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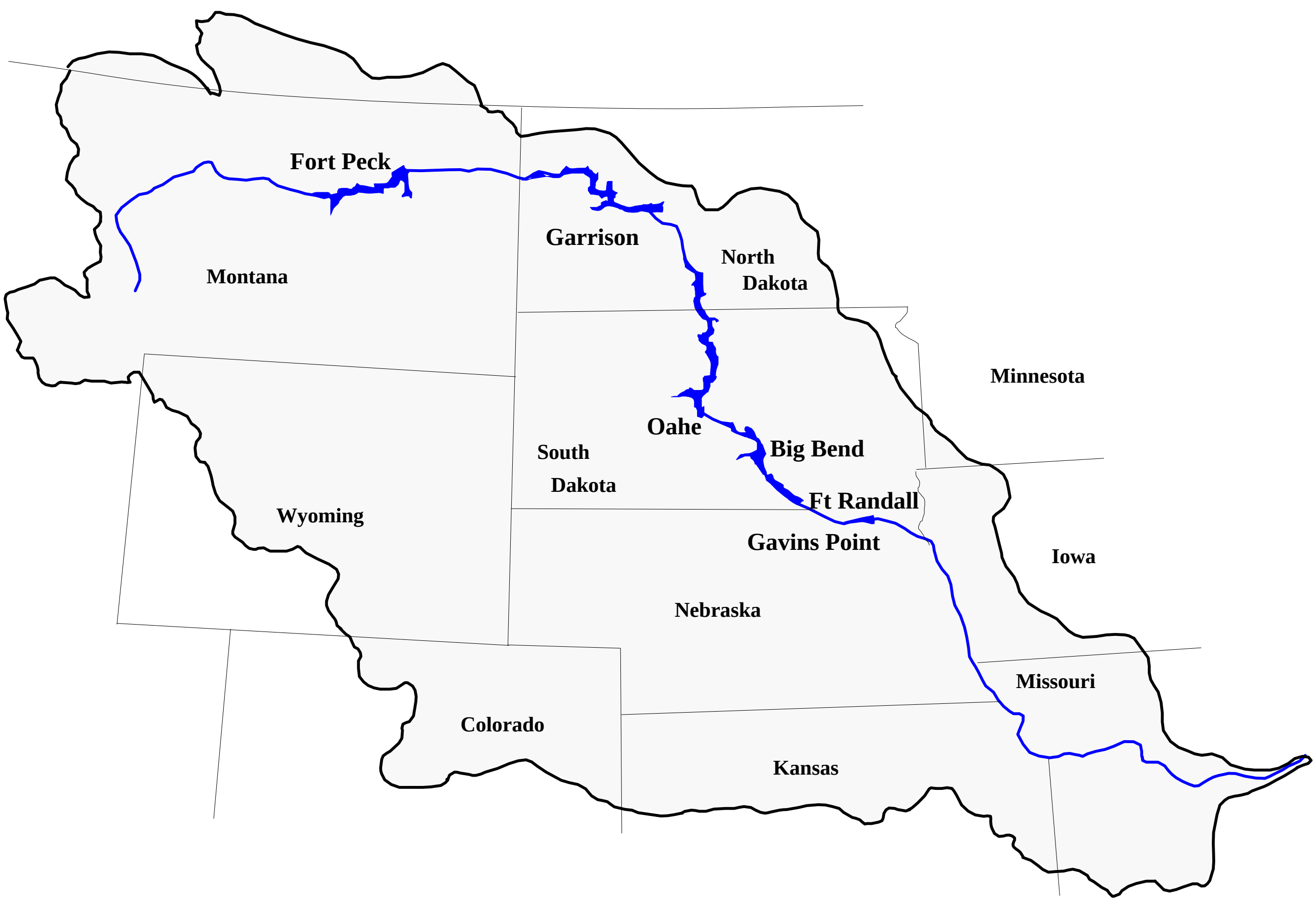

Missouri River Mainstem Reservoirs

Missouri River Stage Trends

RCC Technical Report A-10

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 bank full 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 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 main stem 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.

A similar report 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, two-thirds of this shortening has been concentrated in two reaches, including the reach between Sioux City to Omaha and between Kansas City to Waverly. This shortening has undoubtedly contributed to the lowering of stages, which are evident at these two stations. 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

Stations	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 22. 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. 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 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.

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, with the second power plant coming online in 1961. Because of the location of the two power plants, the stage discharge rating relationship is quite complex at this location. The tailwater stage at either power plant is a function of the discharges at both power plants. 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, releases have not been significantly in excess of the power plant capacity of the project, amounting to about 15,000 cfs after the second power plant was online. Previous studies have indicated that the tailwater rating curve has been stable since about the 1960's. Because of the complex relationship to define the tailwater rating curve at Fort Peck and the apparent stability in the relationship, no updates to the rating curve have been made since 1966. Therefore, the tailwater stage trend could not be evaluated at Fort Peck for this update.

GARRISON

In 1946, construction of the Garrison project was initiated. Dam closure was made in 1953, with power plant operation online in 1956. Since 1956, outflows from Garrison have generally been through the power facilities, having a maximum powerplant capacity of about 38,000 cfs. Exceptions occurred in 1975 when total outflows (powerplant plus spillway) of 65,000 cfs were required for over one month and in 1997 when releases averaged 57,300 cfs during the month of July. ***Figure 1*** shows tailwater rating curves developed at five-year intervals beginning in 1955 and extending through 2009. As illustrated by those curves, a lowering is shown 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 has significantly lessened from 2000 to 2005, which were years of low runoff volume. From 2005 to 2009 there was some aggradation in the 15,000 to 40,000 cfs range. As shown in ***Figure 2***, the increased rate is attributed to the magnitude and duration of project releases experienced during 1997. ***Figure 2*** also 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 about 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. From 1998 to 2009 the rate of tailwater degradation has decreased to almost zero in the 10,000 and 20,000 cfs ranges.

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. Tailwater rating curves developed at five-year intervals beginning in 1965 and extending through 2009 are compared on ***Figure 3***. As shown on those curves, there has generally been about one foot or less change in tailwater stages over the years. From 2000 to 2005, releases greater than 40,000 cfs have indicated increased degradation; however from 2005 to 2009 there was aggradation in the same release range. 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 power plant became fully operational in 1966 with Lake Sharpe pool levels being maintained near the normal operating level of elevation 1420 feet msl. From 1970, there appeared to be a trend towards lower tailwater stages except for upward stage shifts occurring from 1982 to 1984 and 1993 to 1995. From 2005 to 2009 very little degradation has occurred in the entire discharge range of 5,000 to 50,000 cfs. Time trend plots for discharges ranging from 10,000 to 50,000 cfs are shown on ***Figure 4***. The trend plots indicate a slight degradation trend in the 40,000 and 50,000 cfs ranges over the past five years. The degradation rate has decreased to almost zero over the last five years for the lower discharge rates of 10,000, 20,000, and 30,000 cfs.

