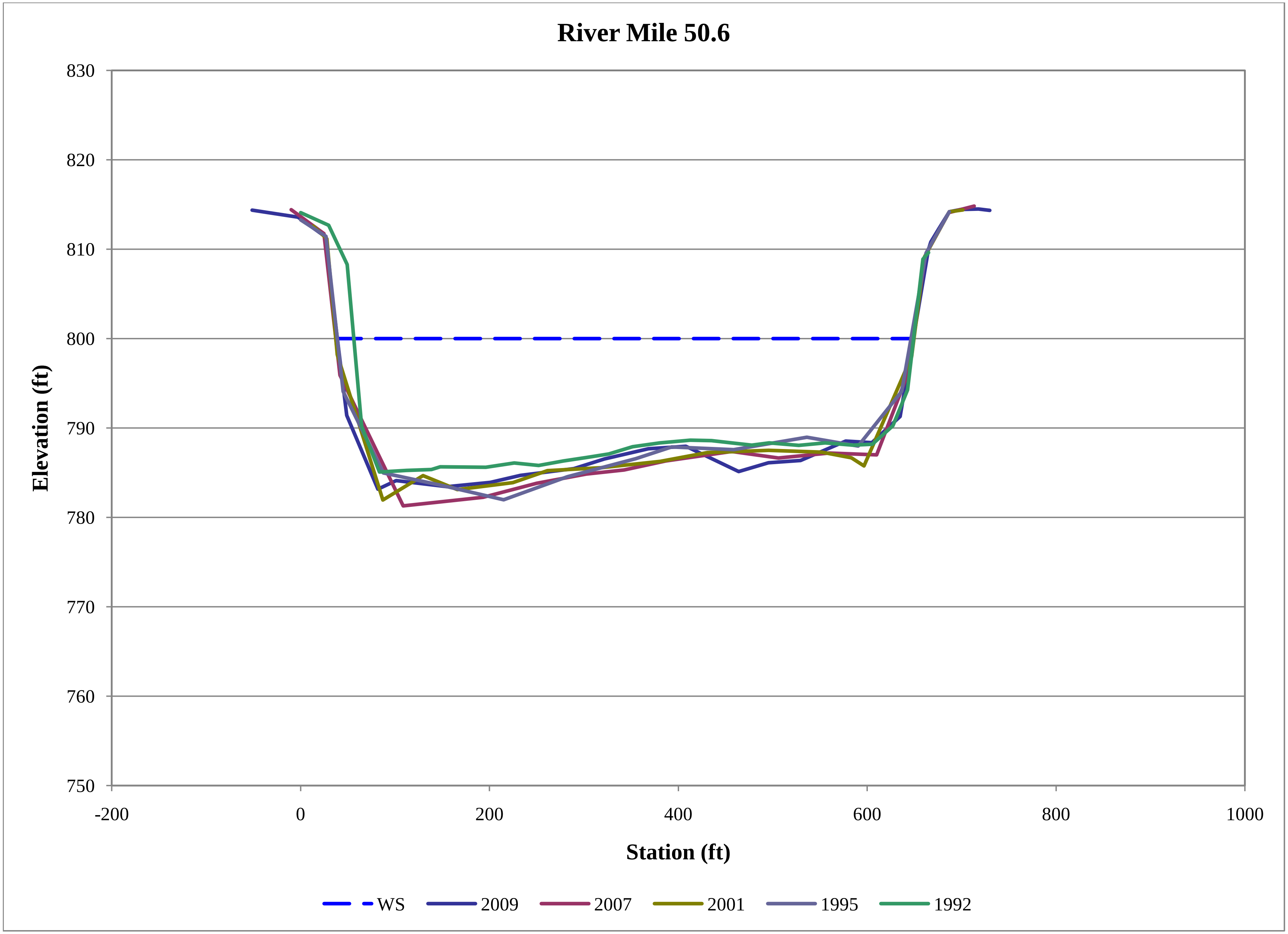

River Mile 27.4
Elevation (ft)
800
790
780
770
760
750
740
730
720
-200
0
200
400
600
800
1000
Station (ft)
WS
2009
2007
2001
1995
1992
1977

