US Army Corps
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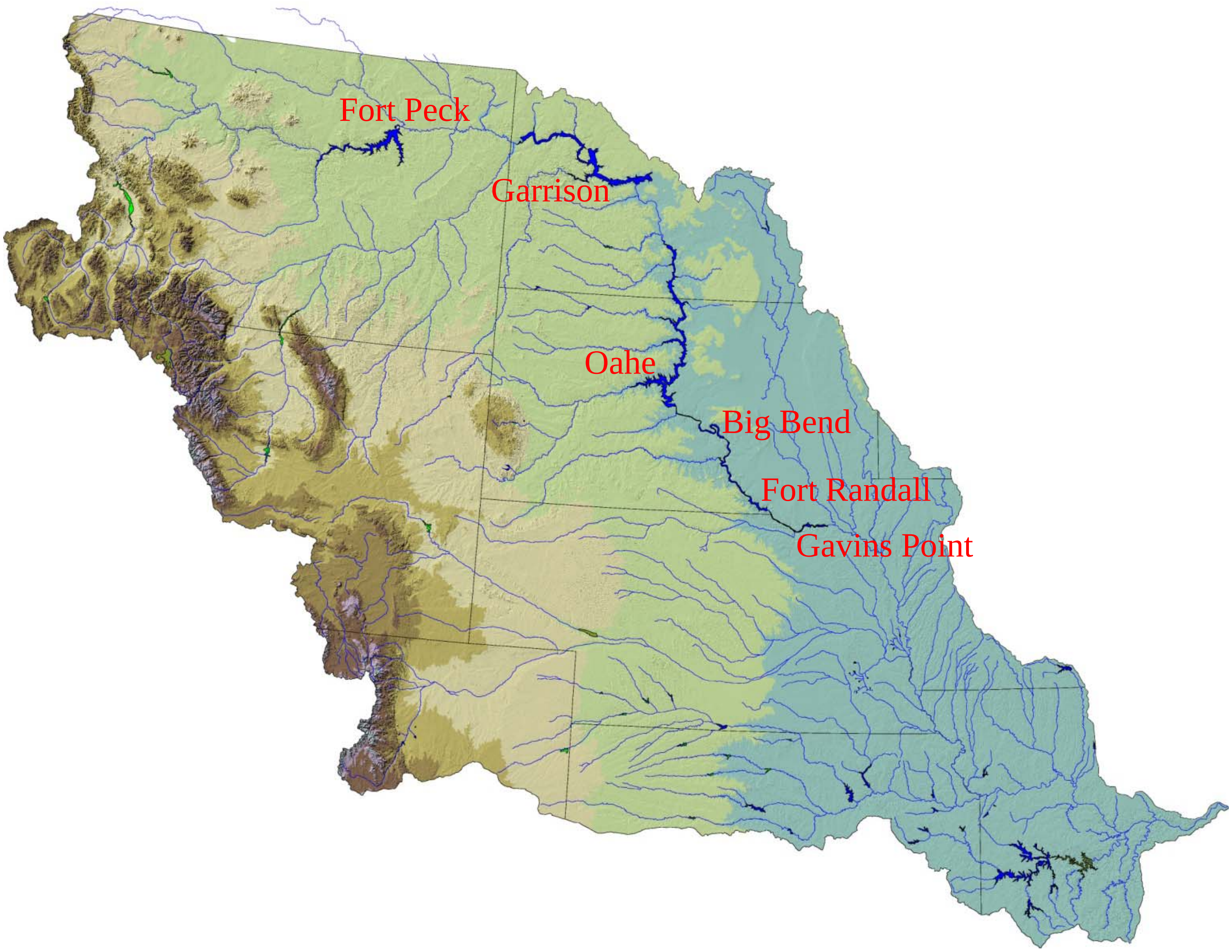
Northwestern Division

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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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 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 records for the Missouri River are available for almost 100 years for each of the eight key mainstem gaging stations below Sioux City. Although a few isolated discharge measurements were made in the early years, it was not until 1929 that a collection of systematic and continuous discharge records by the United States Geological Survey (USGS) began. It was at about this same time that construction of river improvement works was initiated to stabilize and channelize the river. A consultant's board in the mid-1950's 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 discharge of two feet between Omaha and the mouth, and possibly as much as one foot from Omaha to Sioux City.

The board also expressed the opinion that the low water stage of the Missouri River had been lowered on the order of one 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 or by other encroachments in the flood plain or natural events.

This report is mainly being updated this year to document changes in stage trends due to record discharges from all six mainstem dams in 2011. The report is an update to a report titled "Missouri River Stage Trends, RCC Technical Report A-10" published in April 2010. Similar reports titled "Missouri River Stage Trends, MRD-RCC Technical Study S-72" was published in September 1972 and updated in June 1975, August 1981, December 1985, September 1987, February 2000, April 2004, and January 2007.

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). However, over 80% of this shortening has been concentrated in three reaches, including the reaches of Sioux City to Omaha, Nebraska City and St. Joseph, and Kansas City to Waverly. The length of the Missouri River between the System stations for the years 1890, 1941, and 1960 is given 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, and at each of the nine Missouri River gaging stations for four to eight constant discharges, are presented on Figures 1 through 24. The discharges shown for the gaging stations range from 10,000 to 500,000 cfs, depending on the station location.

The sources of data for these figures were the compilations of rating curves, which were initially prepared in the early 1950's 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 since that time by documenting and plotting the USGS flow measurements. The open-water rating curves presented for each station along the navigation channel are frequently seasonal in nature, being a foot or two 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 sand 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. On account of this, sediment will be transported more easily at colder temperatures. The discharge measurement points, which defined the summer rating curve, were given the most weight in developing the stage trends. The stage data used in developing the stage trend curves for the stations along the navigation channel were selected more on the basis of a personal evaluation of the discharge measurement values than on the rating curves presented. 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 immediately downstream. Oahe Dam discharges into 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 discharge 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. Tailwater trends data for 2011 was developed, but due to unprecedented discharges from the spillways and lack of steady releases from the powerhouse, caution should be used in making any analysis using only this data.

FORT PECK

The tailwater stage trend could not be evaluated at Fort Peck for this update. Fort Peck is unique in that it has two powerplants. All other mainstem projects have one powerplant. This results in a complex relationship that defines the tailwater rating curve at Fort Peck and the apparent stability in the relationship. Therefore, no updates to the rating curve have been made since 1966. 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, with the second powerplant coming online in 1961. Because of the location of the two powerplants, the stage discharge rating relationship is quite complex at this location. The tailwater stage at either powerplant is a function of the discharges at both powerplants. Prior to 1956, Fort Peck was the only System project with a significant amount of accumulated storage. As a consequence, releases in the 28,000 cfs range were frequently required for navigation with a maximum mean daily rate of 28,600 cfs in 1948. Since late 1956, with the exception of 1975 and 2011, releases have not been significantly in excess of the powerplant capacity of the project, which is about 15,000 cfs after the second powerplant was online. Previous studies have indicated that the tailwater rating curve has been stable since about the 1960's.

GARRISON

In 1946, construction of the Garrison project was initiated. Dam closure was made in 1953, with powerplant operation online in 1956. Since 1956, outflows from Garrison have generally been through the power facilities, having a maximum powerplant 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 the month of July, and in 2011 when releases reached its peak of 150,600 cfs on June 25 and were above 100,000 cfs for 71 days.

Figure 1 shows tailwater rating curves developed at five-year intervals beginning in 1955 and extending through 2011. As illustrated by those curves, a stage lowering is evident at each five-year update interval with each curve dropping about one to two feet until about 1980. From 1980 to 1995, the total shift was approximately one foot. The rate of degradation had significantly lessened from 2000 to 2005, which were years of lower than normal releases. The 2010 curve is slightly higher than 2005, again occurring in years with lower than normal releases. With record releases in 2011 the curve lowered about half a foot from the 2010 curve. ***Figure 2*** shows the trend over time of the tailwater stage for discharges ranging from 10,000 to 40,000 cfs. As shown by these curves, there has been a lowering of the tailwater stage by a little more than 10 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 lowering during the period of 1997 through 1998 coinciding with higher than normal releases. From 1998 to 2010 the rate of tailwater degradation had decreased to almost zero; releases from 2000 through 2010 were below average. With record releases in 2011 the tailwater curve shows a lowering of about half a foot for all shown discharges.

OAHE

Diversion and closure of Oahe were completed in 1958 following ten years of construction. In April 1962, the first power unit came online with all units operational in July 1966. Since 1962, outflows from Oahe have generally been through the power facilities, which have a maximum powerplant capacity of about 54,000 cfs. In 2011, outflows exceeded 50,000 cfs for 132 days; 100,000 cfs for 82 days; 150,000 cfs for 34 days; and peaked at 160,000 cfs on June 20. Tailwater rating curves developed at five-year intervals beginning in 1965 and extending through 2011 are compared on ***Figure 3***. As shown on those curves, there has generally been about one foot or less change in tailwater stages from one five-year curve to another. Also, since 2000 it appears that the rate of stage lowering is greater at the higher flows. Construction of channel block No. 6 was completed in June 1967 with an extension to River Island completed in July 1970. As shown by the change in tailwater stage from 1965 to 1970, construction of channel block No. 6 appeared to increase the tailwater stage. It should also be noted that the Big Bend powerplant became fully operational in 1966 with Lake Sharpe pool levels being maintained near the normal operating level of elevation 1420 feet msl. Time trend plots for discharges ranging from 10,000 to 50,000 cfs are shown on ***Figure 4***. From 2000 to 2011, releases at 40,000 and 50,000 cfs have indicated a steady lowering of the stage with the exception of two spike years in 2004 and 2010, where stages at 30,000, 20,000, and 10,000 cfs have lowered slightly over that time and the stage at 10,000 cfs was fairly steady through 2008 then dropped about 0.5 foot by 2010. Over the historic record the stage at a given discharge has decreased more as the flows increase. Since 1970 the stage for a 10,000 cfs flow has decreased 0.8 foot and for a 50,000 cfs the decrease is almost two feet. It should be noted that Oahe is a hydropower peaking project and it rarely has steady releases for extended periods of time, therefore slight variance in stage verses discharge will occur between years.

BIG BEND

Big Bend discharges directly into the Fort Randall pool. Consequently, tailwater stages are influenced by Fort Randall pool elevations. Therefore, 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 online in 1956. Since 1956, outflows from Fort Randall have generally been made through the power facilities, which have a maximum powerplant capacity of about 44,500 cfs. In 2011, outflows exceeded 50,000 cfs for 146 days; 100,000 cfs for 85 days; 150,000 cfs for 37 days; and outflows peaked at 160,000 cfs on July 26. As shown on ***Figure 5***, a lowering of the tailwater stage of a little more than five feet had occurred over a 50-year time span from 1955 to 2005 and since 2005 little change has occurred. As seen on ***Figure 6***, a two-foot decrease in stage occurred from 1952 to 1955 when discharges ranged from 10,000 to 40,000 cfs. It should be noted that the 1994 through 1997 trend lines shown on ***Figure 6*** have been adjusted to account for a one-foot shift in the gage datum. During 1994, it was determined that the tailwater gage at Fort Randall has been recording water surface elevations one 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***. 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 one foot in the 30,000 to 40,000 cfs range and about 0.5 foot in the 10,000 to 20,000 cfs range.

GAVINS POINT

As shown on ***Figure 7*** and ***Figure 8***, Gavins Point tailwater has lowered about 12 feet at flows of 10,000 cfs and 20,000 cfs, and about 12.5 feet at 35,000 cfs, since closure of the project in 1955. Since 1955, outflows from Gavins Point have generally been through the power facilities, which have a maximum powerplant capacity of about 36,000 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. ***Figure 8*** shows the overall trend of a reduced degradation rate with time, except during years of high discharges. After the first year after closure a drop of one foot at the lower discharges 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 one foot or a rate of about 0.1 foot per year. Higher than normal flows in the years 1995 through 1999 saw the stage drop about one foot by 2000 or a rate of 0.2 foot per year. From 2000 to 2010 the rate decreased to about 0.05 foot per year. The record releases during 2011 resulted in the stage dropping between 0.4 foot and 1 foot depending on the releases.

PROJECT COMPARISONS

A comparison of tailwater trends for the Gavins Point, Fort Randall and Garrison projects is shown on ***Figure 9***. As illustrated on that figure, 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 stages decreased in 2011 more than in recent years. There was insufficient data at Fort Randall for the 20,000 cfs flow to discern a definite trend, but the higher flows at Fort Randall showed very little change from 2010. The total decrease in tailwater stage at these projects is 12 feet at Gavins Point, 11 feet at Garrison, and slightly more than eight feet at Fort Randall.

IMPACTS FROM 2011

Due to the extended period of record high discharges from the mainstem dams in 2011 the amount of data for relatively steady discharges at the lower and normal discharge ranges were reduced. The plots at Garrison and Gavins Point Projects show a decrease in stage at all historic trend line discharges in 2011, whereas the Fort Randall and Oahe Projects did not have enough data at the lower discharges to plot in 2011. At the higher historic trend lines Oahe showed a decrease in stage in 2011 and Fort Randall showed little change. If dam releases in 2012 are closer to normal, this should provide more data at the historic trend line discharges. A better understanding of the 2011 short-term and long-term impacts should be more evident after the 2012 and subsequent years' data, has been acquired and plotted.

NAVIGATION CHANNEL STAGE TRENDS

Downstream from Gavins Point Dam to Ponca State Park, Nebraska, the Missouri River remains in a semi-natural state as a National Wild and Scenic River. In this 59-mile river reach, the Missouri River is somewhat free to meander throughout a wide flood plain. 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 navigation channel extends for 735 miles from near Sioux City, Iowa to the mouth near St. Louis, Missouri. It varies in width from 600 feet at Sioux City to 1,100 feet at the mouth near St. Louis. Flow regulation by the reservoir system has substantially changed the flow regime. Although the average annual discharge at Sioux City has not changed appreciably, maximum flood peaks have been significantly reduced, low flows have increased and the distribution of the annual runoff has been altered substantially. The reservoirs have also had a profound effect on downstream Missouri River sediment loads. In the natural river, the average annual sediment load at Gavins Point was about 135 million tons per year. With System dam closure, virtually all the incoming sediment was entrapped in the reservoirs and the sediment loads just below the dam sites were reduced essentially to zero. This, along with other physical effects including deposition of sediments on berms, channel cutoffs, and construction of levees, has contributed to changes in the stage/discharge relationship at downstream stations. Trends at each of the key locations are discussed in the following paragraphs.

SIOUX CITY

As illustrated on ***Figure 10***, there has been a predominant degradation stage trend at Sioux City until about 1979. From the late 1920’s until 1979 the stage had decreased about 9 feet for a 30,000 cfs flow. From 1979 to 1995 the stage fluctuated up and down from one year to the next, but overall remained about the same. The succession of high flow years from 1995 through 1997 resulted in a sharp reduction or degradation in Sioux City stages. Since 1999, the stage trends indicate an aggradation trend up to 2009 of about 0.8 foot at a flow of 30,000 cfs. This period of time covered the drought years 2000 to 2007 and a continuing of lower than normal flows in 2008 and 2009. With above normal discharges from Gavins Point in 2010 the stage lowered between 0.5 foot and 1.0 foot at the lower flows. In 2011, with record discharges from Gavins Point of 160,000 cfs, the stage dropped about four feet due to channel bed scouring from the extended high flows from the System record releases. Four measurements from October 2011 were used in helping to define the lower part of the 2011 rating curve. Due to the high flows during the entire year, it was necessary to extrapolate for the data points representing the flows at and below 40,000 cfs. It is interesting to note that two rating curves could have been drawn in 2011 - one representing the pre-flood event (flows increasing to peak) and one representing the post flood event (flows decreasing from peak). If data from the pre-flood event curve would have been used on ***Figure 10*** the stage would only have decreased by about 1 foot from 2010 data.

Stage reductions at Sioux City have caused numerous problems at marinas and dock facilities. These problems were magnified during the droughts of the mid 1980's through early 1990's and from 2000 through 2007 when less than full service navigation flows were 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 navigation season discharge from 31,000 (full service) to 25,000 cfs (minimum service), which was necessary during the droughts, resulted in Sioux City stages of about 1.5 to 2.0 feet below the river levels experienced during full service navigation releases from Gavins Point Dam.

