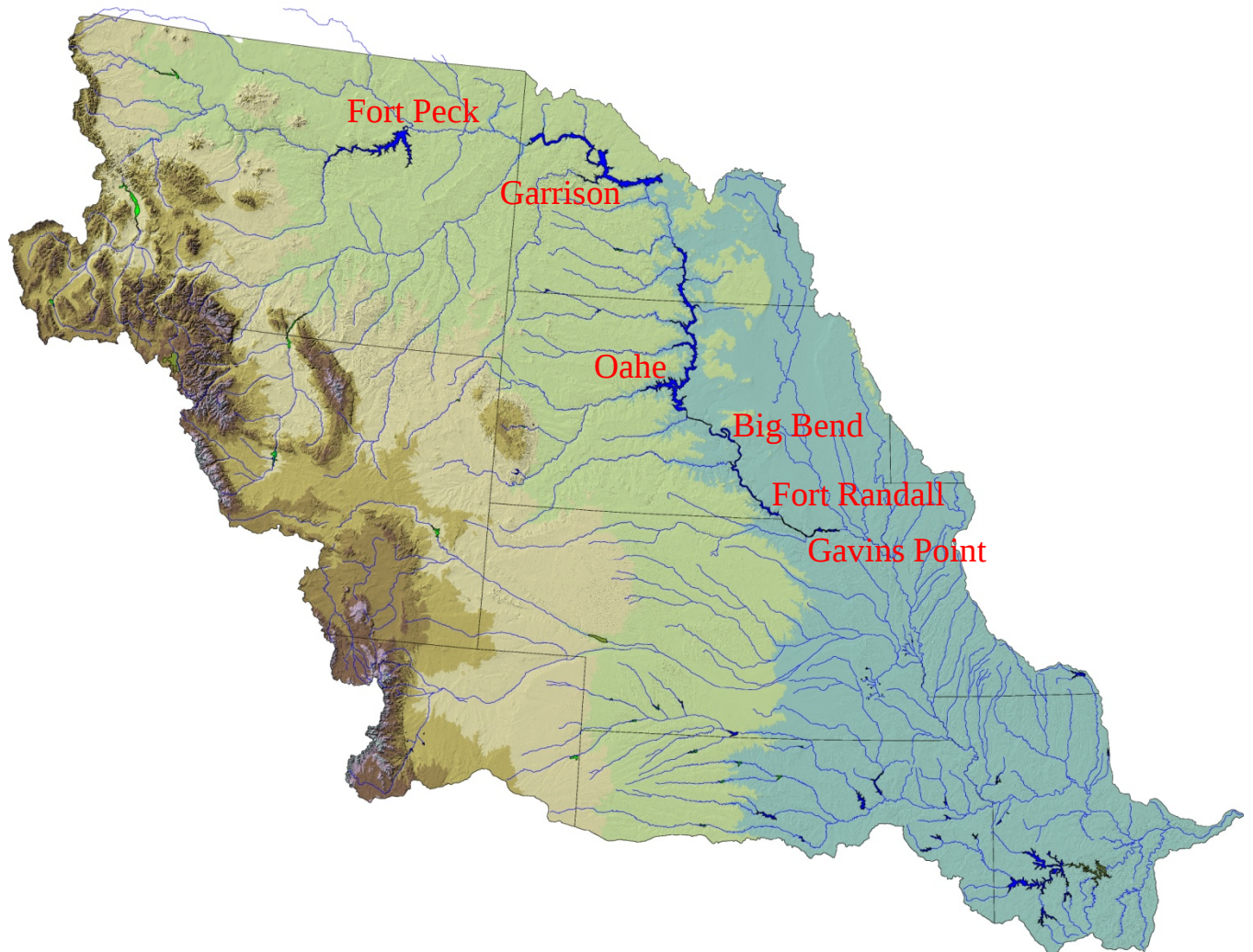




**US Army Corps
of Engineers** ®
Northwestern Division

Missouri River Stage Trends

Technical Report



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MISSOURI RIVER STAGE TRENDS

Table of Contents

Paragraph	Page
INTRODUCTION	
Purpose and Scope.....	1
Missouri River Length Change.....	2
Source of Data for Stage Trend Analyses.....	2
TAILWATER STAGE TRENDS	
Fort Peck.....	5
Garrison.....	5
Oahe.....	6
Big Bend.....	7
Fort Randall.....	7
Gavins Point.....	7
Project Comparisons.....	8
NAVIGATION CHANNEL STAGE TRENDS	
Sioux City.....	9
Omaha	10
Nebraska City	10
St. Joseph	11
Kansas City	11
Waverly	12
Boonville.....	12
Hermann	12
HEADWATER STAGE TRENDS	
Williston.....	13
Bismarck.....	14
Pierre.....	14
Springfield.....	14
SUMMARY	17

LIST OF FIGURES

Figure No.

- 1 Garrison Tailwater Rating Curves, 1955-2016
- 2 Garrison Tailwater Trends, 10,000 to 40,000 cfs
- 3 Oahe Tailwater Rating Curves, 1965-2016
- 4 Oahe Tailwater Trends, 10,000 to 50,000 cfs
- 5 Fort Randall Tailwater Rating Curves, 1955-2016
- 6 Fort Randall Tailwater Trends, 10,000 to 40,000 cfs
- 7 Gavins Point Tailwater Rating Curves, 1955-2016
- 8 Gavins Point Tailwater Trends, 10,000 to 35,000 cfs
- 9 Comparison of Tailwater Trends for Releases of 20,000 cfs
- 10 Missouri River at Sioux City Stage Trends, 10,000 to 100,000 cfs
- 11 Missouri River at Omaha Stage Trends, 10,000 to 100,000 cfs
- 12 Missouri River at Nebraska City Stage Trends, 20,000 to 100,000 cfs
- 13 Missouri River at Nebraska City Stage Trends, 100,000 to 180,000 cfs
- 14 Missouri River at St. Joseph Stage Trends, 20,000 to 100,000 cfs
- 15 Missouri River at St. Joseph Stage Trends, 100,000 to 200,000 cfs
- 16 Missouri River at Kansas City Stage Trends, 20,000 to 100,000 cfs
- 17 Missouri River at Kansas City Stage Trends, 200,000 to 500,000 cfs
- 18 Missouri River at Waverly Stage Trends, 20,000 to 100,000 cfs
- 19 Missouri River at Waverly Stage Trends, 200,000 to 300,000 cfs
- 20 Missouri River at Boonville Stage Trends, 20,000 to 100,000 cfs
- 21 Missouri River at Boonville Stage Trends, 200,000 to 300,000 cfs
- 22 Missouri River at Hermann Stage Trends, 20,000 to 100,000 cfs
- 23 Missouri River at Hermann Stage Trends, 200,000 to 500,000 cfs
- 24 Missouri River at Bismarck Stage Trends, 10,000 to 100,000 cfs

INTRODUCTION

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 below 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 during the past 30 to 40 years, 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 Au-12*" published in August 2012. 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, and April 2010.

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 is 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

SOURCE OF DATA FOR STAGE TREND ANALYSES

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

The sources of data for these figures 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 stations along the navigation channel were selected using engineering judgment and the USGS stage-discharge measurements. Data were also obtained for headwater and tailwater locations from published Corps reports and memoranda.

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TAILWATER STAGE TRENDS

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. Tailwater trends are monitored annually at all of the projects and are discussed in the following paragraphs. Curves are developed annually for Garrison, Oahe, Fort Randall, and Gavins Point. To make trends more apparent, figures present curves every fifth year (e.g., 2000, 2005, 2015). 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.

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, and 2011, Fort Peck releases have not been significantly in excess of the powerplant capacity of the project, which is about 15,000 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.

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 when releases of 65,000 cfs were required for over one month, in 1997 when releases averaged 57,300 cfs during July, and in 2011. In 2011, releases exceeded 100,000 cfs for 71 days and releases peaked at 150,600 cfs on June 25. **Figure 1** presents Garrison tailwater rating curves every fifth year beginning in 1955 and extending through 2016.

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 2016 curve continues to show the degradation trend, lowering about 0.2 foot from the 2015 curve.

Figure 2 shows the trend of the Garrison tailwater stages for releases 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. **Figure 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. The lowering trend can be seen, 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.

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. Tailwater rating curves from every fifth year beginning in 1965 and extending through 2016 are shown on **Figure 3**. The Big Bend powerplant became fully operational in 1966. As a run-of-the-river project, the Lake Sharpe pool levels are maintained in a very 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. The 2016 curve shows aggradation at higher and lower releases while showing a slight degradation trend at average releases.

Stage trend plots for releases ranging from 10,000 to 50,000 cfs are shown on **Figure 4**. The overall trend at all releases, with the exception of the 10,000 cfs release, is a 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. 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.

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.

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. In the fall of 2014, a late-year precipitation event resulted in the need for releases above 45,000 cfs for about two months. As shown on **Figure 5**, a lowering of the tailwater stage of about 5 feet had 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 2016, the lowering trend continued.

As seen on **Figure 6**, a decrease of about 2 feet in stage occurred from 1952 to 1955 when releases ranged from 10,000 to 40,000 cfs. The 1994 through 1997 trend lines shown on **Figure 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 **Figure 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 2016, 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.

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. 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. In 2012, dry conditions necessitated releases of over 38,000 cfs for almost four months to meet Missouri River navigation requirements. In the fall of 2014, flood storage evacuation resulted in Gavins Point releases of 45,500 cfs for about two months. **Figure 7** shows tailwater rating curves from every fifth year beginning in 1955 and extending through 2016. As illustrated by those curves, a stage lowering is evident at each interval.

As shown on **Figure 8**, the Gavins Point tailwater has lowered about 13 feet at flows of 10,000, 20,000, and 35,000 cfs since closure of the project in 1955. The trends show an overall reduced degradation rate, except during years of high releases. 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 2016 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.

PROJECT COMPARISONS

A comparison of tailwater trends for the Gavins Point, Fort Randall and Garrison projects is shown on **Figure 9**. As illustrated on **Figure 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 fairly constant from 1997 to 2010. **Figure 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. In 2012, Gavins Point tailwater stages continued a sharper degradation trend. Since that time, Gavins Point shows very little change in stages when releases are 20,000 cfs. Since 2011, the slight degradation trend continued for Garrison and Fort Randall. The total decrease in tailwater stage at these projects is 13 feet at Gavins Point, 11.5 feet at Garrison, and 9 feet at Fort Randall.

NAVIGATION CHANNEL STAGE TRENDS

In the reach from Gavins Point Dam to Ponca State Park, Nebraska, 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, Nebraska, and Sioux City, Iowa, 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, Iowa to its mouth near St. Louis, Missouri. 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, South Dakota, 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. Trends at each of the key locations are discussed in the following paragraphs.

SIOUX CITY

As illustrated on **Figure 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 2010, the stage trends reversed and aggradation ranging from 0.5 to 1 foot occurred. This 11-year period covered 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. Since 2011 the stage trends indicate some aggradation, with the stage increasing 1 to 2 feet at various flows.

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.

OMAHA

As shown on **Figure 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. 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 in following years. For the stage trend at 60,000 cfs, degradation of about 1 foot was noted in 2011; since 2011, stages have shown little change. 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 2013-16. 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.

NEBRASKA CITY

Stage trends at the Nebraska City location are shown on **Figure 12** and **Figure 13**. 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 85,000 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.

ST. JOSEPH

As seen on **Figure 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. In the early 1970s, stages for flows of 20,000 and 40,000 cfs declined from 1 to 2 feet. Since the Flood of 1993, stages for flows of 20,000 and 40,000 cfs have lowered a little more than 2 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 2 to 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 to 2006. **Figure 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. By 2008 the stages lowered about 1 foot, then increased slightly from 2008 to 2011. Since that time 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.

KANSAS CITY

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

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

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 **Figure 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.

Figure 17 shows data points representing flows between 200,000 and 500,000 cfs; data for flows above 200,000 cfs are very sparse. 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. Since 1999 the stage has decreased by about 4 feet. The stage trend for the 300,000 cfs flow seems to follow the trend for the 200,000 cfs flow; however, there are only a few data points for the 300,000 cfs flow level.

WAVERLY

Figure 18 shows data points representing flows between 20,000 cfs and 100,000 cfs. Stages at the 100,000 cfs flow level are about 6 feet higher than those experienced during the 1930s. Stages showed an increasing trend until the late 1990s, and since then have decreased about 1 foot. The stages for the 70,000 and 40,000 cfs flows generally increased through 1990 by about 3 feet, then stayed fairly constant through 2008, before decreasing about 1 foot by 2011. In 2012, stages increased at the 70,000 cfs flow by about 1 foot, and remained steady from 2012 through 2016. Stages never increased for the 40,000 cfs flow after 2011, but have remained steady from 2011 through 2016. Stages at the 40,000 cfs flow remained steady from 2010 through 2016. From 1970 to 2009 the stages for the 20,000 cfs flow has shown periods of fluctuations, but overall has shown little change. **Figure 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.