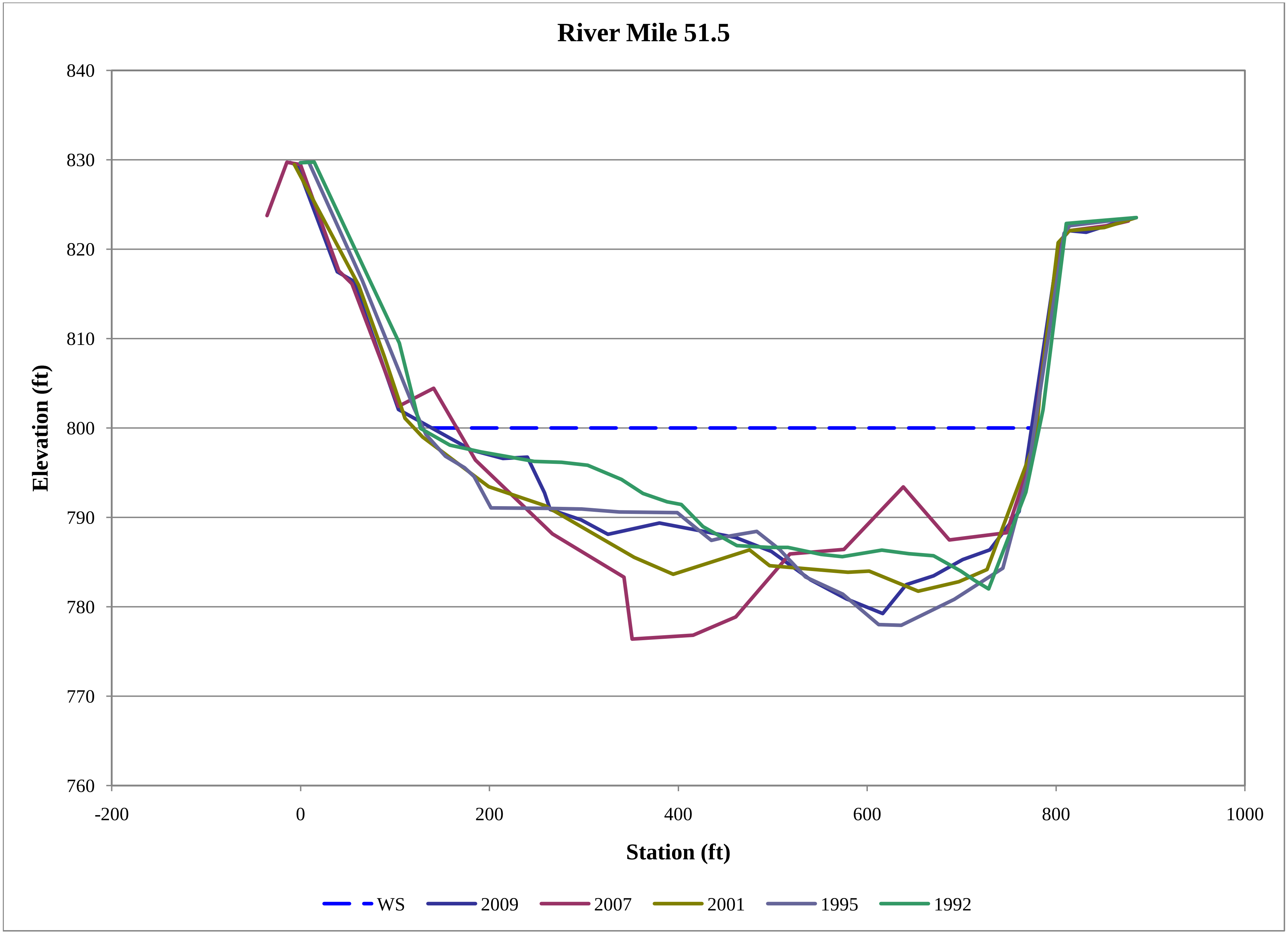

River Mile 29
Elevation (ft)
800
790
780
770
760
750
740
730
720
-200
0
200
400
600
800
1000
1200
1400
1600
Station (ft)
WS
2009
2007
2001
1995
1992
1977


River Mile 31.1
810
800
790
780
770
760
750
740
730
Elevation (ft)
-200
0
200
400
600
800
1000
Station (ft)
WS
2009
2007
2001
1995
1992
1977