OMAHA

In 2011, the USGS completed 11 discharge measurements when the flow was above 160,000 cfs. The highest Missouri River flow measurement was 207,000 cfs on July 1 with a corresponding stage of 35.90 feet. As shown on ***Figure 11***, the overall stage trend between the mid-1930's and the early 1950's was degradation, totaling about five feet. The stages increase between two and four feet by the mid 1970’s. Since that time the stage for a 100,000 cfs flow appears to have increased slightly, the normal flows of 40,000 cfs and 60,000 cfs show no significant changes and the flows at 30,000 cfs and lower have steadily decreased two to four feet.

The lowest stages for a discharge of 30,000 cfs and above occurred following the 1952 flood. However, in 2011 the 30,000 cfs stage was only about 0.7 feet higher than in 1953 whereas the stage for the 100,000 cfs flow was about 6 feet higher. At below normal discharges of 10,000 to 20,000 cfs the stage is lower in 2011 than 1953.

The highest stages for flows at 40,000 cfs and below occurred in the mid-1930’s. At the 60,000 cfs flow the highest stage over a period of time occurred in the mid-1930’s, and also was reached in 1990 and in 2004. By 2011 the stage is about 2 feet lower than those high readings. Although the data for 100,000 cfs is less frequent it appears that the stage since 1990 has frequently been above the stage measured in the mid-1930’s.

NEBRASKA CITY

Stage trends at the Nebraska City gage 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 around 1950 to the early 1990’s. However, since the early 1990’s, the stages have shown yearly fluctuations but overall little change for these flows. The stages for flows of 20,000, 30,000, and 40,000 cfs have remained fairly steady over the last 30 years.

Since 1955 the channel capacity of the Missouri River at flood stage of 18 feet at Nebraska City has been reduced from about 150,000 to approximately 85,000 cfs. An overall rise in stage of five to six feet has occurred for a discharge of 100,000 cfs. The flood of 1993 reduced stages for a 70,000 cfs flow for one year before rebounding, after the high flows in the late 1990’s the stage lowered again, but stages did not appear to have rebounded.

Most of the flood plain of the Missouri River is protected by levees in the Nebraska City reach, but agricultural pursuits riverward of the levees and in low-lying, unprotected or under-protected areas are vulnerable to flooding from the tributaries with only normal releases from Gavins Point. Normal spring/summer releases from Gavins range from 30,000 to 35,000 cfs. Incremental runoff in the reach downstream of Gavins Point to Nebraska City, including the Platte River, along with the releases from Gavins Point account for the total flow in the Missouri River at Nebraska City. Interior drainage problems occur in this area and have worsened due to the long-term increasing river stages at above normal flow levels. It appears that the sediment load provided by the Platte River is not removed by scouring flow as it was during pre-reservoir conditions.

ST. JOSEPH

As seen on ***Figure 14***, from 1928 to the early 1950's stages at St. Joseph in the 20,000 to 40,000 cfs range were relatively constant until the 1952 Flood occurred and caused the St. Joseph cutoff upstream of the gaging station. This resulted in a shift in the rating curve of about two feet. In the early 1970's, stages for these discharges declined one to two feet. Since the Flood of 1993, stages have lowered about two feet for both discharges. Since the mid-1940's the stage trends for the 70,000 and 100,000 cfs flows increased about 4 feet by the early 1970's. Then the stage for 70,000 cfs increased slightly by 1993 whereas the stage for 100,000 cfs increased about 2 feet. Since 1993 stages for both flows have decreased between 2 and 3 feet. Due to the drought conditions and minimum service System releases, no flow measurements were taken in the 70,000 cfs to 100,000 cfs range from 2000 to 2006. ***Figure 15*** shows stages for flows between 100,000 and 200,000 cfs. Although there are fewer flow measurements above 100,000 cfs, the data reveals an increasing trend of about 6 feet until the early 1990's for these flows, by 2008 the stages lowered about one foot, and then increased from 0.2 to 1.1 feet by 2011.

KANSAS CITY

The Missouri River stage trend at Kansas City has been consistently downward for all discharge levels up through 100,000 cfs 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 downstream channel cutoffs that have shortened the downstream reach by about 20 percent since 1890, the reduced Kansas River sediment loads due to reservoir construction, and gravel mining operations. Stages, in general, average eight to 12 feet lower than those experienced in the 1930's for 20,000, 40,000 and 70,000 cfs, and about six feet lower at 100,000 cfs. Kansas City stages, for each flow represented on ***Figure 16***, recover after a period of lowering stage, but generally do not recover to the previous heights. 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, although data for flows above 200,000 cfs are very sparse. The stage at the 200,000 cfs flow decreased about four feet between 1941 and 1952, this was followed by an increasing stage trend that by 1999 had increased by more than 2 feet. Since 1999 the stage has decreased by about four feet. The few points representing the 300,000 cfs flow seems to follow the 200,000 cfs trend.

WAVERLY

Missouri River stage trends at Waverly are generally four to six feet higher at the 300,000, 200,000, and 100,000 cfs discharge levels than those experienced during the 1930's. The stage for the 70,000 and 40,000 cfs flows generally increased through 1990 by about 3 to 4 feet, then stayed fairly constant to 2008 before decreasing about foot by 2011. From 1970 to 2009 the stages for the 20,000 cfs flow, has shown periods of fluctuations, but overall has shown little change. Following the Flood of 1993 stage reductions of less than a foot occurred for flows in the 40,000 to 100,000 cfs range as shown on ***Figure 18.*** ***Figure 19*** displays the stage trends for discharges of 200,000 and 300,000 cfs. The upward trend appears to be continuing although the data at discharges in this 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 one foot over a four to five year period have been observed, but these changes are minor compared to changes at other locations on the river. Missouri River stages have remained relatively constant between 1930 and 1970 for the low flows of 20,000 and 40,000 cfs. A decreasing trend has developed at these flows such that the stage is now about 1.5 to three feet lower. Three measurements were made during 2007 at the 20,000 cfs range. These measurements, along with the measurements in the early 1990's and early 2000's, indicate a much more distinct downward trend in this discharge range as compared to the other lower discharge ranges. While there were three measurements made in this range, all the measurements were taken during the colder weather (November) and may not be indicative of bed formation conditions during warmer open channel flow conditions. The 70,000 and 100,000 cfs flows show a slow increase in stage to 1960 of two to 3 feet, and then remain fairly consistent to 2002. Since 2002 the stages have lowered about 1.5 feet. The data available for the higher discharges of 200,000 and 300,000 cfs demonstrate an upward trend of two to four feet has occurred at this station since 1960. The highest USGS stage/discharge measurement in 2010 occurred at 272,000 cfs; the data point at 300,000 was obtained by extending the rating curve.

HERMANN

At Hermann, the Missouri River stage trends indicate an overall upward stage shift of about one to three feet from the mid-1930's through the late 1950's for flows of 200,000 cfs and less. For about 10 years following the late 1950's, the stage trend flattened for flows at and below 100,000 cfs, then from about 1970 to 2007 a decreasing stage trend existed, and since 2007 the stages have remained flat, as shown in ***Figure 22.*** ***Figure 23*** shows the trends for Missouri River flows between 200,000 and 500,000 cfs. At the 300,000 cfs discharge level, a three-foot increase in stage has been noted prior to the Flood of 1993. Post-1993 flood recovery data have demonstrated an erratic but slightly downward trend. Both the 200,000 and 300,000 cfs flow levels show little change in the last three years. Since USGS stage/discharge measurements in 2010 and 2011 plotted fairly close to the latest base rating curve, data points for 300,000 cfs flow were extrapolated.

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 of several of the main stem reservoir 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 Lake Sakakawea 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 Lake Sakakawea headwaters was completed by the Corps in September 1990.

It has been observed that aggradation and delta formation has occurred in Lake Sakakawea headwaters since construction of the Garrison Dam project in 1953 and the filling of Lake Sakakawea in about 1965. Lake Sakakawea backwater and aggradation effects resulted in a dramatic rise in the stage-discharge rating curves for the period 1966 to 1972 and then subsequently a more moderate increased rate that appears to be ongoing to the present.

Buildup of the Lake Sakakawea headwaters delta appears to be occurring at a relatively uniform rate (by depth of sediment deposit) over the reach from River Mile 1520 to 1550. This includes the river area near the city of Williston, at about River Mile 1544. Between 1969 and 1987 (the last year sediment range lines were surveyed in this area), the average depth of sediment deposit in this reach has risen about six feet total or about 0.3 feet per year. In the immediate vicinity of Williston, approximately four feet of sediment deposition has been measured on the Missouri River from 1969 to 1987 or about 0.2 feet per year.

Low reservoir elevations from 2001 through 2008 caused sediment to deposit farther downstream. As the reservoir elevations lowered, some previously deposited material re-suspended and moved downstream to lower areas of the reservoir. High pool elevation in 2010 and 2011 has probably caused new sediment to deposit in areas that were vacated during the recent low pool period.

BISMARCK

Bismarck, North Dakota, located in the Lake Oahe headwaters area, is the only station on the Missouri River within the System for which the aforementioned rating curve analyses and records have been maintained. As shown on ***Figure 24***, from the late 1920's to 2010 the stages for the 20,000, 30,000 and 40,000 flows increased between 1 to 3 feet. However, the record discharges in 2011 have lowered the stages for these flows between one and two feet, bring the stages close to the late 1920's measurements. These stage trends are for open channel flow conditions. Ice jam flooding problems have been experienced in this area during the winter at housing developments, which have been constructed since project construction, located in the Missouri River bottomlands near Bismarck. A study completed by the Corps in 1985 "Oahe - Bismarck Area Studies" indicated that aggradation has reduced the size of the channel in the study area, resulting in higher stages for the same discharge. The study concluded that for discharges of 50,000 to over 100,000 cfs, the stages have increased by one to two feet in the study area. It was also estimated that future aggradation will further increase stages for those discharges by an additional 0.8 to 1.4 feet. At this point, it is still too early to determine the long-term effects at Bismarck from the 2011 record releases from Garrison.

PIERRE

Lake Sharpe headwaters extend to the Pierre-Fort Pierre, South Dakota area. Sediments deposited from the Bad River, which enters the headwater area at Fort Pierre, and other unmeasured tributaries and 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 river stages had increased by about 1.1 feet for open water discharges of 70,000 cfs and would continue to increase due to future aggradation. That study also indicated that currently the increase in ice-affected stages has been more severe than the increase in open water stages, resulting in an increase of about two feet. The Oahe Dam – Lake Oahe, South Dakota (Pierre-Ft Pierre Sedimentation) Study was authorized by Section 441 of the Water Resources Development Act (WRDA) of 1996. This study, completed in October 2000, identified the present and future sedimentation conditions on the Missouri River in the vicinity of the Pierre-Fort Pierre area. At this point, it is still too early to determine the long-term effects at Pierre from the 2011 record releases from Oahe.

SPRINGFIELD

Headwaters of Lewis and Clark Lake at the Gavins Point project extend upstream of the Springfield, South Dakota area. Sediment deposition in the vicinity of Springfield has restricted access to Lewis and Clark Lake from the Springfield boat ramp. Farther upstream, a large delta continues to develop near the mouth of the Niobrara River. This sediment deposition from

Niobrara to Springfield has increased river stages in this reach. A water surface profile (WSP) for a steady discharge of 29,500 cfs in 2009 had a similar elevation as a 35,000 cfs WSP obtained in 1944 from upstream of Verdel, Nebraska to below the mouth of the Niobrara River. Both of these WSP's were approximately one foot higher than a WSP obtained in the mid-1980's with a discharge of 44,000 cfs and one obtained in 1975 with a discharge of 60,000 cfs in 1975.

A Corps study was published in September of 1992 entitled "Sedimentation near the confluence of the Missouri and Niobrara Rivers 1954 to 1990." That study found that there has been an overall reduction in channel depth of approximately three to five feet downstream of the confluence of the Niobrara River and two feet upstream of the confluence between 1954 and 1984. This change in channel depth has caused an increase in stage of about six feet downstream from the confluence for a discharge of 20,000 cfs. Since that study the stage at the Missouri River gage near Niobrara had increased another 4 feet by 2009, and then decreased about 3 feet by late 2011. The most rapid increase in stage occurred between 1957 and 1960 when the stage for 30,000 cfs rose approximately three feet. A large flood on the Niobrara occurred in 1960 with discharges of 39,000 cfs resulting in extensive sediment deposition on the Niobrara River delta.

Further upstream, at the Missouri River at Verdel gage, located approximately two miles upstream from the confluence of the Niobrara, Missouri River stages have increased by about four feet during the period of 1977 to 1990 for discharges of 20,000 cfs to 40,000 cfs. The average rate of increase of about 0.3 feet per year during this period is a faster rate than that observed downstream of the Niobrara confluence. At Greenwood, approximately 20 miles upstream from the Niobrara confluence, the stages associated with discharges of 20,000 cfs to 40,000 cfs had not changed more than one foot between 1960 and 1987. The gage was moved to its present location in October 1989. Since 1989 the stage showed some fluctuations but overall to 2010 had changed very little; however in 2011 the stage dropped between one and one and half feet for discharges between 20,000 to 40,000 cfs.

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SUMMARY

Record releases of 160,000 cfs were made from Gavins Point Dam in 2011. This had a major impact to the river system above Kansas City, but did not impact the system below Kansas City as much due to low tributary flows below Gavins Point. Of the streamgaging locations in this report the Sioux City location was impacted the most where the stages for all flows at 50,000 cfs and below decreased about 4 feet. Other Missouri River streamgaging locations showed moderate to no changes due to 2011 Gavins Point releases.

In recent years, stages have generally shifted downward in the open river reach from Gavins Point Dam to Omaha, Nebraska and in the St. Joseph to Kansas City, Missouri reach. 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 in old oxbow lakes, particularly if they are still connected to the river. These potential problems were somewhat masked during the late 1970's and portions of the early 1980's due to the above normal inflows above and below the mainstem reservoir system. However, the impacts became very obvious during the drought years 1987 through early 1993 and 2000 through 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 good communications to alert those affected to what is happening and how to adapt to the situation to maintain access. Positive impacts include the greater flood protection provided to those adjacent to the river due to lower stages for some flows.

Flow measurements in the mid to late 1990’s indicated upward stage shifts for the higher discharges at all stations located along the navigation channel or in headwater areas. This trend still exists for the Missouri River at Nebraska City and St. Joseph. However, the latest measurements at Kansas City at 200,000 cfs indicate a downward shift of almost four feet. The upward trend is most apparent at Nebraska City and St. Joseph, where flows of 80,000 to 90,000 cfs now go overbank compared to bank full discharges 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 difficult and less effective. However, the chances of getting flows in excess of the channel capacity have been greatly reduced due to the regulation of the upstream reservoirs. 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 river.