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. As shown on ***Figure 6***, a lowering of the tailwater stage of about five feet has occurred over a 40-year time span. It should be noted that the 1994 through 1997 trend lines shown on that figure 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 to 1980 time period, which corresponds to a significant decrease in the stage trend curve shown on ***Figure 6***. On that figure, stage trends are shown for discharges ranging from 10,000 to 40,000 cfs. 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 a foot in the 30,000 to 45,000 cfs range and about a half foot in the 5,000 to 25,000 cfs range. During the period from 2005 to 2009 the degradation rate has lessened. ***Figure 5*** indicates that there was slight degradation in the range from 35,000 cfs from 45,000 cfs from 2005 to 2009. ***Figure 6*** indicates the same for the 30,000 and 40,000 cfs curves.

GAVINS POINT

As shown on ***Figure 7*** and ***Figure 8***, the Gavins Point tailwater has lowered about 11 feet since closure of that project in 1955. The rate of degradation has been reasonably constant, except for the increased rates observed for the first two years after closure and during high flow in the mid-80's. Stages remained relatively constant during the low release years of the 1987 to early 1993 drought. The high flow years from 1995 through 1997 have resulted in an increase in the rate of tailwater lowering experienced below Gavins Point Dam. During the period from 2000 to 2006, the total degradation has been about 0.2 feet in the 20,000 to 40,000 cfs range. In the 1949 Gavins Point Definite Project Report, ultimate degradation of about 15 feet was projected and allowed for in the design of the project structures. The rate of expected degradation was not specified. ***Figure 7*** shows the Gavins Point tailwater rating curves, while ***Figure 8*** shows the Gavins Point tailwater trends for the 10,000, 20,000, and 35,000 cfs discharge levels. ***Figure 7*** suggests that from 2005 to 2009 degradation did occur in the 5,000 to 25,000 cfs range. ***Figure 8*** shows no degradation in the lower discharge range of 10,000 cfs from 2000 to 2006, but lower tailwater stage trends during 2007 to 2009.

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, it appeared 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 flow years of 1995 through 1997. From 1997 to 2009 there has been only a small decrease in tailwater stage at Garrison. From 2001 to 2009 there is more variability with the Fort Randall tailwater stage. Comparatively, the rate of decrease of the Gavins Point tailwater is fairly constant from 1997 to 2009. The total decrease in tailwater stage at these projects is 11 feet at Gavins Point, 10 feet at Garrison, and eight feet at Fort Randall.

NAVIGATION CHANNEL STAGE TRENDS

Downstream from Gavins Point Dam, the Missouri River remains in a semi-natural state for a distance of about 59 miles in which it is somewhat free to meander throughout a wide flood plain. 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 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***, the predominant stage trend at Sioux City has been downward until 1997. At normal full-service discharge levels, this downward shift of almost 11 feet since 1955 is essentially the same magnitude as what has occurred in the Gavins Point tailwaters during the same period. A combination of factors is responsible for this marked reduction in stages at normal to lower flows. In the early 1980’s, it appeared that stage reductions had slowed significantly, almost to the point of stabilizing at normal flows, from those experienced in the 1960's and early 1970's.

Stage reductions at Sioux City have caused numerous problems at marinas and dock facilities. These problems were magnified during the six-year drought of the mid 1980's through early 1990's 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 lake 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 drought, 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. During the drought years 1987 to early 1993 when there were less than normal flows from Gavins Point Dam, the stage trends at Sioux City rose about a foot. High flows of up to 72,000 cfs during the summer of 1993 reversed the trend. The succession of high flow years 1995, 1996 and record breaking 1997 resulted in a sharp reduction in Sioux City stages. Since 1999, the stage trends indicate some aggradation during the drought years of 2000 to 2007 and the last two non-drought years of 2008 and 2009, especially in the lower flow ranges.

OMAHA

Missouri River stages at Omaha have reversed in recent years. As shown on ***Figure 11***, the overall stage trend between the mid-1930's and the early 1950's was downward, totaling about five feet. However, since the 1960’s, no significant changes have been noted, particularly at normal discharges. The lowest stages for normal discharges occurred following the 1952 Flood. Since that time, stages have actually risen one or two feet. At below normal discharges of 10,000 to 20,000 cfs stages rose several feet between 1952 and the mid-1960's. Since then, the stages have dropped, once more returning to the levels reached in the early 1950's or lower. At 10,000 cfs stages are about four to five feet lower than those experienced during the early 1950's.

At 60,000 cfs, high stages were experienced in the late 1930's, followed by a gradual fall totaling about five feet by the mid-1950's. Between the mid-1950's and mid-1960's the stages recovered approximately four feet and have risen only slightly since then. At 100,000 cfs, higher stages were also experienced in the late 1930's, followed by a gradual fall of about four feet by the mid-1950's. Stages had risen to their former high level by the mid-1970's and rose another two feet by 1993 before falling back with the high flows of the late 1990's. In the 20,000 to 60,000 cfs range the stage trends have remained relatively stable.

NEBRASKA CITY

Stage trends at the Nebraska City gage are shown on ***Figure 12***. The corresponding stages for flows between 70,000 and 100,000 cfs demonstrated a consistent rise since 1950. However, over the last 10 years the stages have shown a slight downward trend for these flows. The stages for flows of 20,000, 30,000, and 40,000 cfs have remained fairly steady over the last 20 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. Based on 1994 data, the flood of 1993 reduced stages roughly one foot at Nebraska City for 70,000 and 100,000 cfs. These flood induced stage decreases appear to have returned to pre-1993 trends.

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. 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 13***, from 1925 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 discharges of 20,000 cfs. The stage trends for 40,000 cfs and 70,000 cfs have been generally stable over the last 10 years. At 70,000 cfs, the overall rise in the Missouri River stage has been about two to three feet since the 1940's. At 100,000 cfs, the overall rise in the Missouri River stage has been about four feet. The stage for a 100,000 cfs discharge has increased steadily since the early 1940's, but has been generally stable since the System closed in 1967. 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. However, measurements from 2007 to 2009 indicate fairly steady stage trends for the 70,000 and 100,000 cfs flows. Similar to the Missouri River reach near Nebraska City, it appears that the sediment load provided by the tributary streams is not removed by scouring flow as it was during pre-reservoir conditions.

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 14***. 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 and 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 and 40,000 cfs, and four to six feet lower at 70,000 and 100,000 cfs. Kansas City stages for 40,000 and 70,000 cfs recovered one to two feet during the drought years of 1987 to early 1993, but then declined dramatically following the Flood of 1993 with little recovery since. Stage estimates for 2006 indicate a two to four foot drop in stages from the 1993 pre-flood conditions in the 20,000 to 70,000 cfs range. Stage estimates for 2008 and 2009 have remained steady for that range. Stages at 100,000 cfs have been relatively stable since the late 1950's, with the exception of 2006-2008. Stage observations in 1995 indicated a recovery to the pre-1993 trend following the dramatic shift after the Flood of 1993.