BOONVILLE

Figure 20 and **Figure 21** 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 have remained relatively constant from 1930 to 1970 for the lower flows of 20,000 and 40,000 cfs. A decreasing trend has developed at these flows such that the stage is now 2 to 3 feet lower. For the 70,000 and 100,000 cfs flows the trend indicates a slow increase in stage from 1930 to 1960 of about 2 to 3 feet. From 1960 to 2000, the stages remain fairly steady. Since 2002, the stages for flows 100,000 cfs and less 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, which is sparse, indicate a decreasing trend with stages similar to those observed in the 1960s.

HERMANN

At Hermann, the Missouri River stage trends 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 (see **Figure 22** and **Figure 23**). 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 early 2000s, when degradation of about 1 foot occurred. Since that time, stages at that flow level remained fairly stable. 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. **Figure 23** shows the trends for Missouri River flows between 200,000 and 500,000 cfs. Stage trends at these flows indicate an increase in stage prior to the late 1980s of 3 to 5 feet. Since the late 1980s the stage trends have varied year to year but the overall trend is fairly steady.

HEADWATER AREA STAGE TRENDS

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.

WILLISTON

The Garrison reservoir headwaters extend upstream past the city of Williston, North Dakota, 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 feet 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 feet 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.

BISMARCK

Bismarck, North Dakota, 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 **Figure 24**, from the late 1920s to 2010 the stages for the 20,000, 30,000 and 40,000 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. Stage-discharge measurements in recent years show a slight increasing trend for flows at and below 40,000 cfs. 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.

PIERRE

The Big Bend reservoir headwaters extend upstream to the Pierre-Fort Pierre, South Dakota 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.

SPRINGFIELD

Headwaters of the Gavins Point reservoir extend upstream of the Springfield, South Dakota 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, Nebraska 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 entitled *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 occurred in 1960 with a peak flow of 39,000 cfs. This flood resulted in extensive sediment deposition on the Niobrara River delta.

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 feet 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.

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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.

Since 2011 stages have generally shifted upward in the open river reach from Gavins Point Dam to Omaha, Nebraska and have shown little change in the open river reaches downstream to Hermann, Missouri. 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 indicate upward stage shifts for the higher flows at all stations located along the navigation channel or in System reservoir headwater areas. This trend still exists for the Missouri River at Nebraska City and St. Joseph. However, the latest stage-discharge measurements at Kansas City at 200,000 cfs indicate a downward shift of almost 4 feet. The upward trend is most apparent at Nebraska City and St. Joseph, where flows of 80,000 to 90,000 cfs now exceed the bank compared to bankfull flows of around 150,000 cfs about 40 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 13 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 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 this period. An exception to the tailwater stage reduction occurred below Oahe at the lower releases, where the tailwater stages had increased slightly through 1995. Since 1995, the tailwater stage has decreased about a foot.

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 <http://www.nwd-mr.usace.army.mil/rcc/> under Reports & Publications, Technical Reports.

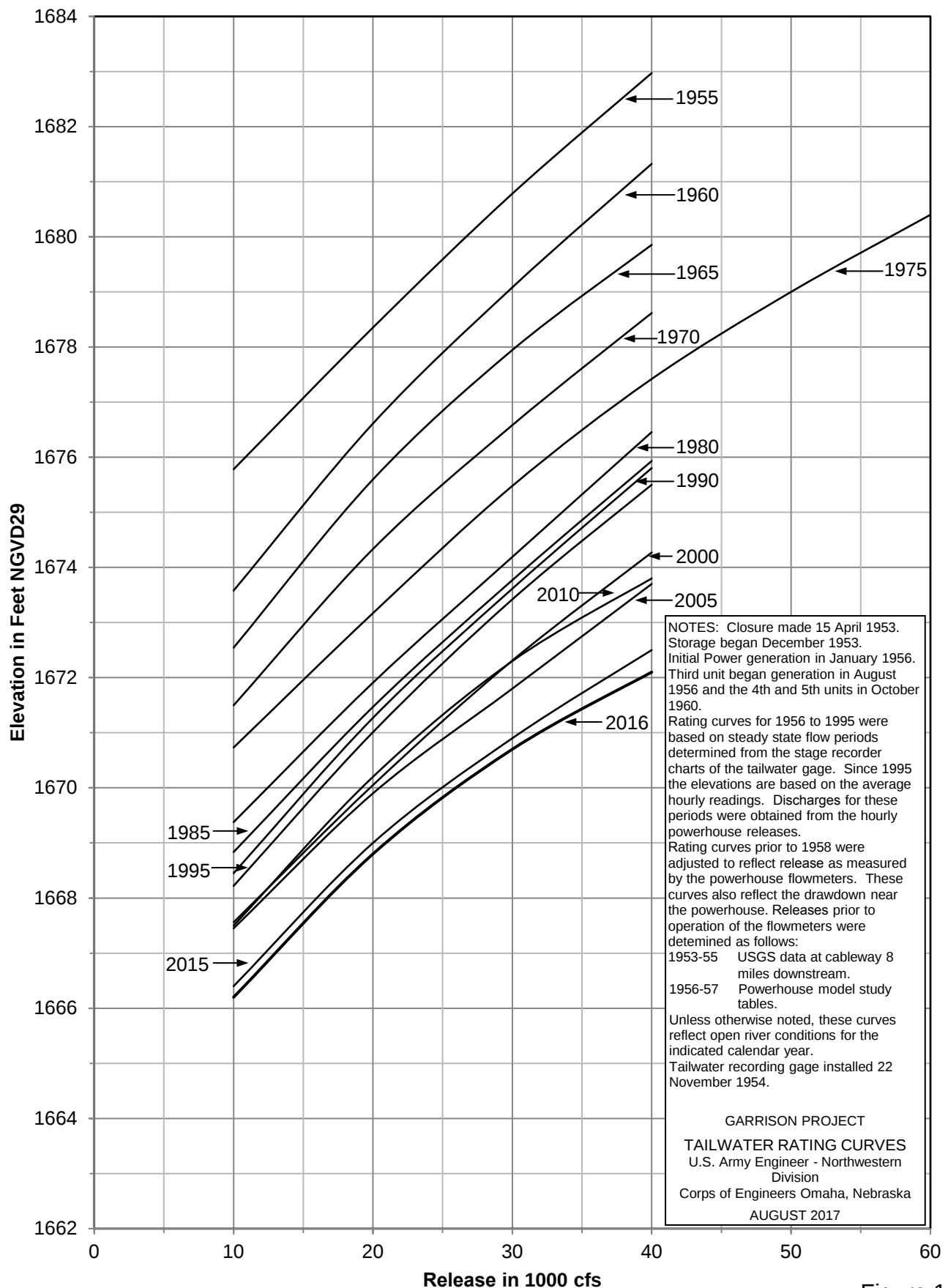
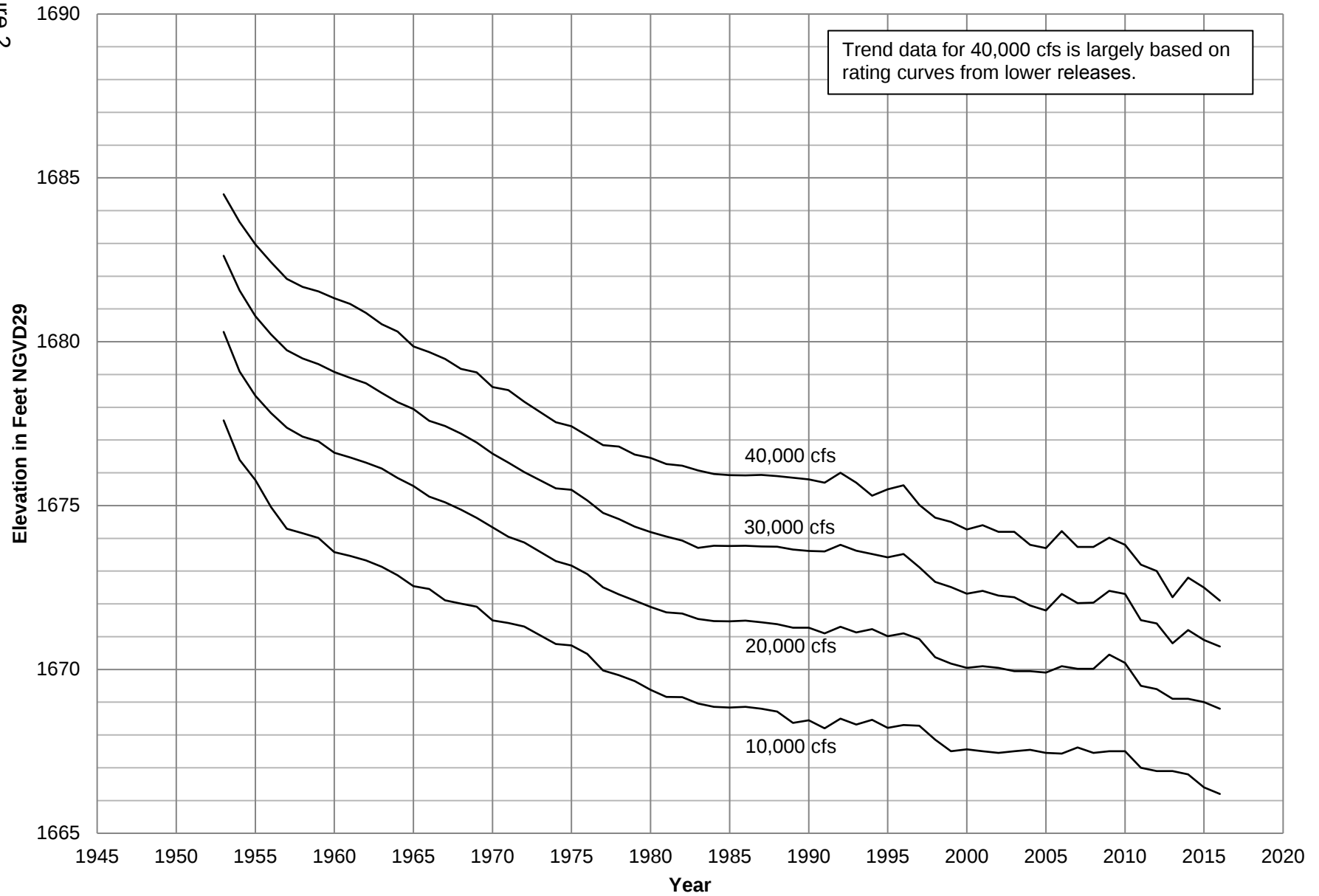