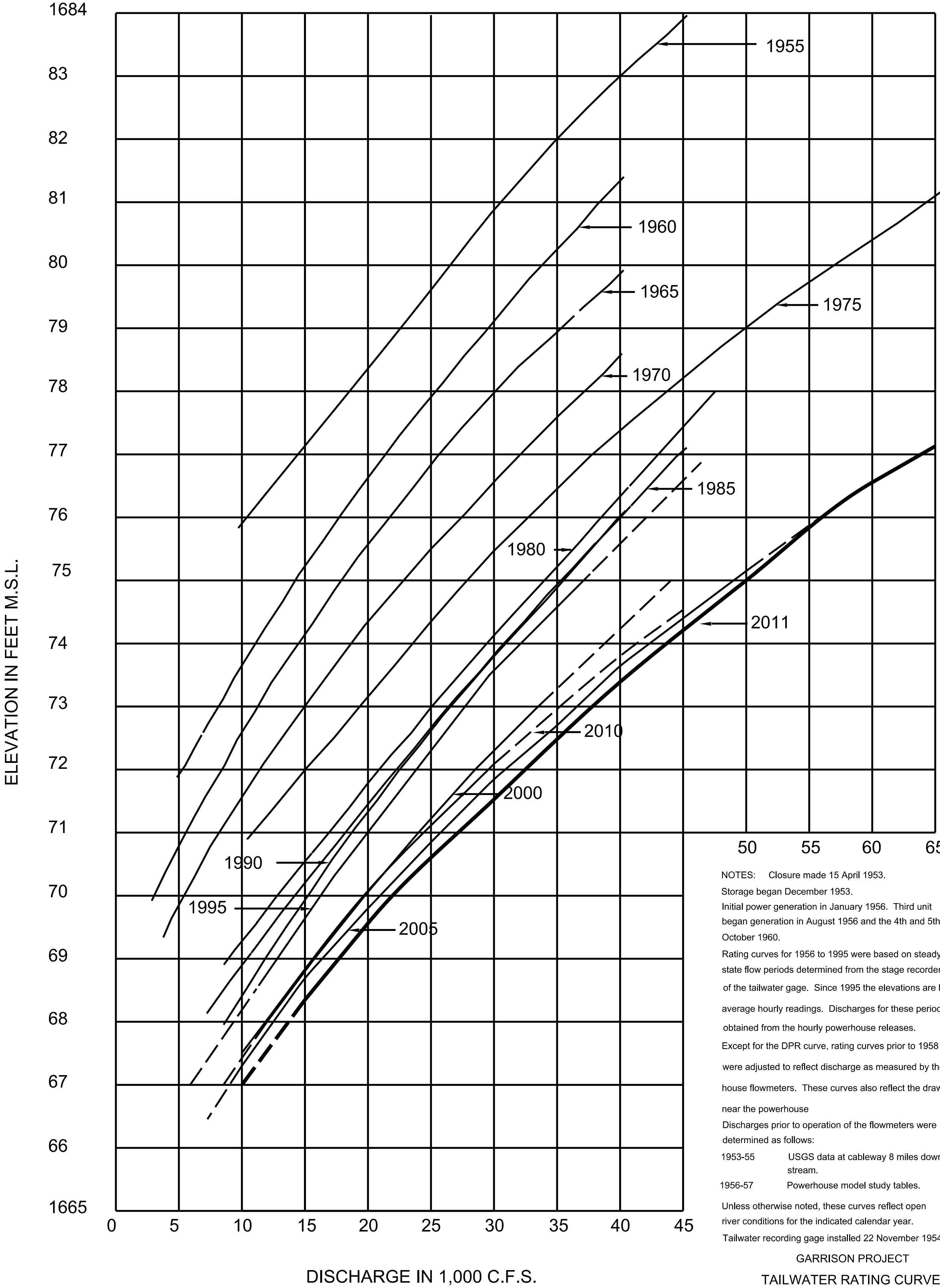
The increases in stages at stations below Kansas City, for flow levels near bank full are limited to about two to six feet. Increases of this magnitude agree quite well with the values presented in referenced consultants' report of November 1955 relating to the effect of navigation structures on river levels. The consultant board also expressed the opinion that the effect of the navigation works would be reduced above bank full flows and 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 flood discharges on the lower Missouri River, it seems apparent that the stage increases are due largely to factors other than navigation structures, primarily private levees and deposition of sediment on the floodplain above the navigation channel during high flow events.

Stage trends at normal discharge levels, whether up or down, affect the design and subsequent functioning 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 and 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 eight to 12 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 with the high system releases. An exception to the tailwater stage reduction was occurring below Oahe at the lower flows, where the tailwater stages had increased slightly through 1995, but since then has decreased about a foot.

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

An electronic version of this RCC 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.



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 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 power-house flowmeters. These curves also reflect the drawdown near the powerhouse
Discharges prior to operation of the flowmeters were determined as follows:

1953-55	USGS data at cableway 8 miles down stream.
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 PROJECT

TAILWATER RATING CURVES

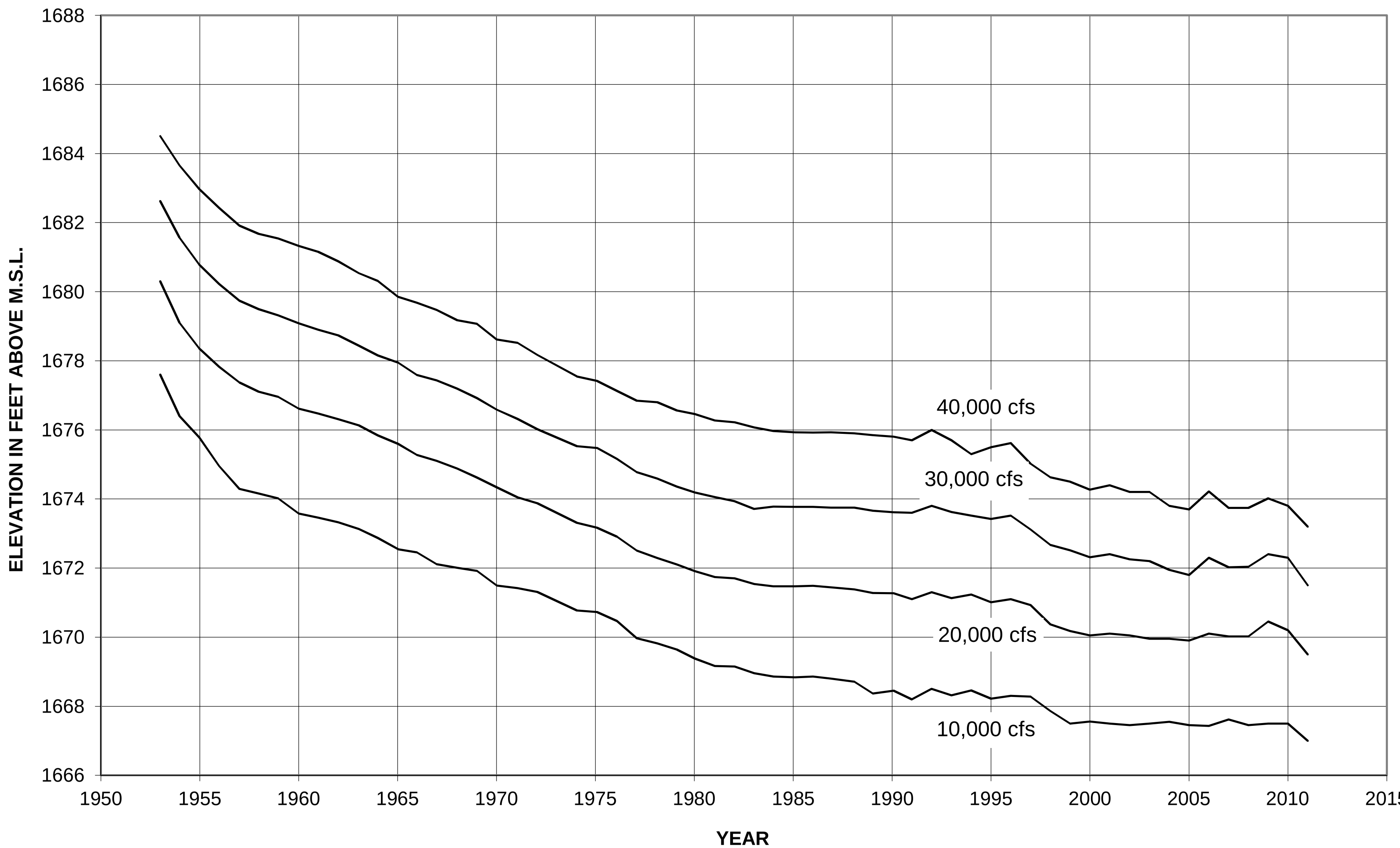
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

FEBRUARY 2012

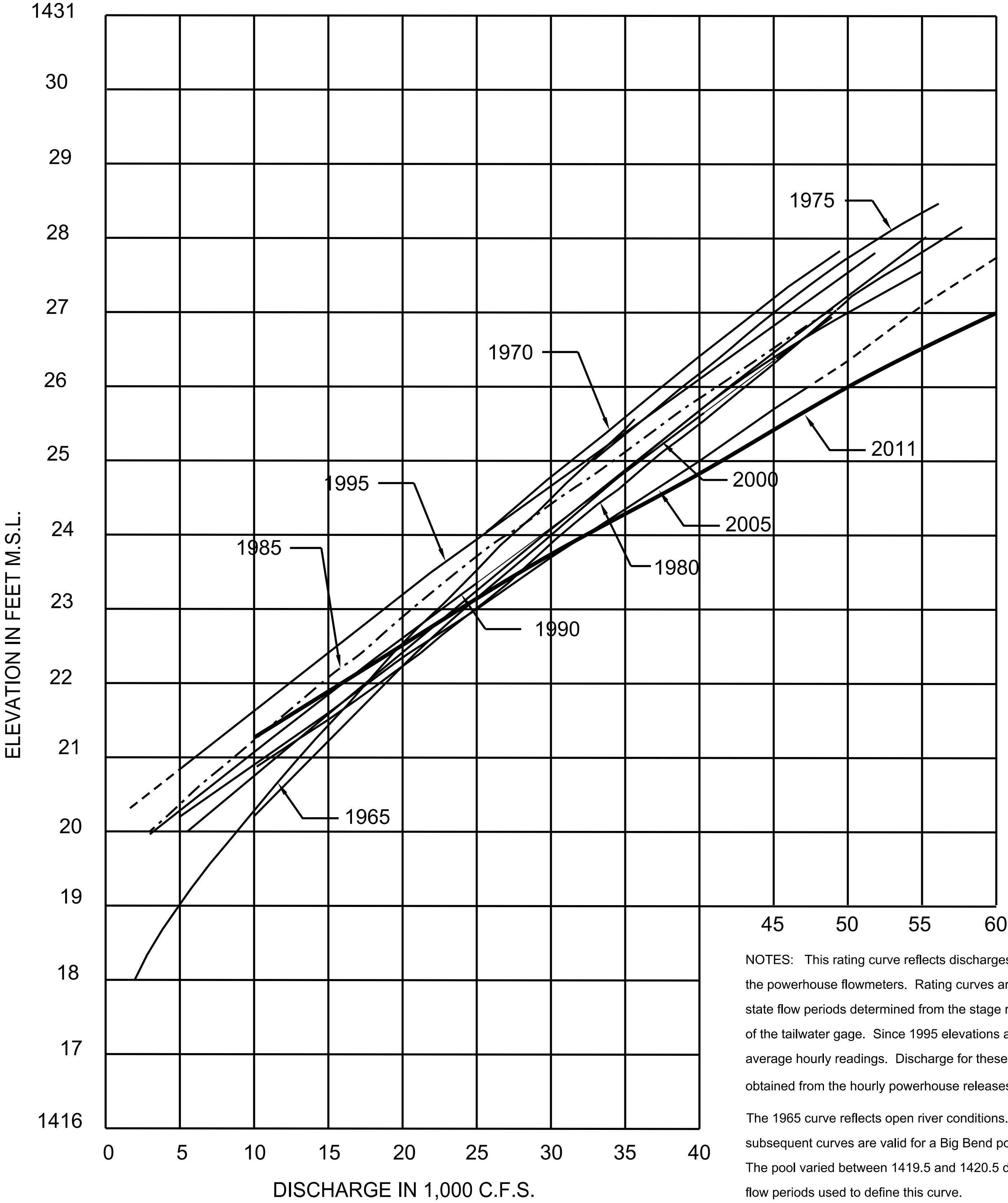
Figure 1

Figure 2

GARRISON PROJECT TAILWATER TRENDS



February 2012



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.

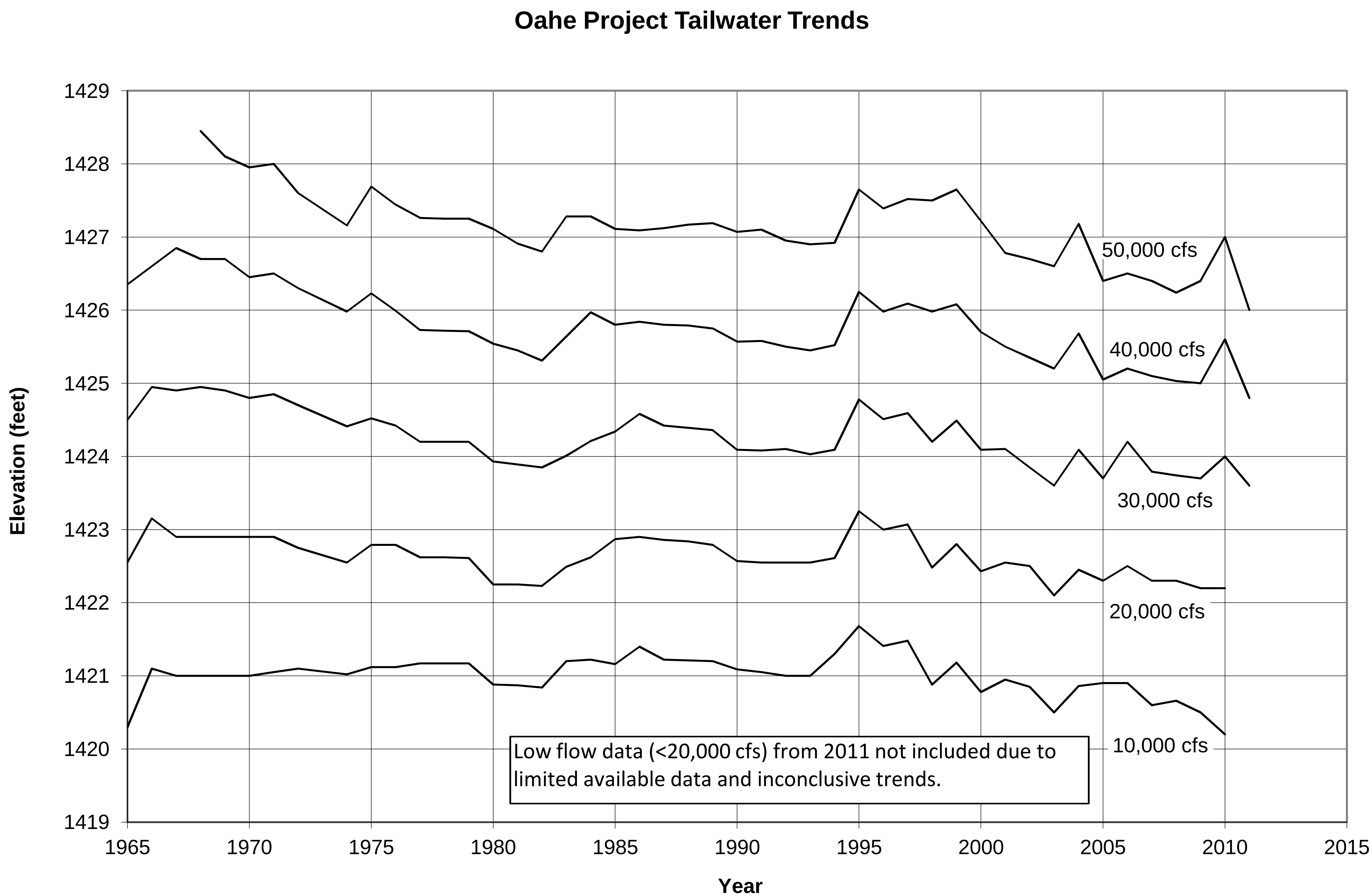
The construction of channel block No. 6 was completed 15 June 1967. An extension of channel block No. 6 to River Island was completed 12 July 1970.

