US Army Corps
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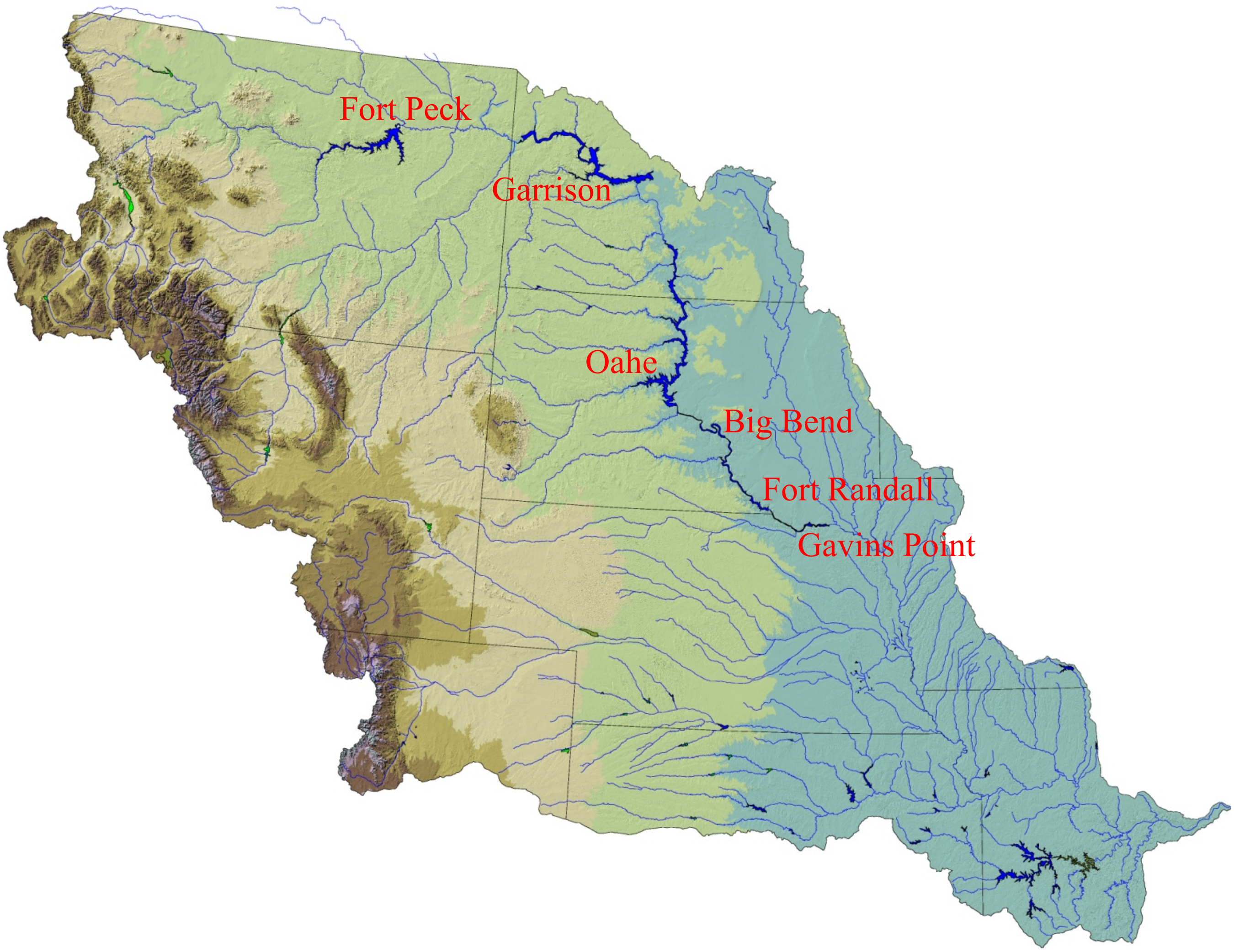
Northwestern Division

Missouri River Stage Trends

Technical Report



Missouri River Basin Water Management Division
Omaha, Nebraska

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MISSOURI RIVER STAGE TRENDS

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I. INTRODUCTION

A. Purpose and Scope

The purpose of this report is to present the data used and results of the update of the Missouri River stage trends analysis. Trends in Missouri River stages are presented for tailwater locations, the navigation channel and headwater locations. Tailwater locations are subject to scour, generally resulting in a lowering of the river stages over time. Headwater locations are subject to sediment deposition, resulting in an increase in river stages over time. Locations along the navigation channel are subject to a variety of factors that can cause increases or decreases in stages over time.

Stage-discharge records for the Missouri River are available for almost 100 years for each of the eight key main stem streamgaging stations downstream of Sioux City. Although a few isolated stage-discharge measurements were made in the early years, it was not until 1929 that a collection of systematic and continuous stage-discharge records by the United States Geological Survey (USGS) began. It was at about this same time that construction of Missouri River improvement works was initiated to stabilize and channelize the river. In the mid-1950s a consultant's board completed an analysis of the effects of these works on Missouri River levels. The board's report of November 1955 concluded that the navigation and stabilization works may have caused an increase in stages near bankfull flows of 2 feet between Omaha and the mouth, and possibly as much as 1 foot from Omaha to Sioux City.

The board also opined that the low water stage of the Missouri River had been lowered on the order of 1 foot. Since publication of that report, the Missouri River Mainstem Reservoir System (System) has been completed and has significantly altered the flow regime throughout most of the length of the Missouri River. The control of floods and the supplementation of low flows by these mainstem and tributary reservoirs have undoubtedly contributed to changes in the stage-discharge relationship on the Missouri River since the System was closed in 1967, but no attempt has been made in this report to differentiate between the effects of this control and those exerted by the river control works, other encroachments in the floodplain, or natural events.

This report is an update to a report titled "*Missouri River Stage Trends, MRBWM Technical Report*" published in September 2017. Similar reports titled were published in September 1972 and updated in June 1975, August 1981, December 1985, September 1987, February 2000, April 2004, January 2007, April 2010, and August 2012.

B. Missouri River Length Change

Since 1890 the length of the Missouri River between Sioux City and the mouth has been shortened by about 75 miles (almost 10 percent). Over 80 percent of this shortening has been concentrated in three reaches: Sioux City to Omaha, Nebraska City to St. Joseph, and Kansas City to Waverly. The length of the Missouri River reaches for the years 1890, 1941, and 1960 are presented in Table 1.

Table 1
Missouri River Channel Lengths

River Reaches	Missouri River Length Between Stations - in Miles			1890-1960 Length Change	
	1890	1941	1960	Miles	%
Sioux City to Omaha	147.7	128.0	116.4	-31.3	-21.2
Omaha to Nebraska City	52.1	52.7	54.0	1.9	3.6
Nebraska City to St. Joseph	129.0	119.3	114.0	-15.0	-11.6
St. Joseph to Kansas City	88.0	82.5	81.8	-6.2	-7.1
Kansas City to Waverly	91.5	80.3	72.7	-18.8	-20.5
Waverly to Boonville	93.8	101.0	96.8	3.0	3.2
Boonville to Hermann	101.9	99.3	98.7	-3.2	-3.1
Hermann to Mouth	103.5	96.9	97.9	-5.6	-5.4
Total (Sioux City to mouth)	807.5	760.0	732.3	-75.2	-9.3

C. Source of Data for Stage Trend Analyses

Stage trends, observed in the System reservoir tailwaters for three to five constant releases, are presented on Plate 1 through Plate 9. Stage trends at each of the nine Missouri River streamgaging stations for four to eight constant flow levels are presented on Plate 10 through Plate 24. The flows shown for the streamgaging stations range from 10,000 to 500,000 cfs, depending on the location of the streamgaging station.

The sources of data for these plates were the compilations of rating curves, which were initially prepared in the early 1950s in connection with the consultants' study of the effects of the navigation and stabilization works. These rating curve compilations have been kept up-to-date by documenting and plotting the USGS stage-discharge measurements. The open-water rating curves presented for each station along the navigation channel are frequently seasonal in nature, being 1 or 2 feet higher in the summer than in the spring and fall. Measurements both in the laboratory and in the field show that the rate at which sediment is transported in suspension varies significantly with water temperature. The colder the water, the more viscous it becomes and the slower a particle will settle out. Thus, sediment will be transported more easily at colder temperatures. The stage-discharge measurement points which defined the summer rating curve were given the most weight in developing the stage trends. The stage-discharge data used in developing the stage trend curves for the Missouri River streamgaging stations along the navigation channel and at Bismarck, ND were obtained from the USGS.

Hourly reservoir releases and tailwater data were obtained from the Missouri River Basin Water Management's (MRBWM) Corps Water Management System Oracle database.

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II. TAILWATER STAGE TRENDS

A. General

The release of the essentially sediment-free water through the System dams has resulted in a lowering of the downstream tailwater elevation. Pre-construction estimates predicted that the water surface elevations immediately downstream of the dams would lower a maximum of 15 feet at each project where no fixed downstream scour control existed. Turbine elevations were set to account for this eventual lowering. At Big Bend Dam, the tailwater elevations are controlled by the Fort Randall pool, which is immediately downstream of Big Bend Dam. Releases from Oahe Dam enter a short reach of open river before entering the headwaters of the Big Bend reservoir. The Fort Peck, Garrison, Fort Randall, and Gavins Point projects release directly into open-river channel reaches that lie in alluvial deposits. The tailwater rating curves are developed for Garrison, Oahe, Fort Randall and Gavins Point by the Omaha District's River and Reservoir Engineering Section of the Hydrologic Engineering Branch and are published annually. To make trends more apparent, plates present curves every fifth year (e.g., 2005, 2010, 2020). Due to record releases in 2011 from the spillways and lack of steady releases from the powerhouses, caution should be used in making any analysis using only the 2011 data. Tailwater trends are monitored annually at all of the projects and are discussed in the following paragraphs.

B. Fort Peck

Construction of the Fort Peck project began in 1933. Dam closure was made in 1937, and the project was placed in operation for purposes of navigation and flood control in 1938. Powerplant No. 1 at Fort Peck became operational in 1943 and Powerplant No. 2 came online in 1961. Because of the location of the two powerplants, determination of the tailwater stage-discharge rating relationship is quite complex. The tailwater stage at either powerplant is a function of the releases at both powerplants. Prior to 1956, Fort Peck was the only System project with a significant amount of accumulated storage. As a consequence, Fort Peck releases in the 28,000 cfs range were frequently required for lower Missouri River navigation. Since late 1956 when several of the other mainstem System projects were online and with the exception of 1975, 1997, 2018, and 2011, Fort Peck releases have not been significantly in excess of the powerplant capacity of the project, which is about 13,500 cfs. Previous studies have indicated that the tailwater rating curve has been stable since about the 1960s. Because of the complex relationship that defines the tailwater rating curve and the apparent stability of that relationship, no updates to the rating curve have been made since 1966. Therefore, the Fort Peck tailwater stage trend was not evaluated for this update.

C. Garrison

Construction of the Garrison project was initiated in 1946. Dam closure was made in 1953; powerplant operation came online in 1956. Since 1956, Garrison releases have generally been through the power facilities, which have a maximum capacity of about 41,000 cfs. Exceptions occurred in 1975, 1997, 2011, 2018, and 2019. In 1975, releases of 65,000 cfs were required for over one month. In 1997 releases reached 59,100 cfs and averaged 57,300 cfs during July. Releases in 2011 exceeded 100,000 cfs for 71 days and releases peaked at 150,600 cfs on June 25. In 2018 releases exceeded the powerplant capacity for three months, peaking at 60,500 cfs, and averaged 58,700 cfs in July. Releases in 2019 exceeded the powerhouse capacity for four months with a peak of 47,000 cfs in October. Plate 1 presents Garrison tailwater rating curves every fifth year beginning in 1955 and extending through 2020. As illustrated by those curves, a stage lowering is evident at each 5-year update interval with each curve dropping 1 to 2 feet until about 1980. From 1980 to 1995, the total shift was approximately 1 foot. The rate of degradation significantly lessened from 2000 to 2005, which were years of lower-than-average releases. The 2010 curve is slightly higher than 2005, again occurring in years with lower-than-average releases. Due to record releases in 2011, the 2015 curve lowered about a foot from the 2010 curve. The 2020 curve continued to show the degradation trend at the lower end of the releases, lowering about a foot from the 2015 curve. However, as releases increased, the two curves started to converge as releases approached 40,000 cfs.

Plate 2 shows the trend of the Garrison tailwater stages for releases in 10,000-cfs increments ranging from 10,000 to 40,000 cfs. There has been a lowering of the tailwater stage by about 11 feet since closure of the dam. During the period from 1980 through 1996, the trend had been relatively stable, decreasing at a rate less than 0.1 foot per year. Plate 2 also shows a sharp increase in the stage lowering during 1997-98, which coincides with higher-than-average releases. From 1998 to 2010 the rate of tailwater degradation had decreased to almost zero; releases from 2000 through 2010 were below average. After record releases of 150,600 cfs were made in 2011, releases of 30,000 and 40,000 cfs show a sharp stage lowering of about 1.5 feet through 2013. A lowering trend is evident, to a lesser extent, at releases of 10,000 and 20,000 cfs. The stage trends decline about 0.5 foot at 10,000 cfs and slightly more than 1 foot at 20,000 cfs. Below-average releases in 2013 resulted in aggradation at the 30,000 and 40,000 cfs release rates, but the overall degradation trend continues through 2016. Stage trends through 2020, at releases of 30,000 and 40,000 cfs, are fairly stable, with a slight increase in 2019 due to prolonged high releases with little to no peaking - allowing the tailwater elevation to stabilize. Thus, the slight increase is not likely due to actual aggradation occurring at the higher releases. Conversely, the stage trends at releases of 10,000 and 20,000 cfs continue to trend downward.

D. Oahe

Oahe Dam was closed in 1958. In April 1962, the first power unit came online with all units operational in July 1966. Since 1962, releases from Oahe have generally been through the power facilities, which have a maximum powerplant capacity of about 54,000 cfs. In 2011, releases exceeded 50,000 cfs for 132 days; 100,000 cfs for 82 days; 150,000 cfs for 34 days; and peaked at 160,300 cfs on June 20. Sustained releases above the powerplant capacity also occurred in 2019 from late August through early December. Tailwater rating curves from every fifth year beginning in 1965 and extending through 2020 are shown on Plate 3. The Big Bend powerplant became fully operational in 1966. As a re-regulation project, the Lake Sharpe pool levels are typically maintained in a narrow operating range from 1419-1421 feet.

Generally, a change of about 1 foot or less in Oahe tailwater stages has occurred from one curve to another. From 2000 through 2015 it appears that the rate of stage lowering is greater at the higher flows. Between 2015 and 2020, stages showed an increase of over a foot at the 50,000 cfs release but converged near the 10,000 cfs release.

Stage trend plots for releases in 10,000-cfs increments ranging from 10,000 to 50,000 cfs are shown on Plate 4. The overall trend at all releases, with the exception of the 10,000 cfs release, is a slight lowering of stage. The stage trends for releases of 10,000 cfs have been stable over the past 50 years. The exception is slight degradation from 1995 through 2010, with aggradation in recent years bringing the trend back near pre-2011 elevations. Between 2015 and 2020, there has been an upward trend in the tailwater for releases at and greater than 20,000 cfs.

Oahe is a hydropower peaking project and rarely has steady releases for extended periods of time. Because of that, slight variances in stage verses release will occur between years. Within a day, Oahe's hourly release may fluctuate from over 50,000 to 0 cfs. However, during high runoff years, Oahe has periods where releases rarely go to 0 cfs and, therefore, the tailwater has a chance to more completely stabilize. This is evident in Plate 4 for the mid-1990s, and 2018 and 2019, when sustained releases were high with little to no fluctuation, causing the tailwater elevation to increase over half a foot.

Overall, the tailwater rating curve at Oahe seems to be very stable with the stages fluctuating within two feet at each of the different releases for the period of record shown (1965-2020).

E. Big Bend

Big Bend releases directly into the Fort Randall reservoir. Because Big Bend tailwater stages are influenced by Fort Randall pool elevations, no stage trend analysis was completed for Big Bend.

F. Fort Randall

Construction of the Fort Randall project was initiated in 1946, with closure made in 1952. Initial power generation began in 1954 with the final unit coming online in 1956. Since 1956, releases from Fort Randall have generally been made through the power facilities, which have a maximum powerplant capacity of about 44,500 cfs. In 2011, releases exceeded 50,000 cfs for 146 days; 100,000 cfs for 85 days; 150,000 cfs for 37 days; and peaked at 160,000 cfs on July 26. More recently, extended releases above 45,000 cfs occurred in 2014, 2018, and 2019. As shown on Plate 5, a lowering of the tailwater stage of about 5 feet has occurred over a 50-year time span from 1955 to 2005. From 2005 to 2010 very little change occurred. After the record releases in 2011, a lowering of about 0.6 foot was seen in the higher range of releases; however, little change was seen in the lower range of releases. Between 2015 and 2019, the tailwater stage continued to drop at the lower end of the curve before slightly rebounding in 2020.

As seen on Plate 6, a decrease of about 2 feet in stage occurred from 1952 to 1955 for releases in 10,000-cfs increments ranging from 10,000 to 40,000 cfs. The 1994 through 1997 trend lines shown on Plate 6 have been adjusted to account for a 1-foot shift in the gage datum. During 1994, it was determined that the tailwater gage at Fort Randall has been recording water surface elevations 1 foot lower than the actual water surface elevations. The source of the error is not known at this time, but may have occurred in the 1979-80 time period, which corresponds to a significant decrease in the stage trend curve shown on Plate 6. Tailwater stages prior to 1994 have not been adjusted to account for the 1-foot shift in gage datum. During the period from 2000 to 2005, the degradation increased almost 1 foot in the 30,000 to 40,000 cfs range and about 0.5 foot in the 10,000 to 20,000 cfs range. Trends were fairly stable between 2005 and 2010. During the period from 2010 to 2015, degradation increased about 1 foot in the 40,000 and 30,000 cfs range, and less than 0.5 foot in the 10,000 cfs range. Between 2015 and 2020 the tailwater trends have been fairly stable.