Figure 1

Figure 2

Garrison Project Tailwater Trends



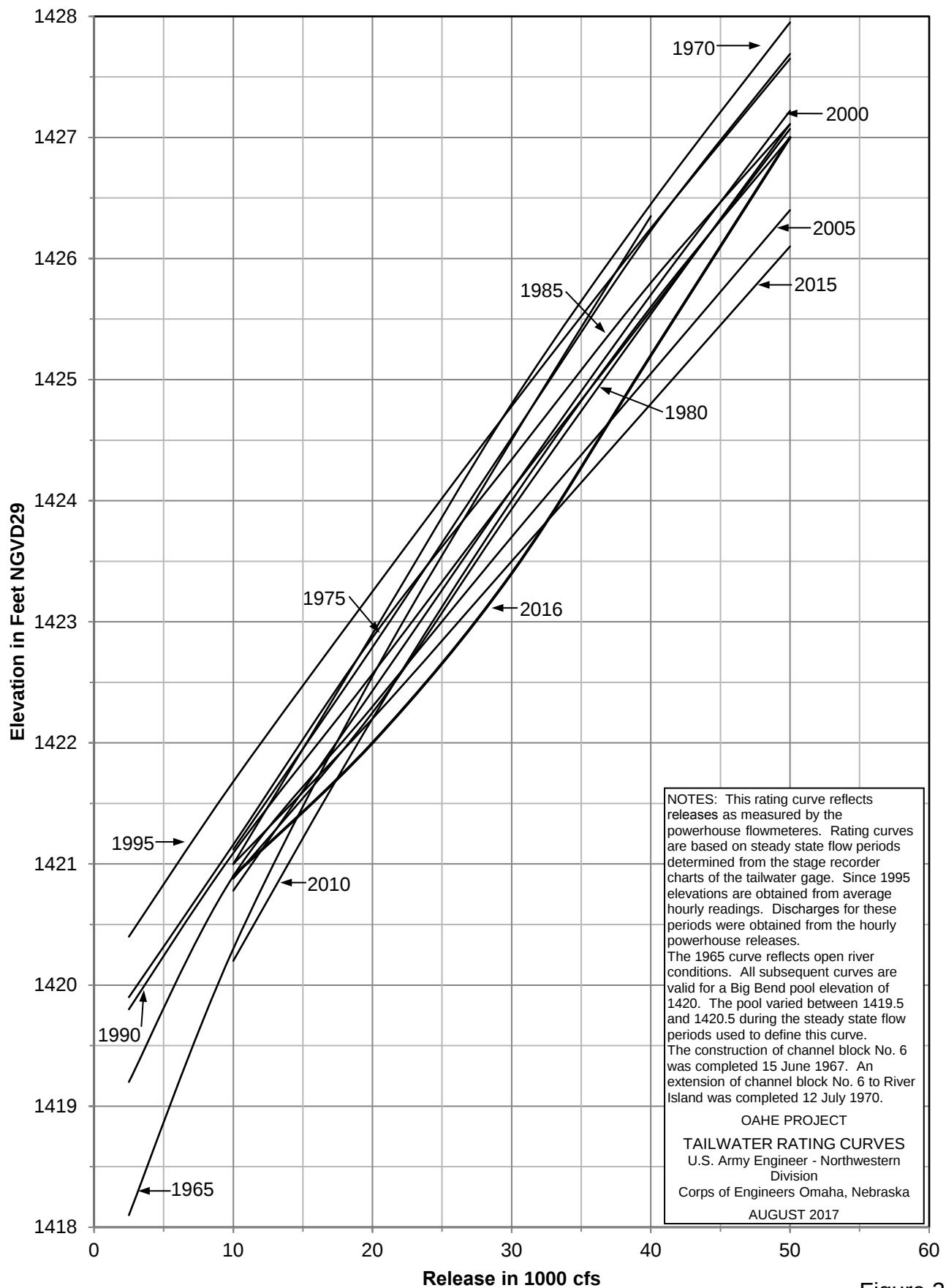
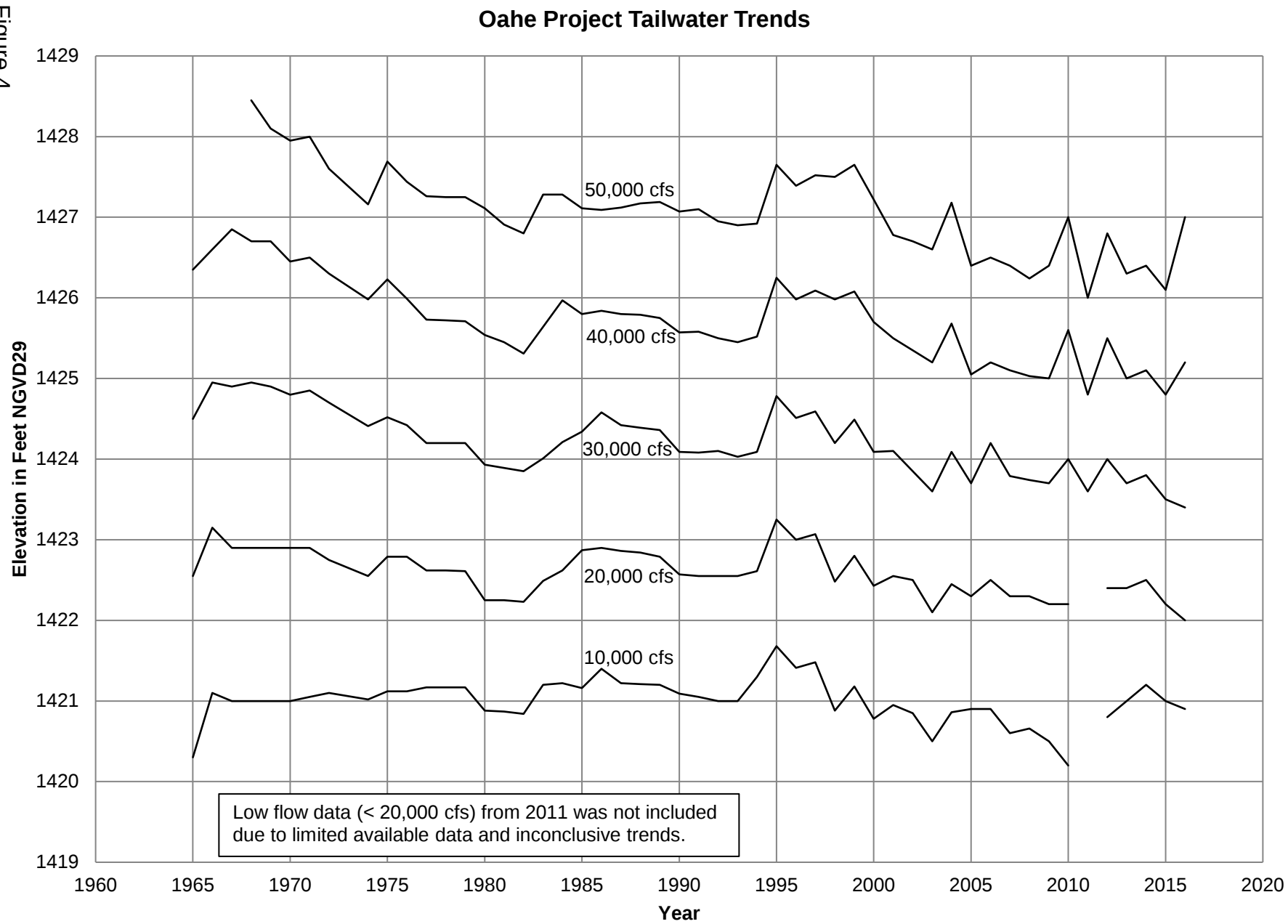


Figure 3

Figure 4



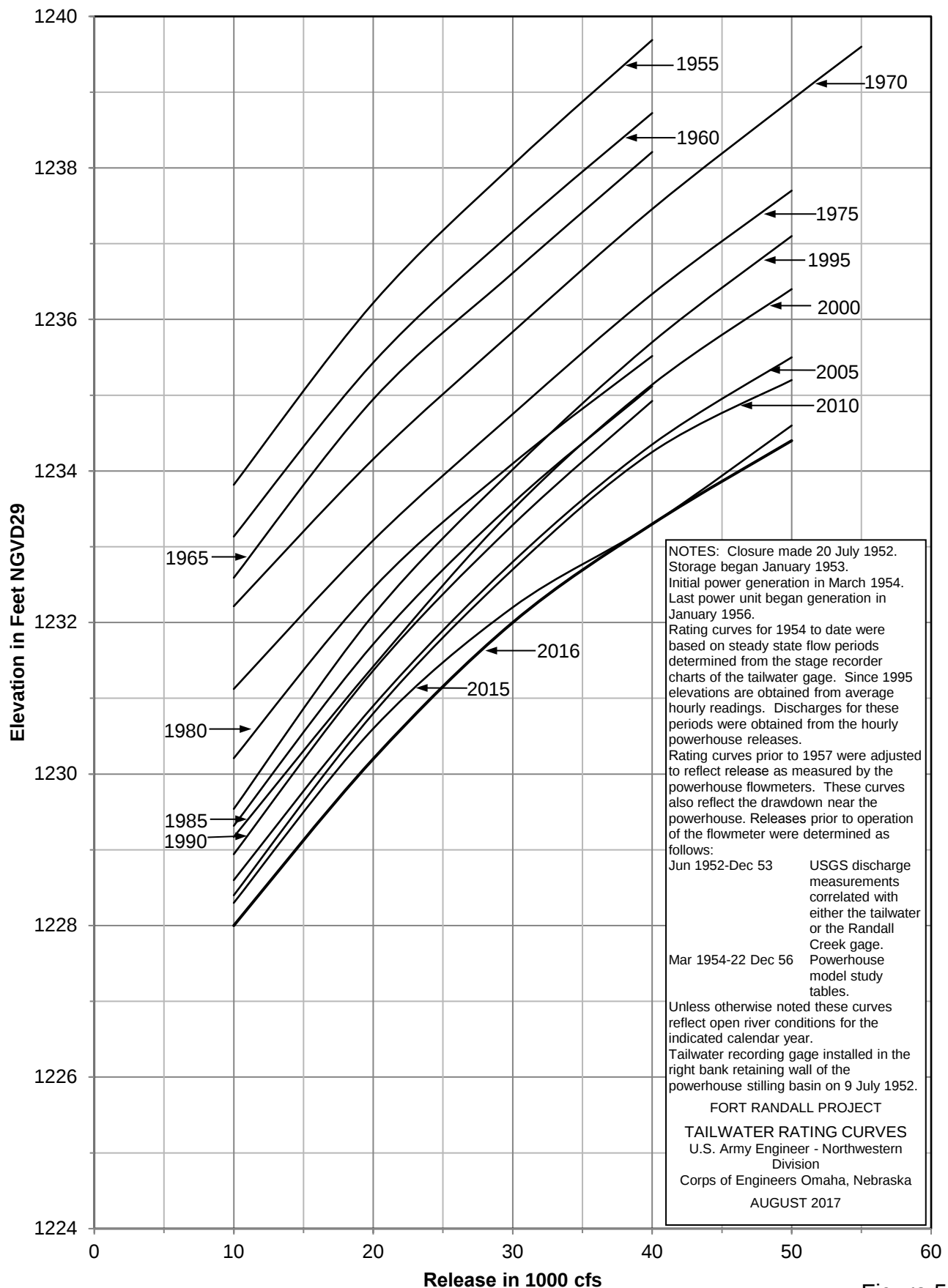
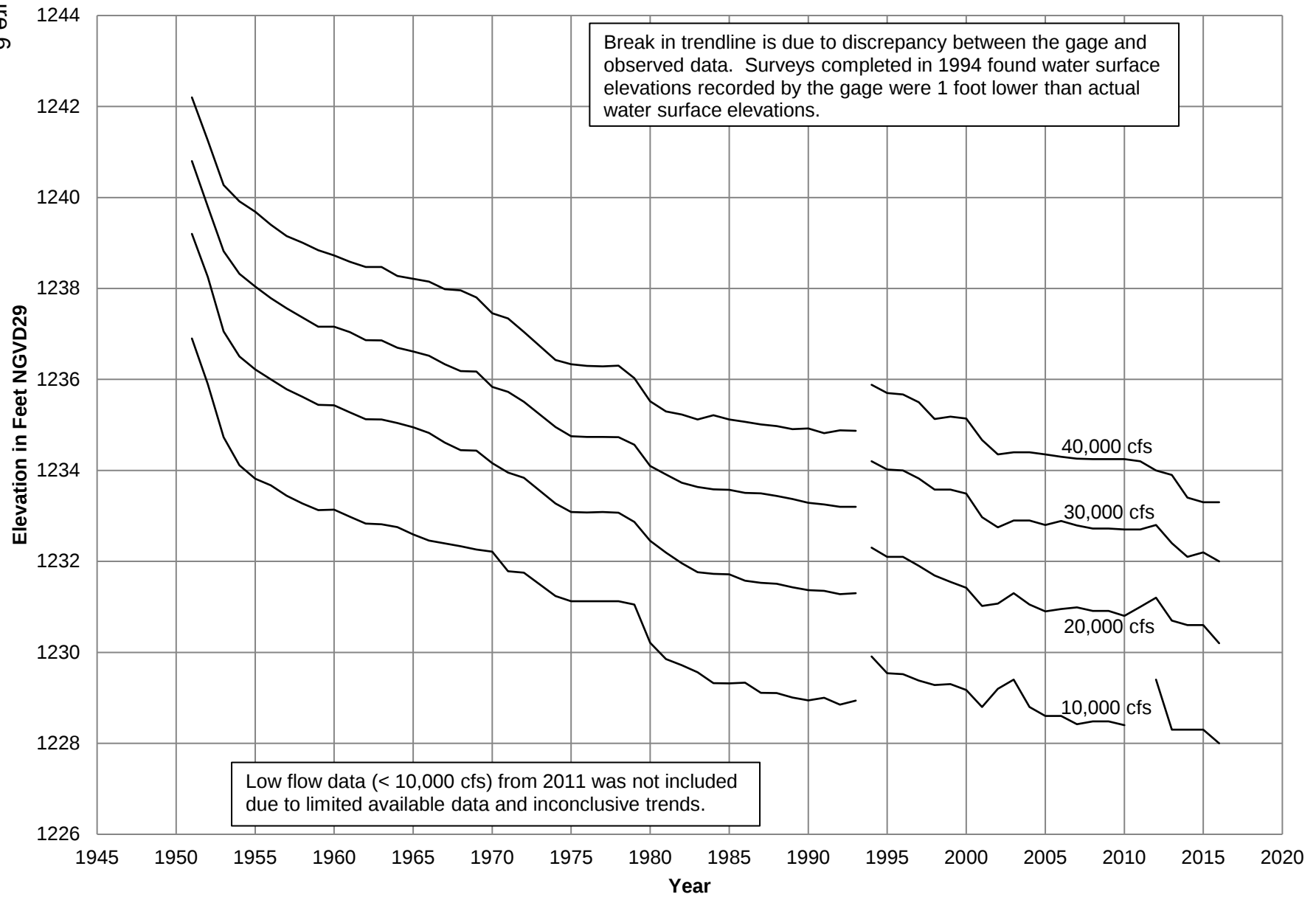