OAHE PROJECT

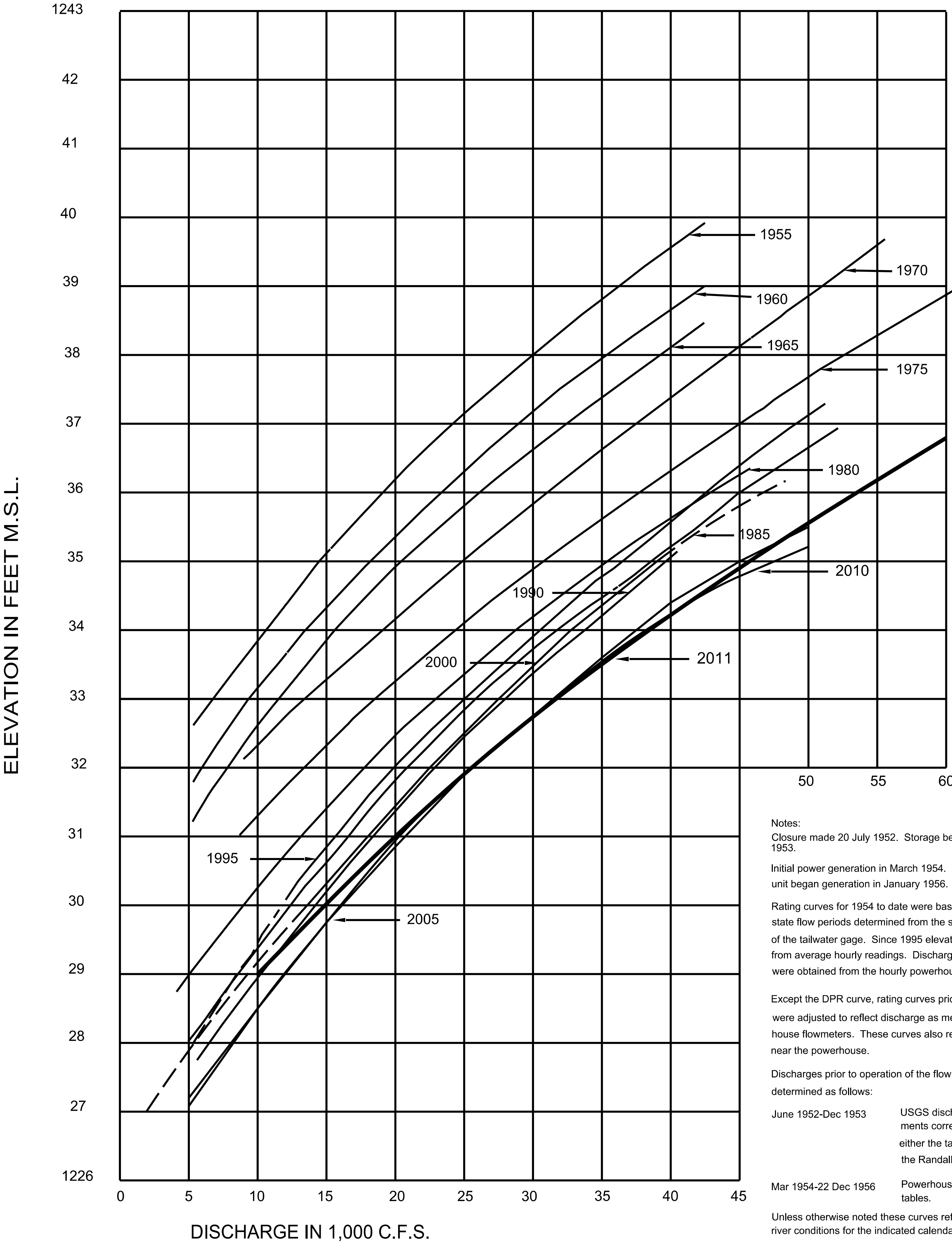
TAILWATER RATING CURVES
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
FEBRUARY 2012

Figure 3

Figure 4



February 2012



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:

June 1952-Dec 1953	USGS discharge measurements correlated with either the tailwater or the Randall Creek gage.
Mar 1954-22 Dec 1956	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.

* 1995 curve shows an adjustment made to the datum. Not an aggradation trend. See trend plot.

FORT RANDALL PROJECT

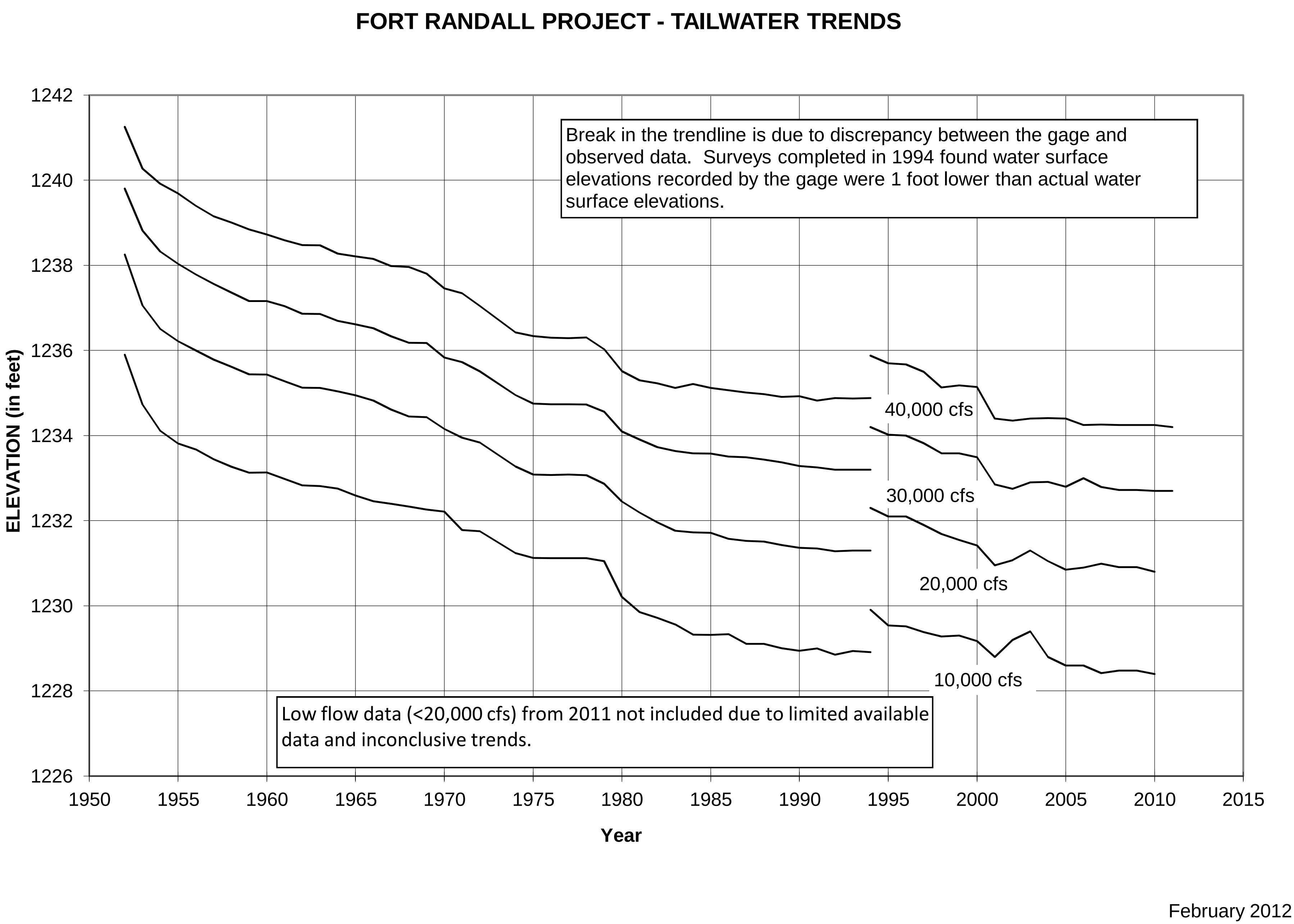
TAILWATER RATING CURVES

U.S.ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA.

FEBRUARY 2012

Figure 5

Figure 6


FORT RANDALL PROJECT - TAILWATER TRENDS
Break in the trendline is due to discrepancy between the gage and observed data. Surveys completed in 1994 found water surface elevations recorded by the gage were 1 foot lower than actual water surface elevations.
Low flow data (<20,000 cfs) from 2011 not included due to limited available data and inconclusive trends.
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
ELEVATION (in feet)
1242
1240
1238
1236
1234
1232
1230
1228
1226
Year
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
February 2012

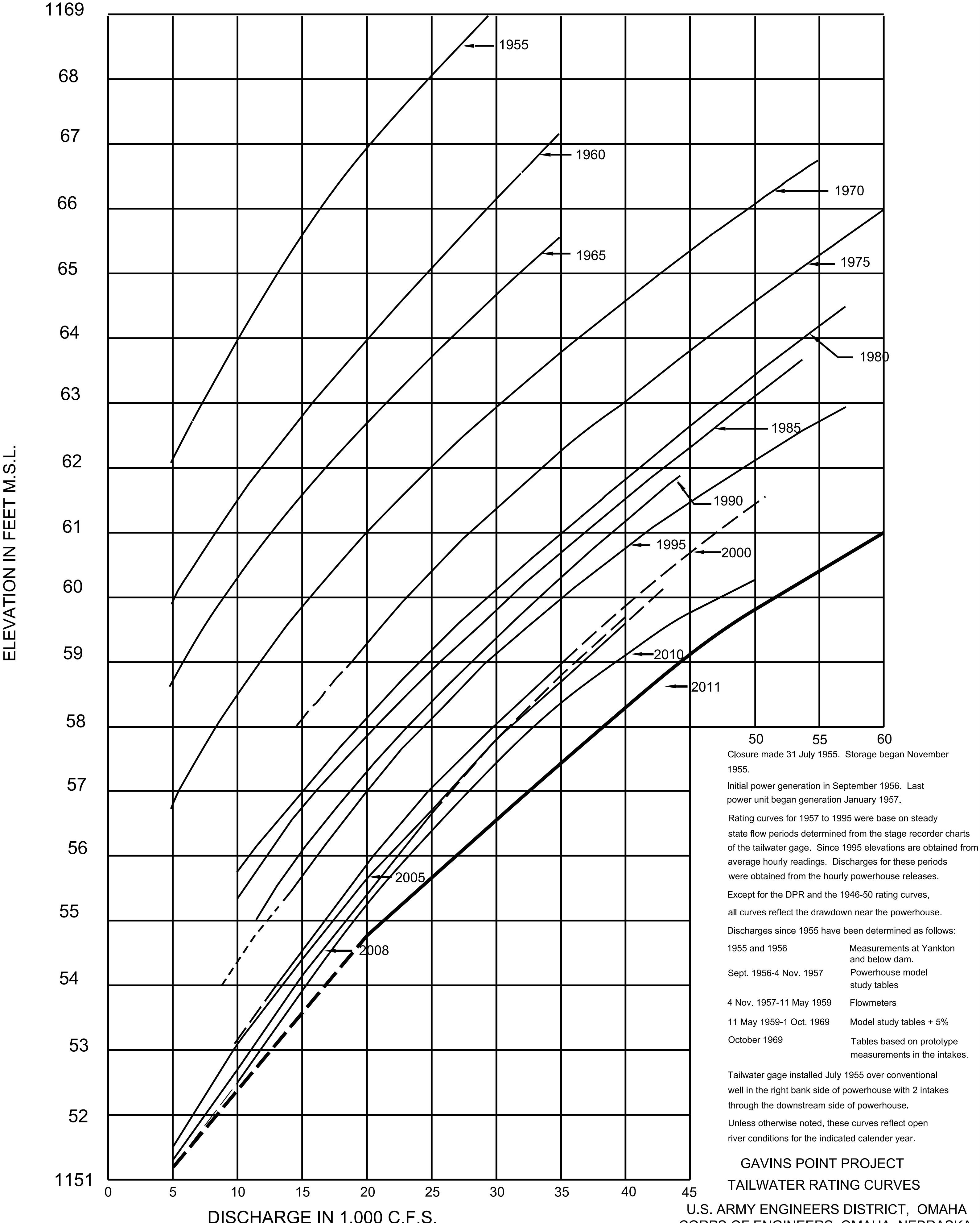
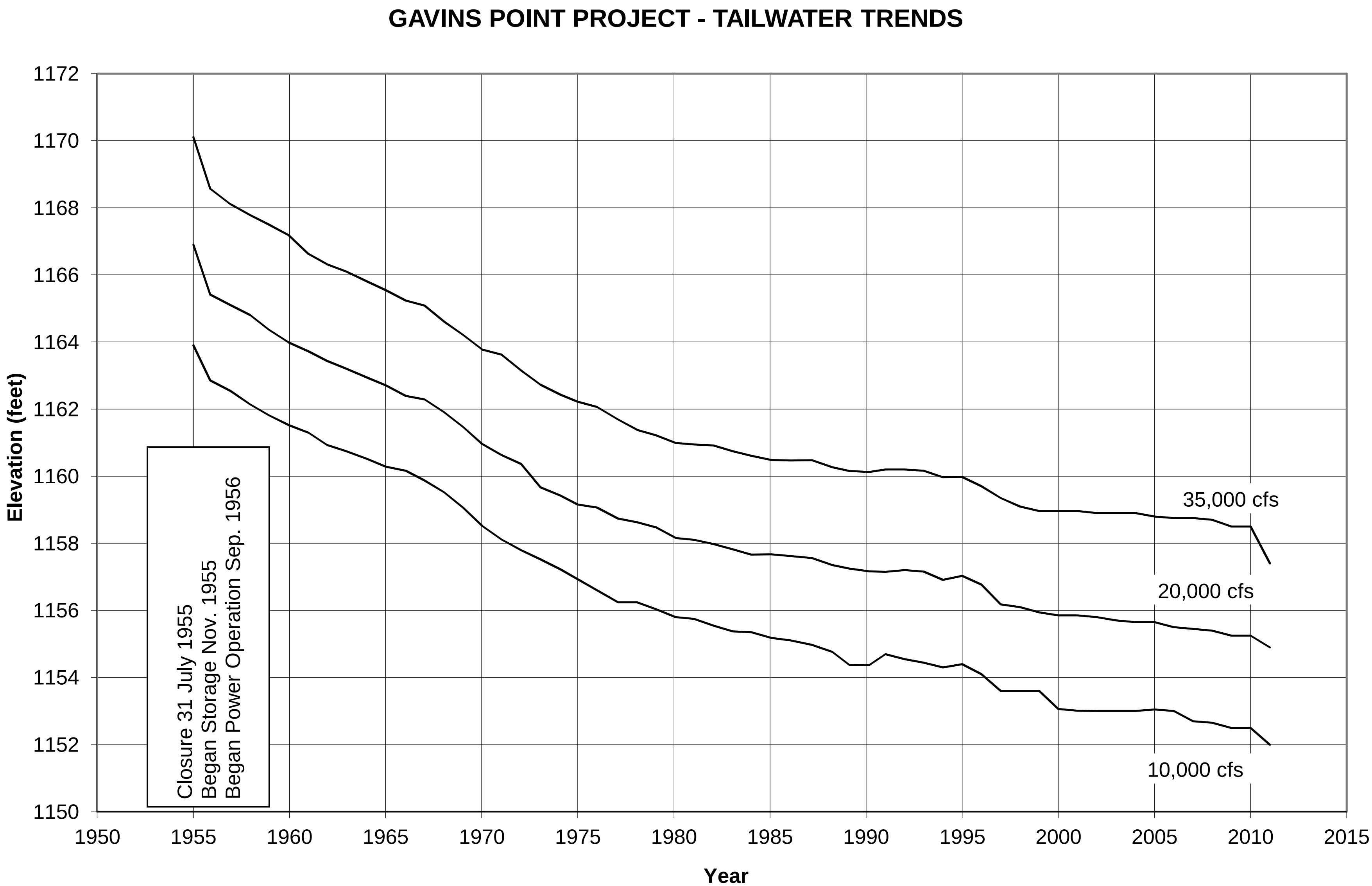

1169
68
67
66
65
64
63
62
61
60
59
58
57
56
55
54
53
52
1151
ELEVATION IN FEET M.S.L.
0
5
10
15
20
25
30
35
40
45
50
55
60
DISCHARGE IN 1,000 C.F.S.
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2008
2010
2011
Closure made 31 July 1955. Storage began November 1955.
Initial power generation in September 1956. Last power unit began generation January 1957.
Rating curves for 1957 to 1995 were base 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.
Sept. 1956-4 Nov. 1957 Powerhouse model study tables
4 Nov. 1957-11 May 1959 Flowmeters
11 May 1959-1 Oct. 1969 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 calender year.
GAVINS POINT PROJECT
TAILWATER RATING CURVES
U.S. ARMY ENGINEERS DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
FEBRUARY 2012