G. Gavins Point

Since 1955, releases from Gavins Point have generally been through the power facilities, which have a maximum powerplant capacity of about 35,000 cfs. Sustained releases for flood storage evacuation above the powerplant capacity and lasting at least six months occurred in 1971, 1972, 1975, 1978, 1996, 1997, 2011, 2018, and 2019. In 2011, outflows exceeded 50,000 cfs for 145 days; 100,000 cfs for 85 days; 150,000 cfs for 65 days; and peaked at 160,700 cfs on June 27. Conversely, in 2012, dry conditions necessitated releases near 38,000 cfs for almost four months to meet Missouri River navigation requirements. Plate 7 shows tailwater rating curves from every fifth year beginning in 1955 and extending through 2019. As illustrated by those curves, a stage lowering is evident at each interval. In 2020 there was a slight rebound in the tailwater curve. However, it was still lower than the 2015 curve and may be a temporary increase following the high release year of 2019.

As shown on Plate 8, the Gavins Point tailwater has lowered between 13 and 14 feet at flows of 10,000, 20,000, and 35,000 cfs since closure of the project in 1955. One year after project closure a drop of 1 foot at the lower releases and about 1.5 feet at 35,000 cfs was observed. From 1956 to 1980 the tailwater stage dropped about 7.5 feet or a rate of 0.3 foot per year. From 1980 to 1995 the stage decreased about 1 foot or a rate of about 0.1 foot per year. Higher-than-average releases from 1995 through 1999 resulted in a total tailwater stage drop of about 1 foot, a rate of 0.2 foot per year. From 2000 to 2010 the rate decreased to less than 0.1 foot per year. The record release of 160,700 cfs during 2011 resulted in the tailwater stage dropping between 0.4 foot and 1 foot, depending on the releases. From 2012 to 2017 the tailwater stage increased slightly on the 10,000 cfs trend line, remained stable on the 20,000 cfs trend line, and decreased slightly on the 35,000 cfs trend line. In 2018 and 2019, all three trend lines started to drop, likely due to higher than normal releases, before slightly rebounding in 2020.

H. Project Comparisons

A comparison of tailwater trends for the Gavins Point, Fort Randall and Garrison projects is shown on Plate 9. As illustrated on Plate 9, the trend in tailwater stages had become more stable 30 years following closure of the dams. The Fort Randall, Garrison, and Gavins Point projects have experienced an increased rate of tailwater lowering following the high release years of 1995 through 1997. From 1997 to 2010 there has been only a small decrease in tailwater stage at Garrison. From 2001 to 2010 there is more variability with the Fort Randall tailwater stage, but little overall change. Comparatively, the rate of decrease of the Gavins Point tailwater is generally constant from 1997 to 2010. Plate 9 also indicates that Garrison and Gavins Point tailwater stages decreased in 2011 more than in recent years. There was insufficient data at Fort Randall for the 20,000 cfs release to discern a definite trend in 2011. Since 2012, Garrison, Fort Randall, and Gavins Point tailwater stages have been showing a degradation trend. The total decrease in tailwater stage at these projects is 14 feet at Gavins Point, 12 feet at Garrison, and 9 feet at Fort Randall.

III. NAVIGATION CHANNEL STAGE TRENDS

A. General

In the reach from Gavins Point Dam to Ponca State Park, NE, the Missouri River remains in a semi-natural state as the National Wild and Scenic River. In this 59-mile river reach, the Missouri River is somewhat free to meander throughout a wide floodplain. In the 17-mile reach between Ponca, NE, and Sioux City, IA the river is confined by revetment and dike structures into a single channel developed for bank stabilization purposes. The Missouri River Bank Stabilization and Navigation Project extends for 735 miles from the confluence of the Big Sioux and Missouri rivers near Sioux City to its mouth near St. Louis, MO. The navigation channel varies in width from about 600 feet at Sioux City to about 1,100 feet at the mouth near St. Louis. Navigation flow support from the System has substantially changed the flow regime. Although the average annual flow volume that passes Sioux City has not changed appreciably, maximum flood peaks have been significantly reduced, low flows have increased, and the distribution of the upper Missouri River basin runoff has been altered substantially. The System has also had a profound effect on downstream Missouri River sediment loads. The Missouri River carried an estimated average annual sediment load of 135 million tons past Yankton, SD, the location of Gavins Point Dam and the lowermost System dam, before any of the System dams were constructed. Since the closure of the six System dams in 1967 virtually all the incoming sediment has been entrapped in the reservoirs and the sediment loads directly below the dam sites have been essentially reduced to zero. The trapping of incoming sediment, along with other physical effects which include deposition of sediments on berms, channel cutoffs, and construction of levees, has contributed to changes in the stage-discharge relationship at downstream Missouri River locations.

The base stage-discharge rating curve and stage-discharge measurements were obtained from the USGS for the stations along the Missouri River. A shifted rating curve was developed based on the base rating curves and a stage-discharge measurement taken sometime during the summer. The stage-discharge measurement used to develop the shifted rating curve was selected using engineering judgment. Trends at each of the key streamgaging locations are discussed in the following paragraphs.

B. Missouri River at Sioux City

As illustrated on Plate 10, a predominant degradation stage trend at Sioux City was observed from the late 1920s until 1979. During that 50-year period the stage had decreased 7 to 11 feet for flows ranging from 10,000 to 50,000 cfs. From 1979 to 1995 the stage remained fairly steady. The high flow years from 1995 through 1997 resulted in significant degradation at Sioux City. From 1999 to 2009, the stage trends reversed and aggradation ranging from 0.5 to 1 foot occurred. This 11-year period included the 8-year drought from 2000-2007 when releases and incremental runoff downstream of Gavins Point were lower than average. During 2010 the stage lowered between 0.5 foot and 1 foot for flows ranging from 10,000 to 30,000 cfs. In 2011, with record releases from Gavins Point of 160,700 cfs, the stage dropped about 4 feet primarily due to channel bed scouring. Following 2011, the stage trends indicated some aggradation, with the stage increasing 1 to 2 feet at various flows. The high flows experienced in 2018 and 2019 resulted in the channel scouring to stages at or below those seen in 2011.

Stage reductions at Sioux City have caused numerous problems at marinas and dock facilities. These problems were magnified during the last two droughts (1987-1992 and 2000-2007) when less-than-full-service navigation flow support was provided. This was also true in cutoff lakes, such as at Miners Bend, where the combination of sedimentation of the lakes and degradation in the river has cut off access to the Missouri River. The reduction of the full service navigation flow support (31,000 cfs) to minimum service navigation flow support (25,000 cfs) at Sioux City is equivalent to a stage reduction of about 1.5 feet.

C. Missouri River at Omaha

As shown on Plate 11, the stage trend between the mid-1930s and the early 1950s was a lowering of about 5 feet for the 10,000 to 40,000 cfs range. Degradation, to a lesser extent, was also observed for higher flows during this time period. From the early 1950s through the late 1960s the stages increased between 2 and 3 feet for the flows in the 10,000 to 40,000 cfs range. From the late 1960s through 2010 the stage for flows of 100,000, 60,000, and 40,000 cfs increased slightly, remained steady for flows of 30,000 cfs, and decreased 2 to 4 feet for flows of 20,000 and 10,000 cfs. The stage for a 100,000 cfs flow shows aggradation in 2012, then slight degradation through 2018 before dropping 2 feet during the high flow years of 2018 and 2019. For the stage trend at 60,000 cfs, degradation of about 1 foot was noted in 2011; since 2011, stages showed little change through 2018 and then dropped a total of about 2 feet in 2019 and 2020. Stages at the flows of 40,000 cfs and lower show sharp degradation of 2 to 3 feet in 2011 and 2012, but then show slight aggradation trends from 2013-19 followed by a 1 foot drop in 2020. Flows at this location have rarely been at the 10,000 cfs level since the closure of the System in 1967.

Prior to 2011, the lowest stages for a flow of 30,000 cfs and above occurred following the 1952 flood. In 2012 the stage for a 30,000 cfs flow was about 1.5 feet lower than in 1953; the stage for the 100,000 cfs flow was about 6 feet higher.

The highest stages for flows at 40,000 cfs and below occurred in the mid-1930s. At the 60,000 cfs flow the highest stage occurred in the mid-1930s, in 1990, and in 2004. Although the stage-discharge data for 100,000 cfs is less frequent, it appears that the stages at this flow have increased since the 1950s.

D. Missouri River at Nebraska City

Stage trends at the Nebraska City location are shown on Plate 12 (flows between 20,000 cfs and 100,000 cfs) and Plate 13 (flows between 100,000 cfs to 180,000 cfs). The corresponding stages for flows between 70,000 and 180,000 cfs demonstrated a consistent rise from 1950 to the early 1990s. Since the early 1990s, the stages have remained fairly steady for these flows. The stages for flows of 20,000, 30,000, and 40,000 cfs have remained fairly steady for the entire observation period.

The National Weather Service has set the Missouri River flood stage at Nebraska City at 18 feet. The Missouri River flow at Nebraska City for a stage of 18 feet has reduced from about 140,000 cfs in 1950 to approximately 90,000 cfs. Since 1950, an overall rise in stage of 5 to 6 feet has occurred for flows above 100,000 cfs; an overall rise of about 4 feet has occurred for flows of 70,000 cfs.

E. Missouri River at St. Joseph

As seen on Plate 14, from 1928 to the early 1950s Missouri River stages at St. Joseph in the 20,000 to 40,000 cfs flow range were relatively constant. During the 1952 Flood the Missouri River created a cutoff upstream of the St. Joseph location. This cutoff resulted in a shift in the St. Joseph rating curve of about 2 feet. Starting in the early 1970s, and continuing through 2020, stages for flows of 20,000 and 40,000 cfs have lowered approximately 3 to 4 feet. From the mid-1940s to the early 1970s the stage trends for the 70,000 and 100,000 cfs flows increased about 4 feet. The stage remained fairly steady for the 70,000 cfs flow and increased slightly for the 100,000 cfs flow for the next 20 years. Since 1993 the stage has declined about 3 feet for both flow levels. Due to the drought conditions and less-than-full service navigation flow support, no stage-discharge measurements were taken in the 70,000 cfs to 100,000 cfs range from 2000-06. Plate 15 shows stage trends for flows between 100,000 and 200,000 cfs. Although there are fewer stage-discharge measurements above 100,000 cfs, the data reveals an increasing trend of about 6 feet from the 1940s to the early 1990s. Since 1993 and through 2020, degradation can be seen at the 130,000 cfs and 160,000 cfs flow levels. Stage trends for the flow levels of 130,000, 160,000, and 200,000 cfs are difficult to accurately discern since very few stage-discharge measurements have been taken at those levels.

F. Missouri River at Kansas City

The Missouri River stage trend at Kansas City has been consistently decreasing for all flow levels at 100,000 cfs and lower, as shown on Plate 16. This trend, which is counter to trends at stations immediately upstream and downstream, began in about 1940 and has continued through 2020. It was likely influenced by:

1) downstream channel cutoffs that have shortened the downstream reach by about 20 percent since 1890, and
2) reduced Kansas River sediment loads due to reservoir construction.

In general, stages average 8 to 11 feet lower than those experienced in the 1930s for 20,000, 40,000, and 70,000 cfs flows, and about 5 feet lower at a flow of 100,000 cfs. Kansas City stages, as shown on Plate 16, seem to recover after a period of lowering stage, but generally do not recover to the previous levels. Stages for each flow have lowered by about 2 to 4 feet since 2000.

Plate 17 shows data points representing flows between 200,000 and 500,000 cfs. Data for flows above 200,000 cfs are very sparse and stage trends are difficult to accurately discern. From the available data the stage at the 200,000 cfs flow decreased about 4 feet between 1941 and 1952. This stage lowering was followed by an increasing stage trend. By 1999, the stage had increased by more than 2 feet. However, between 1999 and 2007 the stage decreased by about 4 feet and then has held fairly steady through 2019. The stage trend for the 300,000 cfs flow seems to follow the trend for the 200,000 cfs through 2007 but appears to rise between 2007 and 2019; however, there are too few data points for the 300,000 cfs flow level to be conclusive.

G. Missouri River at Waverly

Plate 18 shows data points representing flows between 20,000 cfs and 100,000 cfs. Stages at the 100,000 cfs flow level showed an increasing trend until the late 1990s peaking at about 6 feet higher than those experienced during the 1930s. Stages then started to fall and have decreased about 1 foot through 2020. The stages for the 70,000 and 40,000 cfs flows generally increased through 2000 by about 3 feet, then started slowly trending down decreasing by about 1 foot through 2011. In 2012, stages rebounded at the 70,000 cfs flow by about 1 foot and remained steady through 2020. There was no significant rebound for the 40,000 cfs flow after 2011, and stages have remained fairly steady through 2018. From 1970 to 2009 the stages for the 20,000 cfs flow has shown periods of fluctuations, but overall has shown little change. Plate 19 displays the stage trends for flows of 200,000 and 300,000 cfs. Stage trends at Waverly are generally 4 to 6 feet higher at the 300,000 and 200,000 cfs flow levels than those experienced during the 1930s. While an increasing stage appears to be continuing at these flow levels, the stage-discharge data in this flow range are sparse and highly variable.

H. Missouri River at Boonville

Plate 20 (flows between 20,000 cfs and 100,000 cfs) and Plate 21 (flows of 200,000 cfs and 300,000 cfs) show the historical stage trends at Boonville. Generally, short-term variations of plus or minus 1 foot over a 4- to 5-year period have been observed, but these changes are minor compared to changes at other locations on the Missouri River. Stages at Boonville remained relatively constant from 1930 to 1970 for the lower flows of 20,000 and 40,000 cfs. A decreasing trend then developed at these flows such that the stage is now 2 to 4 feet lower. For the 70,000 cfs flow the trend indicates a gradual increase in stage from 1930 to 1960 of about 2 feet. From 1960 to 2000, the stages remain fairly steady before starting to decline and dropping about 1 foot through 2020. For the 100,000 cfs flows the trend indicates a gradual increase in stage from 1930 to 1980 of about 3 feet, holding steady through 2002 and then starting to fall. From 2002 through 2020, the stages for a 100,000 cfs flow have lowered about 1 foot. The data available for the higher flow levels of 200,000 and 300,000 cfs demonstrate an upward trend from 1930 to the mid-1990s. Since the mid-1990s, available data indicates a decreasing trend. However, annual data points are sparse and makes defining a definite trend difficult.

I. Missouri River at Hermann

The Missouri River stage trends at Hermann are shown on Plate 22 (flows between 20,000 cfs and 100,00 cfs) and Plate 23 (flows between 200,000 cfs and 500,000 cfs). The plates indicate an overall increasing stage trend of about 1 to 3 feet from the mid-1930s through the late 1950s for flows of 200,000 cfs and less. From the late 1950s through the late 1960s, the stage trend flattened for flows at and below 100,000 cfs. Stages at the 100,000 cfs flow remained steady until the mid-1980s, and then started to slowly fall, dropping by about 1 foot through 2019. From 1970 to the early 2000s a decreasing stage trend existed for flows at and below 70,000 cfs. Since then the stages have remained fairly steady, except for those at 20,000 cfs. Limited data is available at the 20,000 cfs flow level; however, data from 2013 and 2014 indicate a lowering trend since the early 2000s of about 1 foot. As seen on Plate 23 stage trends for flows between 200,000 and 500,000 cfs indicate an increase in stage prior to 1990 of 3 to 6 feet. Since then the stage trends have varied year to year but the overall trend is a slight downward trend for the 200,000 and 300,000 cfs flows and fairly steady for the 400,000 and 500,000 cfs flows. Data is sparse for the two higher flows.

IV. HEADWATER AREA STAGE TRENDS

A. General

There are two characteristic types of sediment deposits in reservoirs along alluvial rivers:

1) those occurring generally over the reservoir bottom, mostly composed of the finer fractions of the river sediment load, and
2) those occurring in a characteristic delta formation at the head of the reservoir and where tributaries enter the reservoir, including the coarser fractions of the river sediment load.

Delta formation can extend upstream from the reservoir and can cause the reservoir backwater effect to progress upstream, increasing river stages. Delta areas in several of the System projects have been experiencing aggradation problems. These impacts include increased water surface elevations, an increased duration of flooding, higher groundwater levels, reduction in channel capacity, a reduction of farmable land, loss of Cottonwood trees, change of vegetation near the river and changes in infrastructure. Stage trends at several of the impact areas are discussed in the following paragraphs.

B. Missouri River at Williston

The Garrison reservoir headwaters extend upstream past the city of Williston, ND, to near the confluence of the Yellowstone and Missouri rivers. Levees, constructed by the Corps, protect Williston from the aggradation backwater effects. Due to aggradation effects and rising river stages, the level of protection of the levee has been decreasing. An aggradation study of the Garrison reservoir headwaters was completed by the Corps in September 1990.

Aggradation and delta formation has occurred in the Garrison reservoir headwaters since construction of the Garrison Dam project in 1953 and the filling of the reservoir in about 1965. Garrison reservoir backwater and aggradation effects resulted in a dramatic rise in the stage-discharge relationships at Williston for the period from 1966 to 1972, and more moderate increases from 1972 to present.

Delta build-up in the Garrison reservoir's headwaters appears to be occurring at a relatively uniform rate from Missouri River Mile (RM) 1520 to 1550. This includes the area near the city of Williston, at about RM 1544. Between 1969 and 1987, the average depth of sediment deposit in this reach had risen a total of 6 feet or about 0.3 foot per year. In the immediate vicinity of Williston, approximately 4 feet of sediment deposition has been measured on the Missouri River from 1969 to 1987, or about 0.2 foot per year.

Low Garrison reservoir elevations from 2001 through 2008 resulted in sediment depositing farther downstream in the reservoir. As the reservoir elevations lowered, some previously deposited material re-suspended and moved downstream to lower areas of the reservoir. Higher pool elevations in 2010 and 2011 have likely resulted in new sediment depositing in areas that were vacated during the low pool period.

C. Missouri River at Bismarck

Bismarck, ND, located in the Oahe reservoir headwaters area, is the only station on the Missouri River within the System for which rating curve analyses and records have been maintained. As shown on Plate 24, from the late 1920s to 2010 the stages for the 20,000, 30,000, and 40,000 cfs flows increased between 1 to 3 feet. Record releases from Garrison Dam in 2011 lowered the stages between 1 and 2 feet for flows at and below 40,000 cfs. Since then stage-discharge measurements have increased for flows at and below 40,000 cfs with stages up about 1 foot between 2012 and 2020. Stage data for the 100,000 cfs flows show a continued increasing trend since the late 1920s. The most recent data from 2011 shows a stage about 5 feet higher from the late 1920s for the 100,000 cfs flow level. However, data is sparse for the 100,000 cfs curve.