Figure 5

Figure 6

Fort Randall Project Tailwater Trends



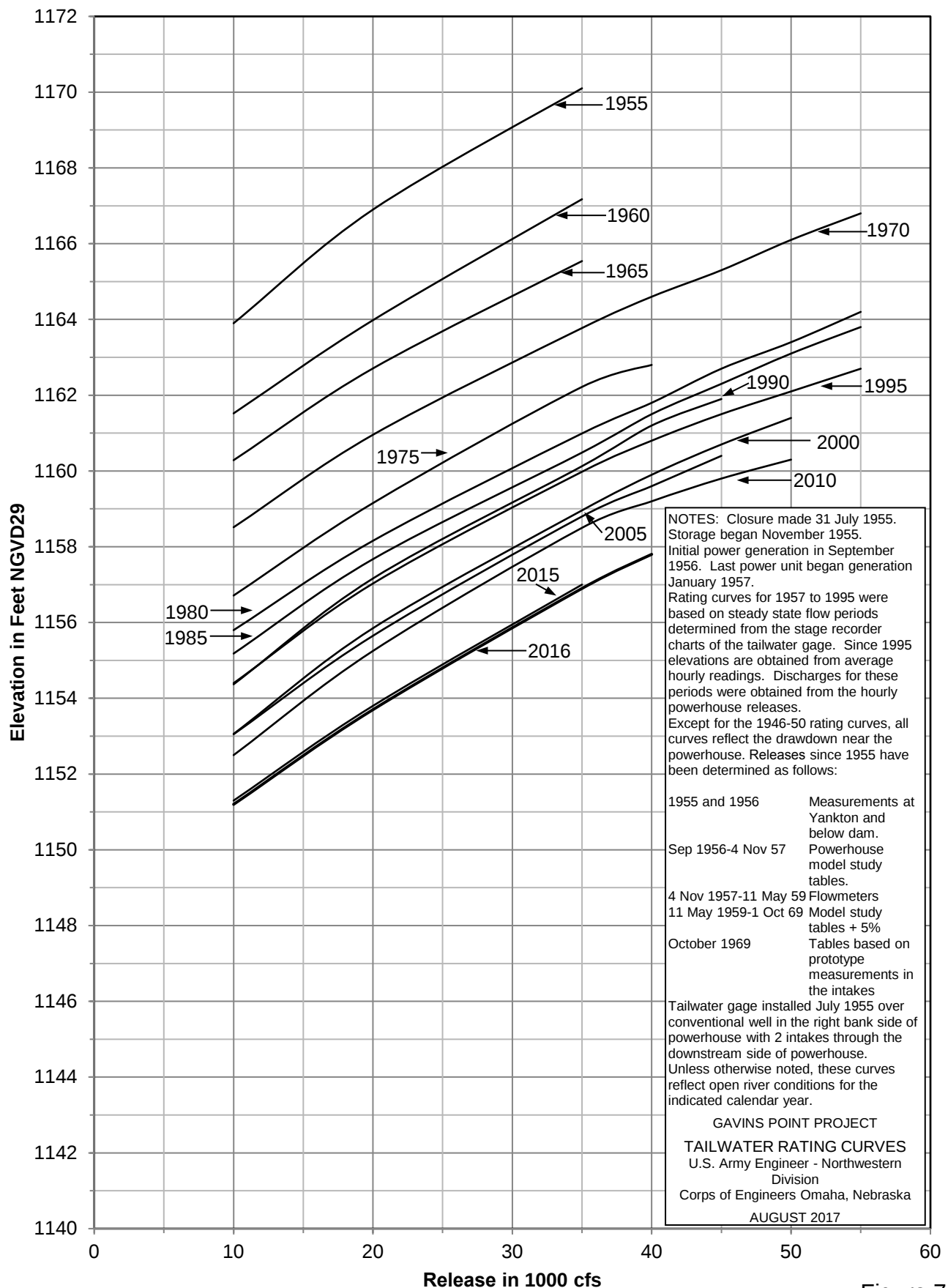
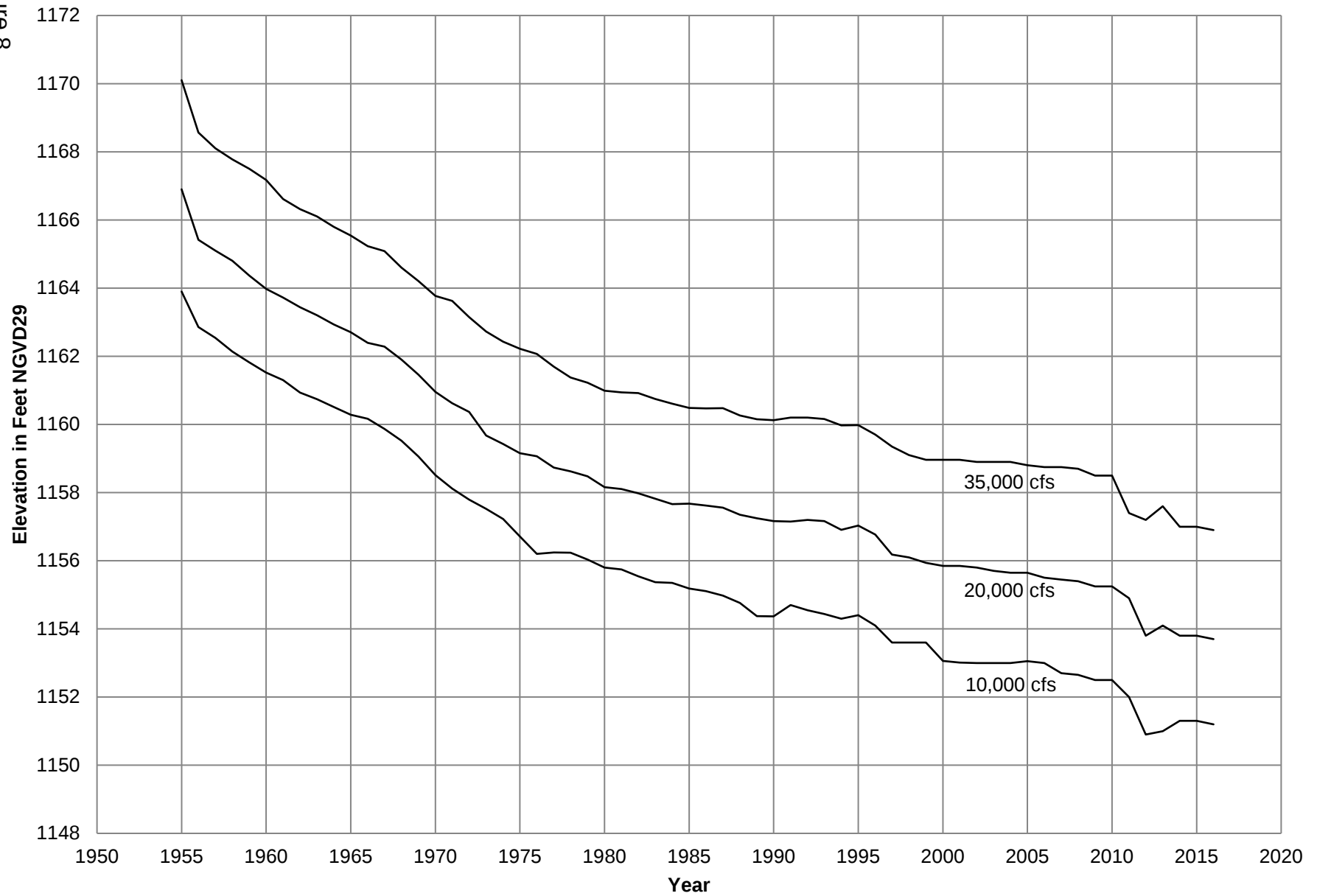


Figure 7

Figure 8

Gavins Point Project Tailwater Trends



Comparison of Tailwater Trends for Releases of 20,000 cfs

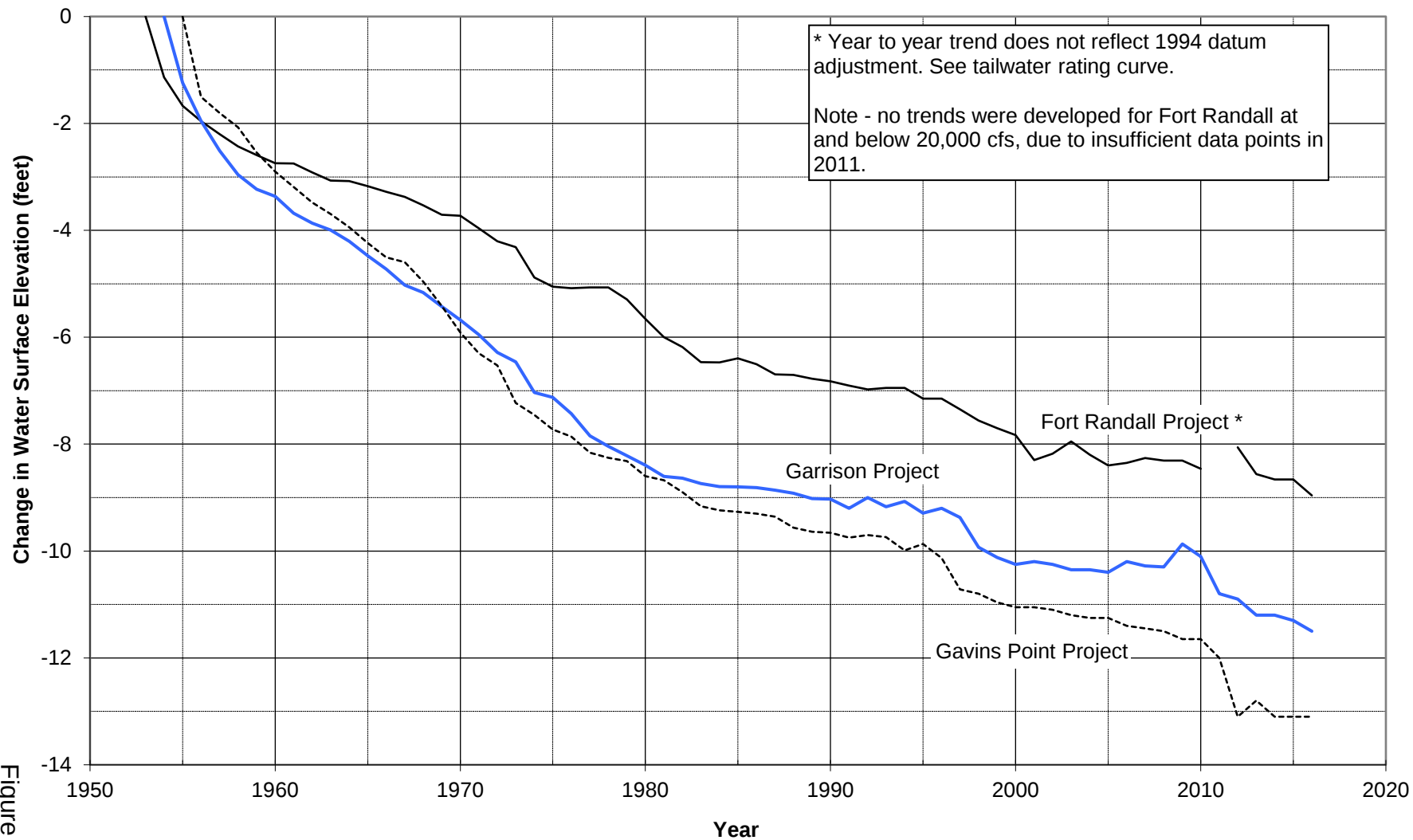
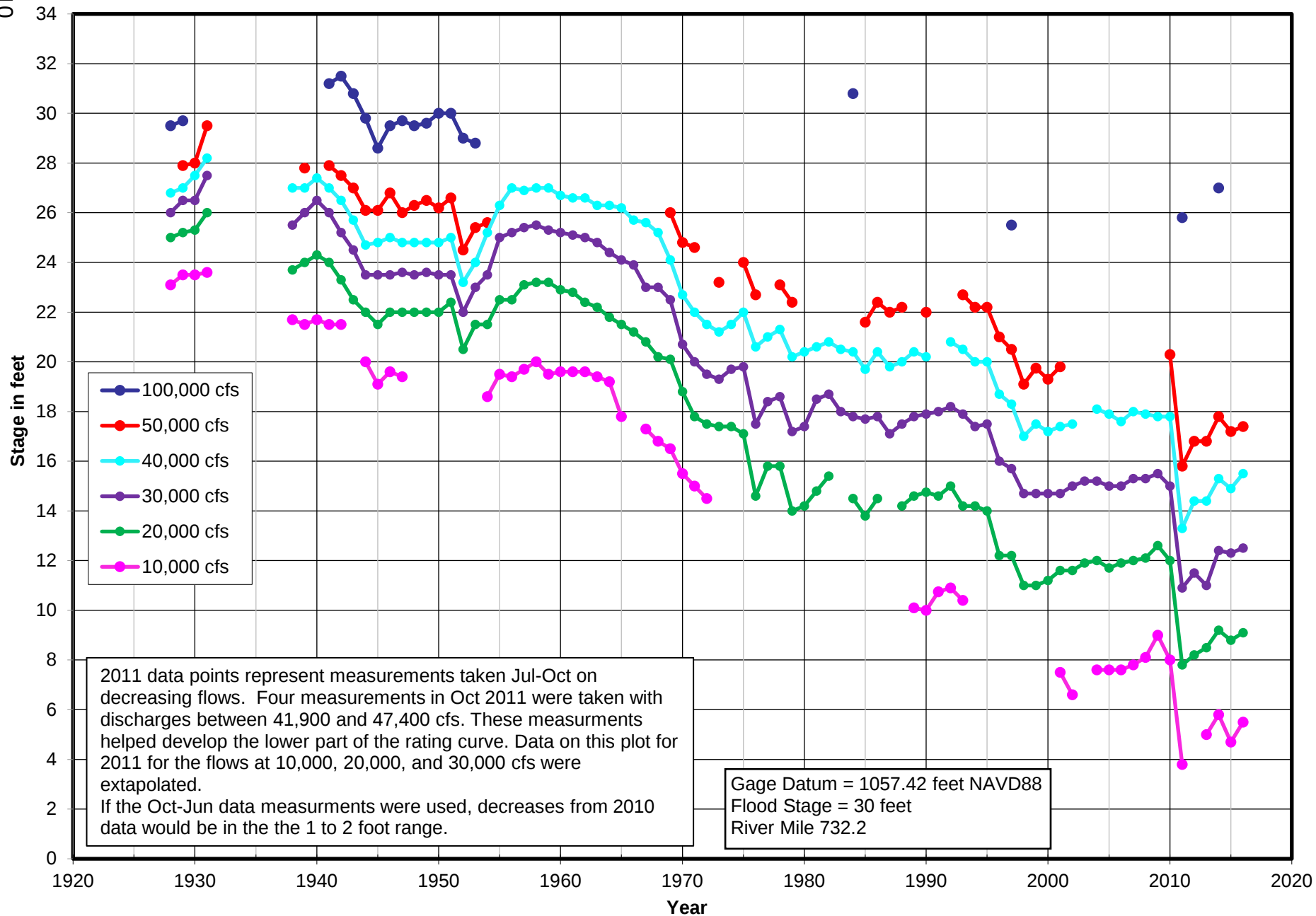