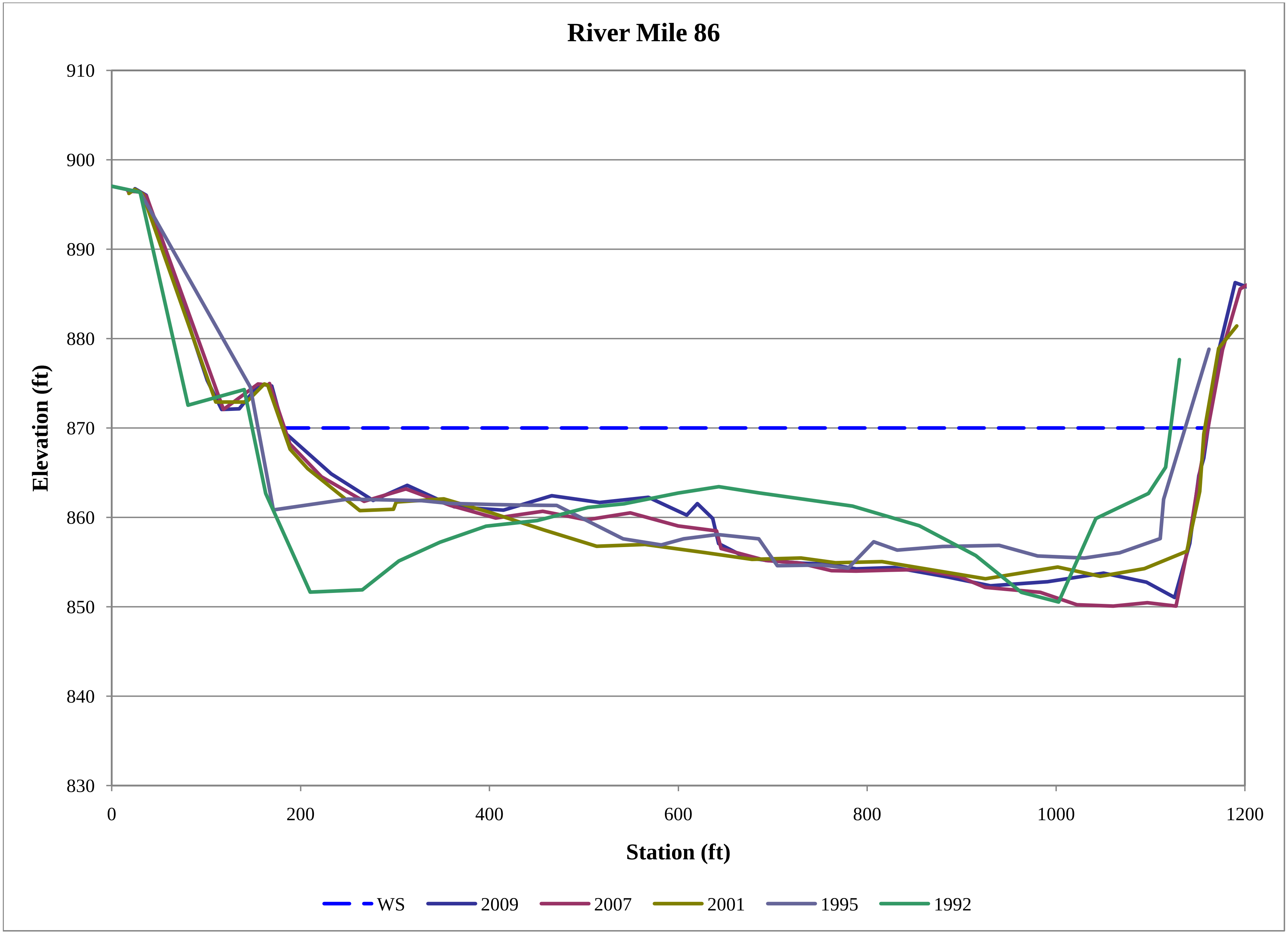

River Mile 46.6
830
820
810
800
790
780
770
760
750
-200
0
200
400
600
800
1000
Elevation (ft)
Station (ft)
WS
2009
2007
2001
1995
1992