Since 1950, prior to the last drought, at a discharge of 200,000 cfs, as shown on ***Figure 15***, stages rose about two feet. However, measurements in 2007 and 2008 indicate that the stages have reduced by four feet since the last measurements in 1999. Sufficient data are not available to establish reliable trends at flows of 300,000 cfs or higher, although 1993 data indicates there has been a rather significant stage increase, on the order of four to five feet. Only one measurement was made (in 2008) in the 300,000 cfs range. Based on that measurement, the stage has decreased almost five feet. However, caution should be taken regarding using the results from a single measurement as a true indicator of channel conditions.

WAVERLY

Missouri River stage trends at Waverly are generally three to five feet higher at the 300,000 cfs 200,000, 100,000, and 70,000 cfs discharge levels than those experienced during the 1930's. The river stages for Missouri River discharges of 20,000 and 40,000 cfs have been nearly constant from 1970 to 2009 with indications of slight variability since then. 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 16***. ***Figure 17*** 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 18 and ***Figure 19*** show the historical stage trends at Boonville. At Boonville, Missouri River stages have remained relatively constant for flows between 40,000 and 100,000 cfs. 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. 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 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.

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. However, for about 10 years following the late 1950's, the stage trend flattened and in recent years (1970 to present) has reversed with a downward trend for discharges of 100,000 cfs and lower. As seen on ***Figure 20*** this downward trend has lessened during the last five years for discharges 100,000 cfs and lower. 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 downward trend. As shown on ***Figure 21***, the data available for 200,000 and 300,000 cfs since 1980 indicate some variability, but no overall change.

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, which lies 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 since 2001 and historic low reservoir levels since 2004 have 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.

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 22***, there have been no marked changes in stage at this station at the 10,000 and 20,000 cfs levels. 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.

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.

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. This increase has occurred at an average rate of about 0.2 feet per year. 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 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 have not changed more than one foot between 1960 and 1990.

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SUMMARY

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 during the current drought (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 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. At Sioux City, sufficient high flow data are not available to reliably establish a trend at flows above 50,000 cfs. 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.

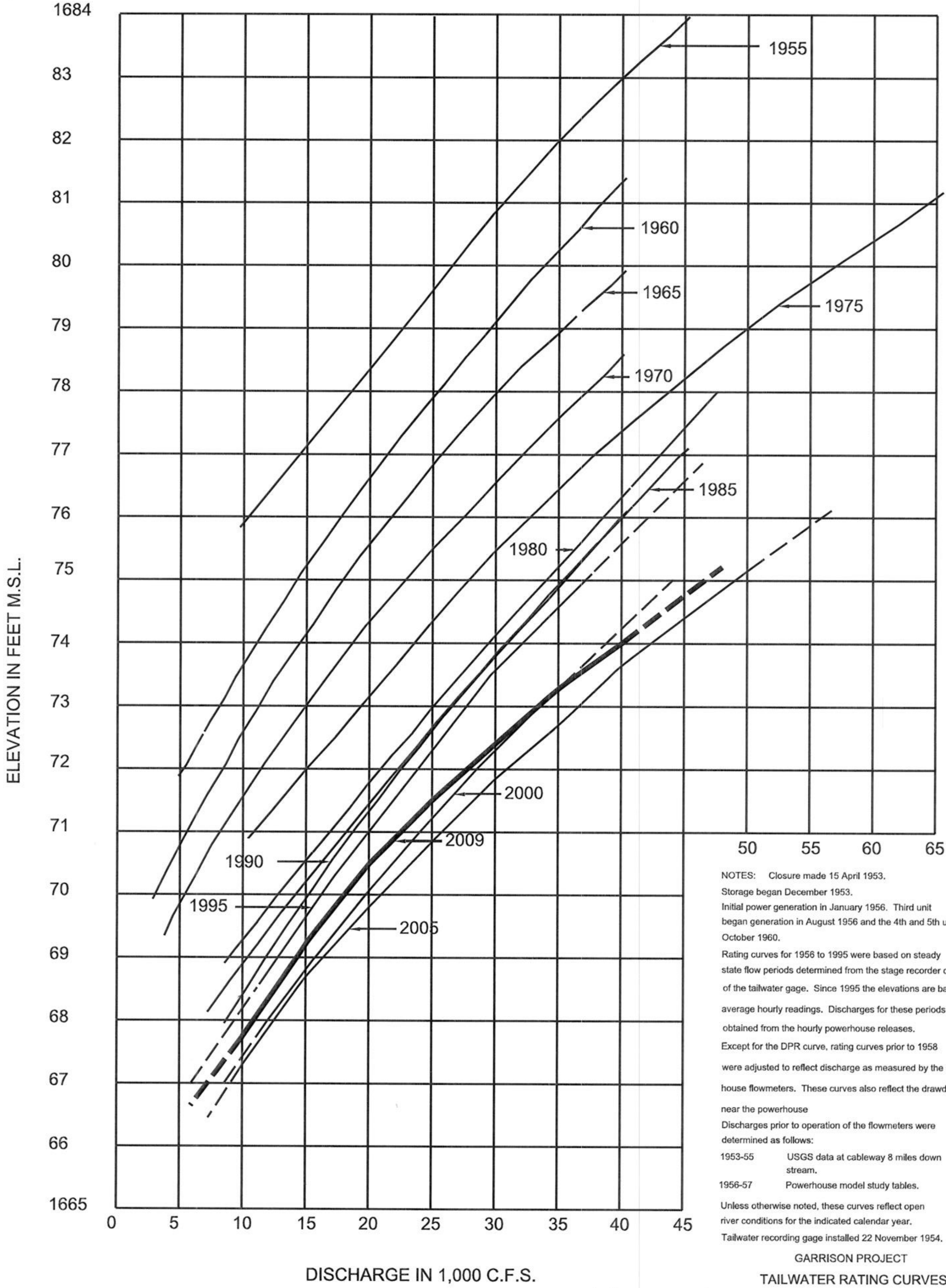
The increases in stages at stations below Kansas City, for flow levels near bank full are limited to about two to six feet. Increases of this magnitude agree quite well with the values presented in referenced consultants' report of November 1955 relating to the effect of navigation structures on river 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 11 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 1995 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 is occurring below Oahe, where the tailwater stages have increased, or aggraded, in the lower range (e.g. less than 15,000 cfs).

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/.