Figure 10

Missouri River at Sioux City Stage Trends, 10,000 to 100,000 cfs



Missouri River at Omaha Stage Trends, 10,000 cfs to 100,000 cfs

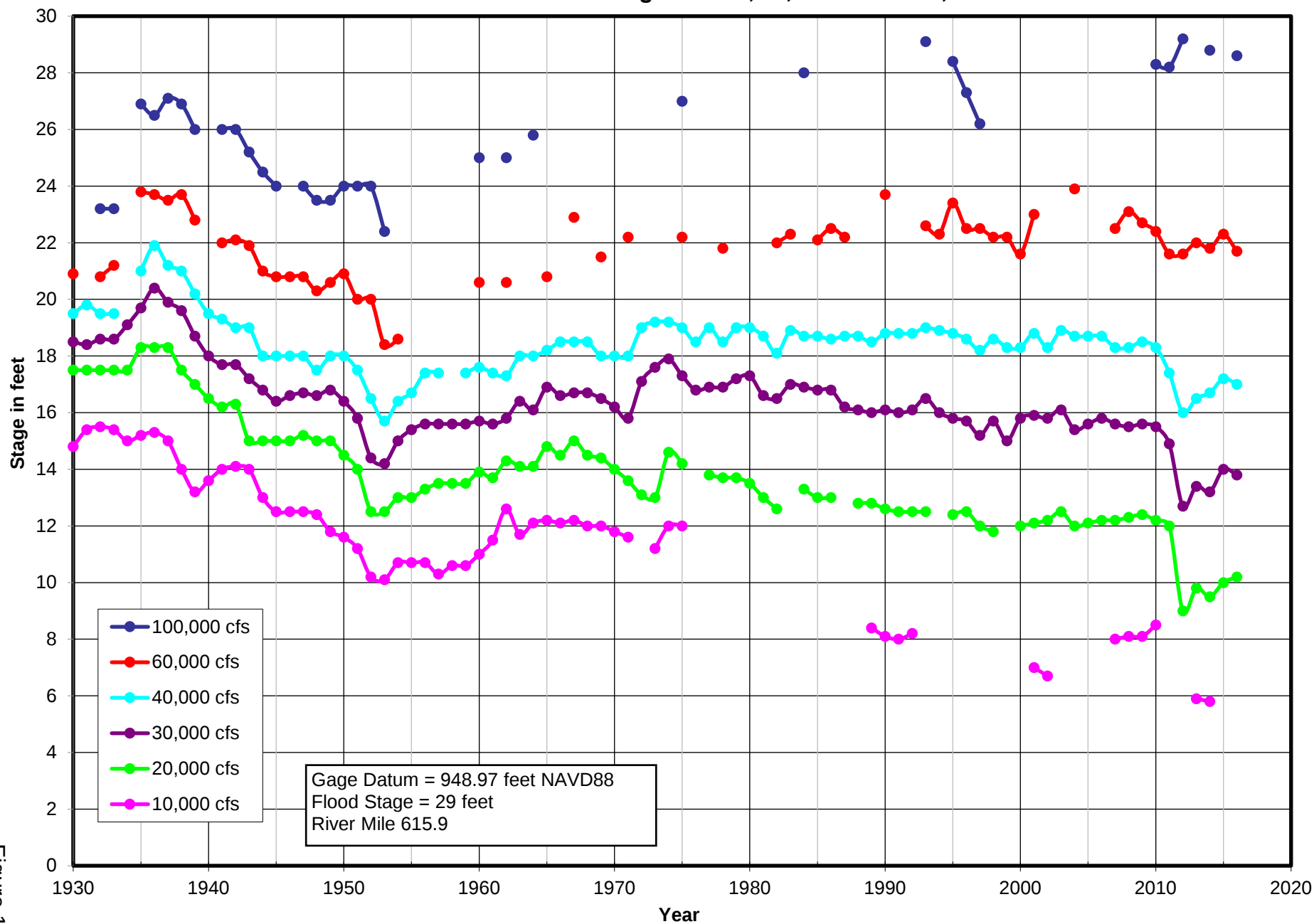
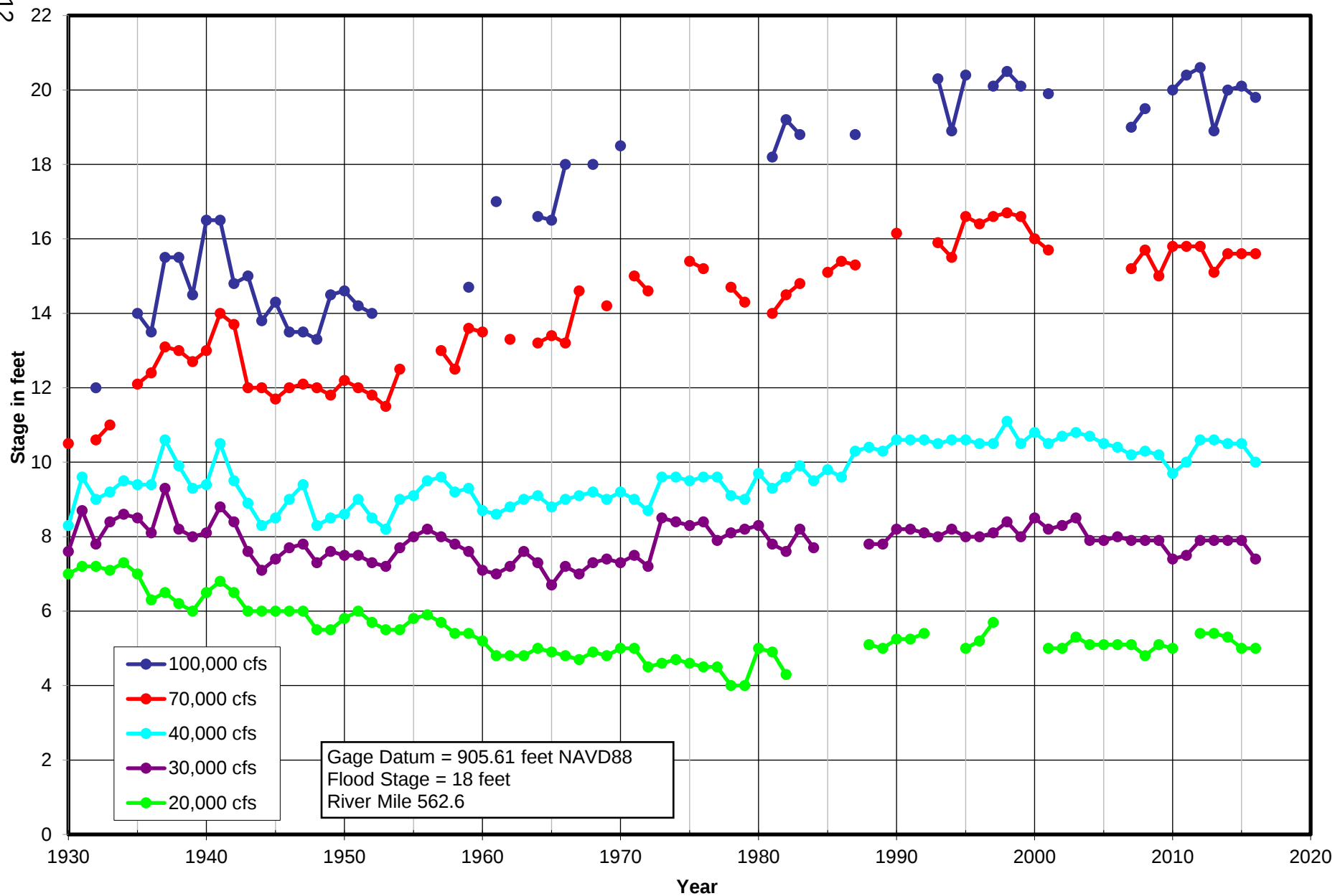