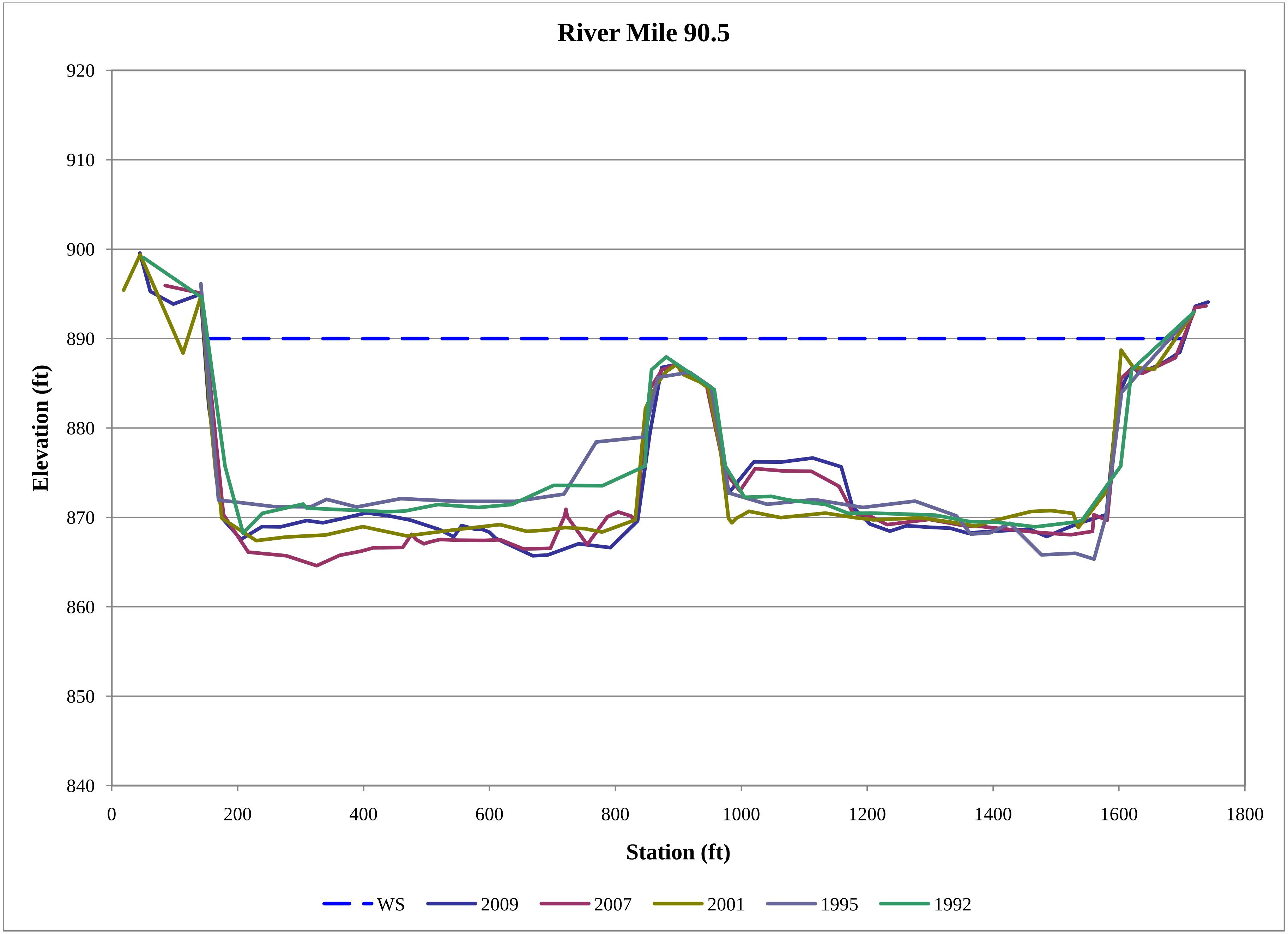

River Mile 47
830
820
810
800
790
780
770
760
750
Elevation (ft)
-200
0
200
400
600
800
1000
Station (ft)
WS
2009
2007
2001
1995
1992