D. Missouri River at Pierre

The Big Bend reservoir headwaters extend upstream to the Pierre-Fort Pierre, SD area. Sediment deposited from the Bad River, which enters the headwater area at Fort Pierre, and other ungaged tributaries and Missouri River bank erosion have averaged over three million tons per year causing significant aggradation in this area. A study completed by the Corps in 1988 indicated that Missouri River stages increased by about 1 foot for open water flows of 70,000 cfs and would continue to increase due to future aggradation. That study also indicated that the increase in ice-affected stages has been more severe than the increase in open water stages, resulting in an increase of about 2 feet under ice conditions. However, the 2015 Lake Sharpe Aggradation Study actually showed that the Missouri River channel has scoured starting near Oahe Dam to approximately 2.4 miles downstream of the Bad River confluence – likely due to the high releases during the 2011 flood.

E. Missouri River at Springfield

Headwaters of the Gavins Point reservoir extend upstream of the Springfield, SD area. Sediment deposition in the vicinity of Springfield has restricted access to the Gavins Point reservoir from the Springfield boat ramp. Farther upstream, a large delta continues to develop near the mouth of the Niobrara River. This sediment deposition from the Niobrara River has increased river stages from the Niobrara-Missouri River confluence to Springfield. A water surface profile (WSP) of the Missouri River reach from Verdel, NE to the mouth of the Niobrara River with a steady Fort Randall release of 29,500 cfs was conducted in 2009. The stages from the 2009 survey were similar to a 35,000-cfs WSP obtained in 1944 when Fort Peck was the only System project in operation. The stages for the 2009 (29,500 cfs) and the 1944 (35,000 cfs) WSPs were approximately 1 foot higher than a WSP obtained in the mid-1980s (with a Fort Randall release of 44,000 cfs) and in 1975 (with a Fort Randall release of 60,000 cfs).

A Corps study was published in September 1992 titled *Sedimentation near the confluence of* *the Missouri and Niobrara Rivers 1954 to 1990*. That study found that between 1954 and 1984 there has been an overall reduction in channel depth of approximately 3 to 5 feet downstream of the Missouri-Niobrara River confluence and 2 feet upstream of the confluence. This change in channel depth has caused an increase in stage of about 6 feet downstream from the confluence for a flow of 20,000 cfs. The most rapid increase in stage occurred between 1957 and 1960 when the stage for a 30,000 cfs flow rose approximately 3 feet. A large flood on the Niobrara River occurred in 1960 with a peak flow of 39,000 cfs and resulted in extensive sediment deposition on the Niobrara River delta. The Missouri River in this reach experienced high flows for long durations in 2011 from Fort Randall releases that peaked at 160,000 cfs. In 2019 a record flood on the Niobrara River resulted in a massive sediment inflow to the Missouri River. However, the impacts to the Missouri River channel had not yet been assessed at the time this report was updated in 2021.

Further upstream at the Missouri River at Verdel streamgaging station, which is located approximately two miles upstream from the Missouri-Niobrara river confluence, Missouri River stages have increased by 3 to 4 feet from 1977 to 1990 for flows of 20,000 to 40,000 cfs. The average rate of stage increase of about 0.3 foot per year during this period is a faster rate than that observed downstream of the Missouri-Niobrara River confluence. At the Missouri River at Greenwood streamgaging station, which is approximately 20 miles upstream from the Missouri-Niobrara River confluence, the stages for flows of 20,000 to 40,000 cfs had not changed more than a foot from 1960 to 1987. The impact on the Missouri River in this reach from the long duration, high releases out of Fort Randall during the flood of 2011 have not been assessed.

V. SUMMARY

Record releases of 160,700 cfs were made from Gavins Point Dam in 2011. This had a major impact to the Missouri River stage trends for locations between Gavins Point and Kansas City. The record releases did not seem to have a significant impact to the Missouri River stage trend downstream of Kansas City. The stage trends for Sioux City, the station located closest to Gavins Point, were most affected. At flows of 50,000 cfs and below, the stage decreased about 4 feet. The other Missouri River streamgaging locations above Kansas City, which are further downstream of Gavins Point and Sioux City, indicated more moderate changes after 2011.

Following 2011, and continuing through 2018, stages started to shift upward in the open-river reach from Gavins Point Dam to Omaha. Starting in 2019, the stages dropped due to the high, sustained releases of greater than 70,000 cfs for six months from Gavins Point Dam. A noticeable drop of two feet occurred at flows of 50,000 cfs and below at Sioux City. At Omaha, the two foot drop occurred at the 60,000 and 100,000 cfs flows and was less than a foot at the lower discharges. At the Nebraska City and St. Joseph streamgages, the drop in stage for the 2019 event was less than a foot. There was little change in the open-river reaches downstream to Hermann. Changing stage-discharge relationships along the Missouri River affect a multitude of water-related activities and facilities, resulting in both positive and negative impacts. Downward-moving stage trends have adversely impacted fish and wildlife as well as caused problems at fixed docks, boat ramps, off-channel marinas, water intakes, and old oxbow lakes, particularly if they are still connected to the river. These potential problems were somewhat masked during the late 1970s and portions of the early 1980s due to the above-normal runoff above and below the System. However, the impacts became more obvious during the drought periods (1987-1992 and 2000-2007) when less-than-full service navigation flows were provided. Since no structural remedy by the Federal government is imminent, this emerging problem will continue to require effective two-way communication between the Corps and the basin stakeholders to alert those affected about what is happening and how to adapt to the situation to maintain access to river flows. Positive impacts include the greater flood protection provided to those locations adjacent to the river due to lower stages for some flows.

Stage-discharge measurements in the mid- to late 1990s indicated upward stage shifts for the higher flows before leveling off or starting to drop through 2020 at all stations located along the navigation channel or in System reservoir headwater areas. The exception is Kansas City where the latest stage-discharge measurements for most flows indicate a downward shift of almost 4 feet starting back in the 1940s. While the upward trend in stages for Nebraska City and St. Joseph may have ended in the mid- to late 1990s and are starting to slowly drop through 2020, flows of 80,000 to 90,000 cfs still exceed the bank compared to bankfull flows of around 150,000 cfs from about 60 years ago. This reduced channel capacity has made regulation of the System and tributary reservoirs for downstream flood control more challenging. Completion of the Federal agricultural levee system would only partially solve the problem, since many of the affected areas are between the Federal levee alignment and the Missouri River.

The increases in stages at locations downstream of Kansas City, specifically for flow levels near bankfull levels, are limited to about 2 to 6 feet. These stage increases correspond with the projections in the previously referenced consultant's board report of November 1955 relating to the effect of navigation structures on river levels. The board also opined that the effect of the navigation works would be reduced above bankfull flows and would be lost in the greater effects of levee confinement, road fills, and other changes in the valley. Since the stage increases are greater at the higher flow levels on the lower Missouri River, it seems apparent that the stage increases are due largely to factors other than navigation structures, primarily continued construction of private levees and deposition of sediment in the floodplain above the navigation channel during high flow events.

Stage trends at normal flow levels, whether increasing or decreasing, affect the design and subsequent function of the navigation and channel stabilization structures. Many of these structures may be either too high or too low under today's stage-discharge conditions. A continuing re-analysis of the reference plane to which these structures are built and maintained is periodically required.

In the tailwater areas directly downstream from the projects decreases in tailwater stage have generally been experienced. The most noticeable stage reductions have occurred at the Garrison, Fort Randall and Gavins Point projects. At these projects the tailwater stage has decreased by about 9 to 14 feet since closure of the dams. In the period from 1980 through 1995, the rate of tailwater degradation had become more stable. During the 1995 through 1998 and 2010 through 2012 period, the Garrison, Fort Randall, and Gavins Point project tailwater trends show a marked increase in the rate of degradation, likely due to the higher-than-average releases during those periods. An exception to the tailwater stage reduction occurred below Oahe at the lower releases, where the tailwater stages had increased slightly through 1995. After 1995, the tailwater stage decreased about a foot before recovering in 2019 to stages similar to 1995. However, the recovery may be due to the high sustained releases with very little powerplant peaking that allowed the tailwater stage to stabilize.

In the System reservoir headwater areas, an upward trend in stages has occurred, primarily due to aggradation effects from sediment deposition. This trend is expected to continue into the future and extend further upstream as more sediment is deposited in the reservoir delta areas.

An electronic version of this technical report can be found on the Missouri River Basin Water Management (MRBWM) Division web site at https://www.nwd-mr.usace.army.mil/rcc/ under Reports & Publications, Technical Reports.

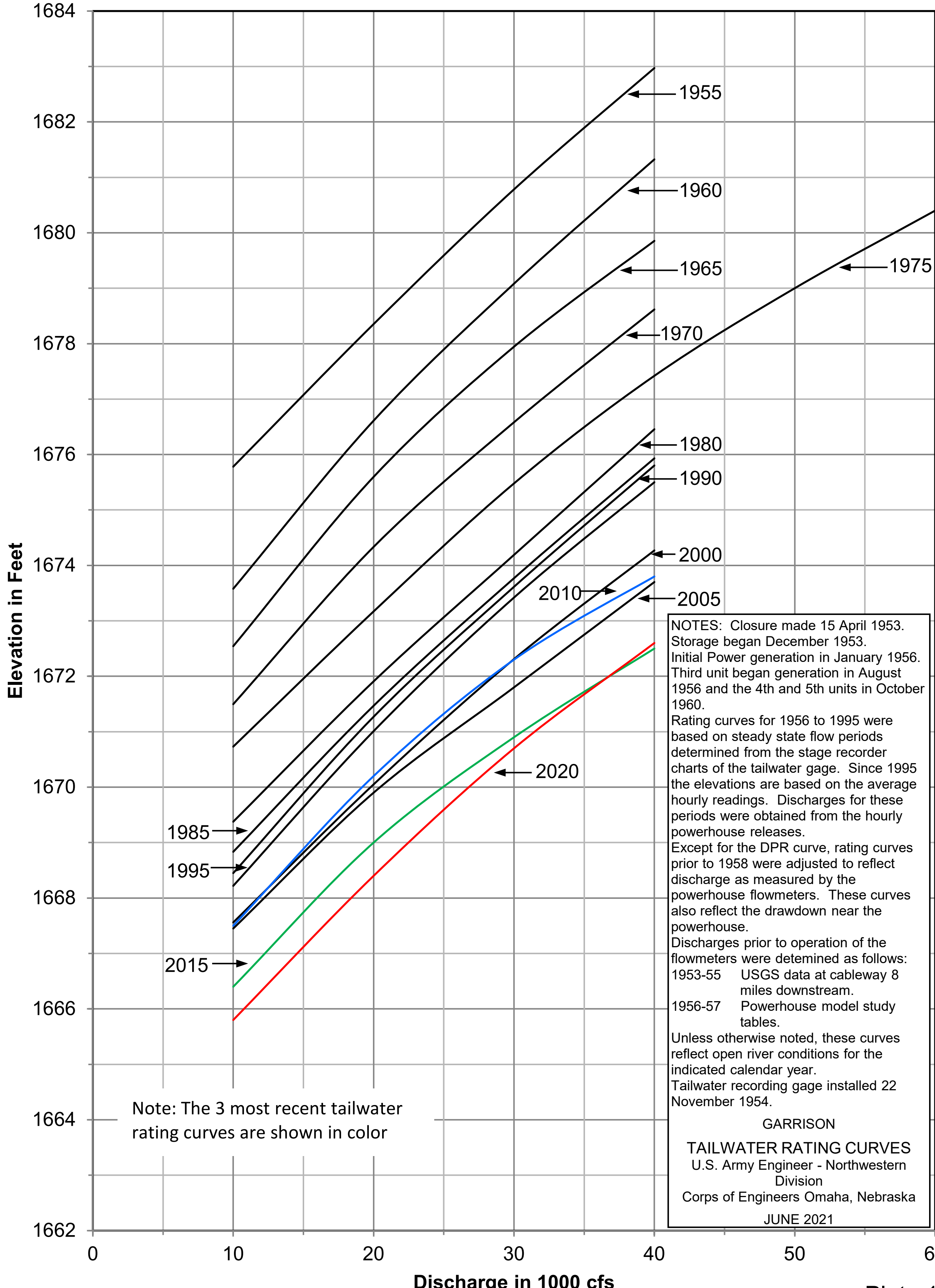
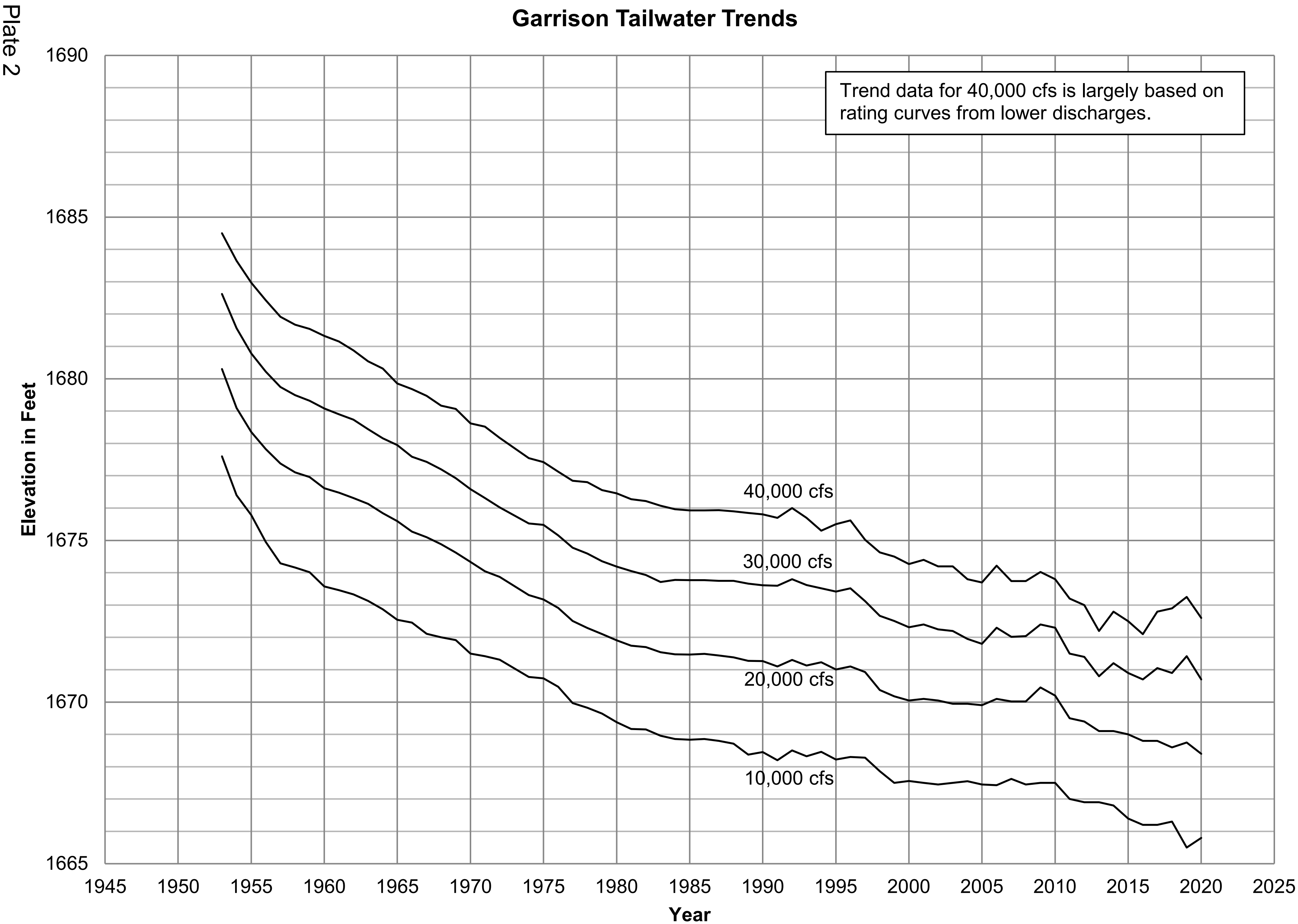
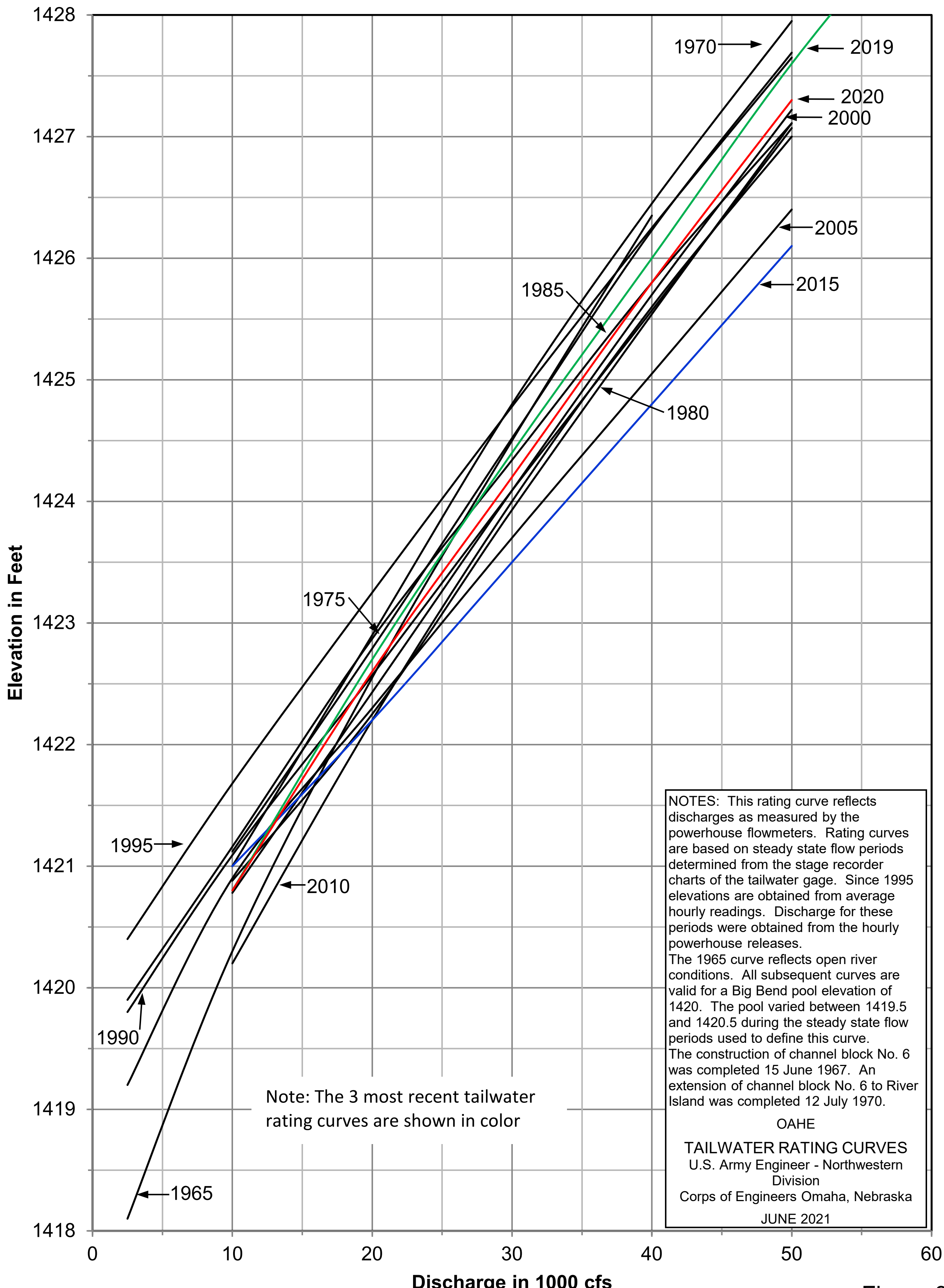