Figure 11

Figure 12

Missouri River at Nebraska City Stage Trends, 20,000 to 100,000 cfs



Missouri River at Nebraska City Stage Trends, 100,000 to 180,000 cfs

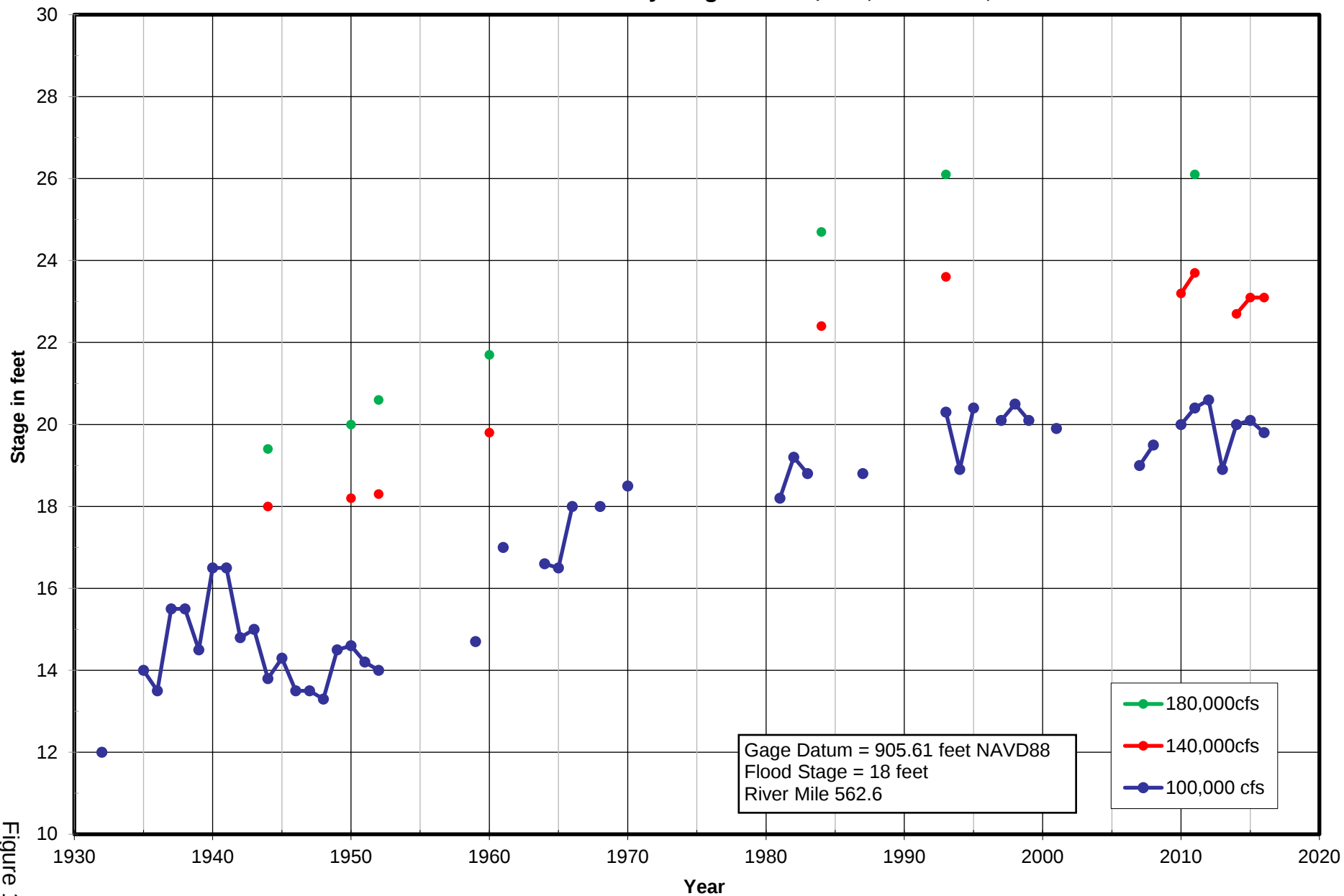
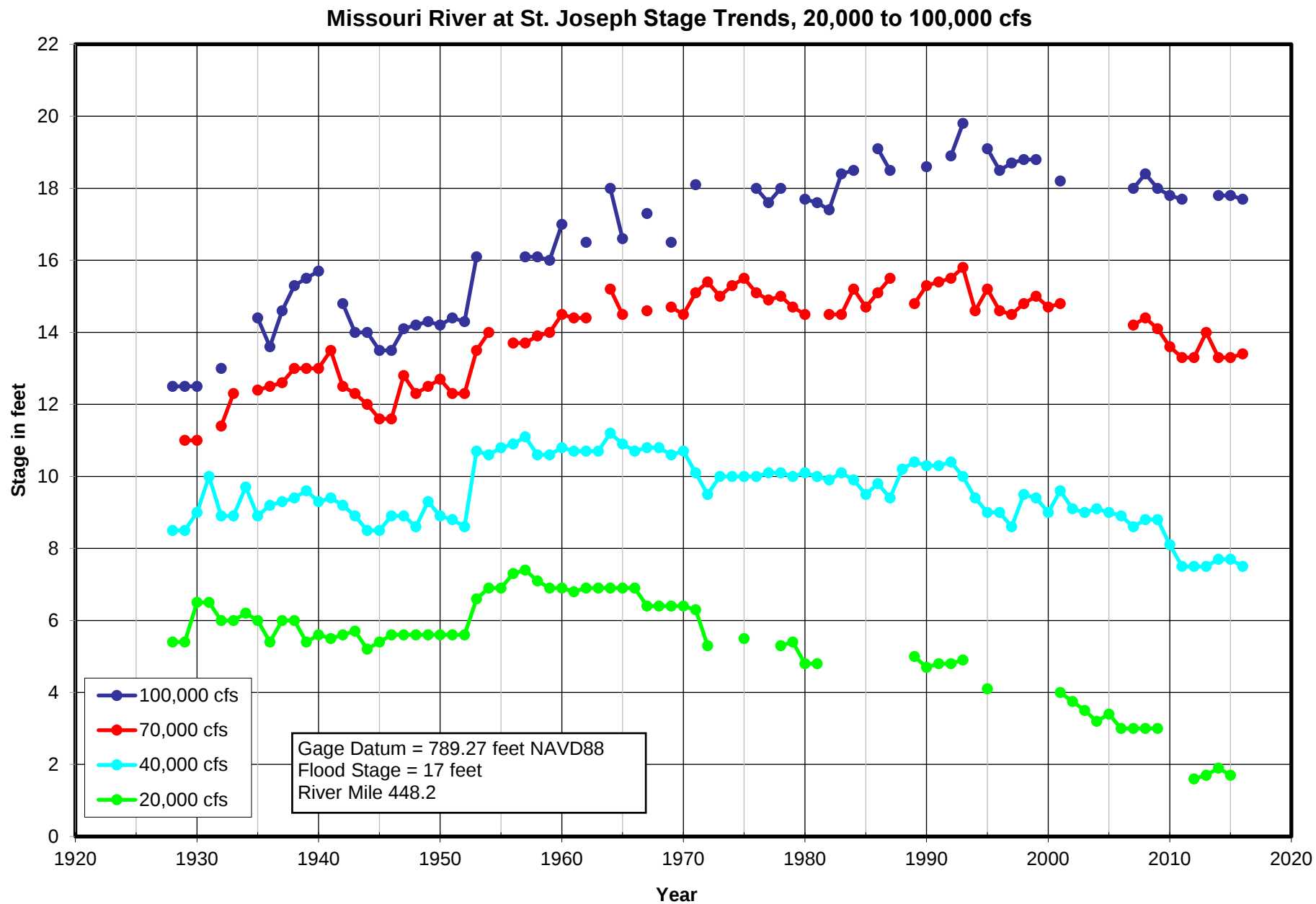


Figure 13

Figure 14



Missouri River at St. Joseph Stage Trends, 100,000 to 200,000 cfs

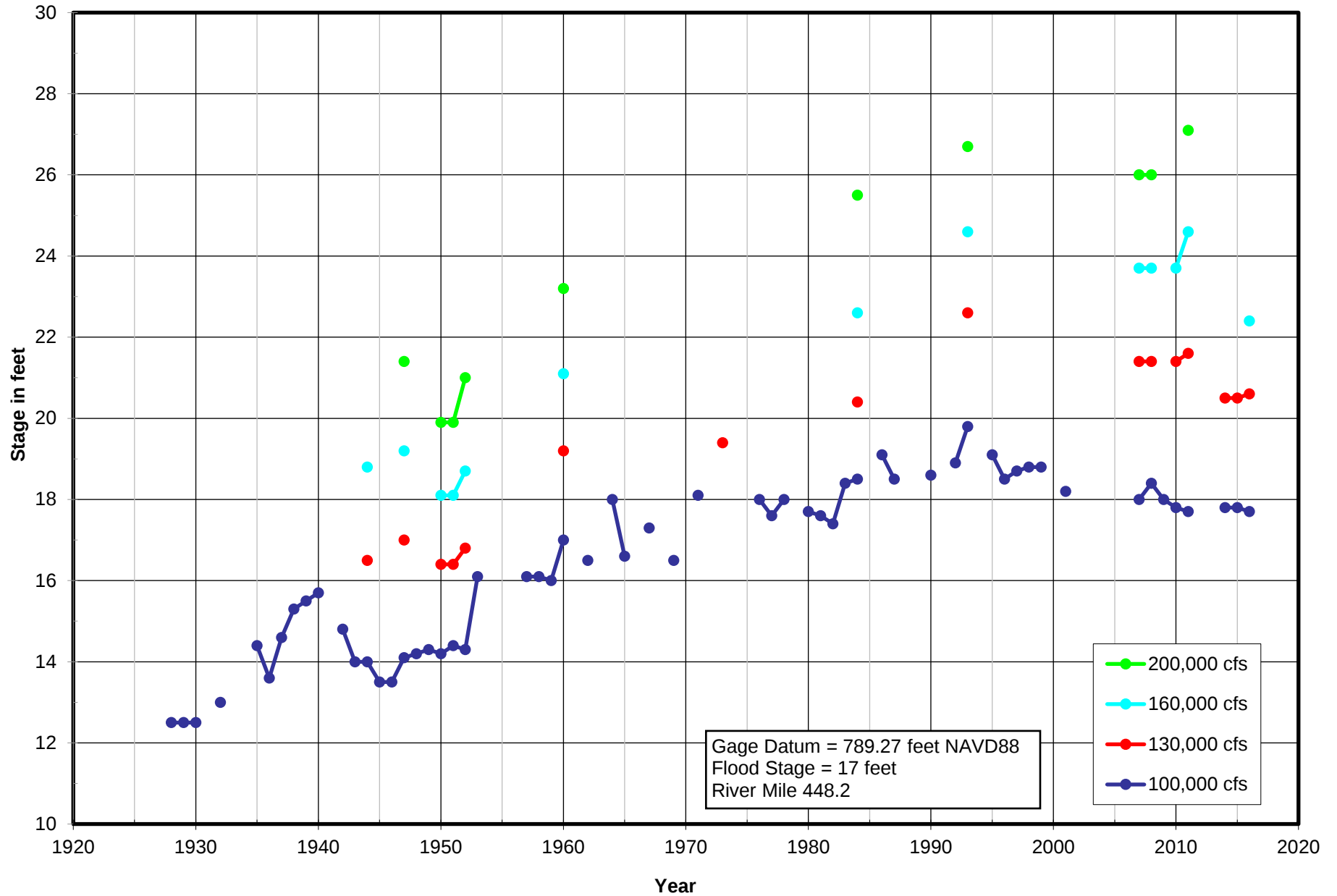
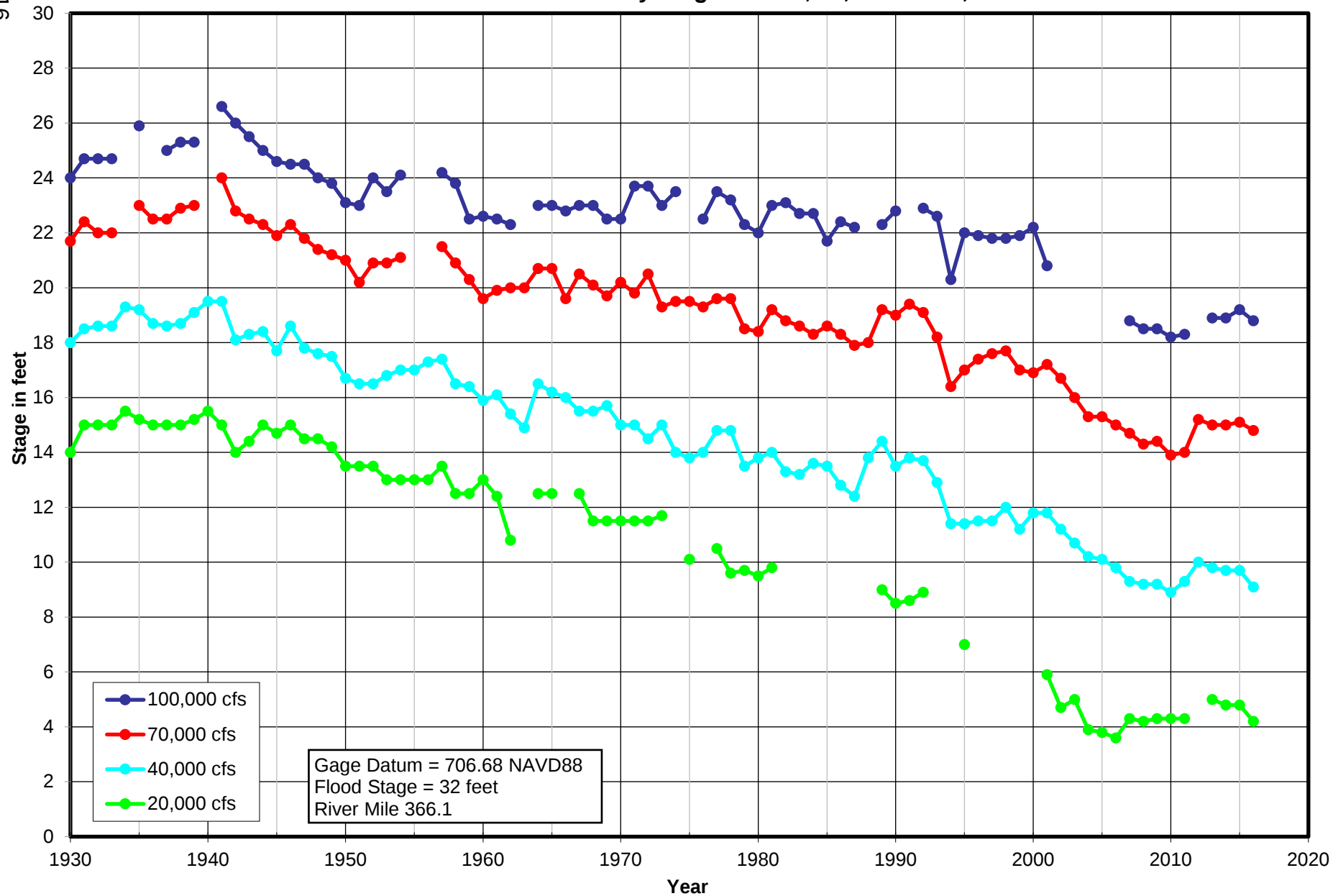