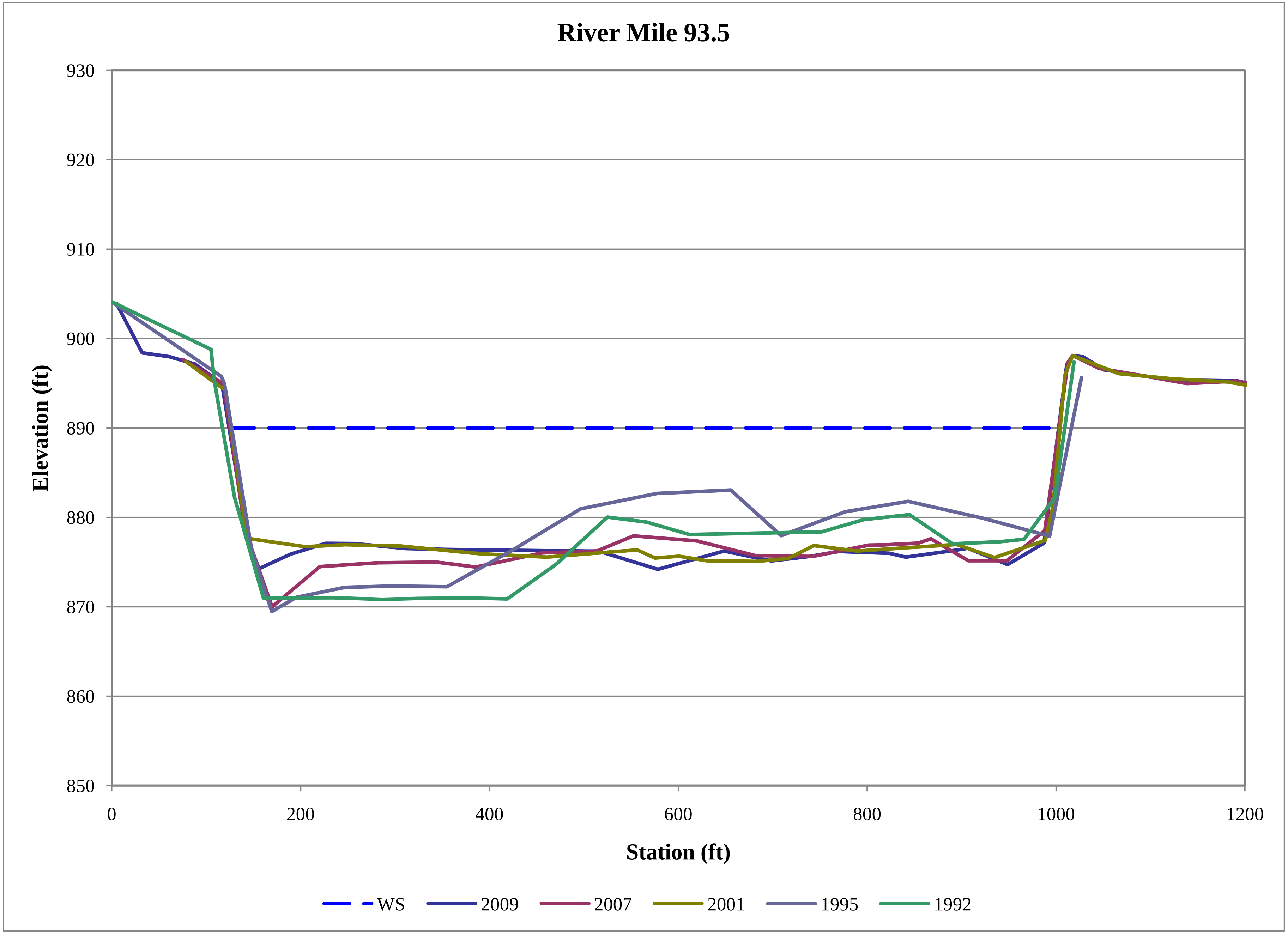

River Mile 50.6
Elevation (ft)
830
820
810
800
790
780
770
760
750
-200
0
200
400
600
800
1000
Station (ft)
WS
2009
2007
2001
1995
1992



River Mile 51.5


River Mile 86
910
900
890
880
870
860
850
840
830
0
200
400
600
800
1000
1200
Elevation (ft)
Station (ft)
WS
2009
2007
2001
1995
1992


River Mile 90.5
Elevation (ft)
920
910
900
890
880
870
860
850
840
0
200
400
600
800
1000
1200
1400
1600
1800
Station (ft)
WS
2009
2007
2001
1995
1992


River Mile 93.5
930
920
910
900
890
880
870
860
850
Elevation (ft)
0
200
400
600
800
1000
1200
Station (ft)
WS
2009
2007
2001
1995
1992