Figure 7

Figure 8



February 2012

COMPARISON OF TAILWATER TRENDS FOR DISCHARGES OF 20,000 CFS

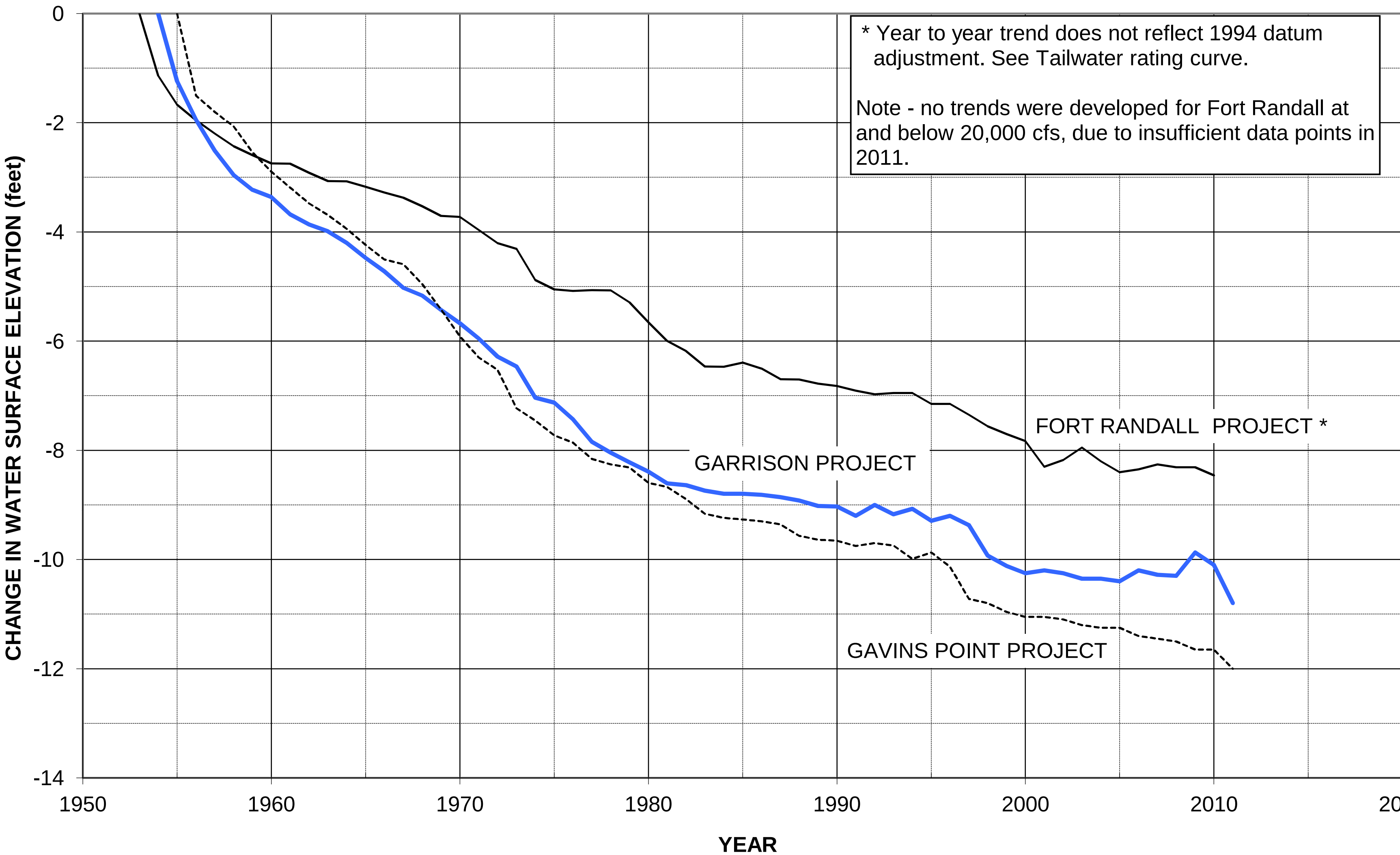
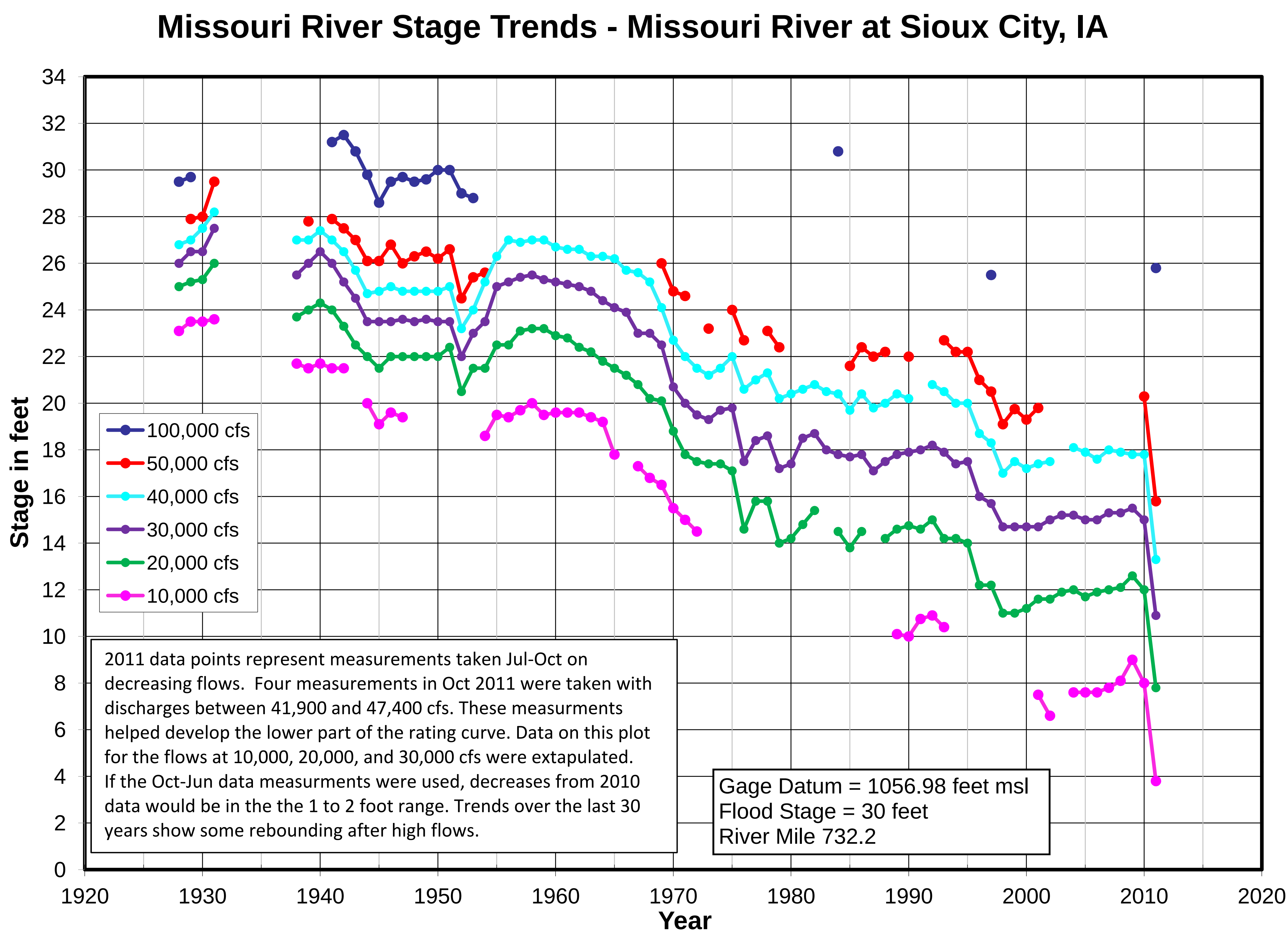


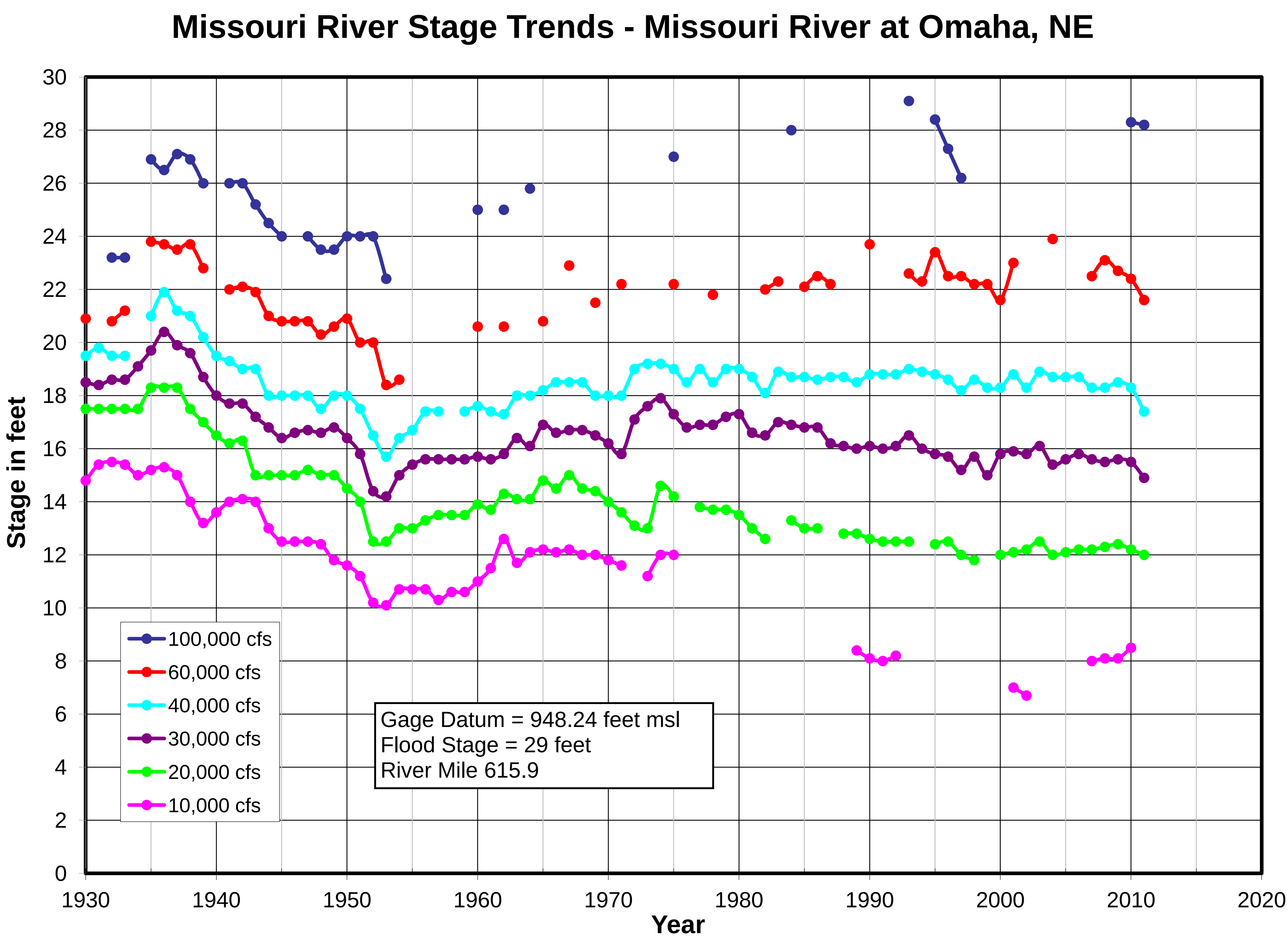
Figure 9

February 2012

Figure 10



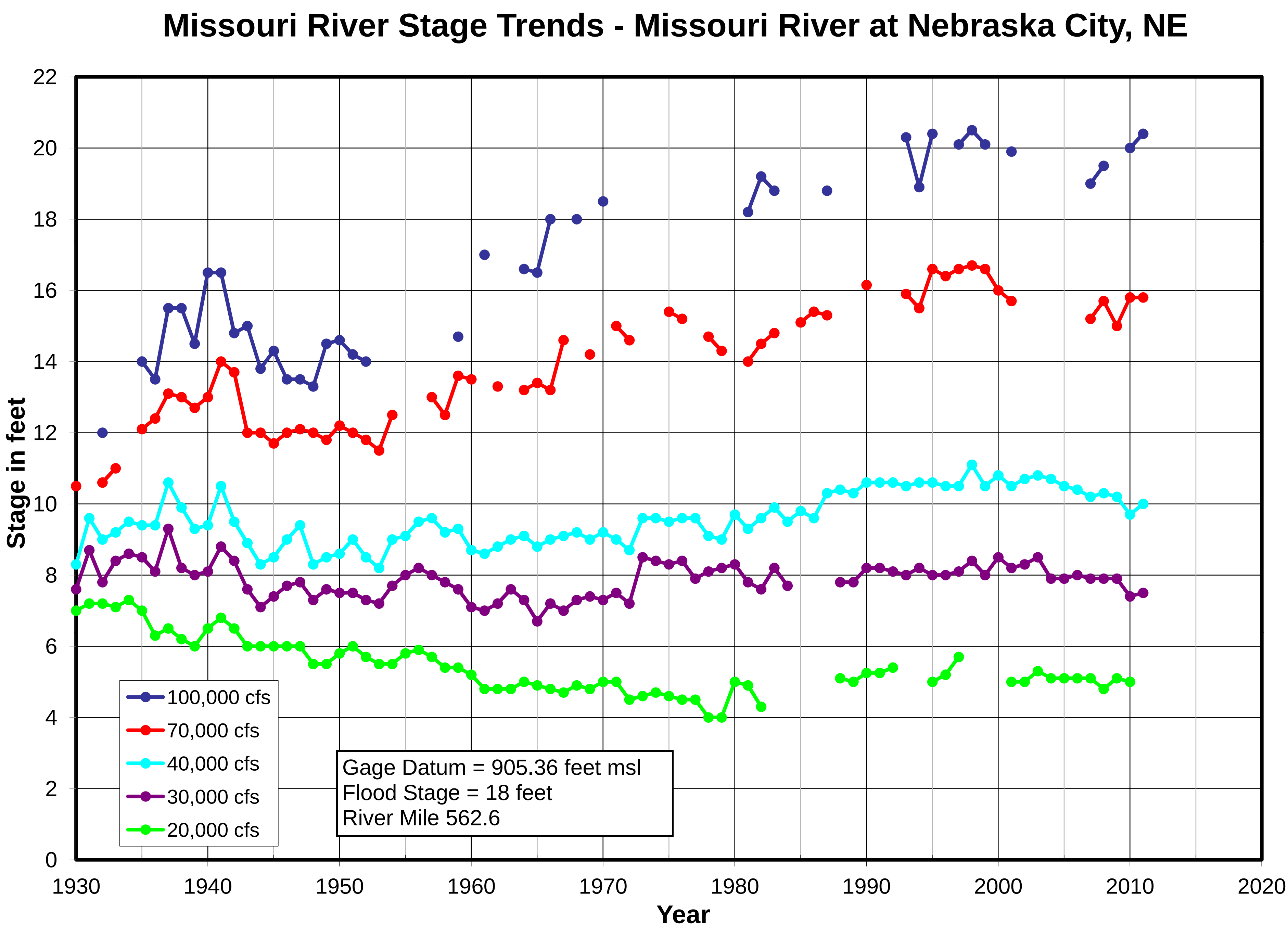
Missouri River Stage Trends - Missouri River at Sioux City, IA
Stage in feet
Year
100,000 cfs
50,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
2011 data points represent measurements taken Jul-Oct on decreasing flows. Four measurements in Oct 2011 were taken with discharges between 41,900 and 47,400 cfs. These measurments helped develop the lower part of the rating curve. Data on this plot for the flows at 10,000, 20,000, and 30,000 cfs were extapulated. If the Oct-Jun data measurments were used, decreases from 2010 data would be in the the 1 to 2 foot range. Trends over the last 30 years show some rebounding after high flows.
Gage Datum = 1056.98 feet msl
Flood Stage = 30 feet
River Mile 732.2



Missouri River Stage Trends - Missouri River at Omaha, NE
Stage in feet
Year
100,000 cfs
60,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
Gage Datum = 948.24 feet msl
Flood Stage = 29 feet
River Mile 615.9
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Figure 11