1684
1682
1680
1678
1676
1674
1672
1670
1668
1666
1664
1662
0
10
20
30
40
50
60
Elevation in Feet
Discharge in 1000 cfs
1955
1960
1965
1970
1975
1980
1990
2000
2005
2010
2020
1985
1995
2015
Note: The 3 most recent tailwater rating curves are shown in color
NOTES: Closure made 15 April 1953. Storage began December 1953. Initial Power generation in January 1956. Third unit began generation in August 1956 and the 4th and 5th units in October 1960.
Rating curves for 1956 to 1995 were based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 the elevations are based on the average hourly readings. Discharges for these periods were obtained from the hourly powerhouse releases.
Except for the DPR curve, rating curves prior to 1958 were adjusted to reflect discharge as measured by the powerhouse flowmeters. These curves also reflect the drawdown near the powerhouse.
Discharges prior to operation of the flowmeters were detemined as follows:
1953-55 USGS data at cableway 8 miles downstream.
1956-57 Powerhouse model study tables.
Unless otherwise noted, these curves reflect open river conditions for the indicated calendar year.
Tailwater recording gage installed 22 November 1954.
GARRISON
TAILWATER RATING CURVES
U.S. Army Engineer - Northwestern Division
Corps of Engineers Omaha, Nebraska
JUNE 2021

Plate 1

Plate 2



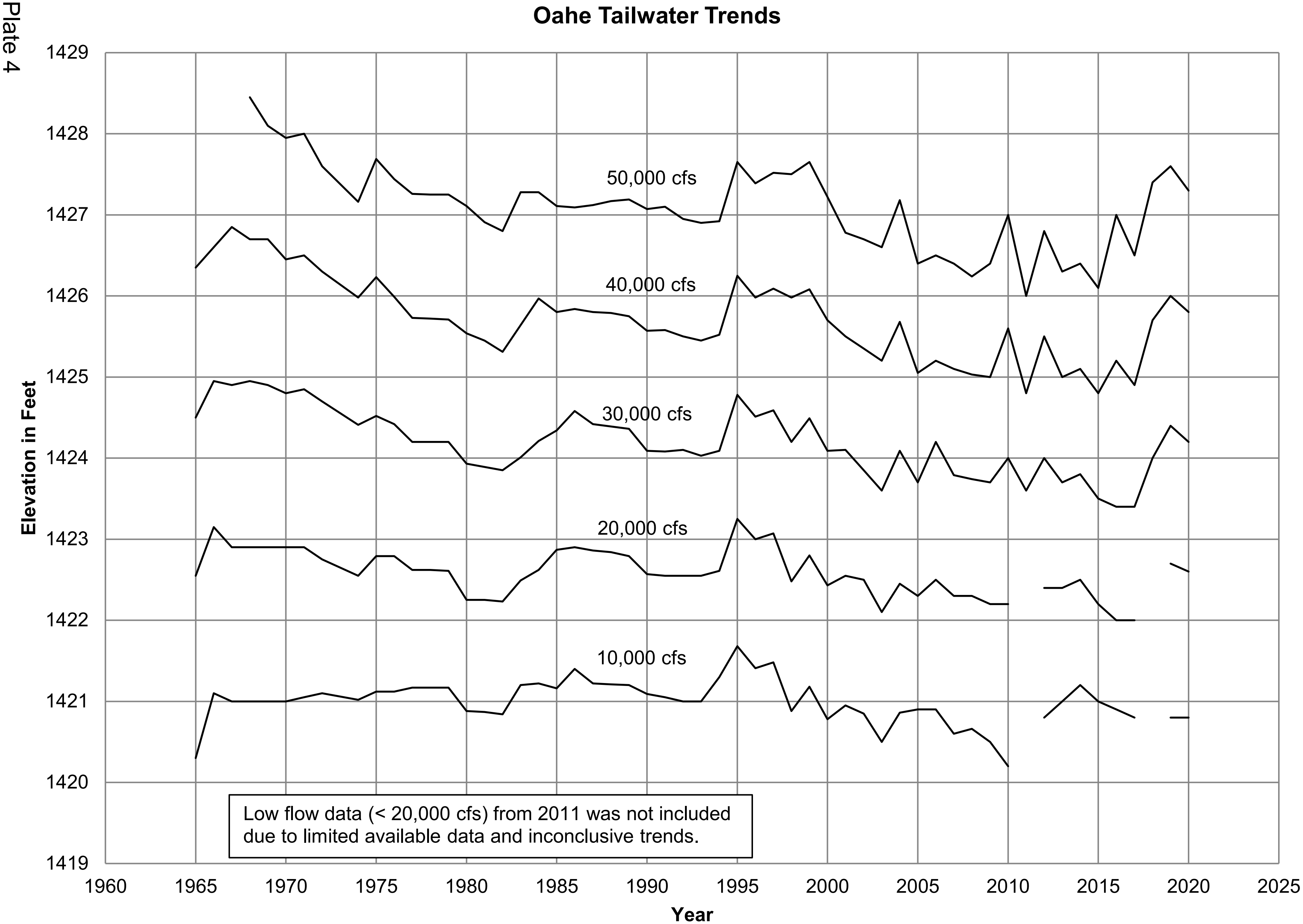
Garrison Tailwater Trends
Trend data for 40,000 cfs is largely based on rating curves from lower discharges.
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
Elevation in Feet
1690
1685
1680
1675
1670
1665
Year
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025



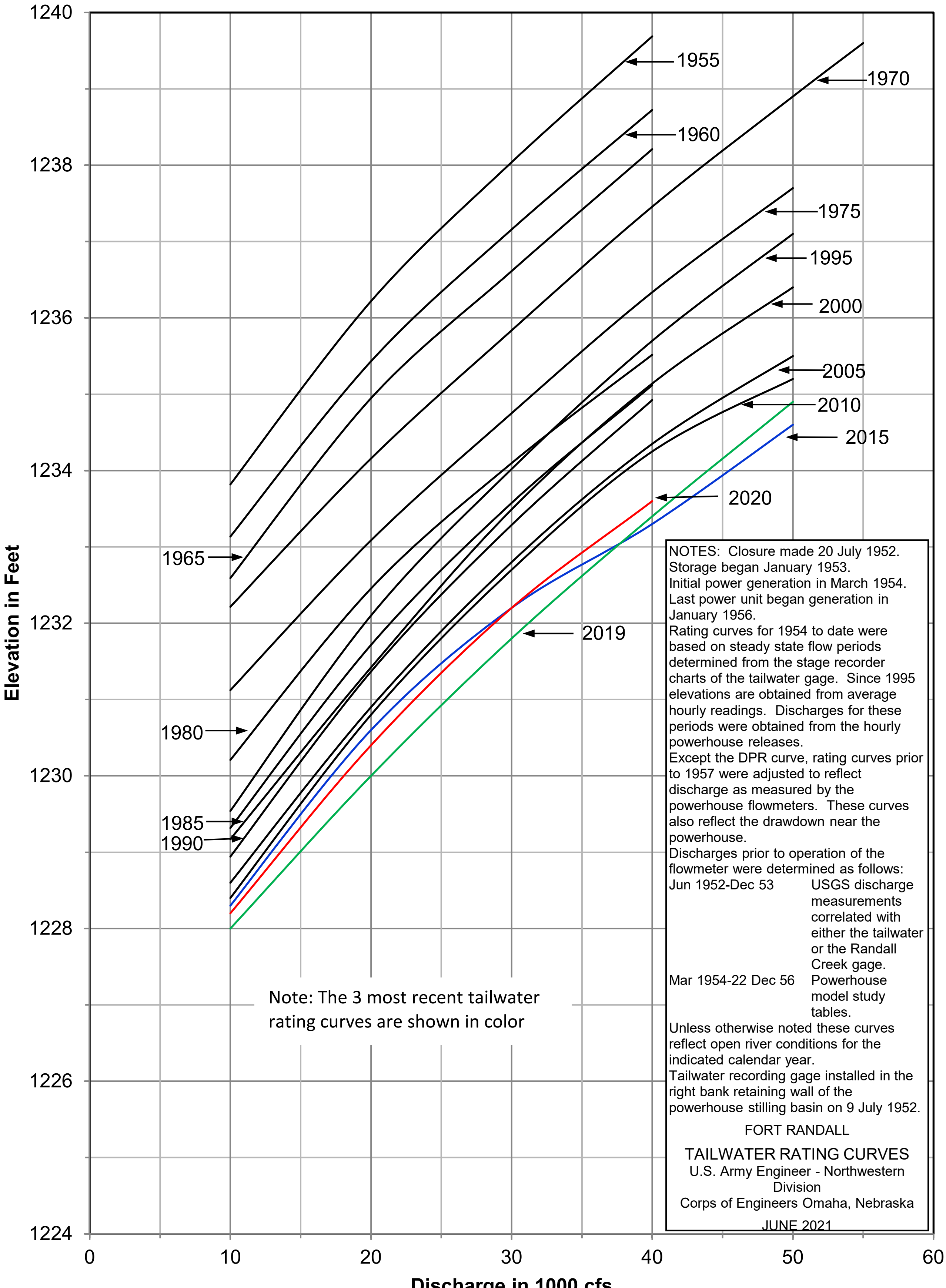
Elevation in Feet
1428
1427
1426
1425
1424
1423
1422
1421
1420
1419
1418
0
10
20
30
40
50
60
Discharge in 1000 cfs
1970
2019
2020
2000
2005
2015
1985
1980
1975
1995
2010
1990
1965
Note: The 3 most recent tailwater rating curves are shown in color
NOTES: This rating curve reflects discharges as measured by the powerhouse flowmeters. Rating curves are based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 elevations are obtained from average hourly readings. Discharge for these periods were obtained from the hourly powerhouse releases.
The 1965 curve reflects open river conditions. All subsequent curves are valid for a Big Bend pool elevation of 1420. The pool varied between 1419.5 and 1420.5 during the steady state flow periods used to define this curve.
The construction of channel block No. 6 was completed 15 June 1967. An extension of channel block No. 6 to River Island was completed 12 July 1970.
OAHE
TAILWATER RATING CURVES
U.S. Army Engineer - Northwestern Division
Corps of Engineers Omaha, Nebraska
JUNE 2021

Figure 3

Plate 4



Oahe Tailwater Trends
Elevation in Feet
Year
1429
1428
1427
1426
1425
1424
1423
1422
1421
1420
1419
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
50,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
Low flow data (< 20,000 cfs) from 2011 was not included
due to limited available data and inconclusive trends.

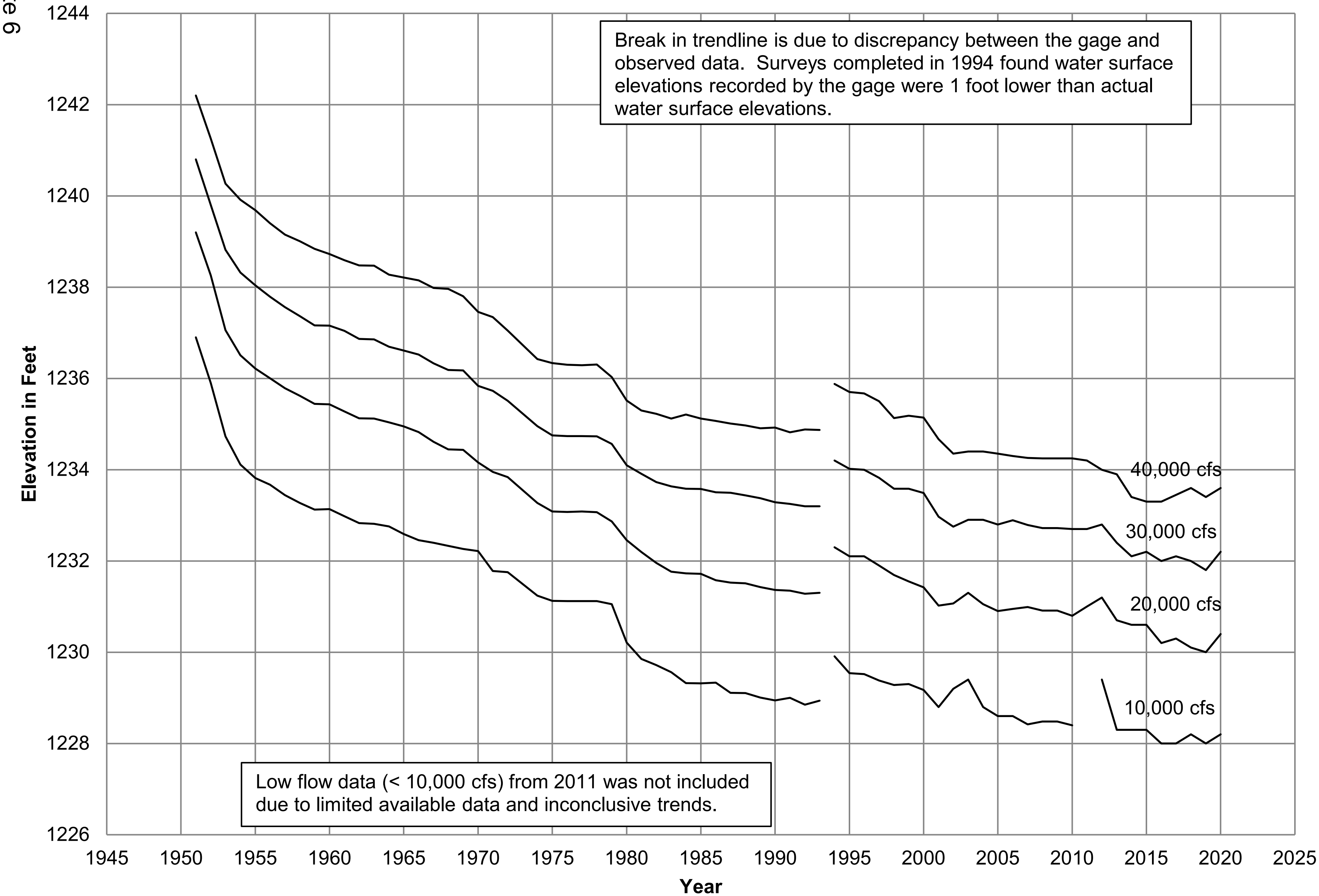


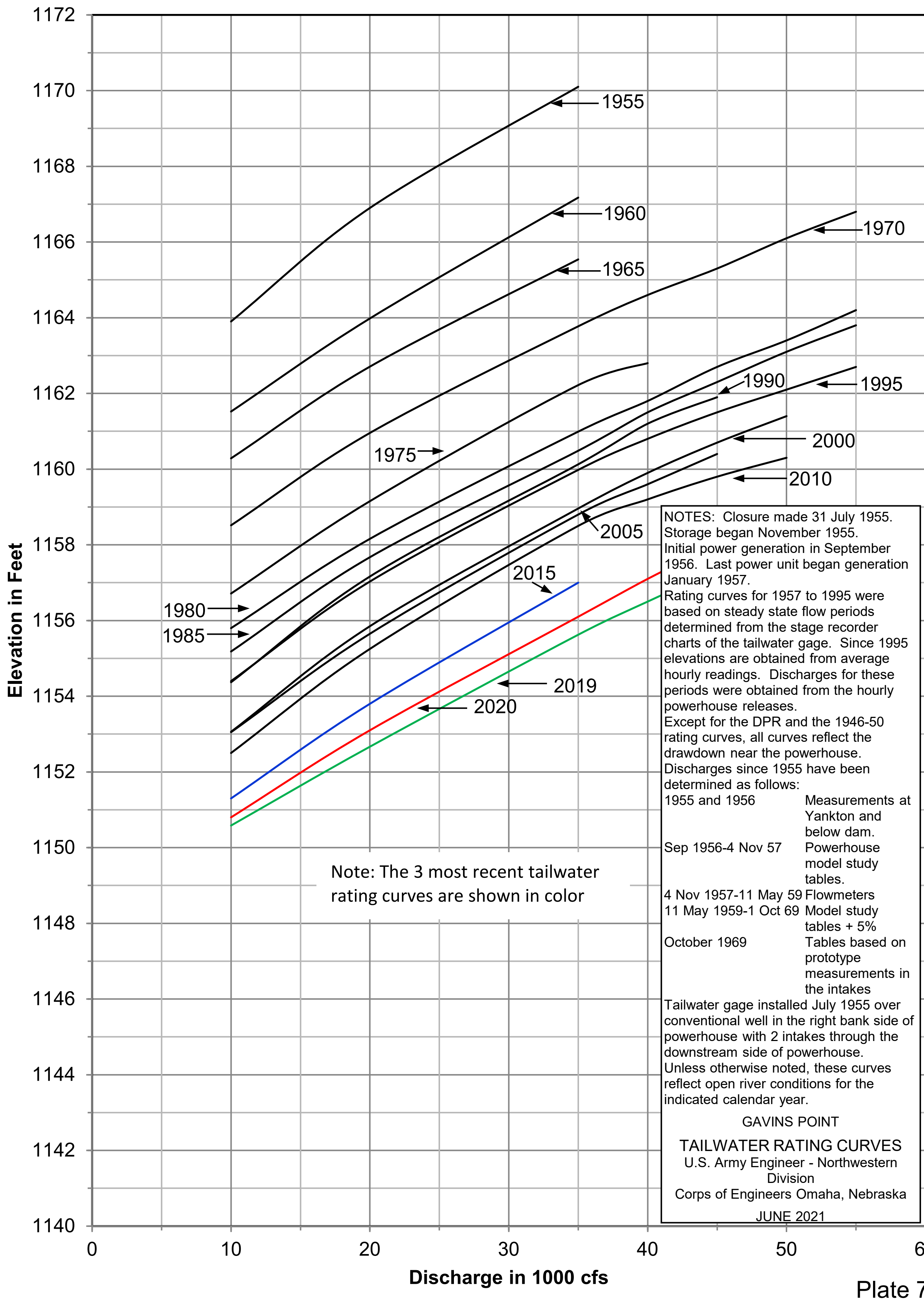
1240
1238
1236
1234
1232
1230
1228
1226
1224
0
10
20
30
40
50
60
Elevation in Feet
Discharge in 1000 cfs
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2019
2020
Note: The 3 most recent tailwater rating curves are shown in color
NOTES: Closure made 20 July 1952. Storage began January 1953. Initial power generation in March 1954. Last power unit began generation in January 1956. Rating curves for 1954 to date were based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 elevations are obtained from average hourly readings. Discharges for these periods were obtained from the hourly powerhouse releases. Except the DPR curve, rating curves prior to 1957 were adjusted to reflect discharge as measured by the powerhouse flowmeters. These curves also reflect the drawdown near the powerhouse. Discharges prior to operation of the flowmeter were determined as follows:
Jun 1952-Dec 53 USGS discharge measurements correlated with either the tailwater or the Randall Creek gage.
Mar 1954-22 Dec 56 Powerhouse model study tables.
Unless otherwise noted these curves reflect open river conditions for the indicated calendar year. Tailwater recording gage installed in the right bank retaining wall of the powerhouse stilling basin on 9 July 1952.
FORT RANDALL
TAILWATER RATING CURVES
U.S. Army Engineer - Northwestern Division
Corps of Engineers Omaha, Nebraska
JUNE 2021