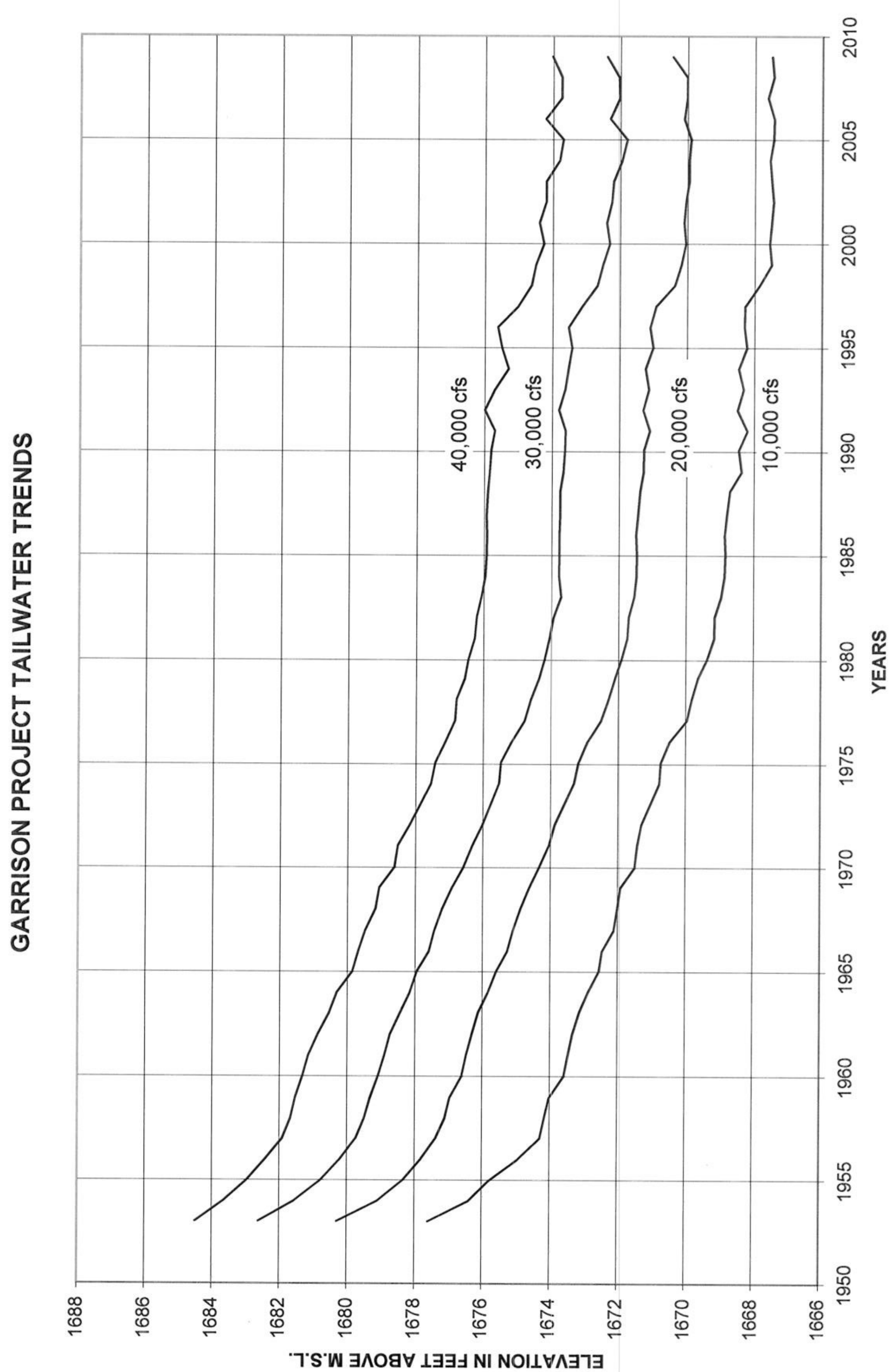
NOTES: Closure made 15 April 1953.
Storage began December 1953.
Initial power generation in January 1956. Third unit began generation in August 1956 and the 4th and 5th units in October 1960.
Rating curves for 1956 to 1995 were based on steady state flow periods determined from the stage recorder charts 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 powerhouse 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.

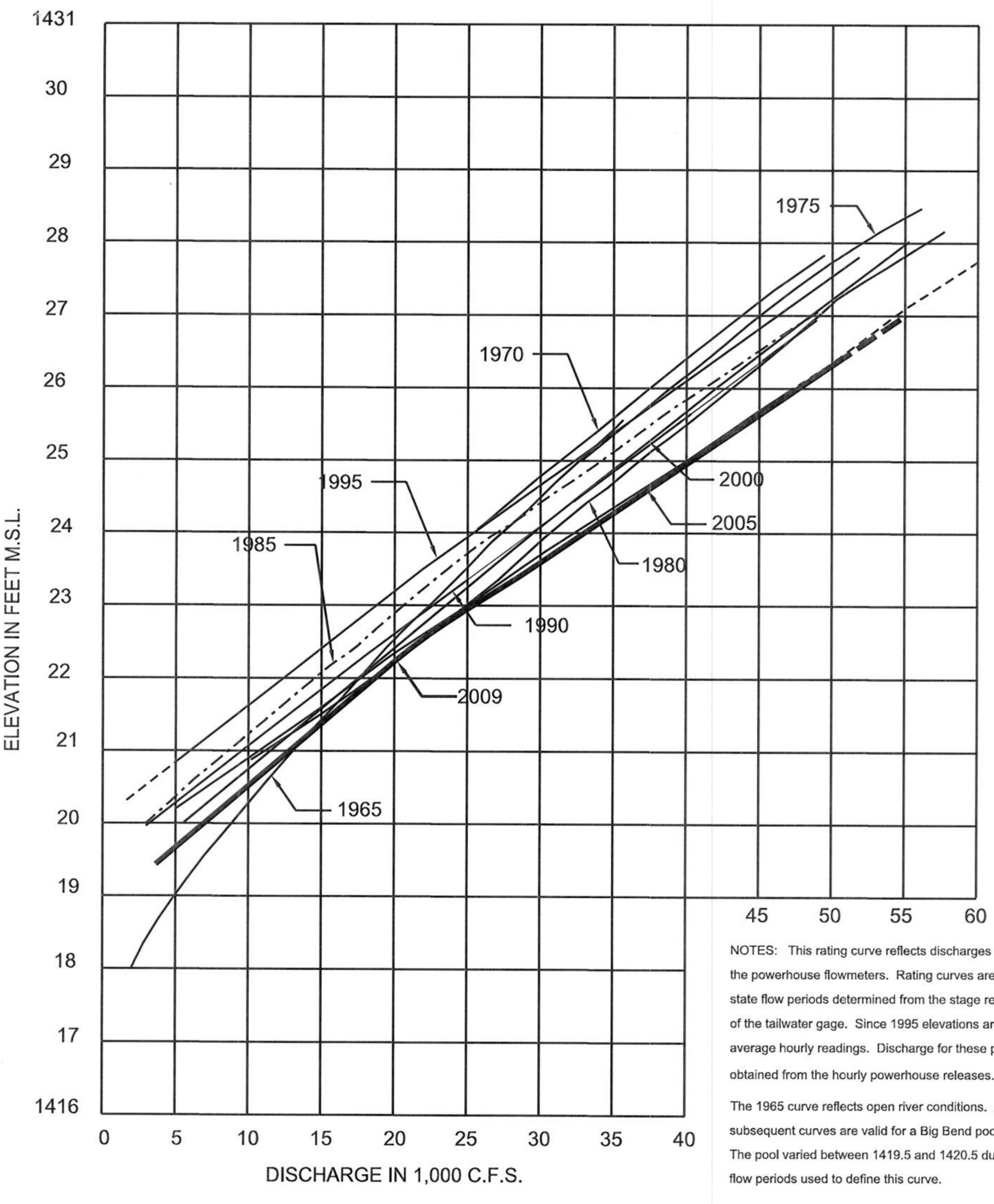
GARRISON PROJECT
TAILWATER RATING CURVES
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
FEBRUARY 2010