Figure 12



Missouri River Stage Trends - Missouri River at Nebraska City, NE
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 = 905.36 feet msl
Flood Stage = 18 feet
River Mile 562.6

Missouri River Stage Trends - Missouri River at Nebraska City, NE

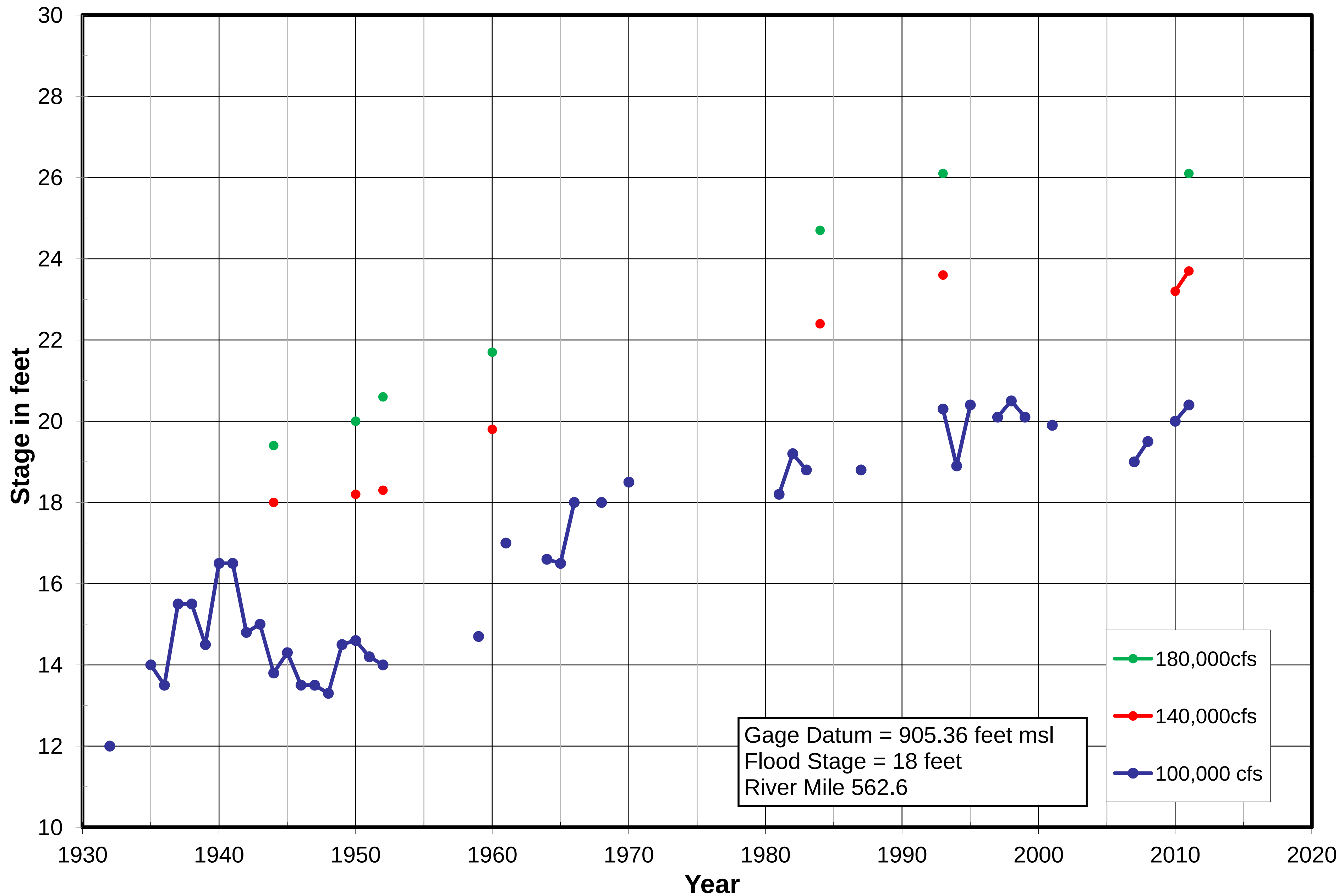
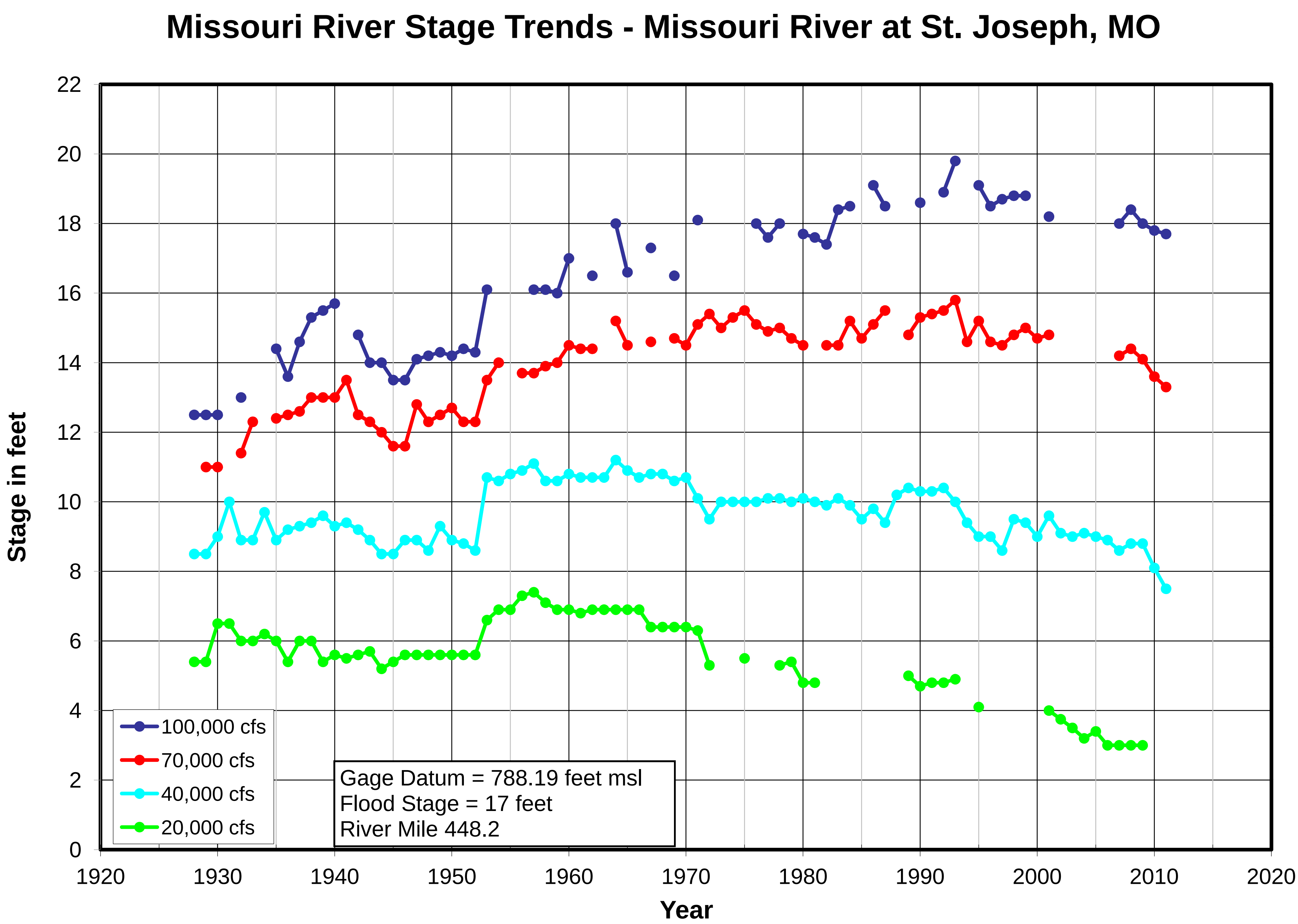


Figure 13

Figure 14



Missouri River Stage Trends - Missouri River at St. Joseph, MO
Stage in feet
Year
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 788.19 feet msl
Flood Stage = 17 feet
River Mile 448.2

Missouri River Stage Trends - Missouri River at St. Joseph, MO

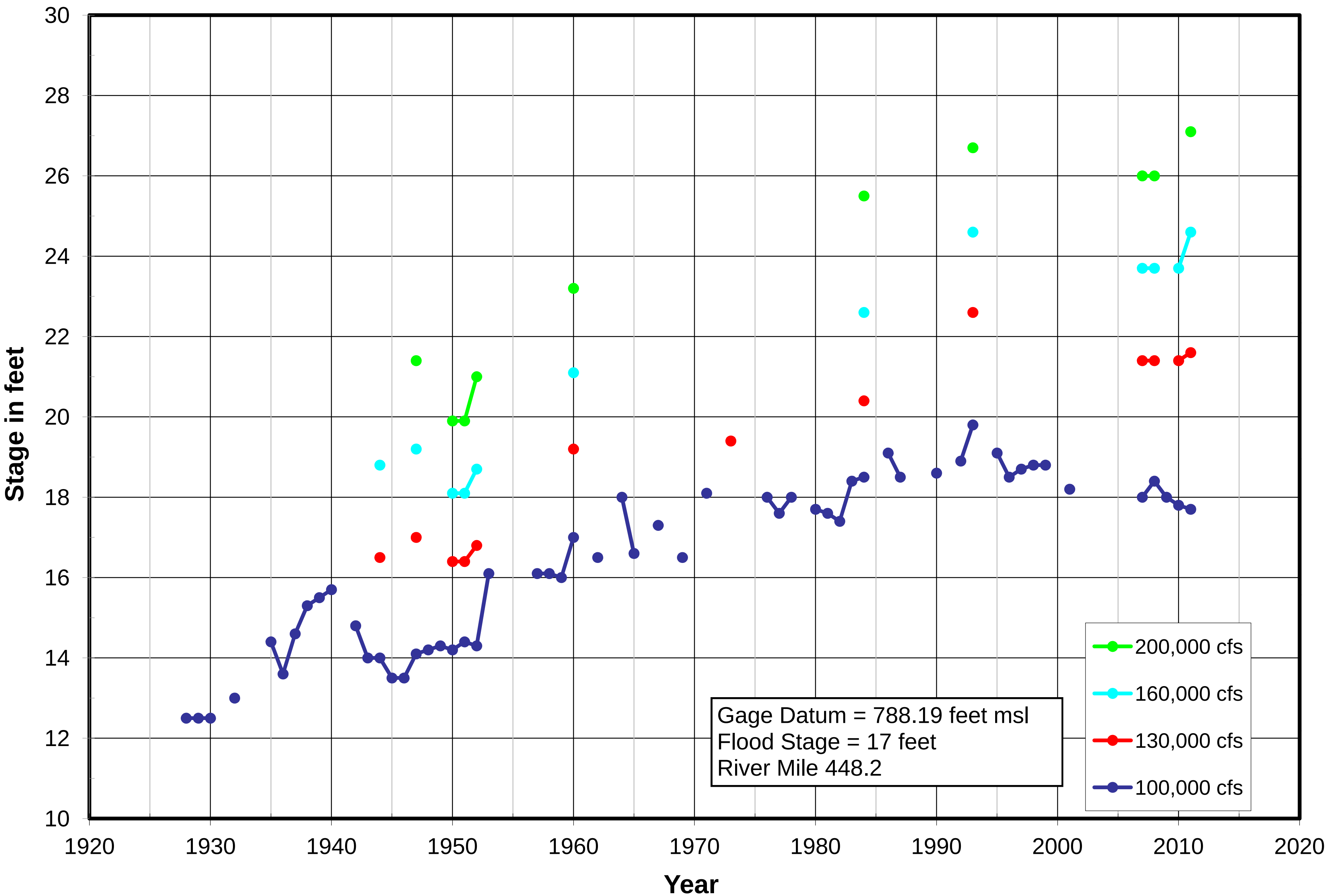
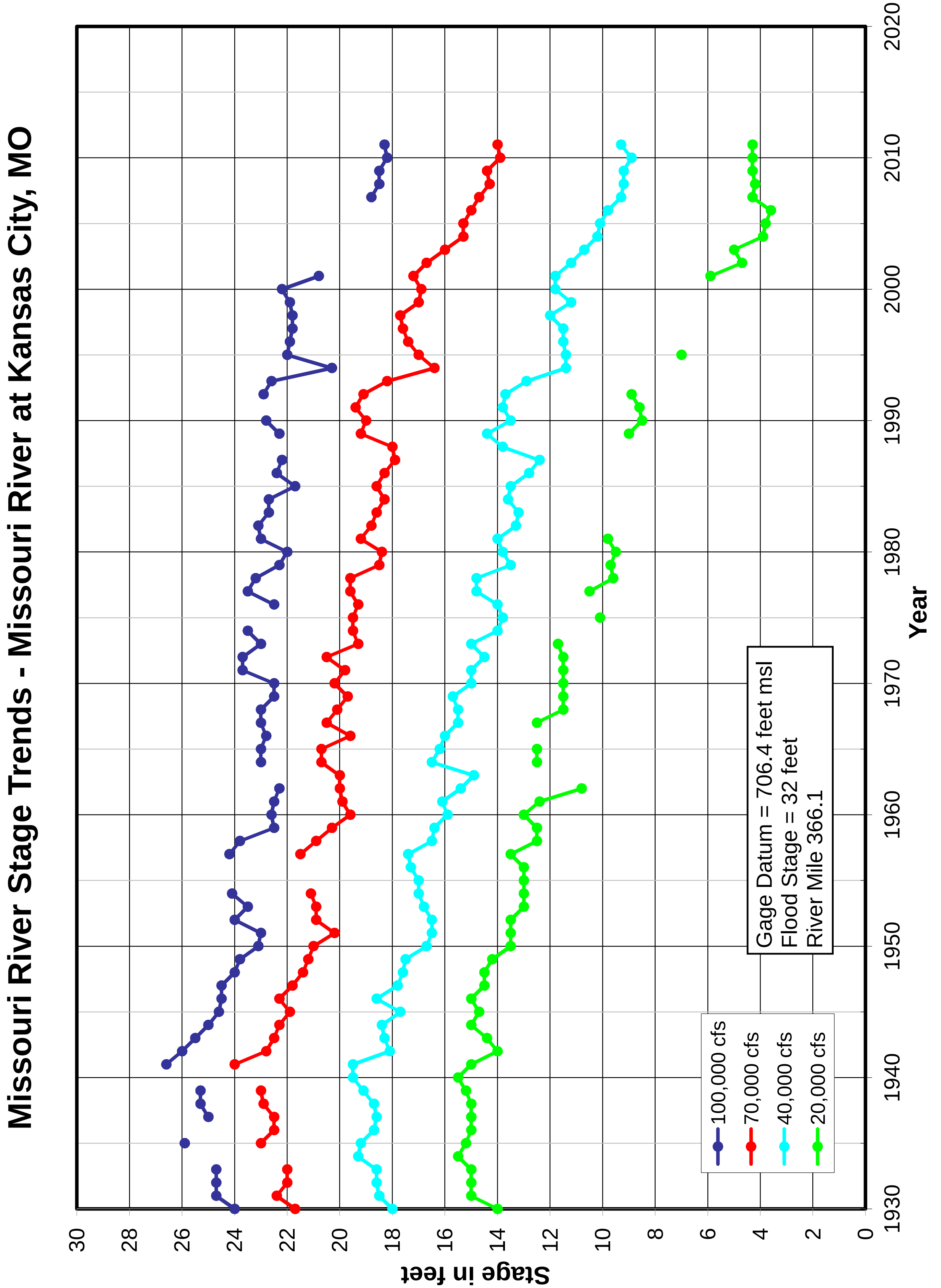


Figure 15



Missouri River Stage Trends - Missouri River at Kansas City, MO
Stage in feet
Year
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 706.4 feet msl
Flood Stage = 32 feet
River Mile 366.1