Plate 5

Plate 6

Fort Randall Tailwater Trends

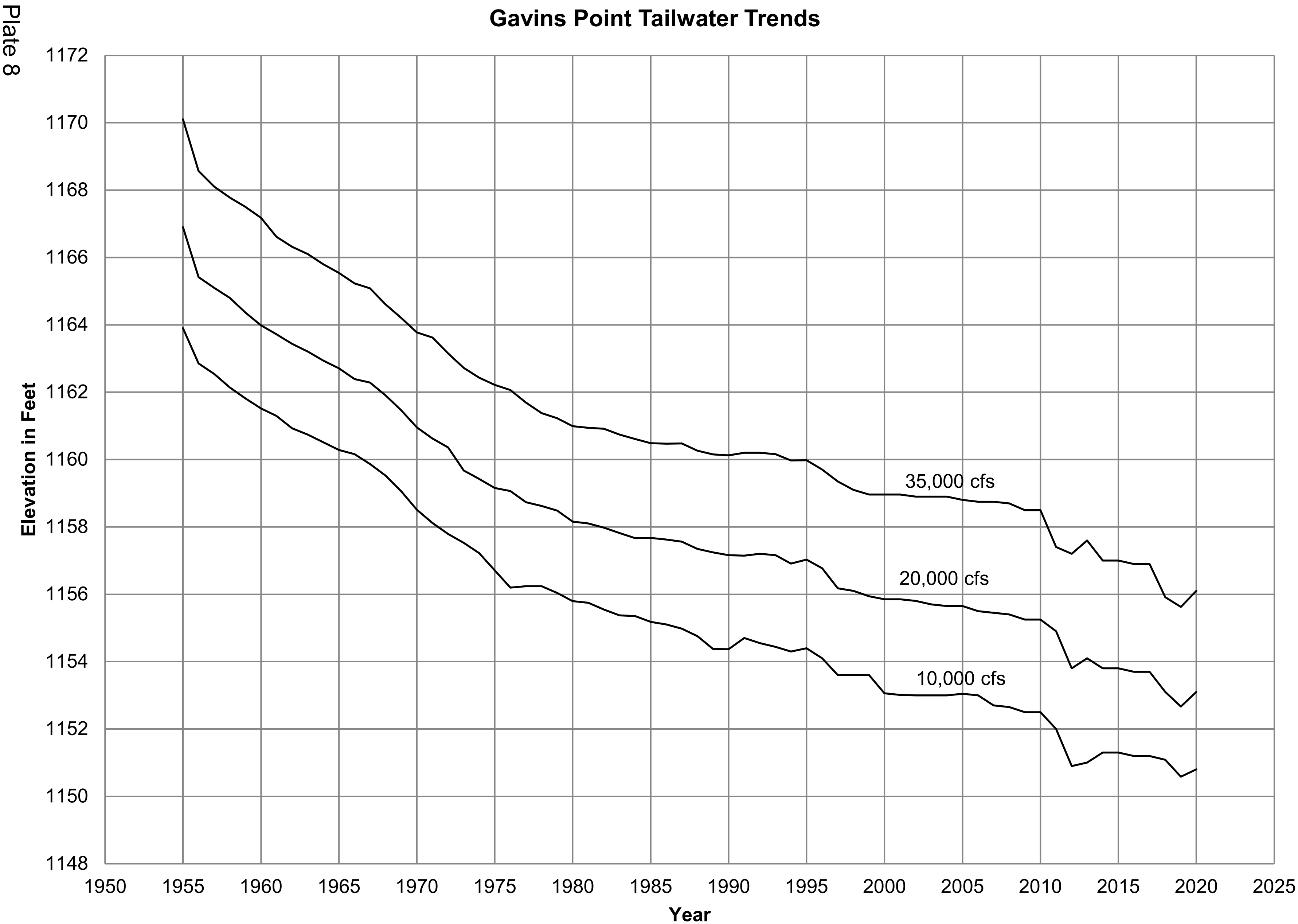




1172
1170
1168
1166
1164
1162
1160
1158
1156
1154
1152
1150
1148
1146
1144
1142
1140
Elevation in Feet
0
10
20
30
40
50
60
Discharge in 1000 cfs
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2019
2020
Note: The 3 most recent tailwater rating curves are shown in color
NOTES: Closure made 31 July 1955. Storage began November 1955. Initial power generation in September 1956. Last power unit began generation January 1957.
Rating curves for 1957 to 1995 were based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 elevations are obtained from average hourly readings. Discharges for these periods were obtained from the hourly powerhouse releases.
Except for the DPR and the 1946-50 rating curves, all curves reflect the drawdown near the powerhouse.
Discharges since 1955 have been determined as follows:
1955 and 1956 Measurements at Yankton and below dam.
Sep 1956-4 Nov 57 Powerhouse model study tables.
4 Nov 1957-11 May 59 Flowmeters
11 May 1959-1 Oct 69 Model study tables + 5%
October 1969 Tables based on prototype measurements in the intakes
Tailwater gage installed July 1955 over conventional well in the right bank side of powerhouse with 2 intakes through the downstream side of powerhouse.
Unless otherwise noted, these curves reflect open river conditions for the indicated calendar year.
GAVINS POINT
TAILWATER RATING CURVES
U.S. Army Engineer - Northwestern Division
Corps of Engineers Omaha, Nebraska
JUNE 2021

Plate 7

Plate 8


Gavins Point Tailwater Trends
Elevation in Feet
Year
1172
1170
1168
1166
1164
1162
1160
1158
1156
1154
1152
1150
1148
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
35,000 cfs
20,000 cfs
10,000 cfs

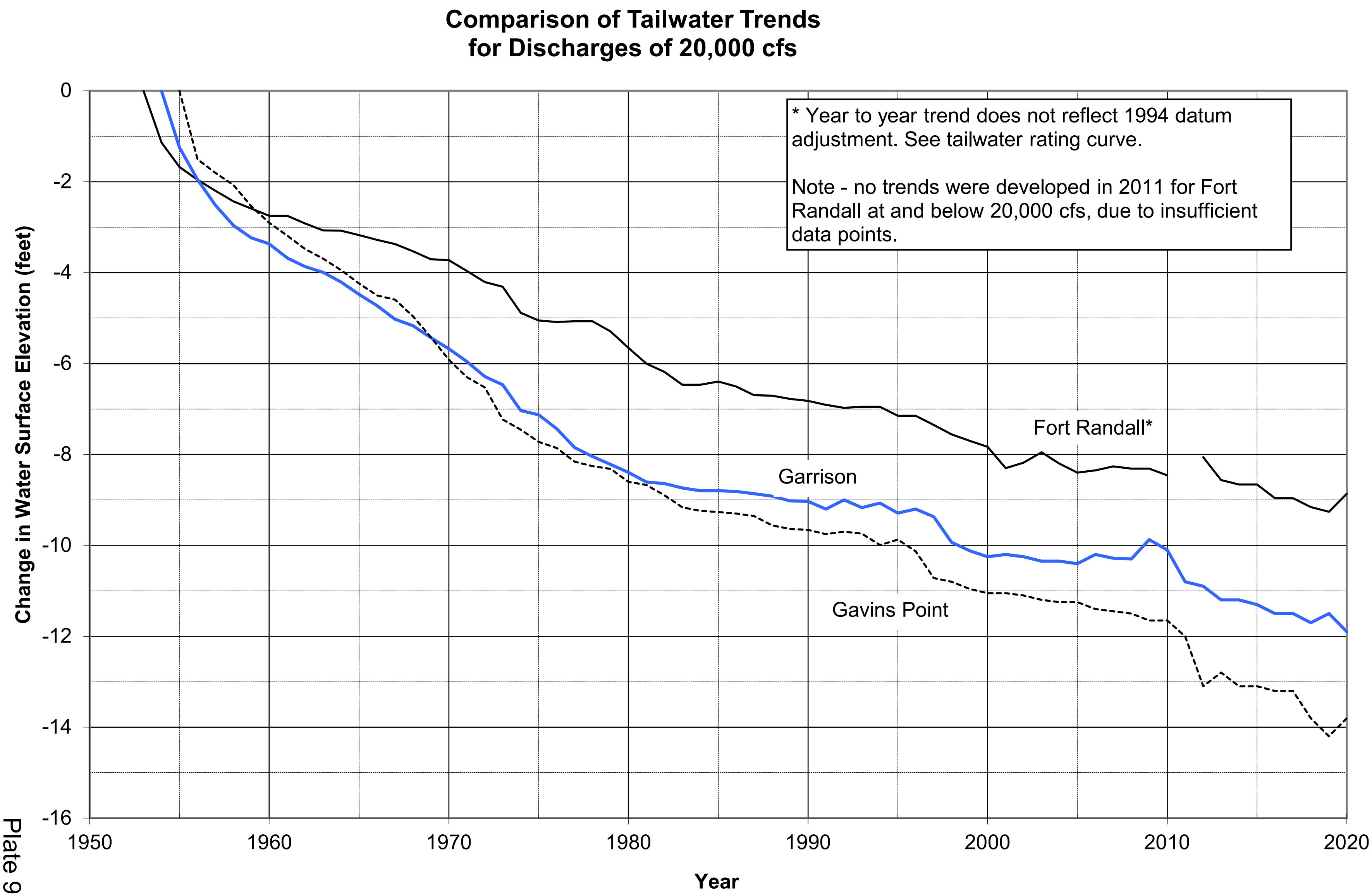
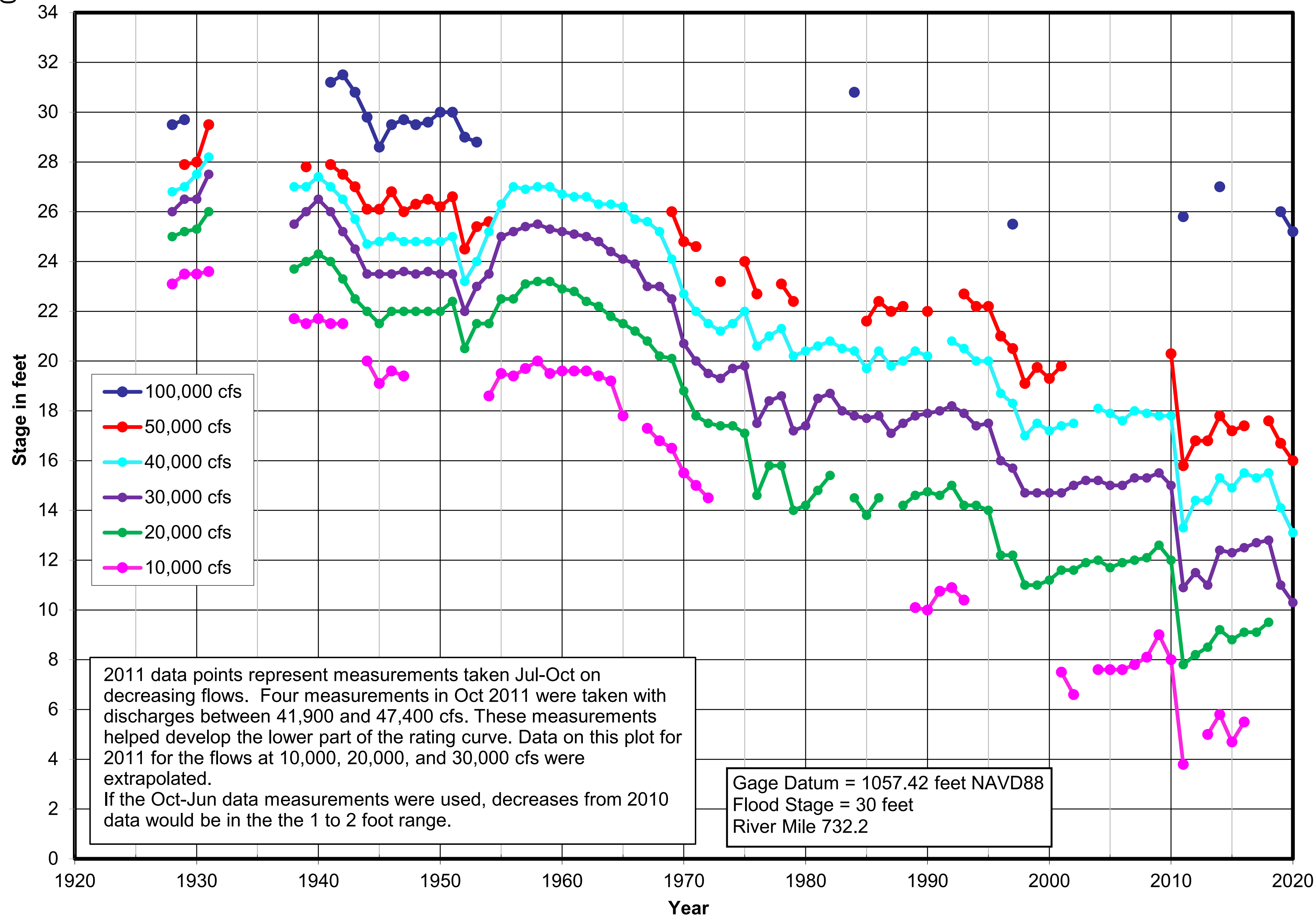

Comparison of Tailwater Trends
for Discharges of 20,000 cfs
* Year to year trend does not reflect 1994 datum adjustment. See tailwater rating curve.
Note - no trends were developed in 2011 for Fort Randall at and below 20,000 cfs, due to insufficient data points.
Fort Randall*
Garrison
Gavins Point
Change in Water Surface Elevation (feet)
Year
0
-2
-4
-6
-8
-10
-12
-14
-16
1950
1960
1970
1980
1990
2000
2010
2020