Figure 15

Figure 16

Missouri River at Kansas City Stage Trends, 20,000 to 100,000 cfs



Missouri River at Kansas City Stage Trends, 200,000 to 500,000 cfs

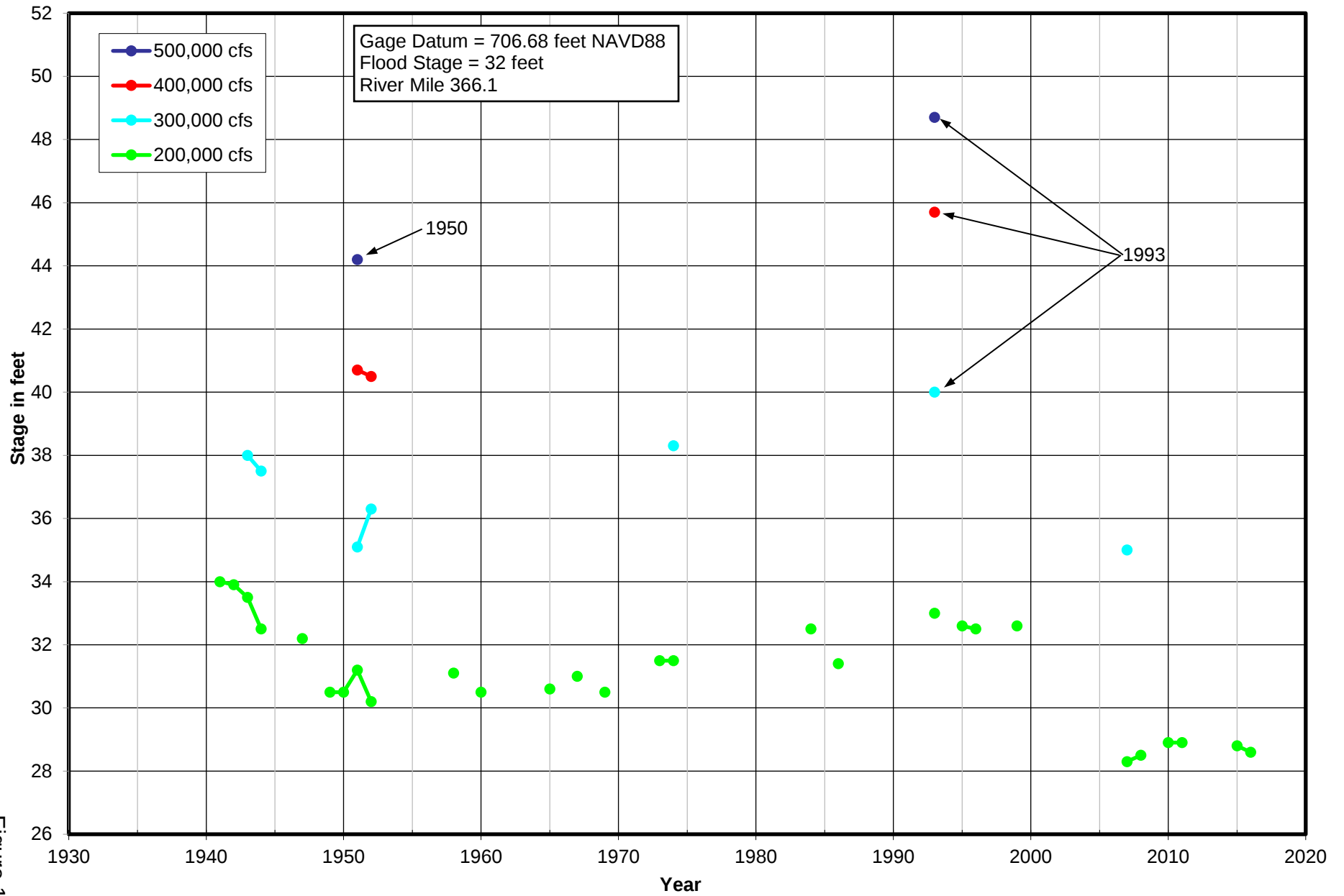
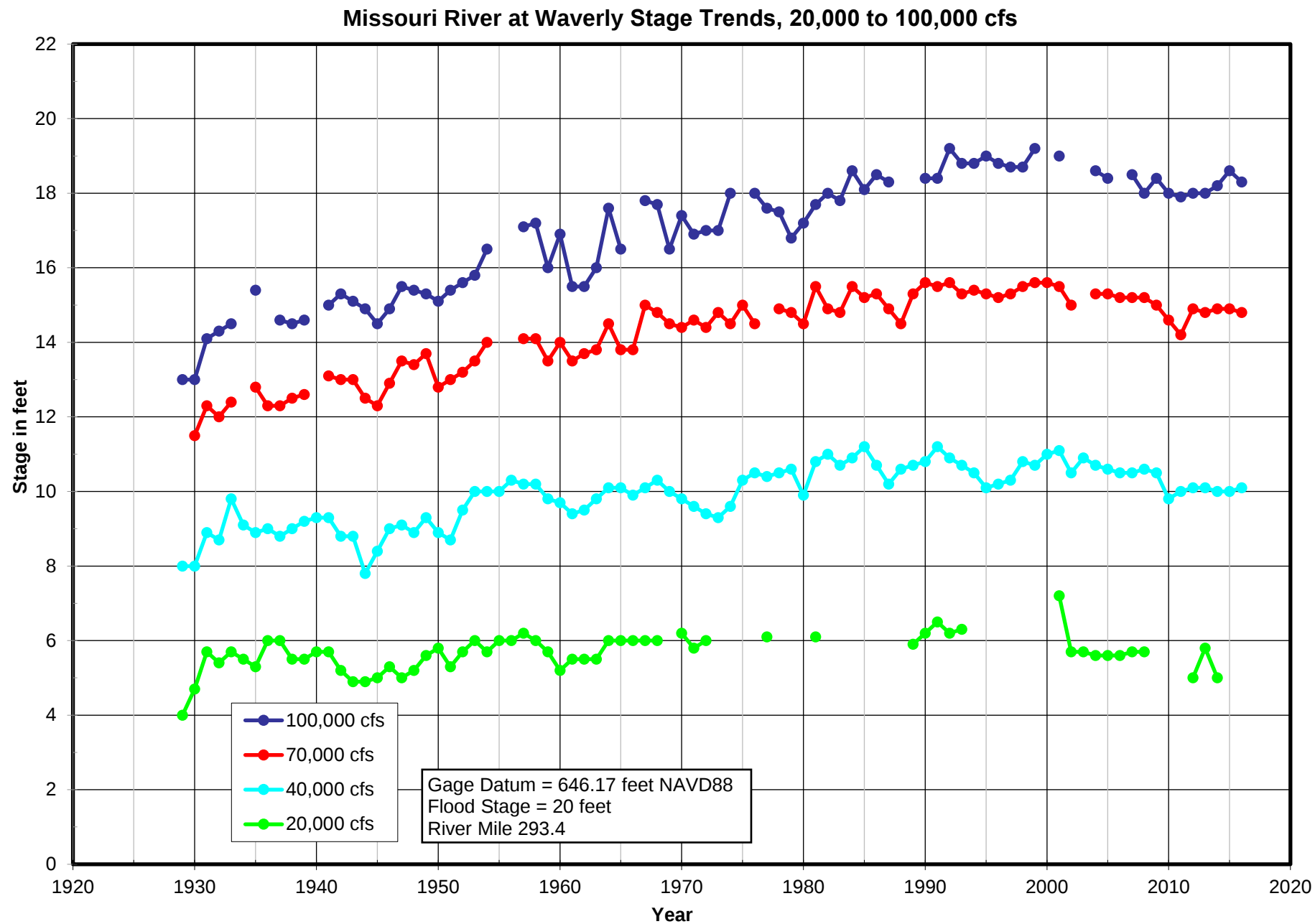


Figure 17

Figure 18



Missouri River at Waverly Stage Trends, 200,000 to 300,000 cfs

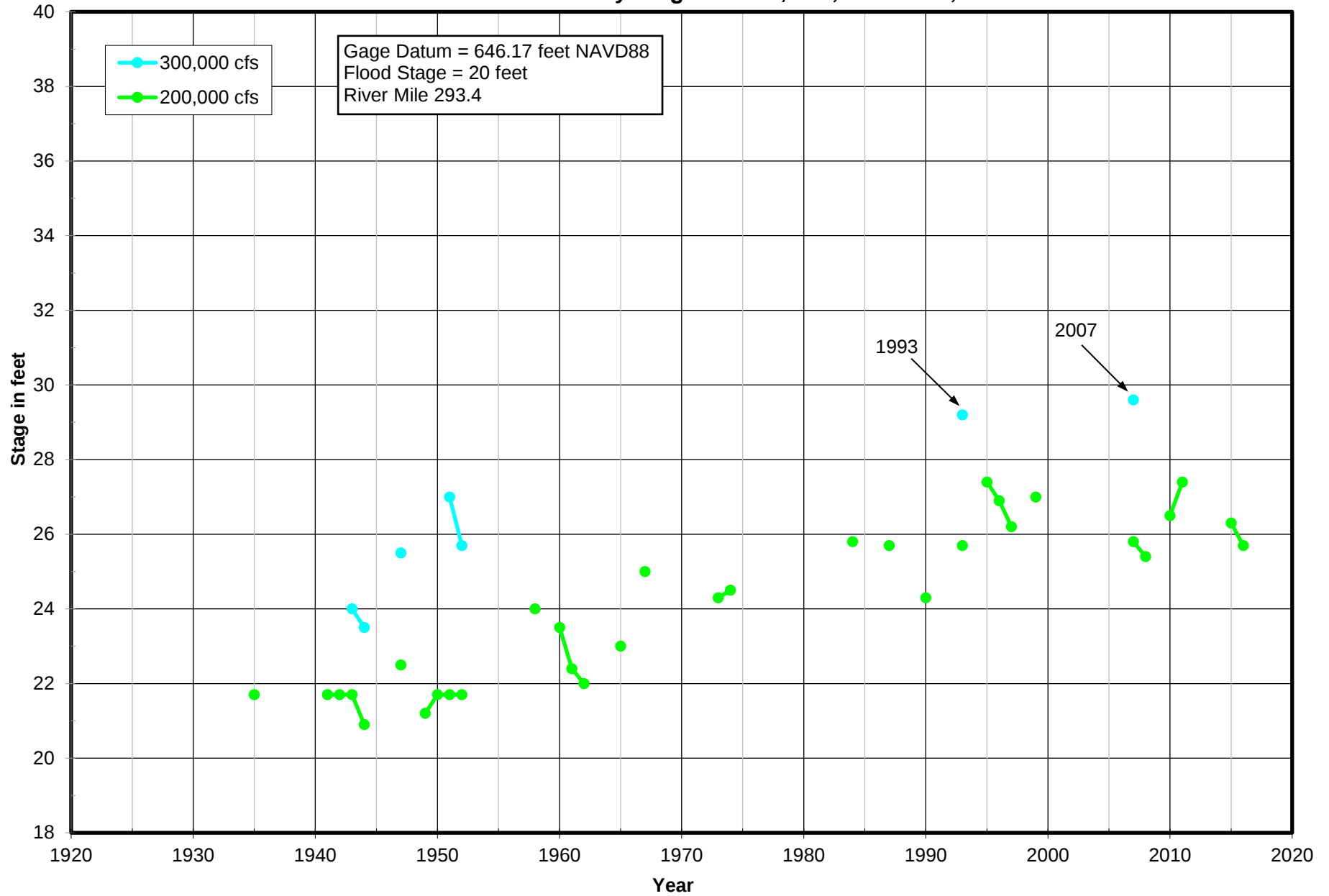
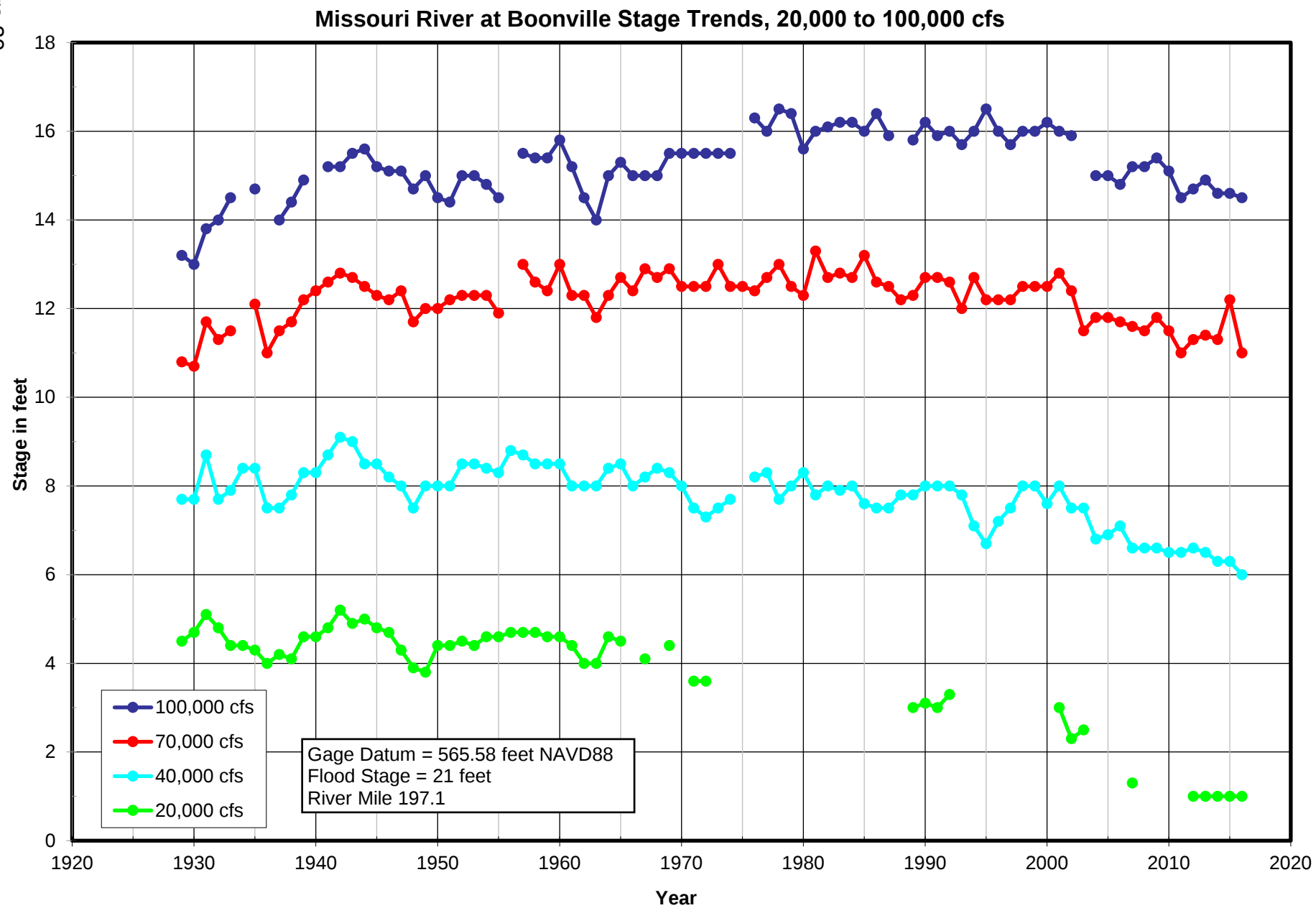