Figure 1



February 2010

Figure 2



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

POWERHOUSE

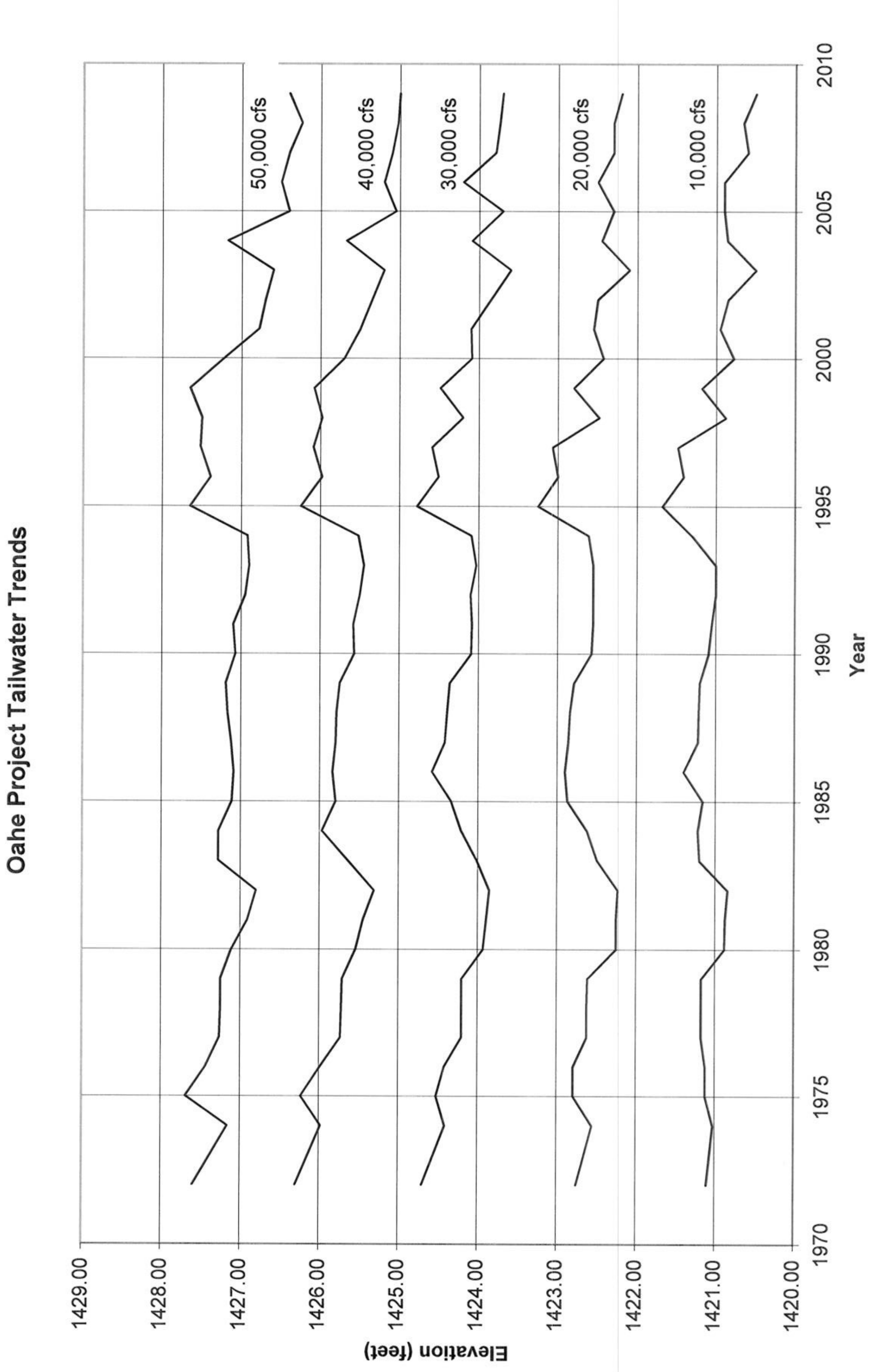
TAILWATER RATING CURVES

U.S. ARMY ENGINEER DISTRICT, OMAHA

CORPS OF ENGINEERS OMAHA, NEBRASKA

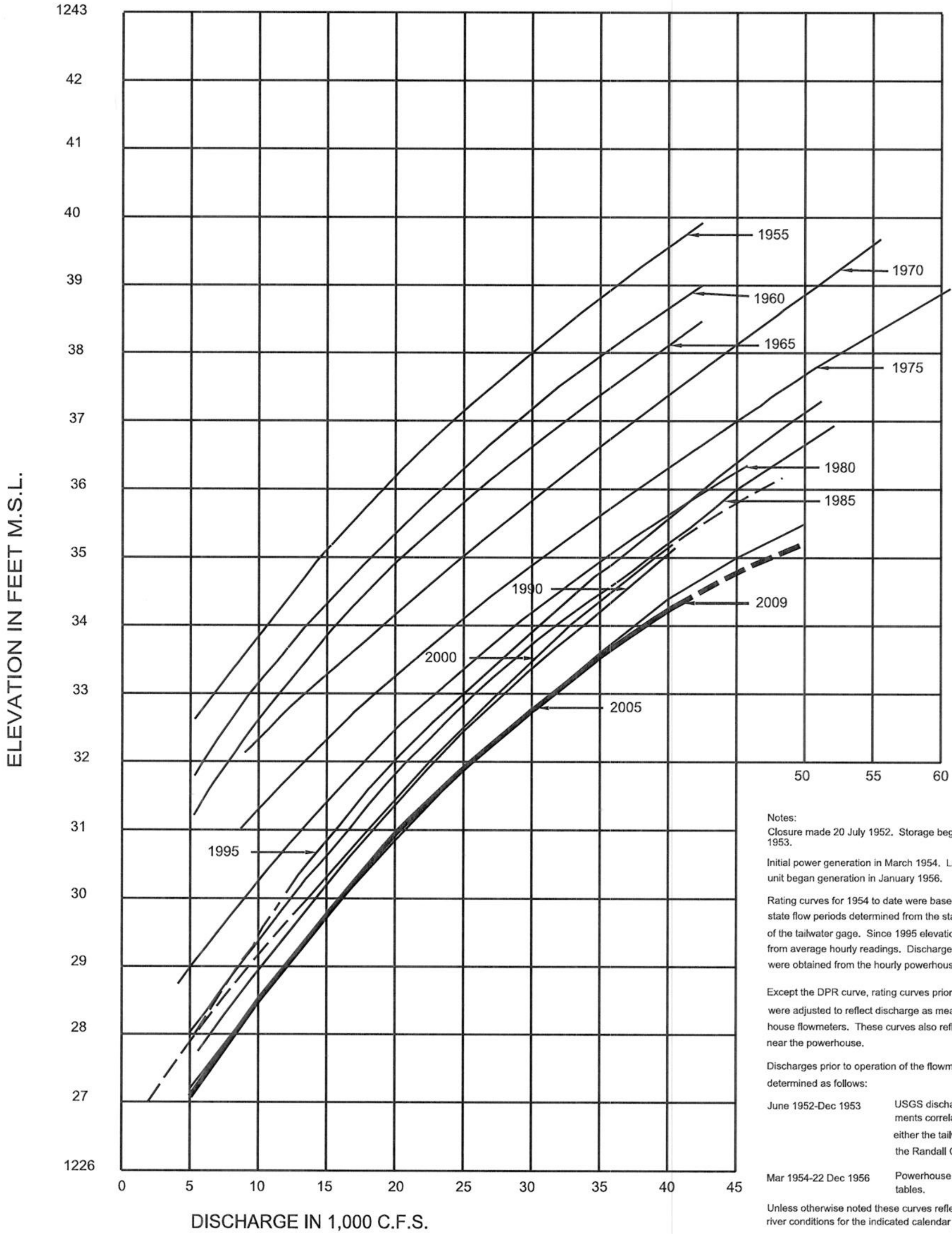
FEBRUARY 2010

Figure 3



February 2010

Figure 4