Plate 9

Plate 10

Missouri River Stage Trends - Missouri River at Sioux City



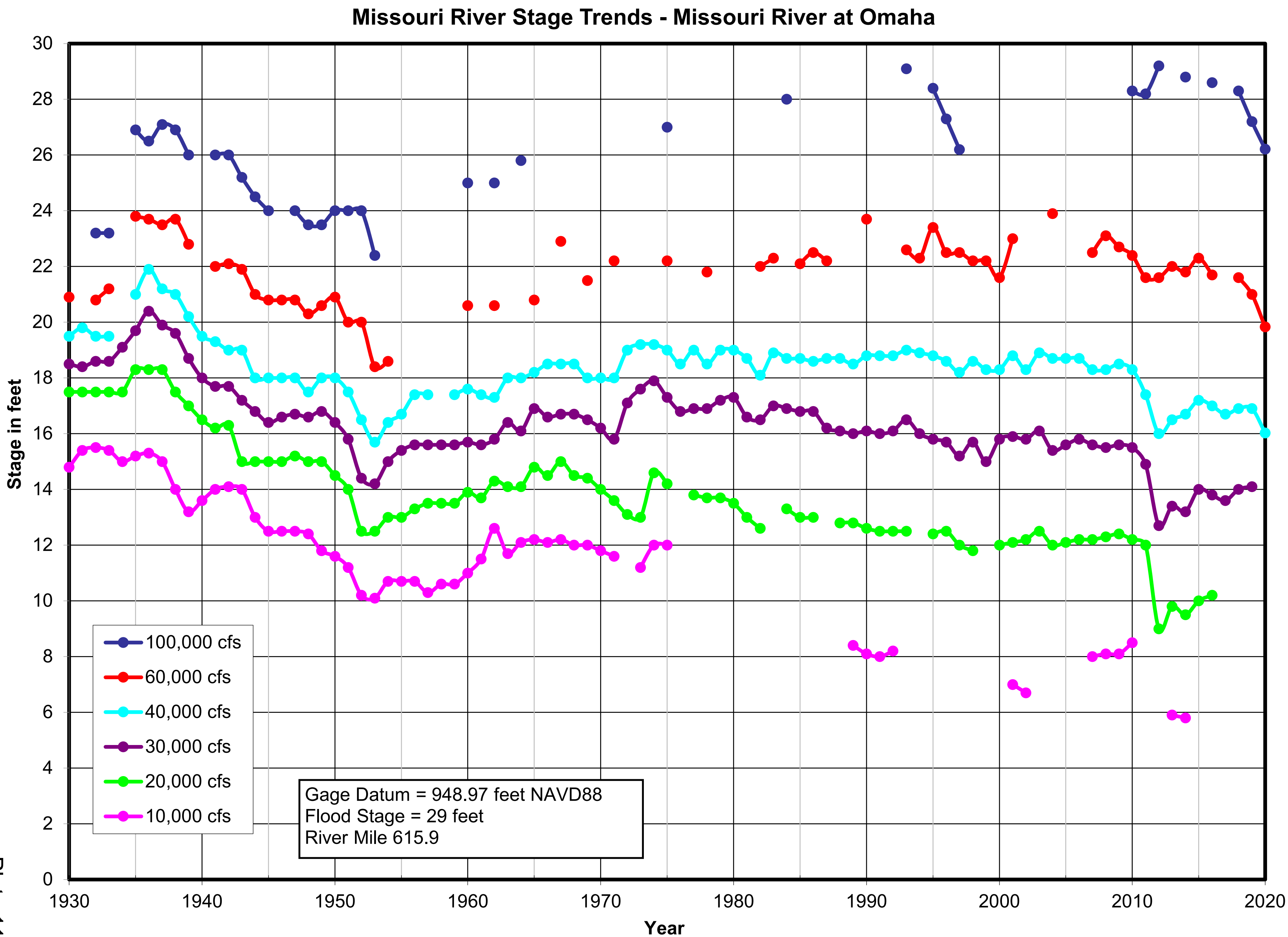
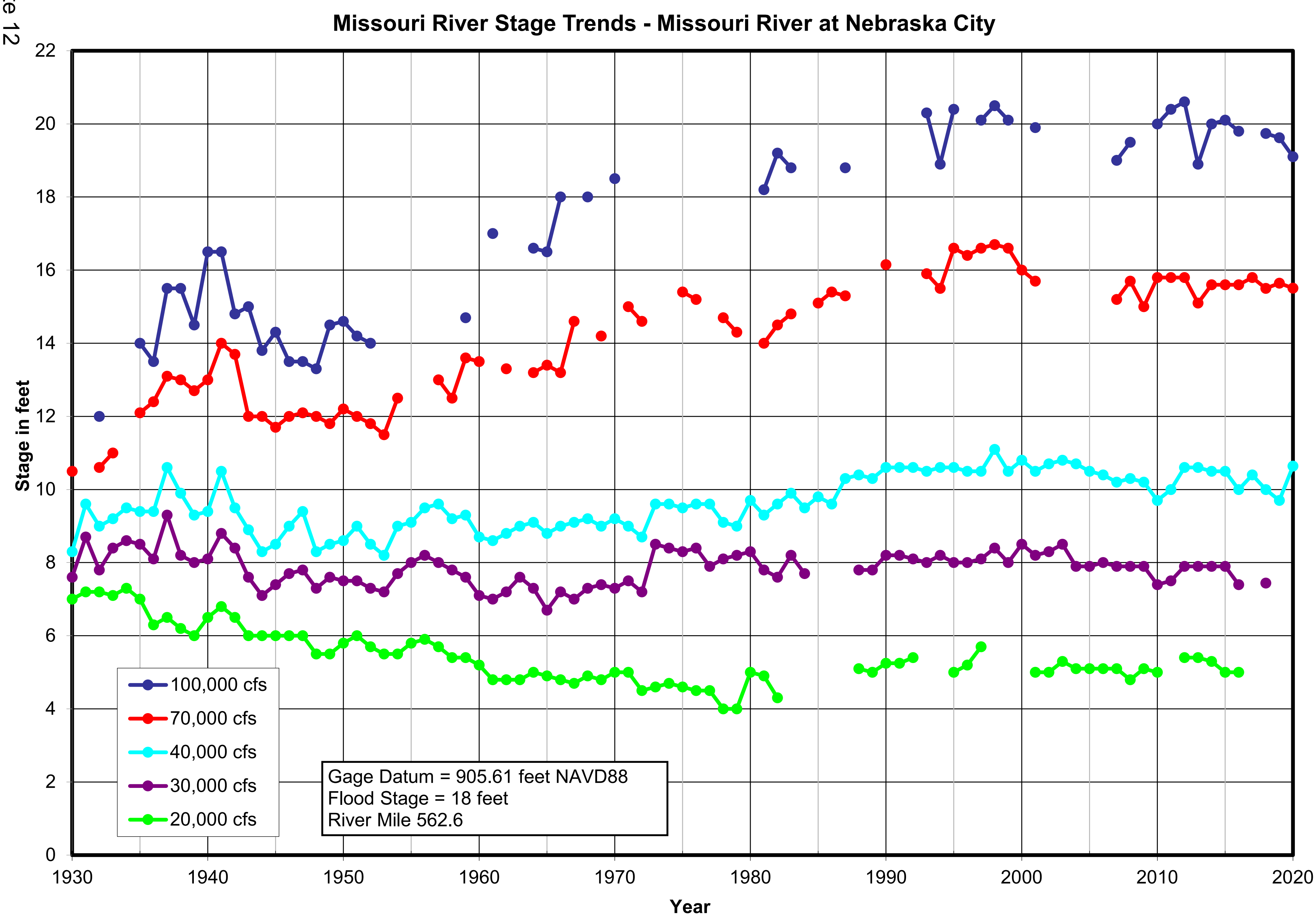
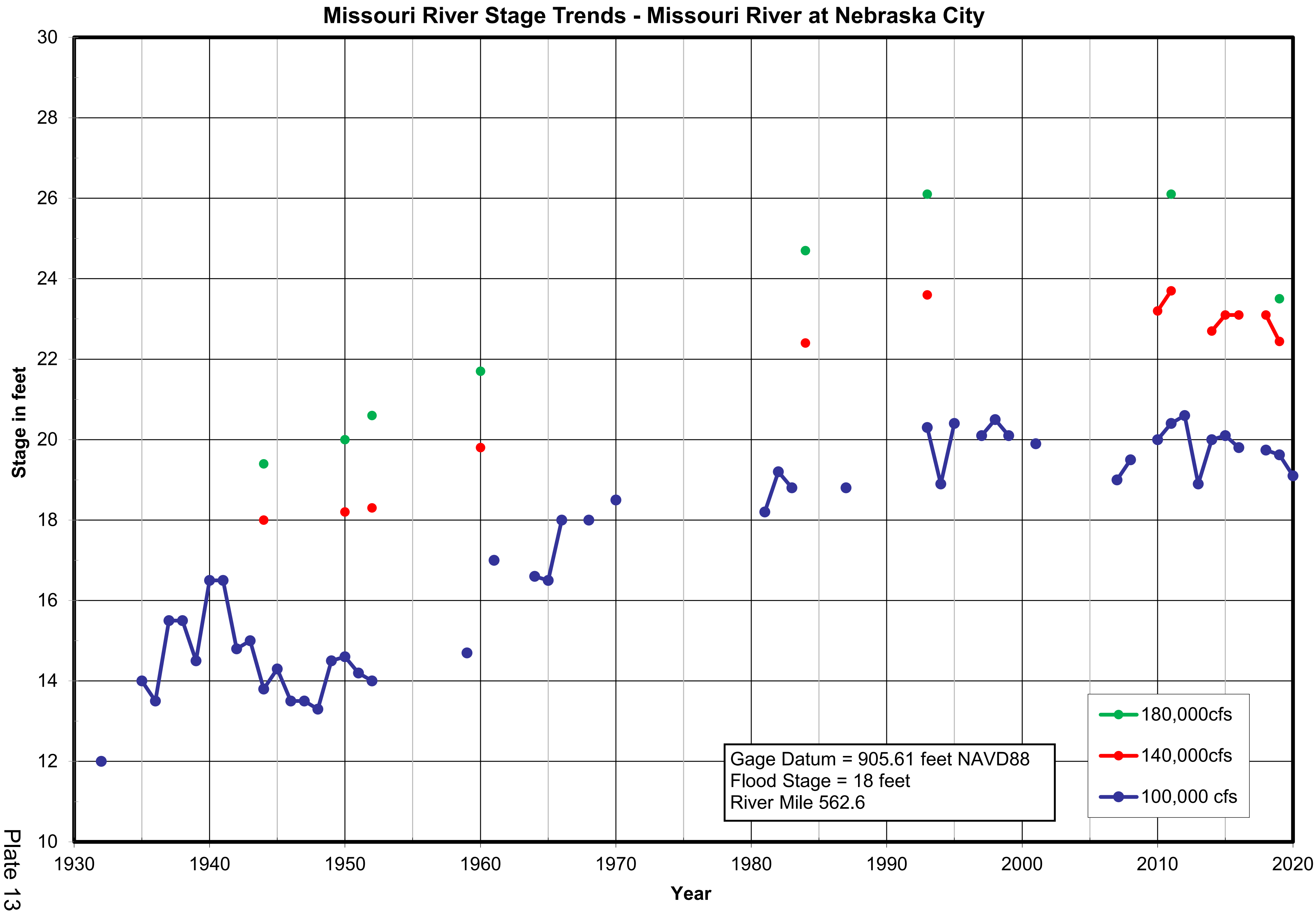

Missouri River Stage Trends - Missouri River at Omaha
Stage in feet
Year
100,000 cfs
60,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
Gage Datum = 948.97 feet NAVD88
Flood Stage = 29 feet
River Mile 615.9

Plate 12



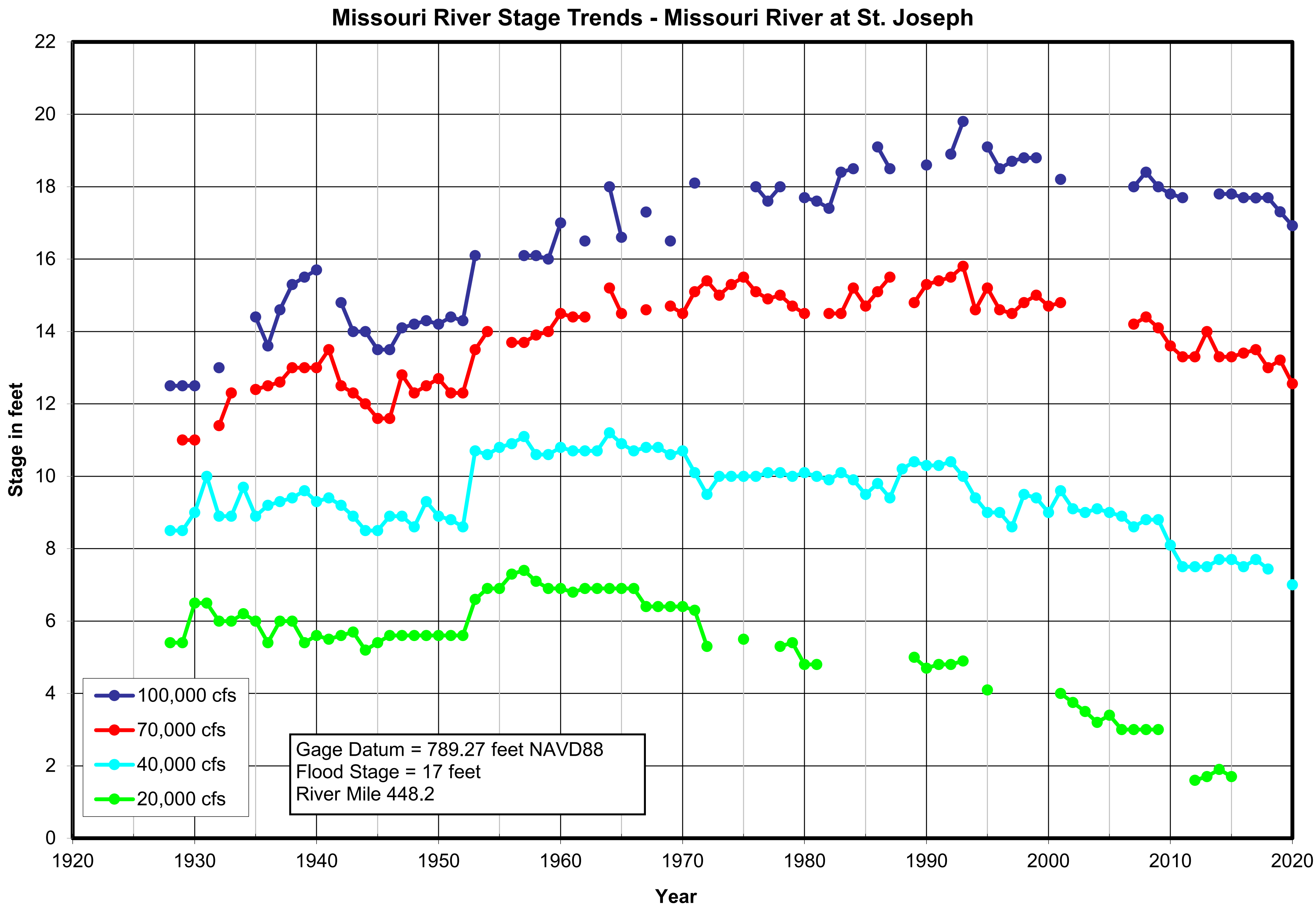
Missouri River Stage Trends - Missouri River at Nebraska City
Stage in feet
Year
0
2
4
6
8
10
12
14
16
18
20
22
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
100,000 cfs
70,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
Gage Datum = 905.61 feet NAVD88
Flood Stage = 18 feet
River Mile 562.6



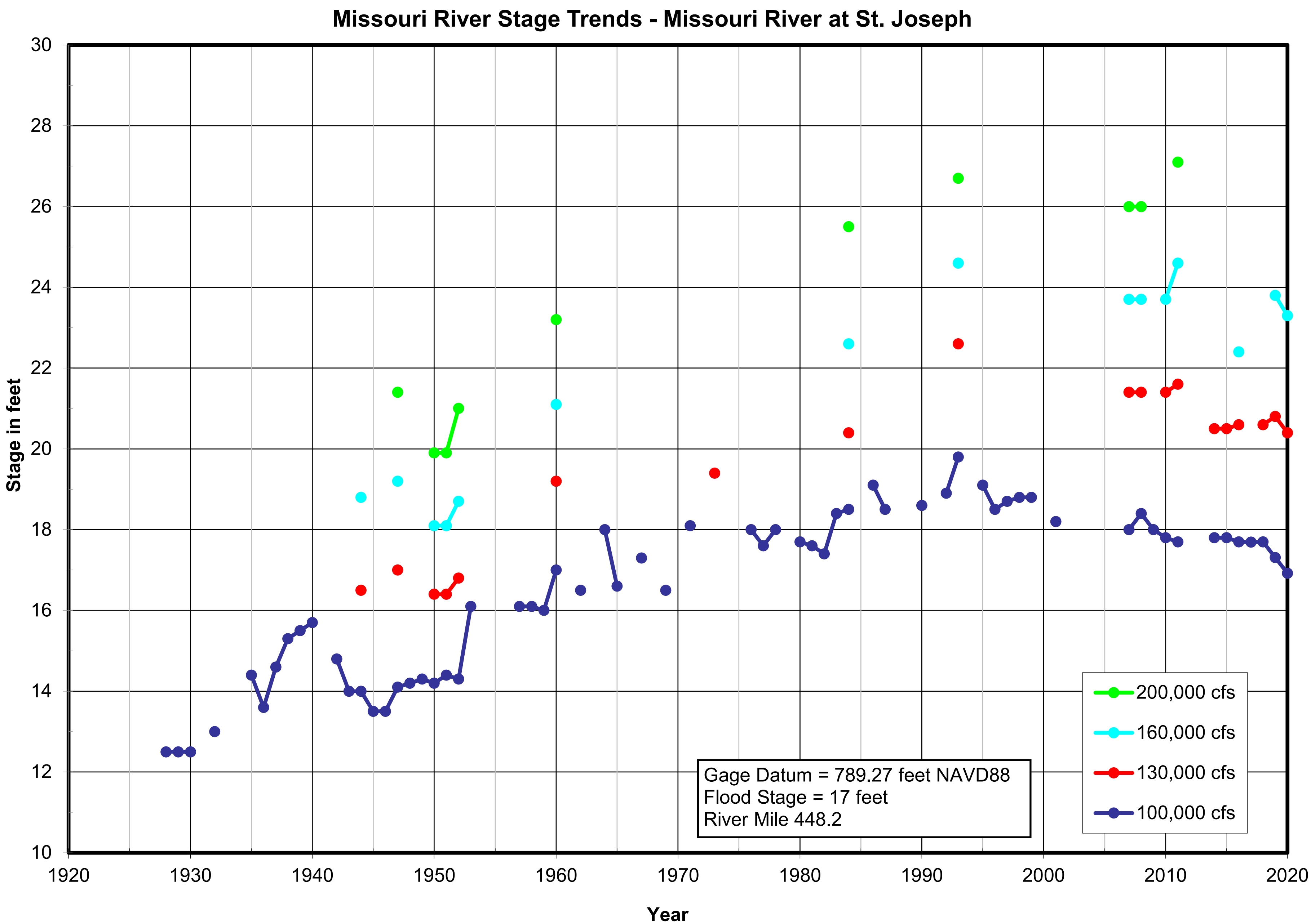
Missouri River Stage Trends - Missouri River at Nebraska City
Stage in feet
Year
30
28
26
24
22
20
18
16
14
12
10
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Gage Datum = 905.61 feet NAVD88
Flood Stage = 18 feet
River Mile 562.6
180,000cfs
140,000cfs
100,000 cfs