Figure 16

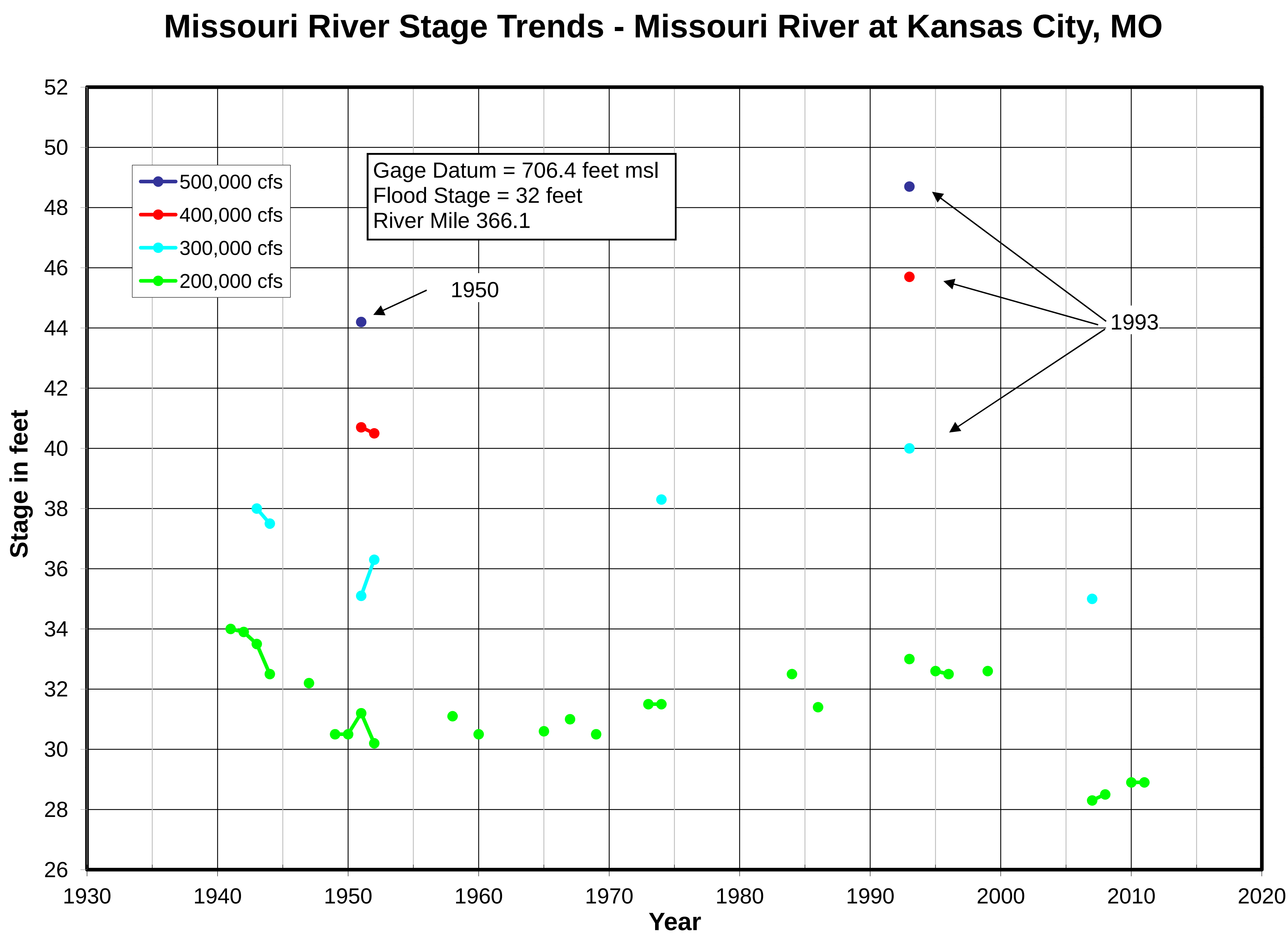

Missouri River Stage Trends - Missouri River at Kansas City, MO
500,000 cfs
400,000 cfs
300,000 cfs
200,000 cfs
Gage Datum = 706.4 feet msl
Flood Stage = 32 feet
River Mile 366.1
1950
1993
Stage in feet
52
50
48
46
44
42
40
38
36
34
32
30
28
26
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Figure 17

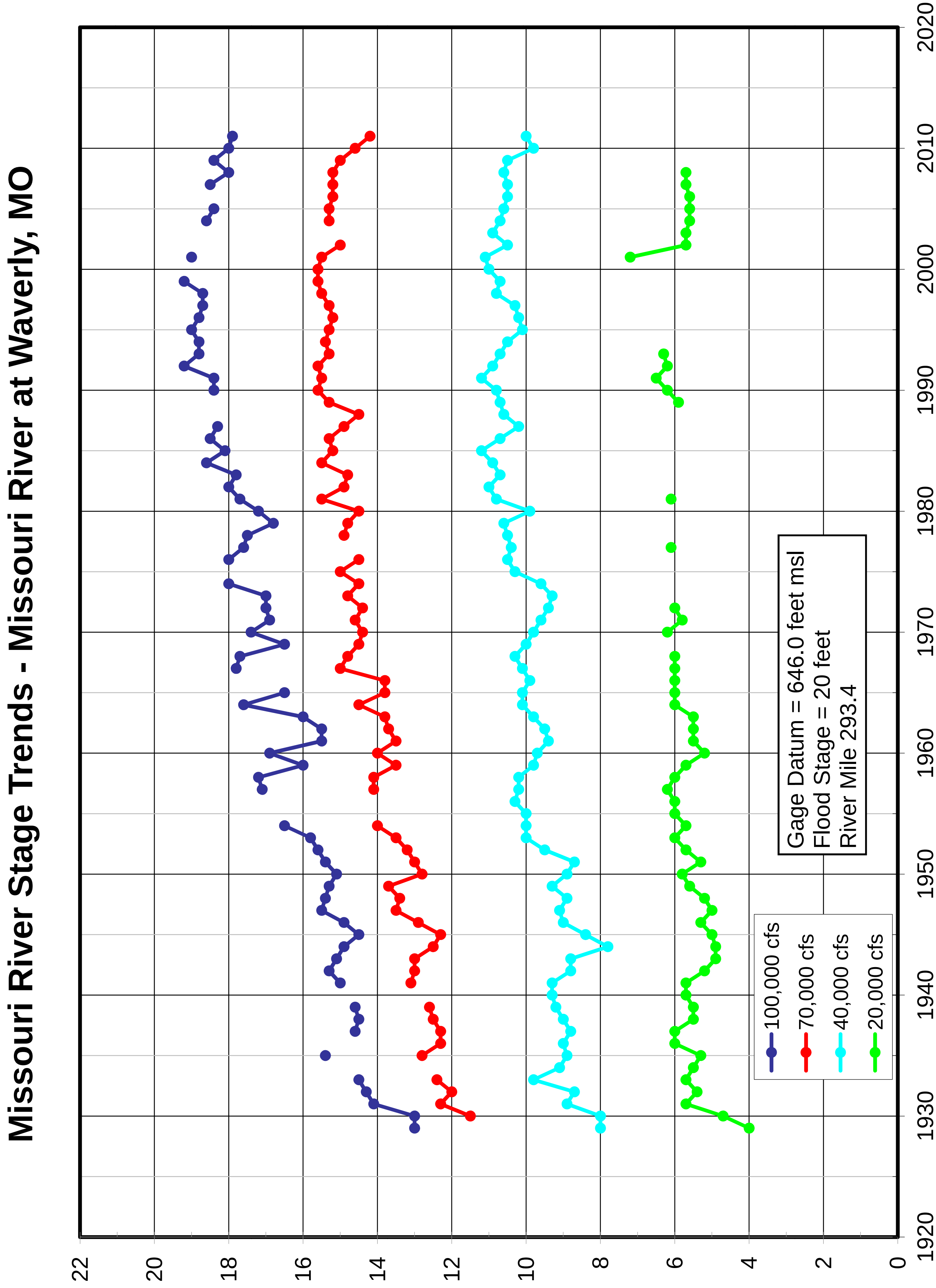
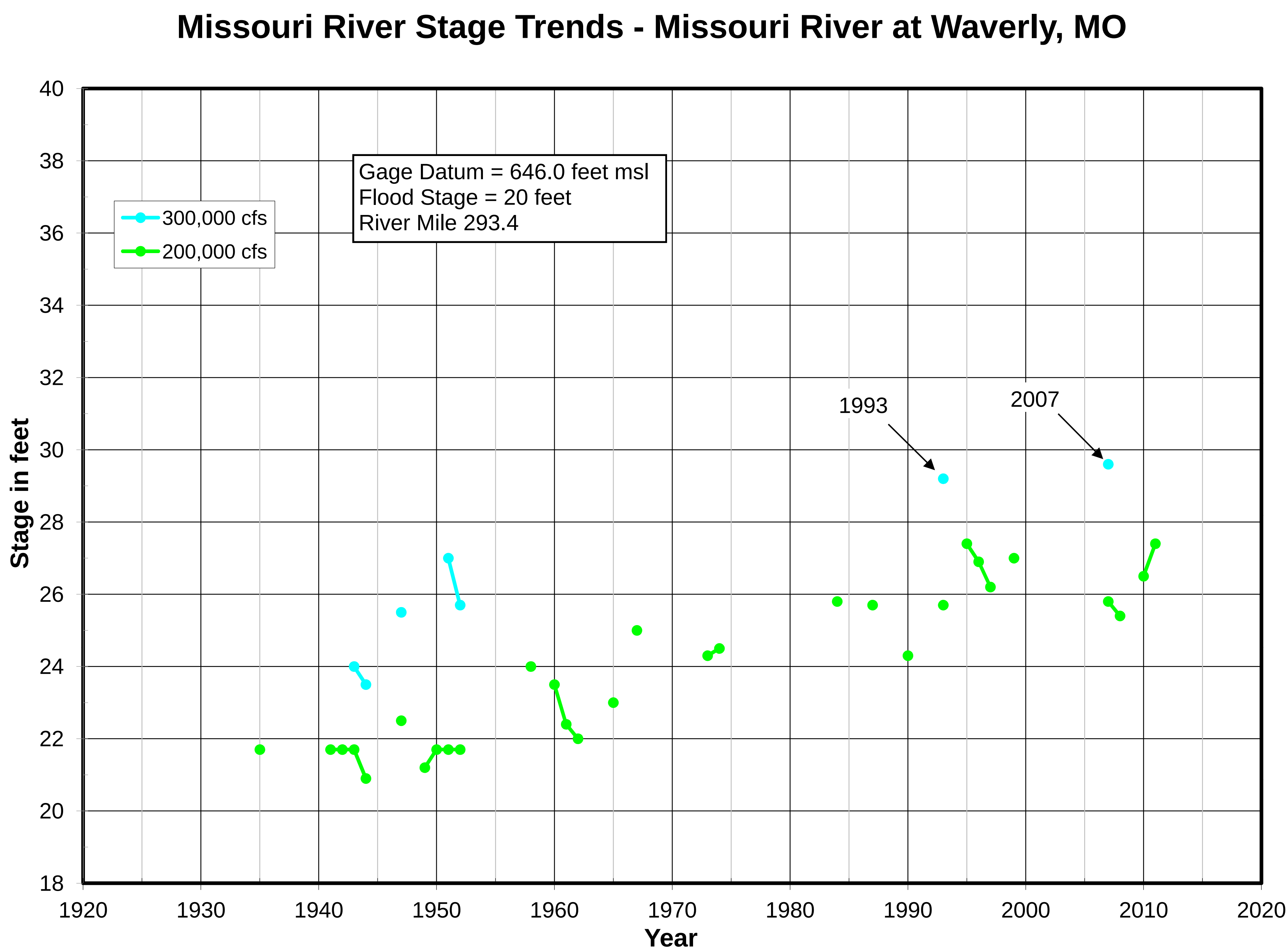

Missouri River Stage Trends - Missouri River at Waverly, MO
Stage in feet
Year
22
20
18
16
14
12
10
8
6
4
2
0
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 646.0 feet msl
Flood Stage = 20 feet
River Mile 293.4

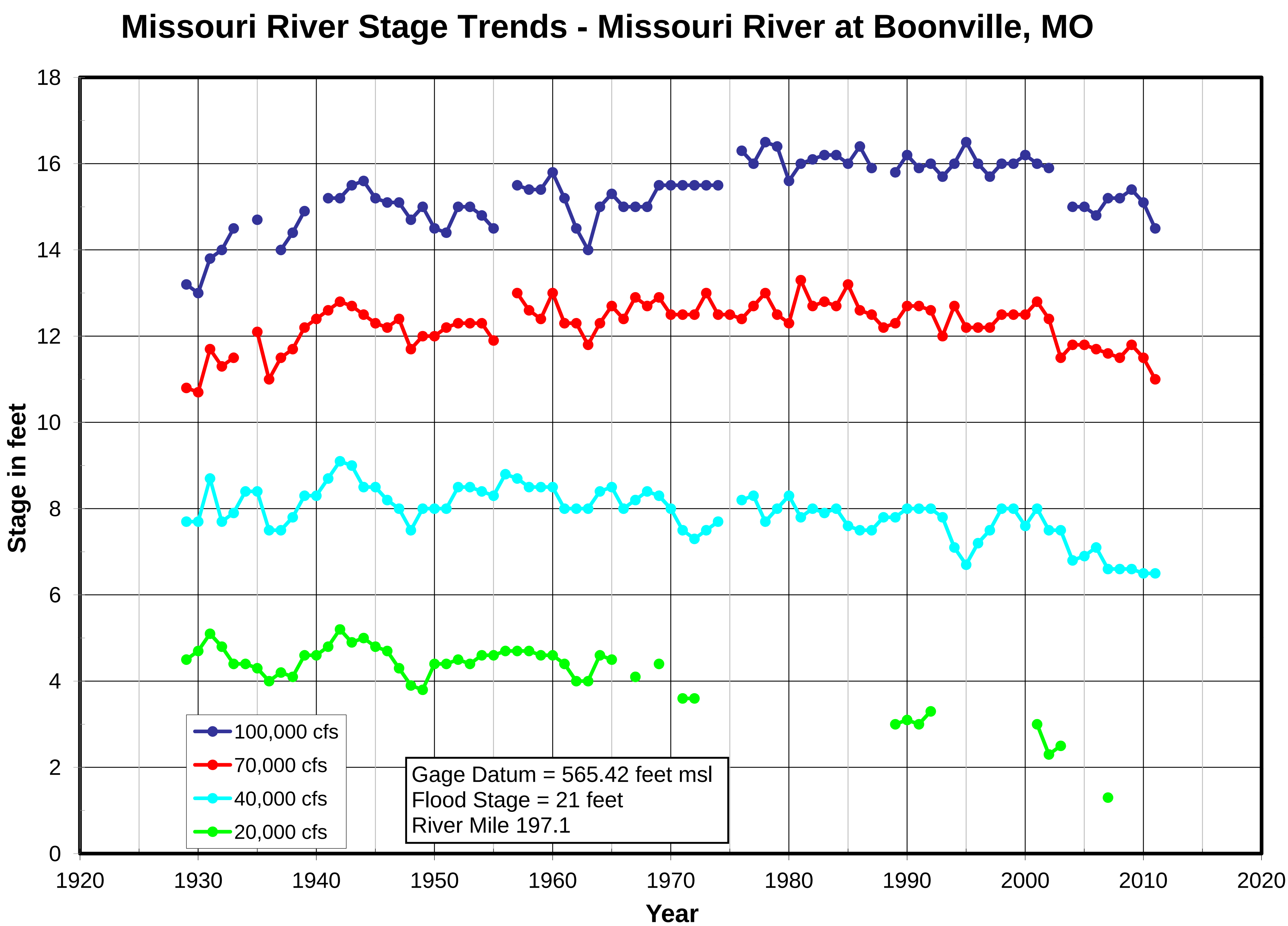
Figure 18



Missouri River Stage Trends - Missouri River at Waverly, MO
300,000 cfs
200,000 cfs
Gage Datum = 646.0 feet msl
Flood Stage = 20 feet
River Mile 293.4
1993
2007
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

Figure 19

Figure 20



Missouri River Stage Trends - Missouri River at Boonville, MO
Stage in feet
Year
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 565.42 feet msl
Flood Stage = 21 feet
River Mile 197.1
0
2
4
6
8
10
12
14
16
18
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