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

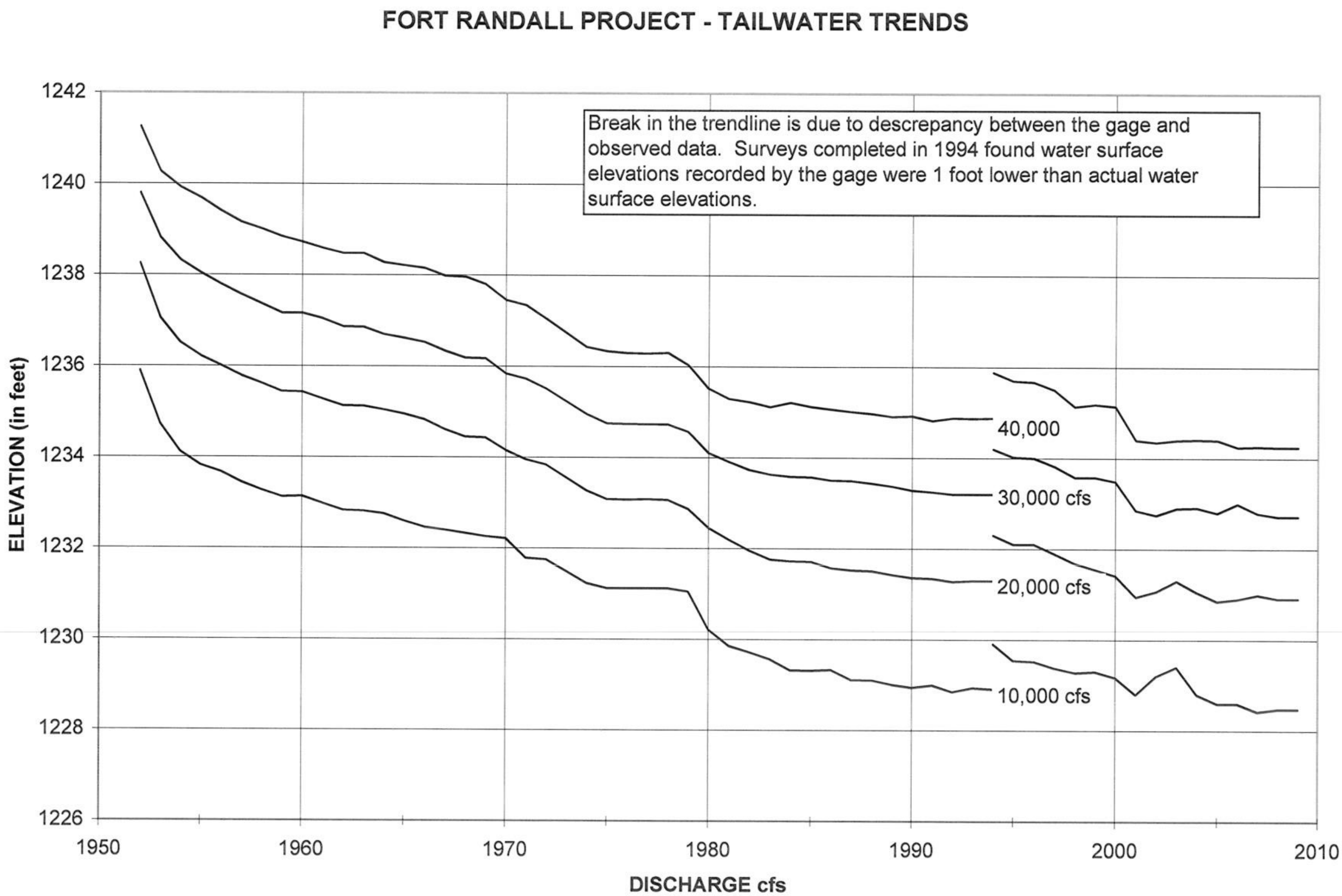
TAILWATER RATING CURVES

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

FEBRUARY 2010

Figure 5

Figure 6



February 2010

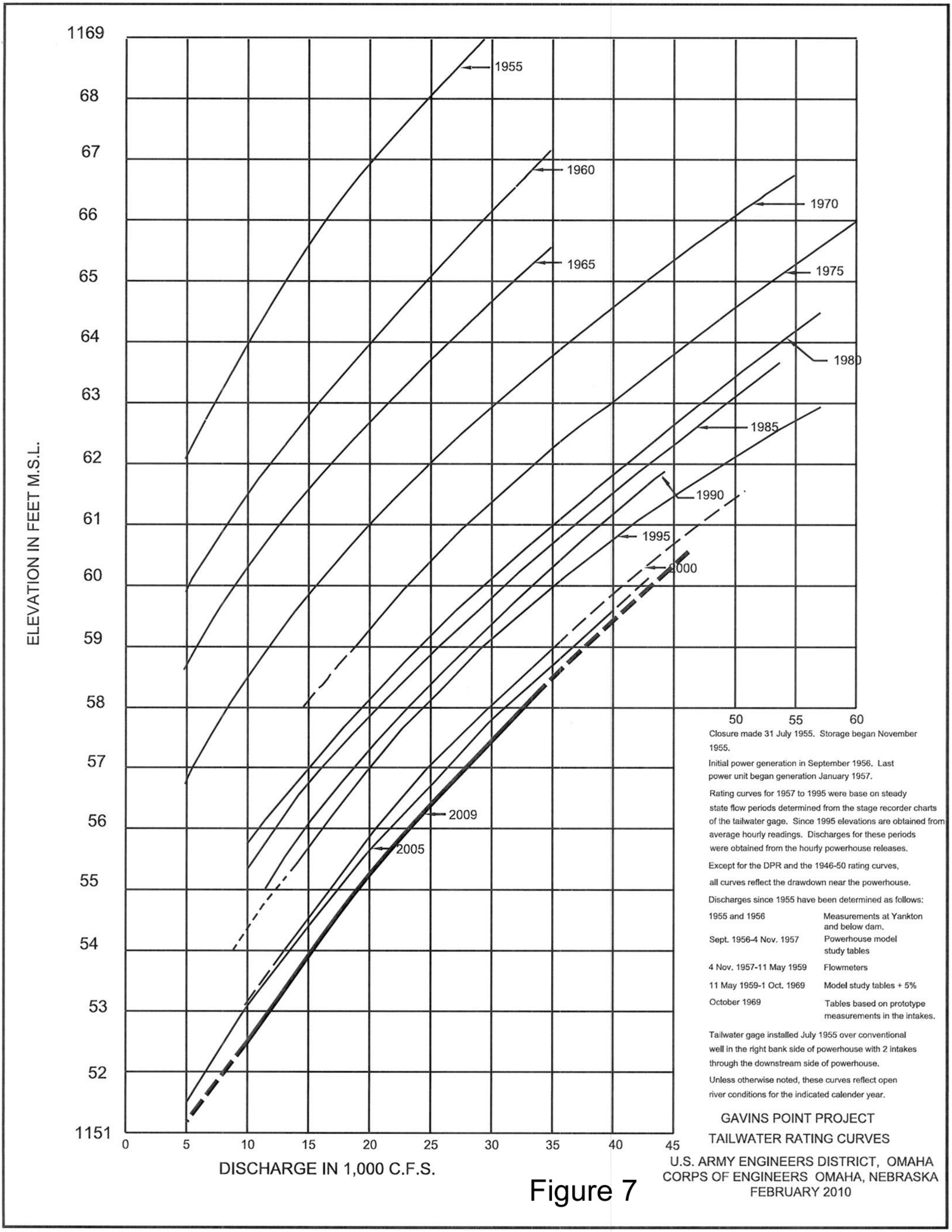
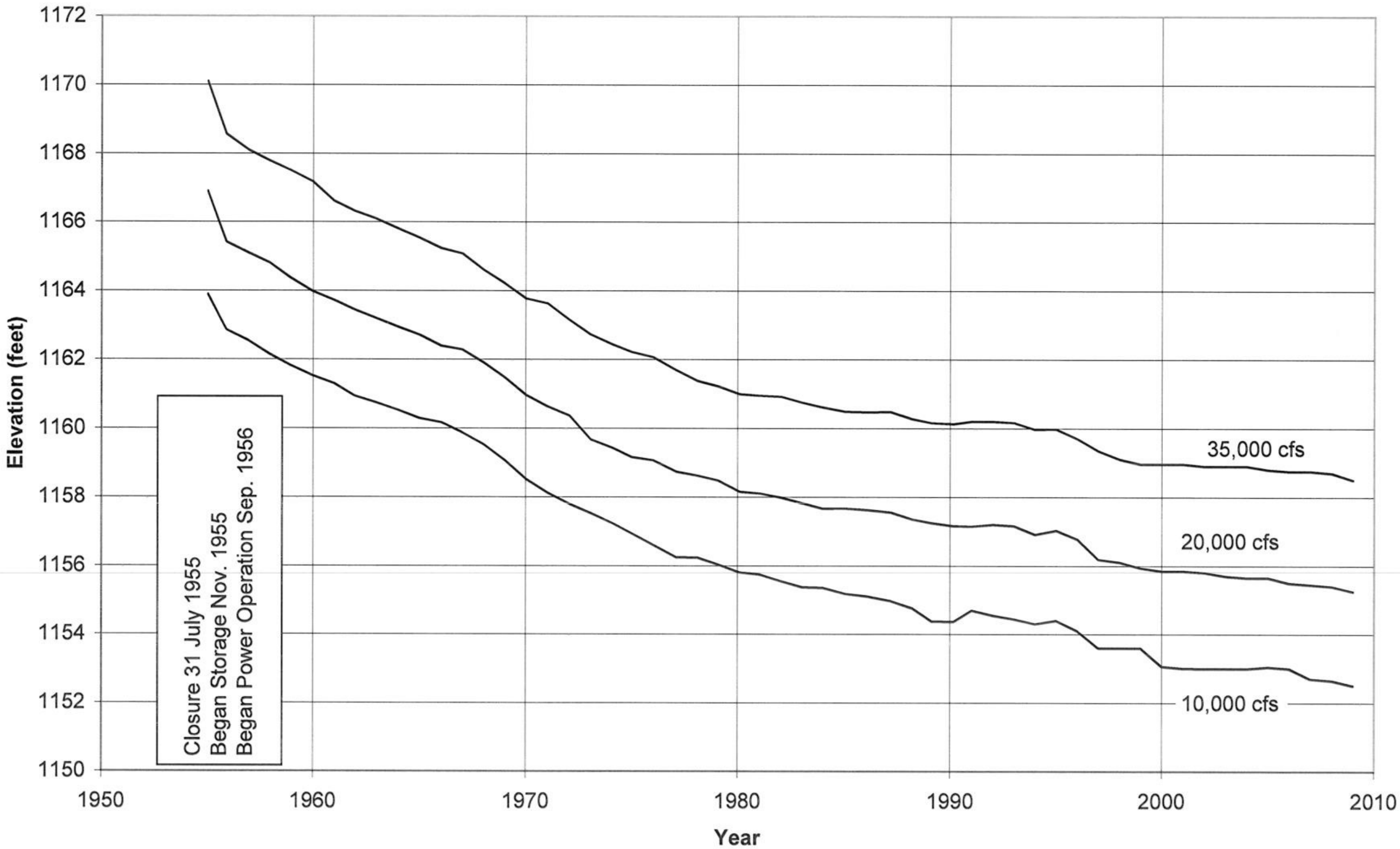

ELEVATION IN FEET M.S.L.
1169
68
67
66
65
64
63
62
61
60
59
58
57
56
55
54
53
52
1151
DISCHARGE IN 1,000 C.F.S.
0
5
10
15
20
25
30
35
40
45
50
55
60
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2009
Closure made 31 July 1955. Storage began November 1955.
Initial power generation in September 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 2010