Plate 13

Plate 14

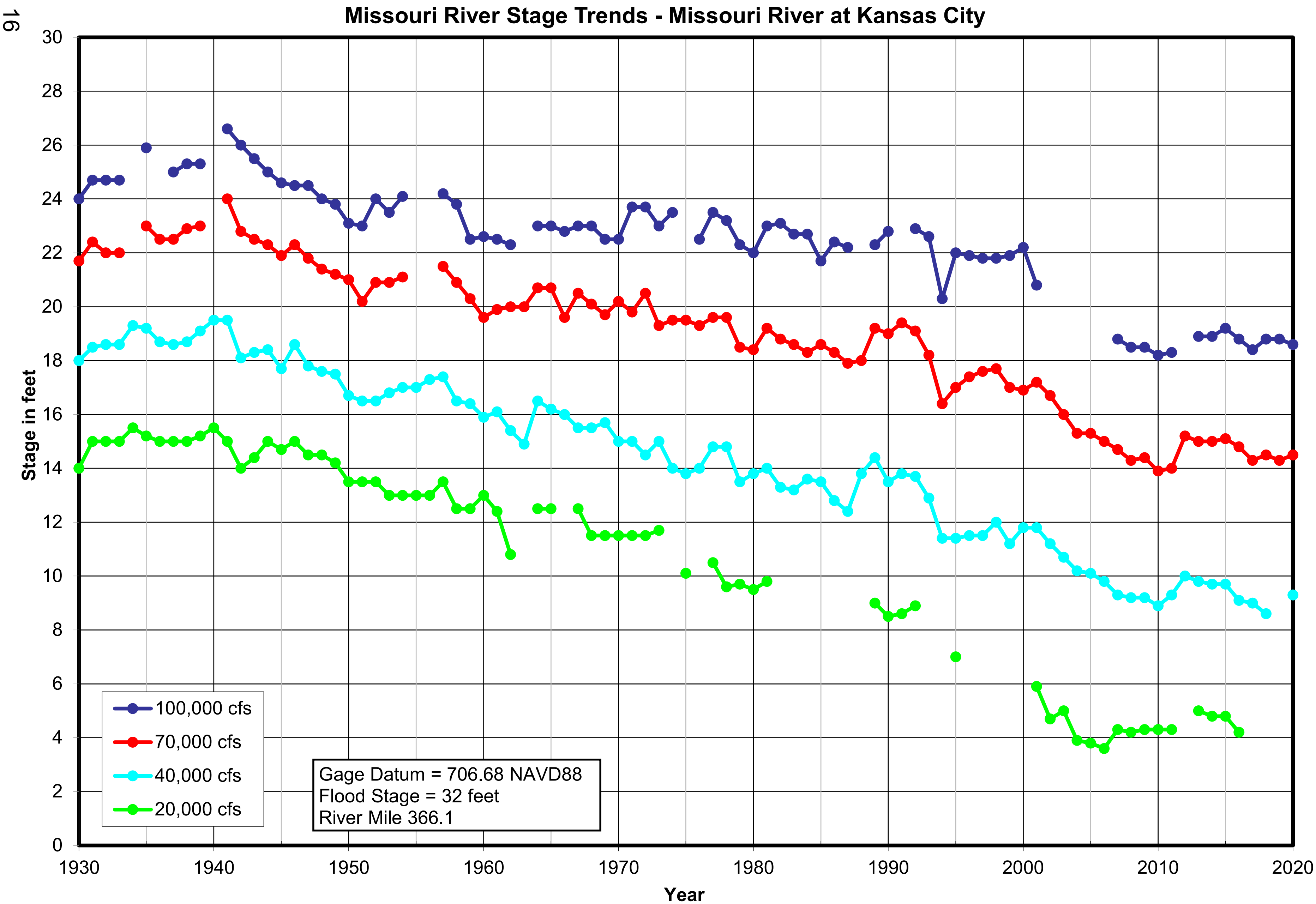


Missouri River Stage Trends - Missouri River at St. Joseph
Stage in feet
Year
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 789.27 feet NAVD88
Flood Stage = 17 feet
River Mile 448.2

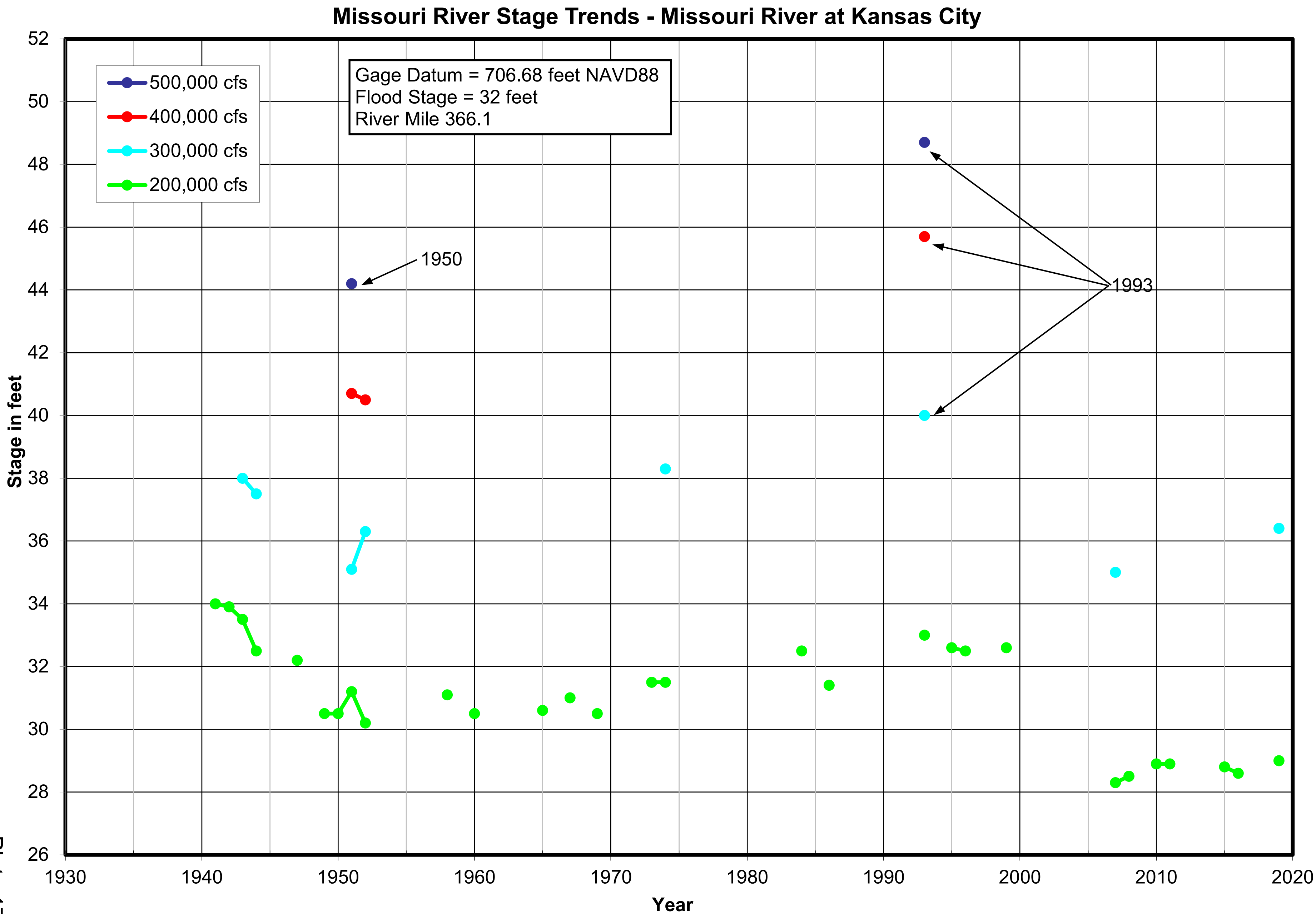


Missouri River Stage Trends - Missouri River at St. Joseph
Stage in feet
Year
30
28
26
24
22
20
18
16
14
12
10
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Gage Datum = 789.27 feet NAVD88
Flood Stage = 17 feet
River Mile 448.2
200,000 cfs
160,000 cfs
130,000 cfs
100,000 cfs

Plate 16

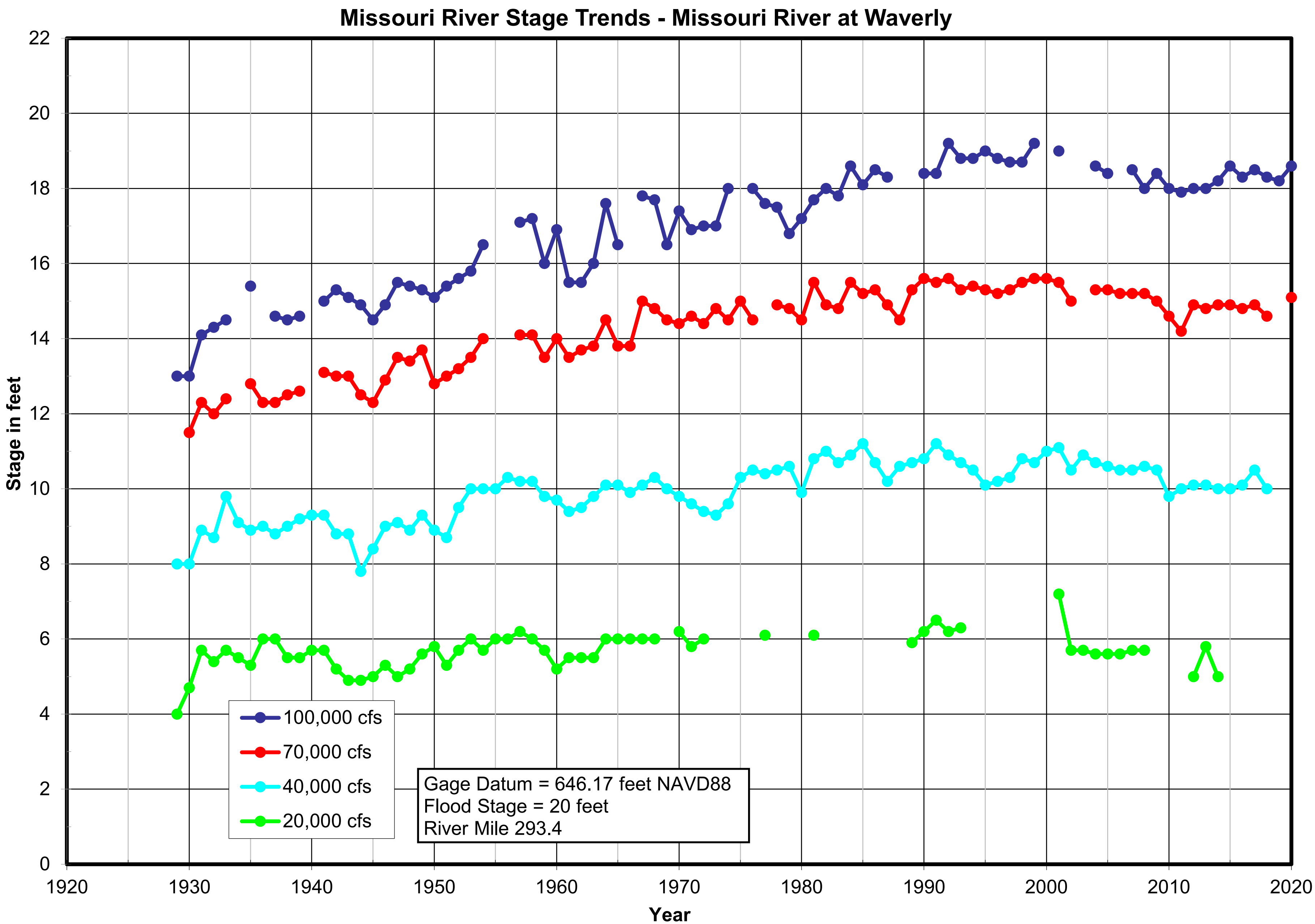


Missouri River Stage Trends - Missouri River at Kansas City
Stage in feet
Year
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 706.68 NAVD88
Flood Stage = 32 feet
River Mile 366.1



Missouri River Stage Trends - Missouri River at Kansas City
500,000 cfs
400,000 cfs
300,000 cfs
200,000 cfs
Gage Datum = 706.68 feet NAVD88
Flood Stage = 32 feet
River Mile 366.1
1950
1993
Stage in feet
Year
52
50
48
46
44
42
40
38
36
34
32
30
28
26
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Plate 18



Missouri River Stage Trends - Missouri River at Waverly
Stage in feet
Year
0
2
4
6
8
10
12
14
16
18
20
22
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 646.17 feet NAVD88
Flood Stage = 20 feet
River Mile 293.4

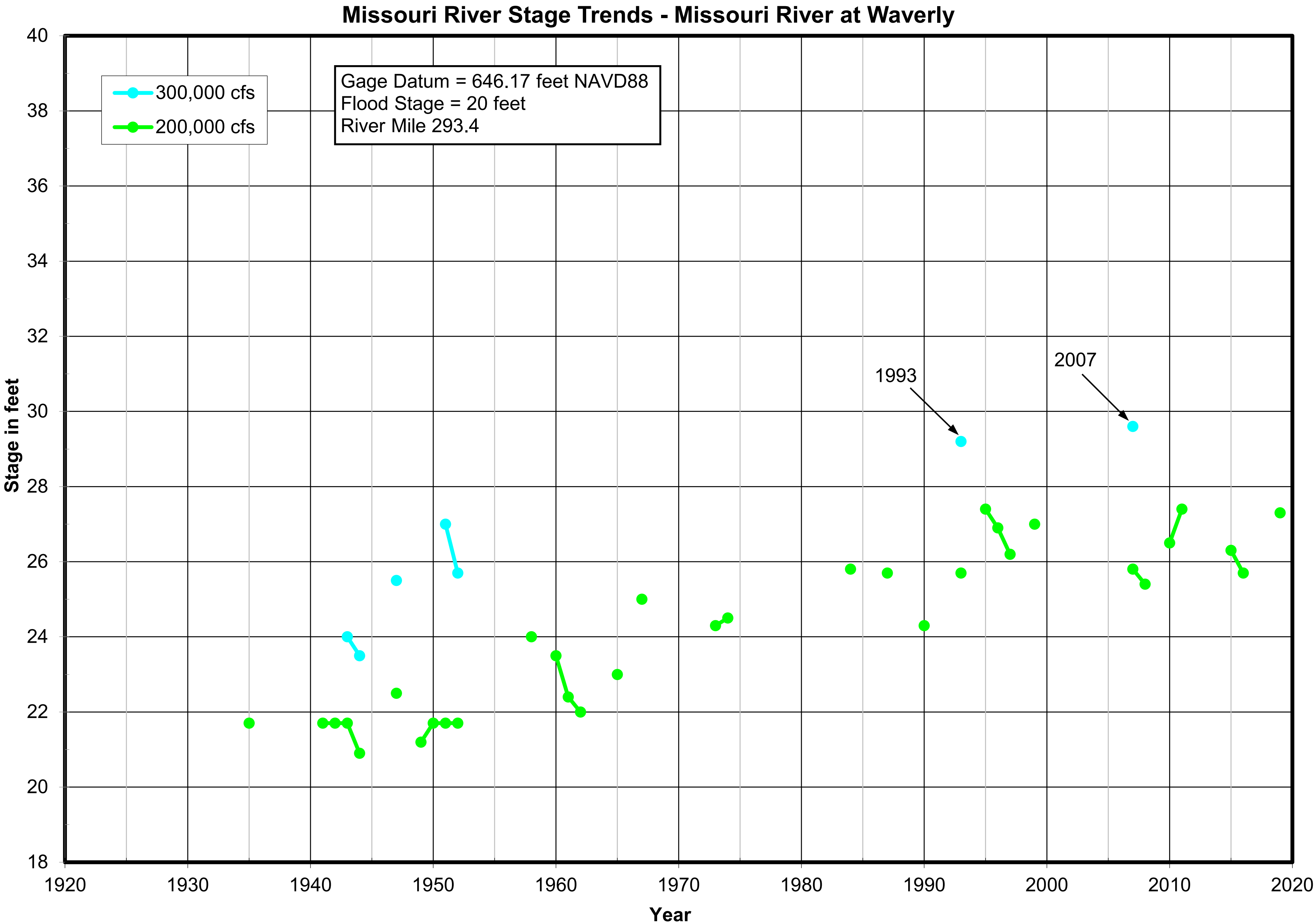
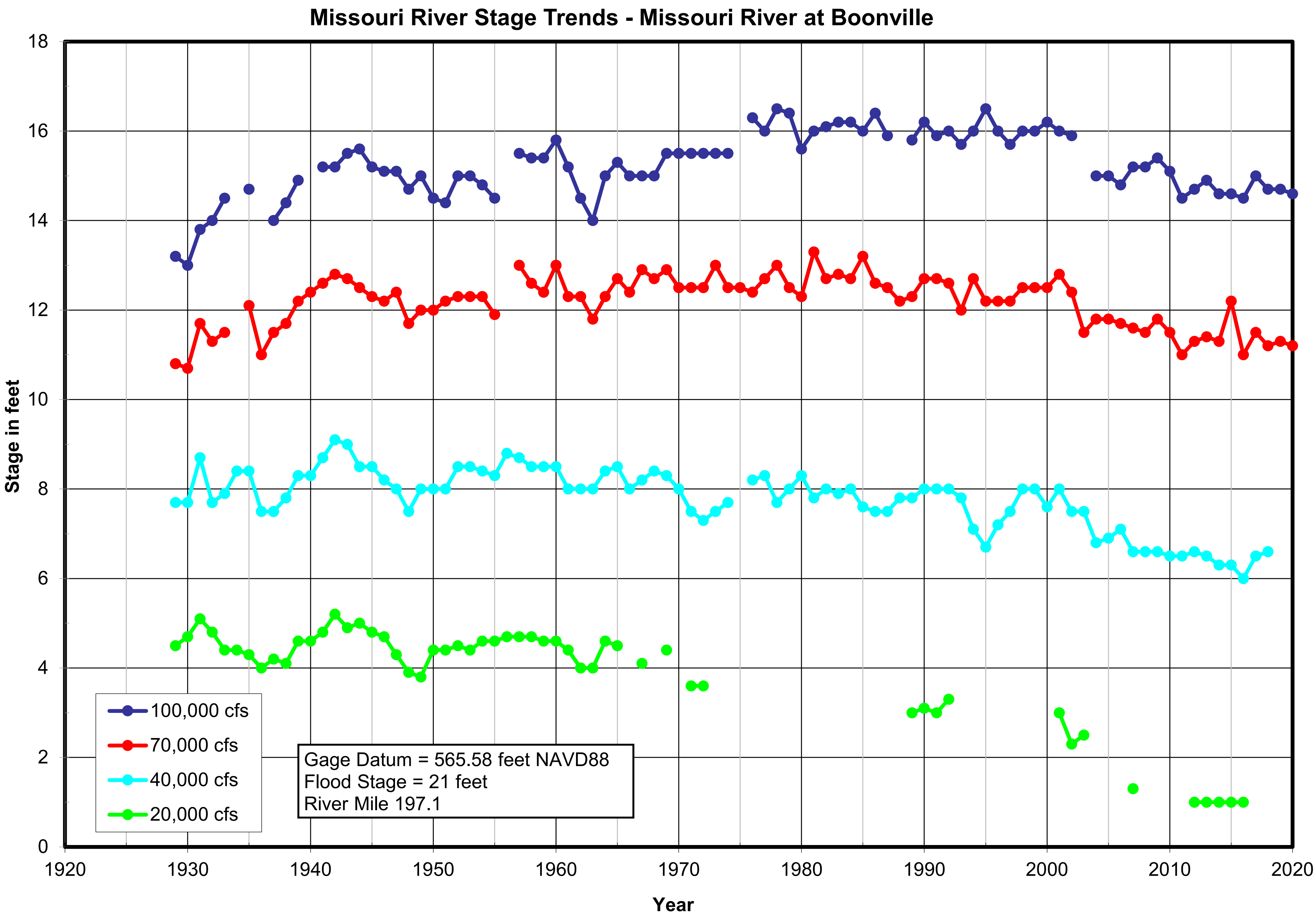
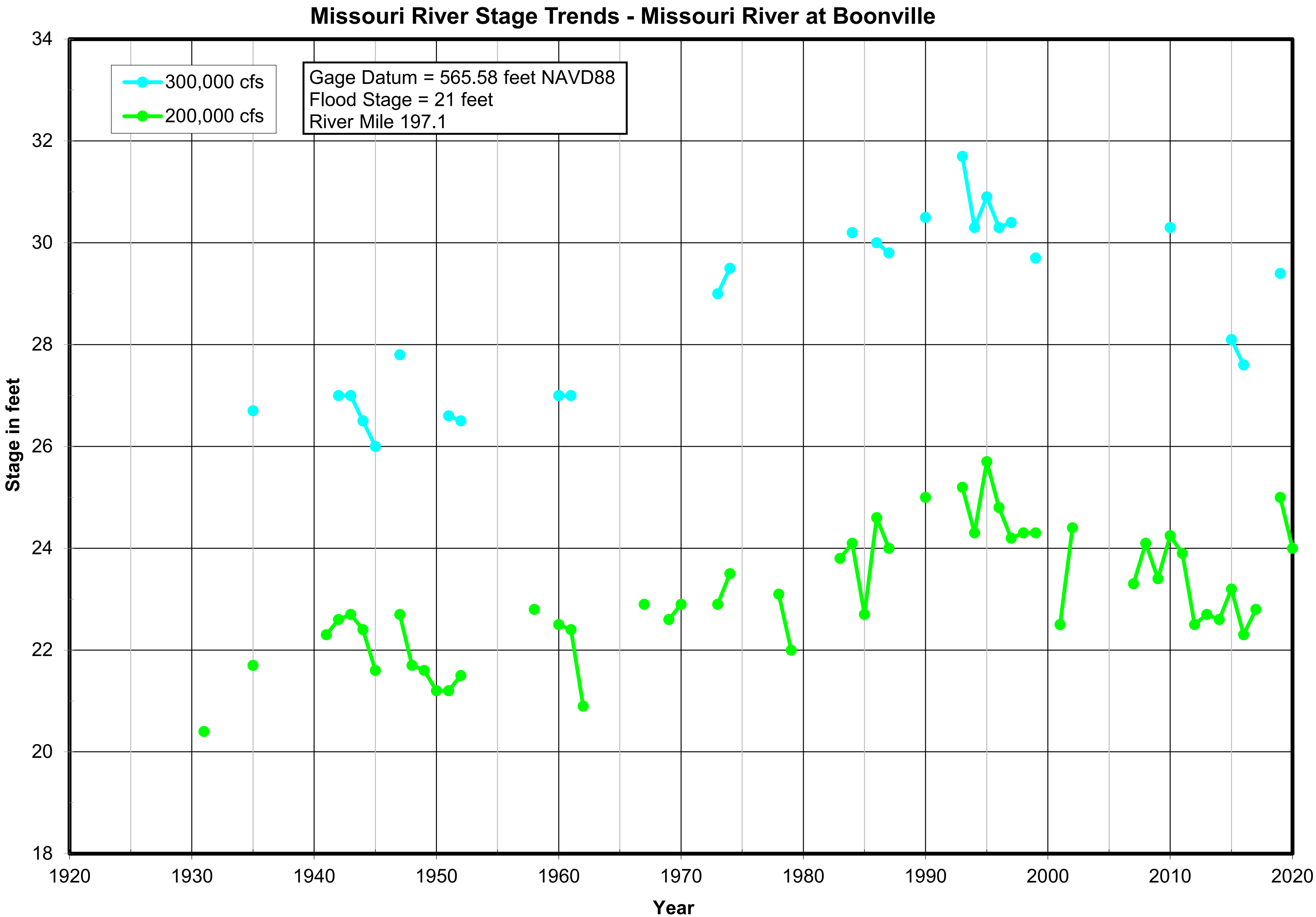