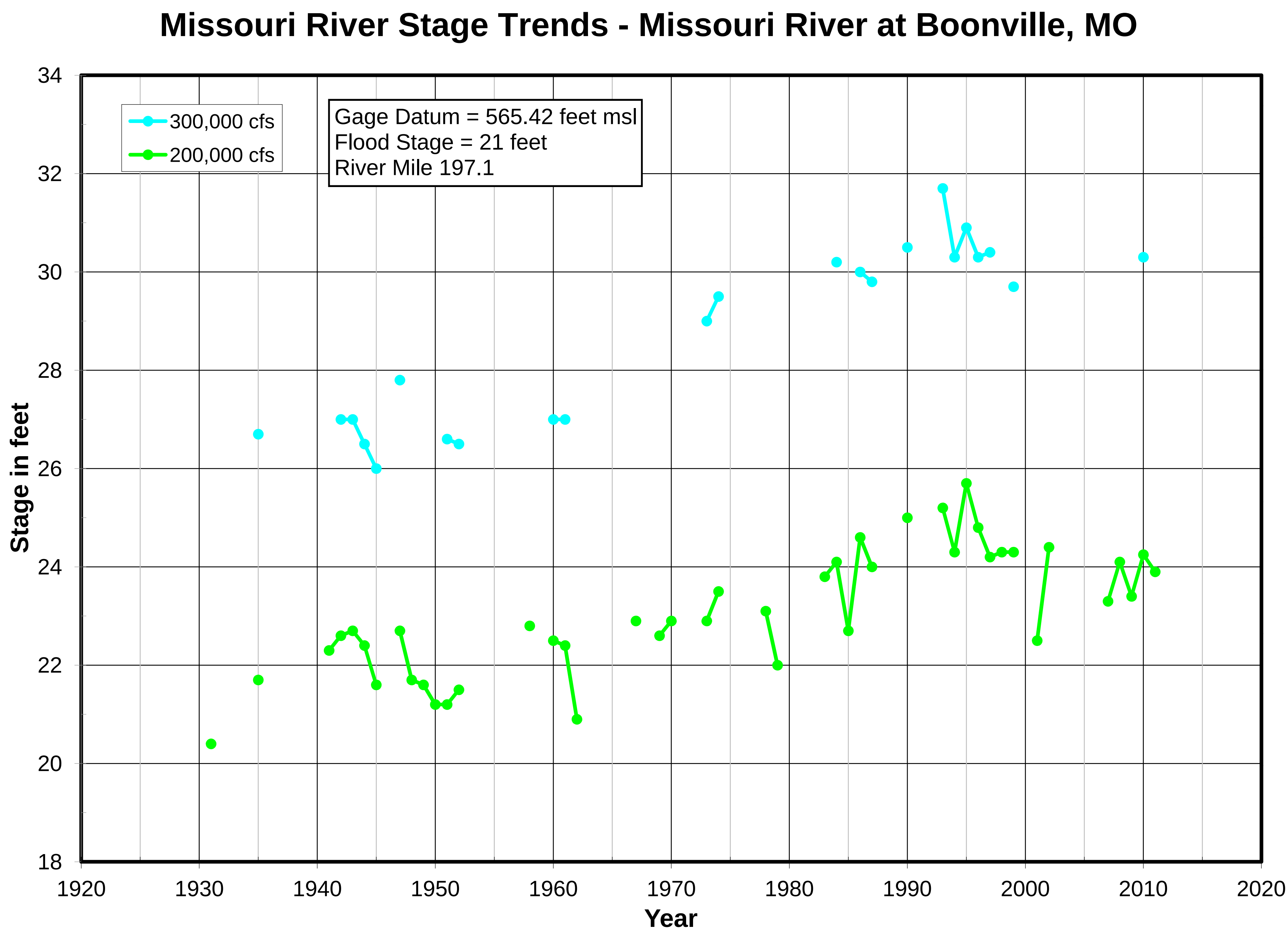
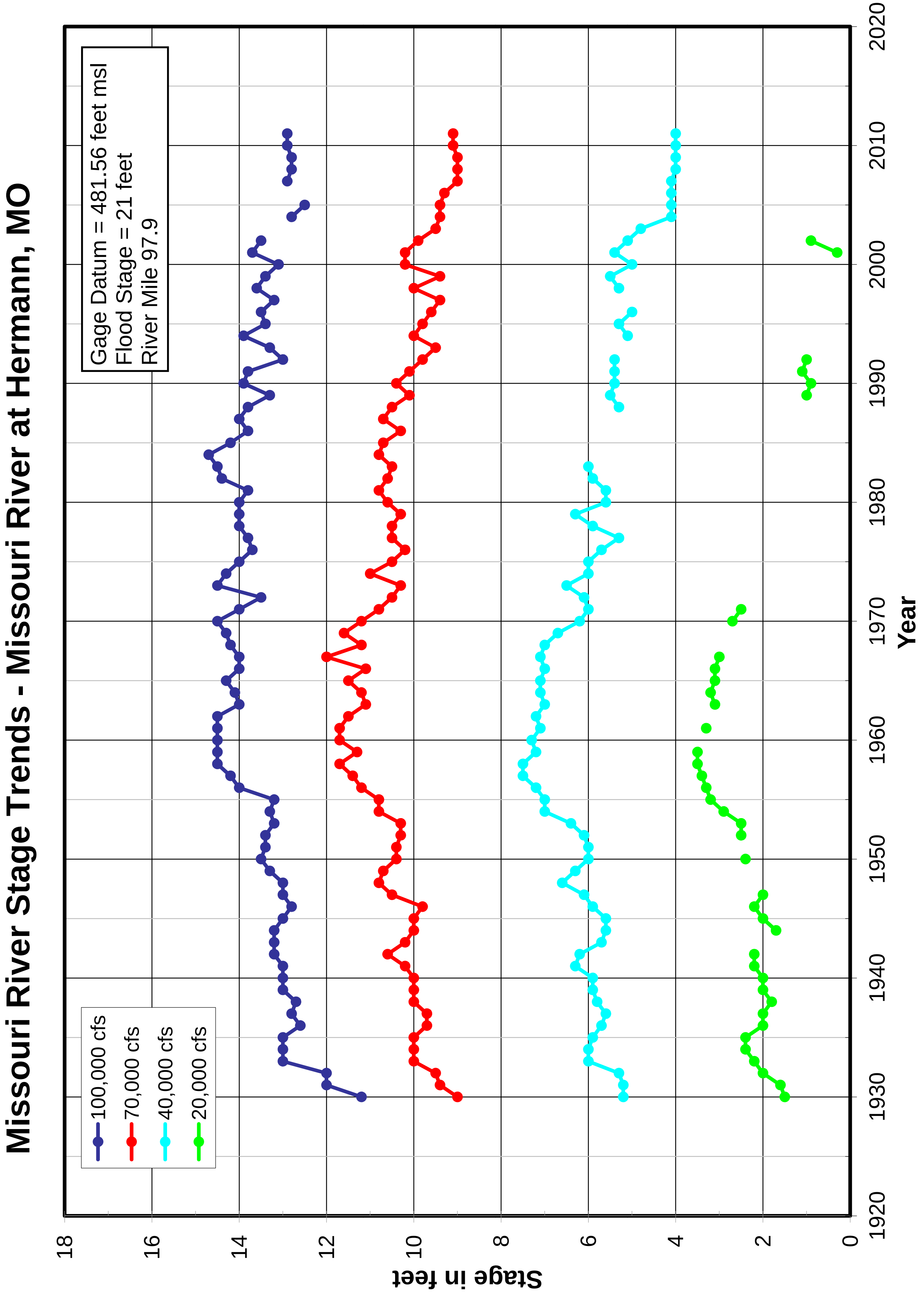
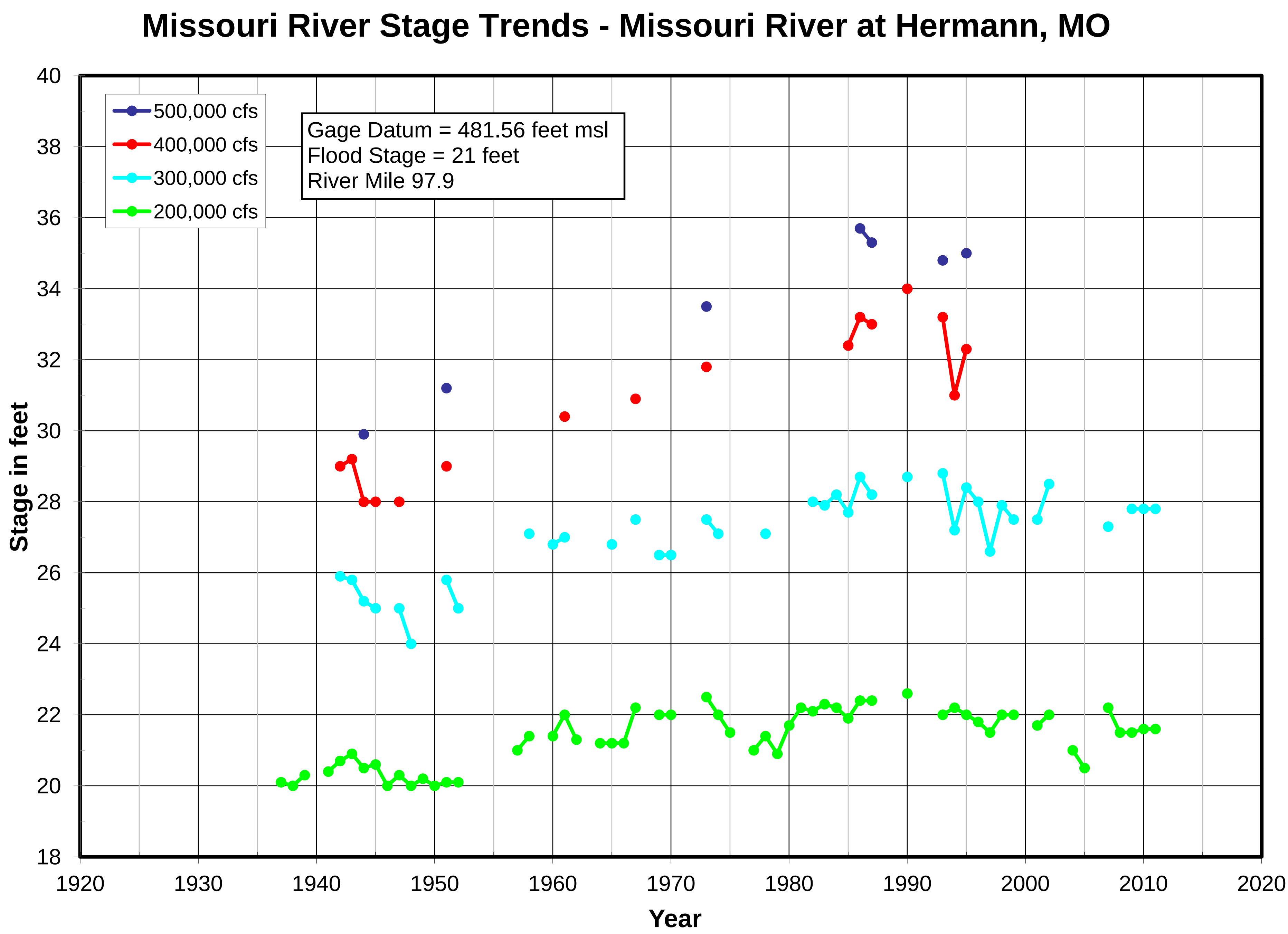

Missouri River Stage Trends - Missouri River at Boonville, MO
300,000 cfs
200,000 cfs
Gage Datum = 565.42 feet msl
Flood Stage = 21 feet
River Mile 197.1
Stage in feet
34
32
30
28
26
24
22
20
18
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Figure 21



Missouri River Stage Trends - Missouri River at Hermann, MO
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 481.56 feet msl
Flood Stage = 21 feet
River Mile 97.9
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

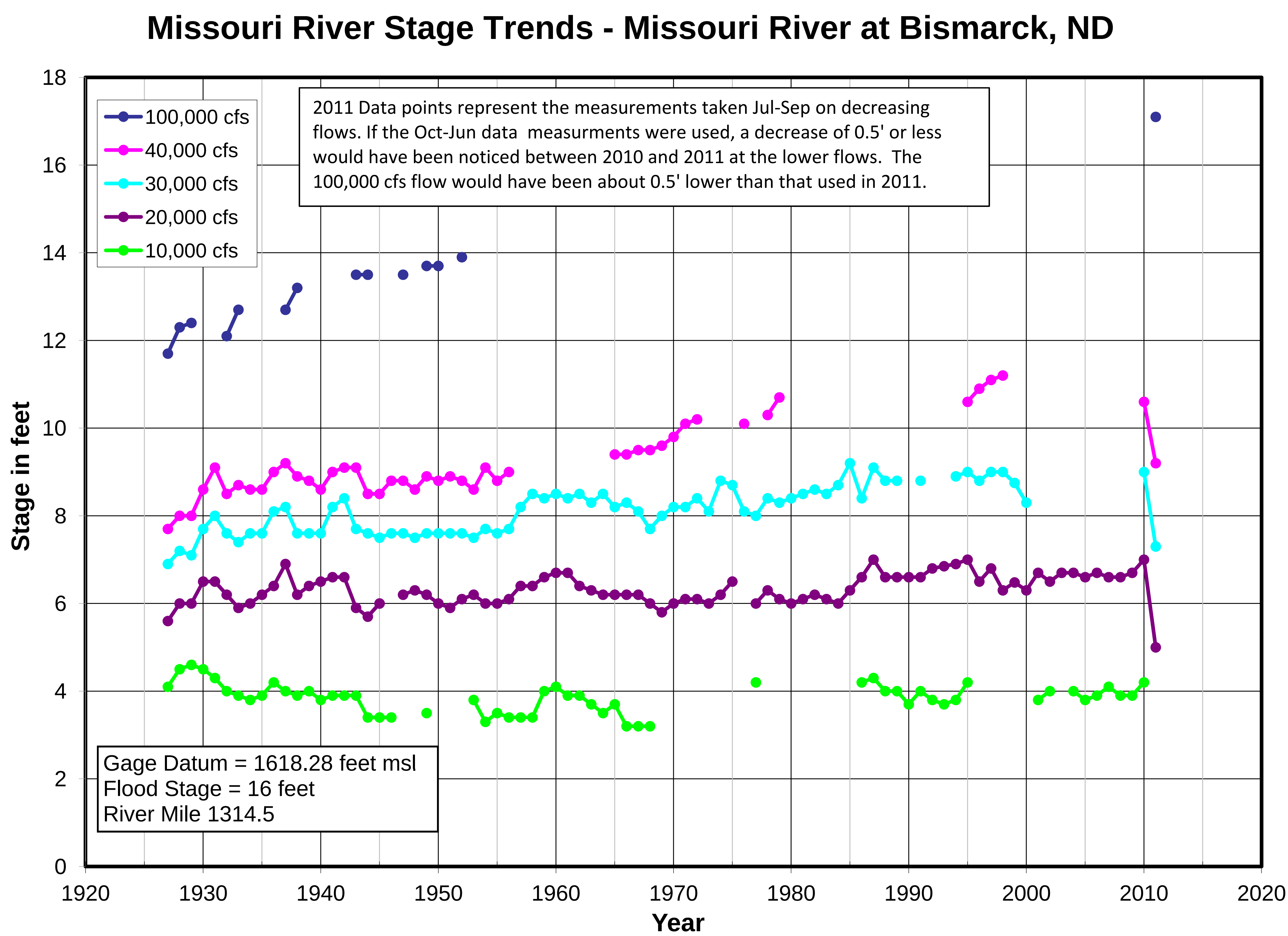
Figure 22



Missouri River Stage Trends - Missouri River at Hermann, MO
500,000 cfs
400,000 cfs
300,000 cfs
200,000 cfs
Gage Datum = 481.56 feet msl
Flood Stage = 21 feet
River Mile 97.9
Stage in feet
40
38
36
34
32
30
28
26
24
22
20
18
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Figure 23

Figure 24


Missouri River Stage Trends - Missouri River at Bismarck, ND
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 = 1618.28 feet msl
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