Figure 19

Figure 20



Missouri River at Boonville Stage Trends, 200,000 to 300,000 cfs

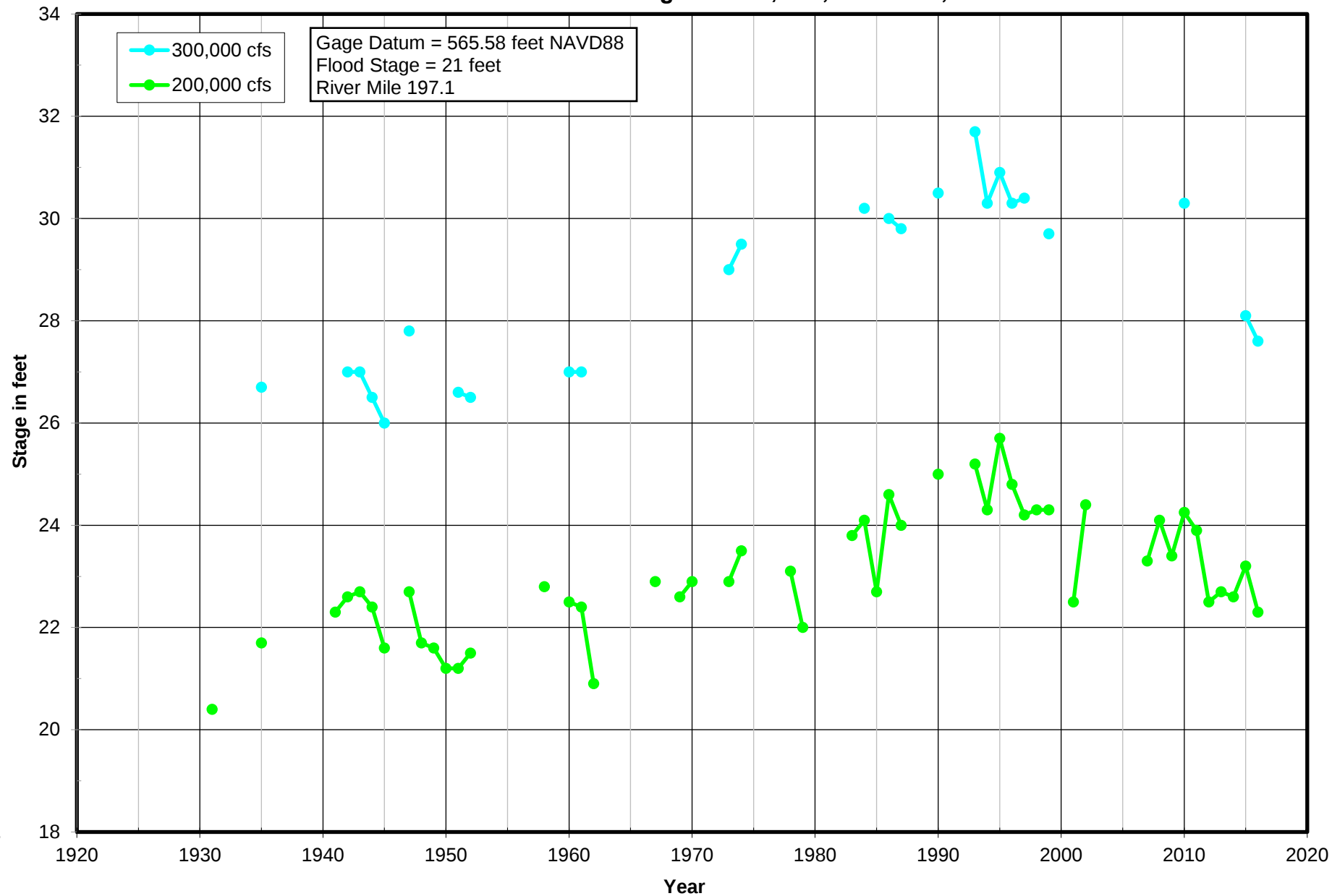
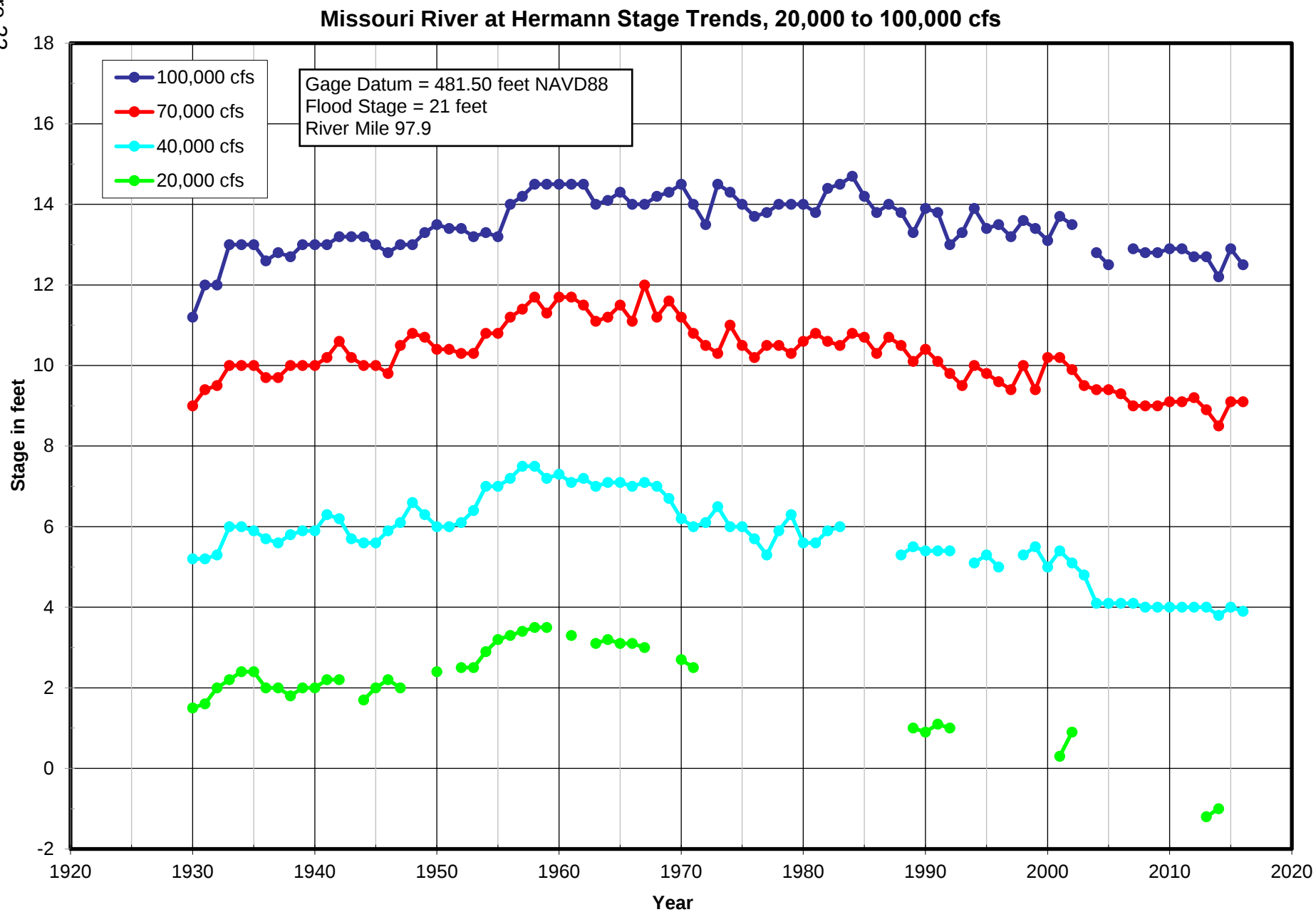


Figure 21

Figure 22



Missouri River at Hermann Stage Trends, 200,000 to 500,000 cfs

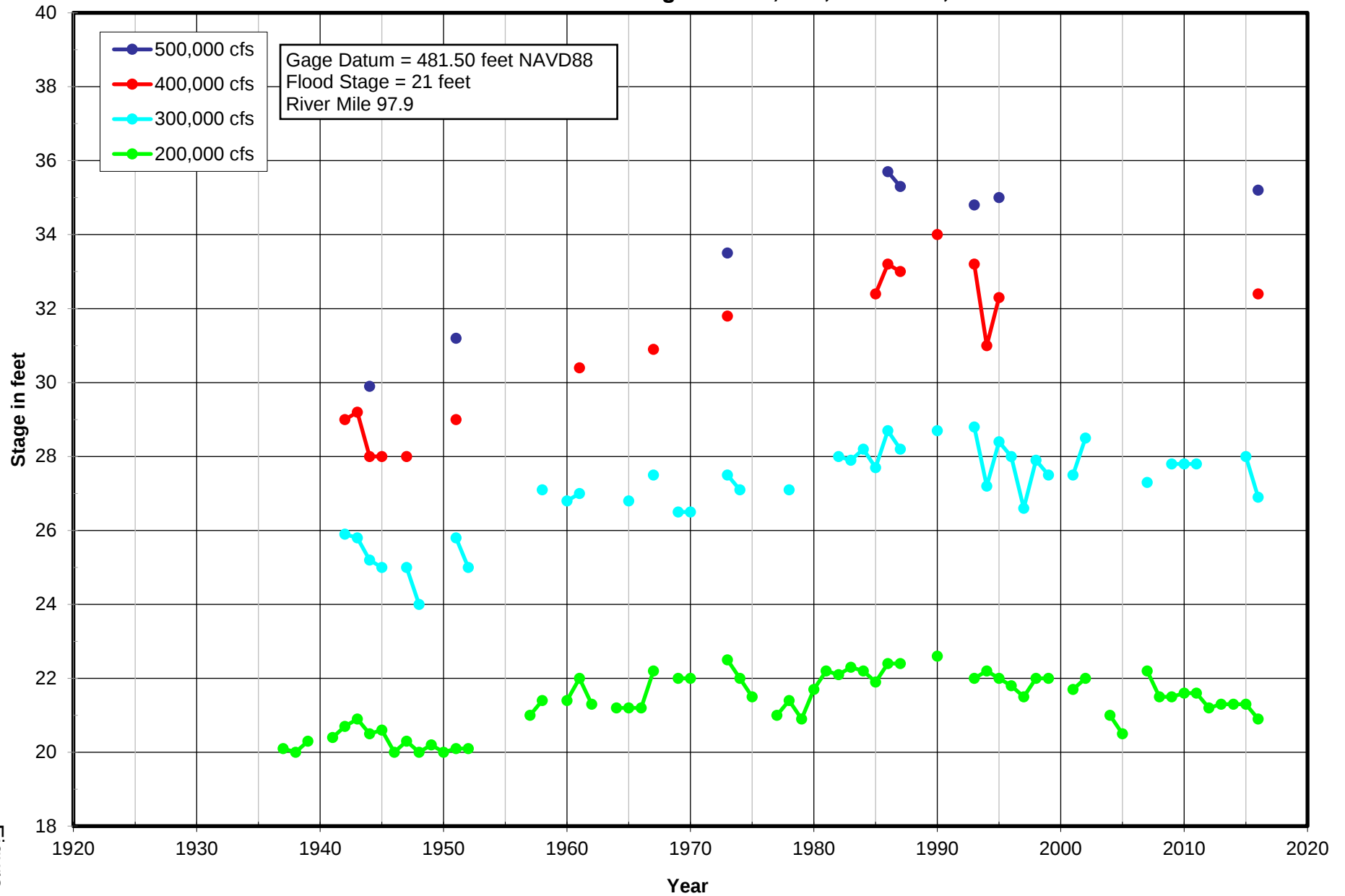


Figure 23

Figure 24