Missouri River Stage Trends - Missouri River at Waverly
300,000 cfs
200,000 cfs
Gage Datum = 646.17 feet NAVD88
Flood Stage = 20 feet
River Mile 293.4
1993
2007
Stage in feet
Year
18
20
22
24
26
28
30
32
34
36
38
40
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Plate 19

Plate 20



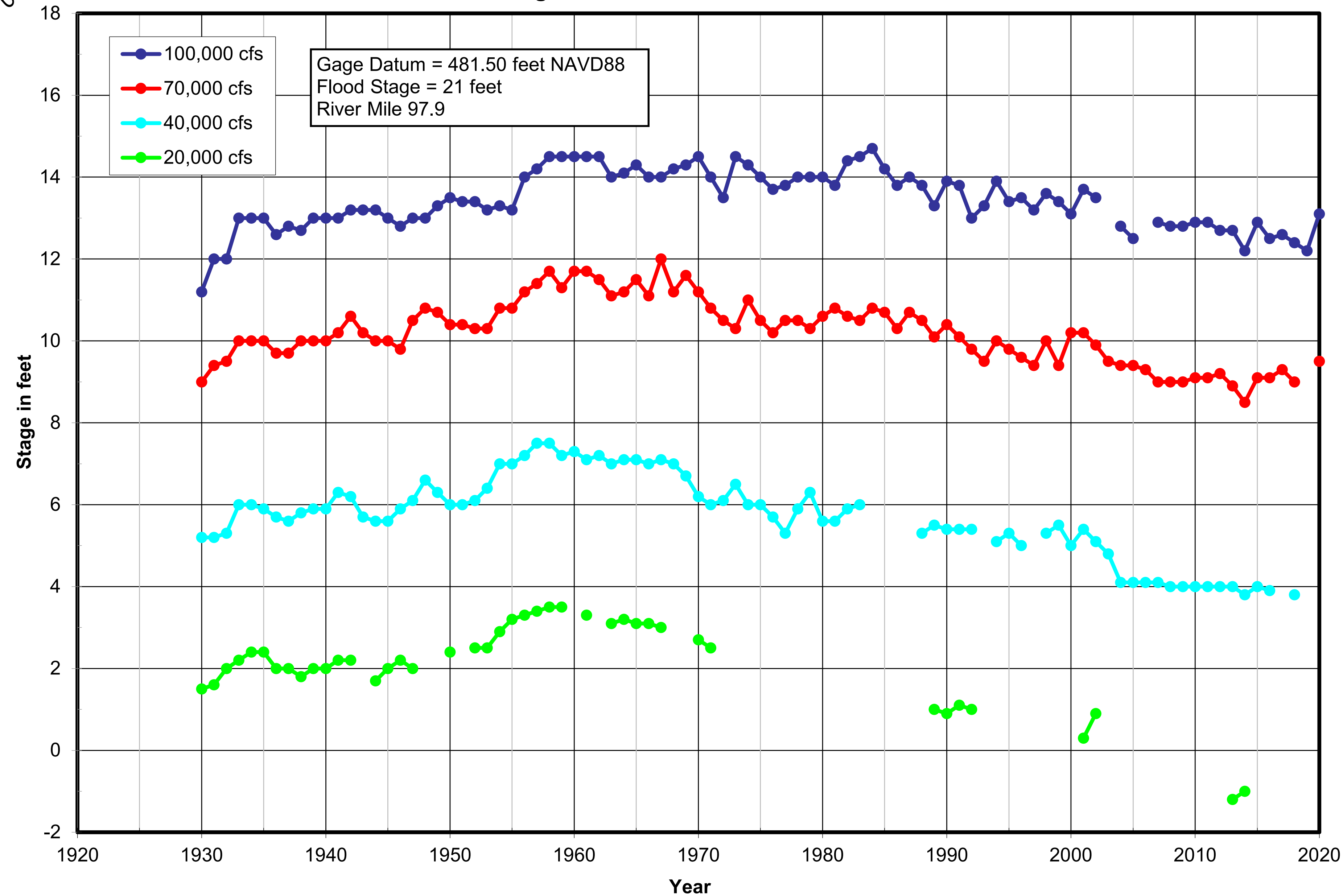
Missouri River Stage Trends - Missouri River at Boonville
Stage in feet
Year
0
2
4
6
8
10
12
14
16
18
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 565.58 feet NAVD88
Flood Stage = 21 feet
River Mile 197.1

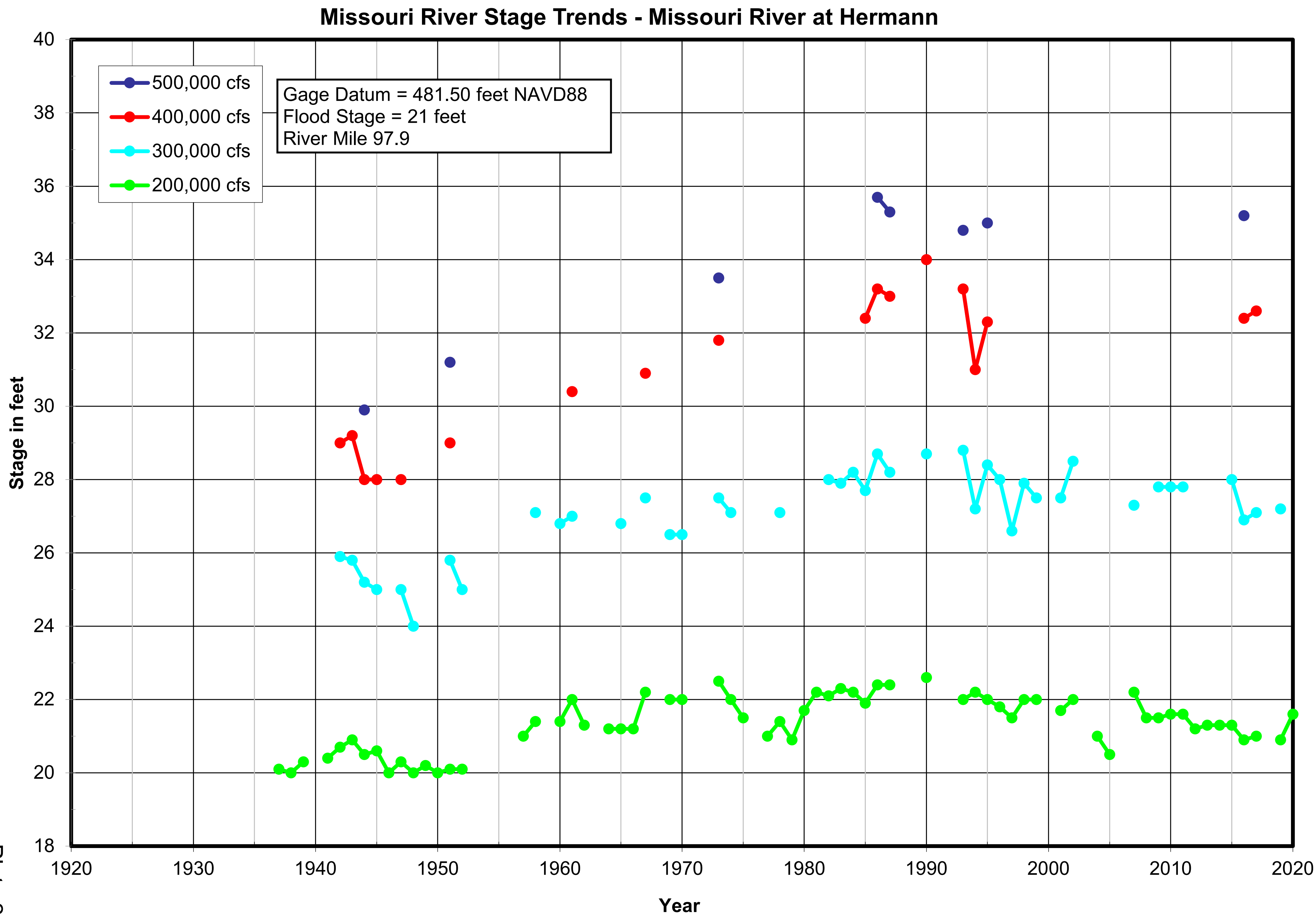


Missouri River Stage Trends - Missouri River at Boonville
300,000 cfs
200,000 cfs
Gage Datum = 565.58 feet NAVD88
Flood Stage = 21 feet
River Mile 197.1
Stage in feet
Year
34
32
30
28
26
24
22
20
18
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Plate 22

Missouri River Stage Trends - Missouri River at Hermann

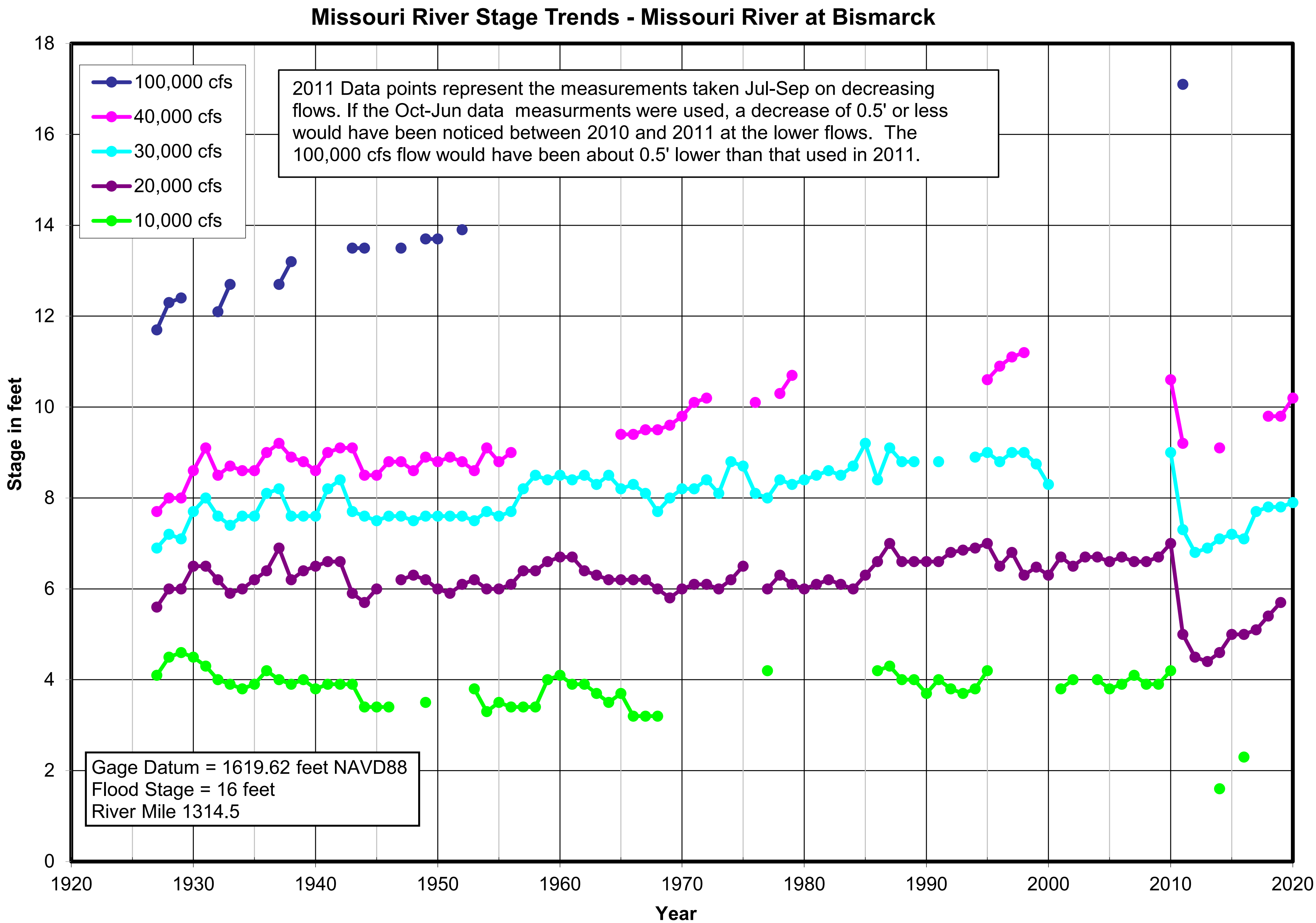




Missouri River Stage Trends - Missouri River at Hermann
500,000 cfs
400,000 cfs
300,000 cfs
200,000 cfs
Gage Datum = 481.50 feet NAVD88
Flood Stage = 21 feet
River Mile 97.9
Stage in feet
Year
40
38
36
34
32
30
28
26
24
22
20
18
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Plate 23

Plate 24



Missouri River Stage Trends - Missouri River at Bismarck
100,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
2011 Data points represent the measurements taken Jul-Sep on decreasing flows. If the Oct-Jun data measurments were used, a decrease of 0.5' or less would have been noticed between 2010 and 2011 at the lower flows. The 100,000 cfs flow would have been about 0.5' lower than that used in 2011.
Gage Datum = 1619.62 feet NAVD88
Flood Stage = 16 feet
River Mile 1314.5
Stage in feet
Year
0
2
4
6
8
10
12
14
16
18
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020