Figure 7

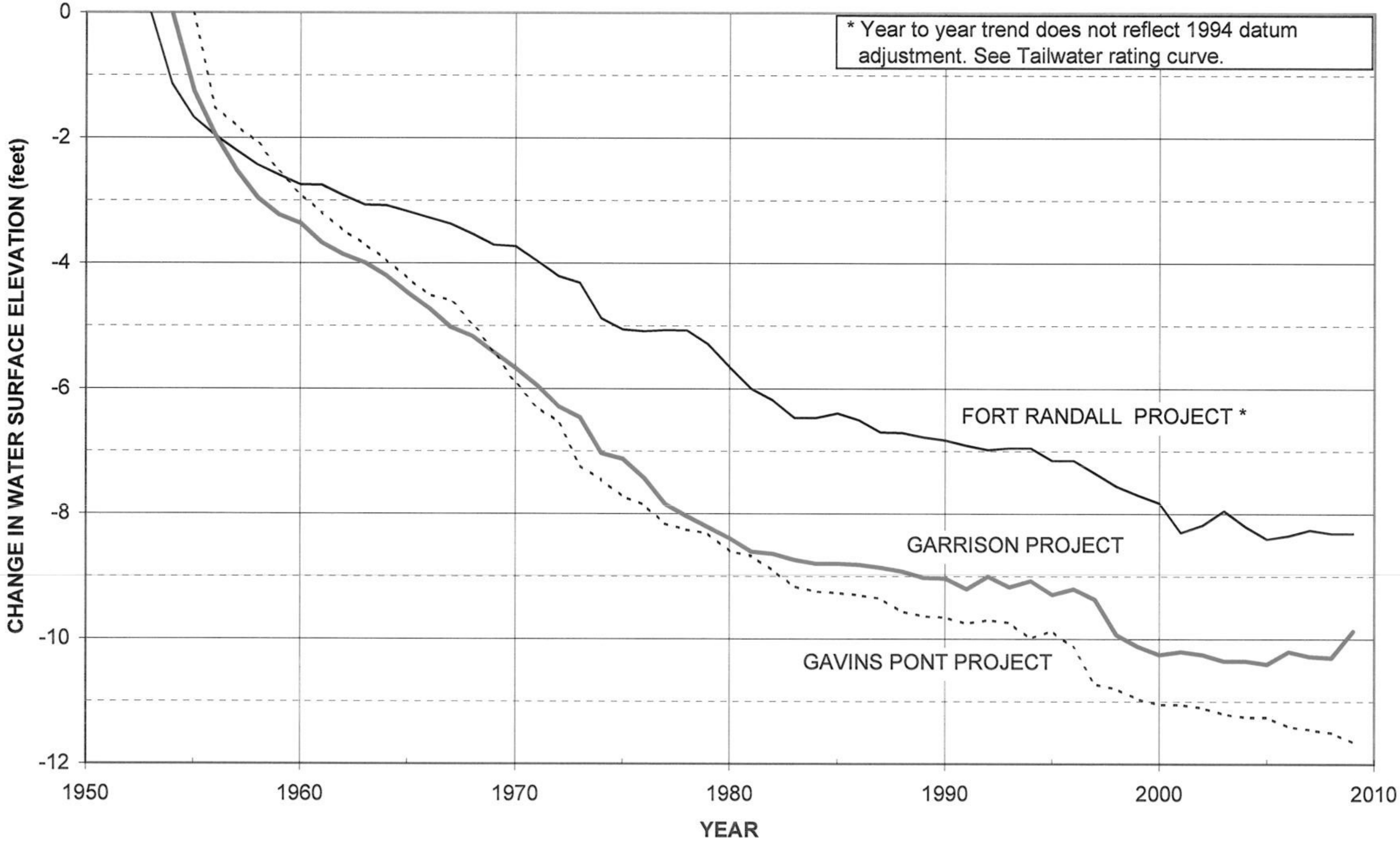
Figure 8

GAVINS POINT PROJECT - TAILWATER TRENDS



February 2010

COMPARISON OF TAILWATER TRENDS FOR DISCHARGES OF 20,000 CFS



February 2009

Figure 9

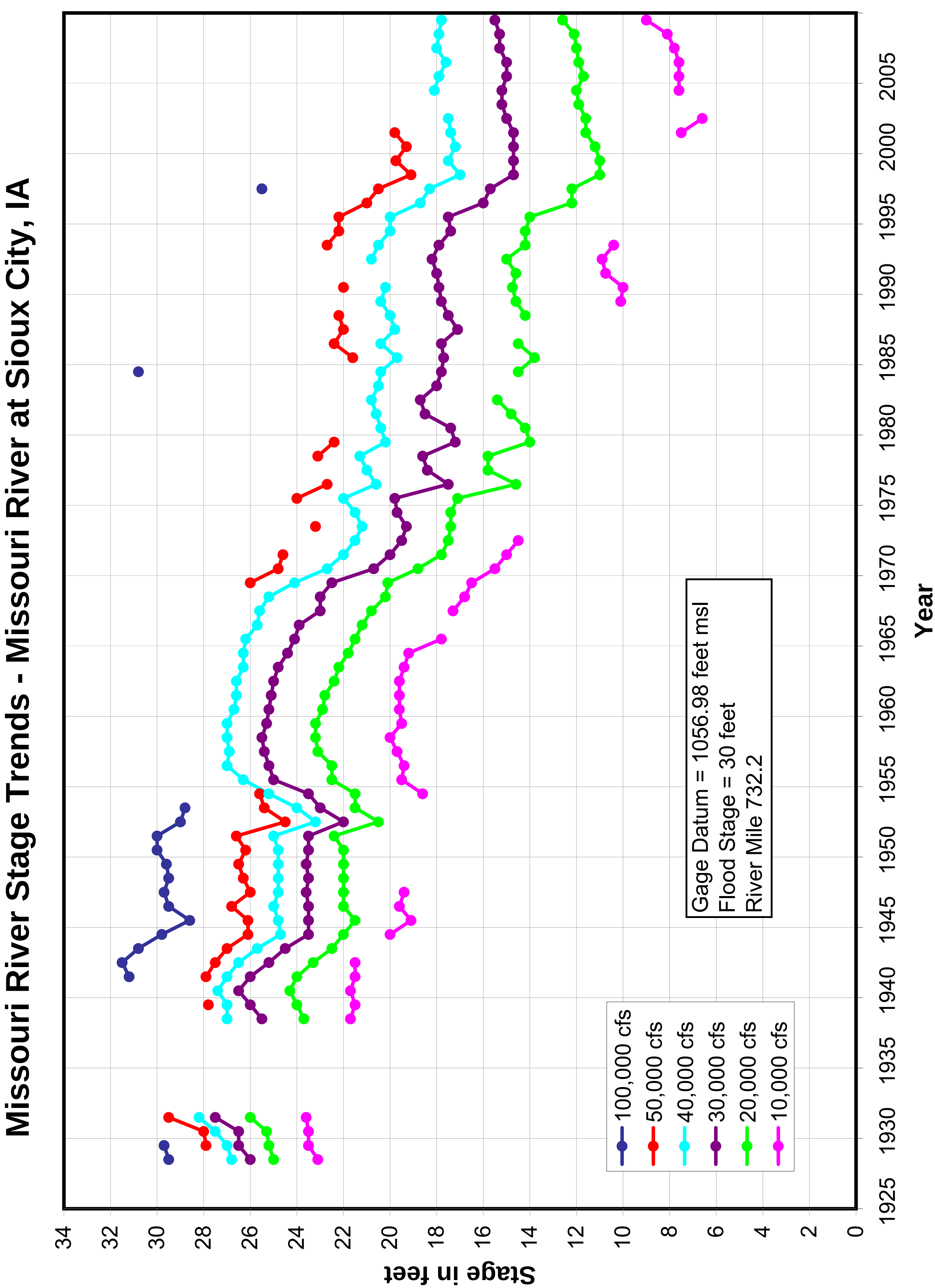

Missouri River Stage Trends - Missouri River at Sioux City, IA
Stage in feet
Year
100,000 cfs
50,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
Gage Datum = 1056.98 feet msl
Flood Stage = 30 feet
River Mile 732.2

Figure 10

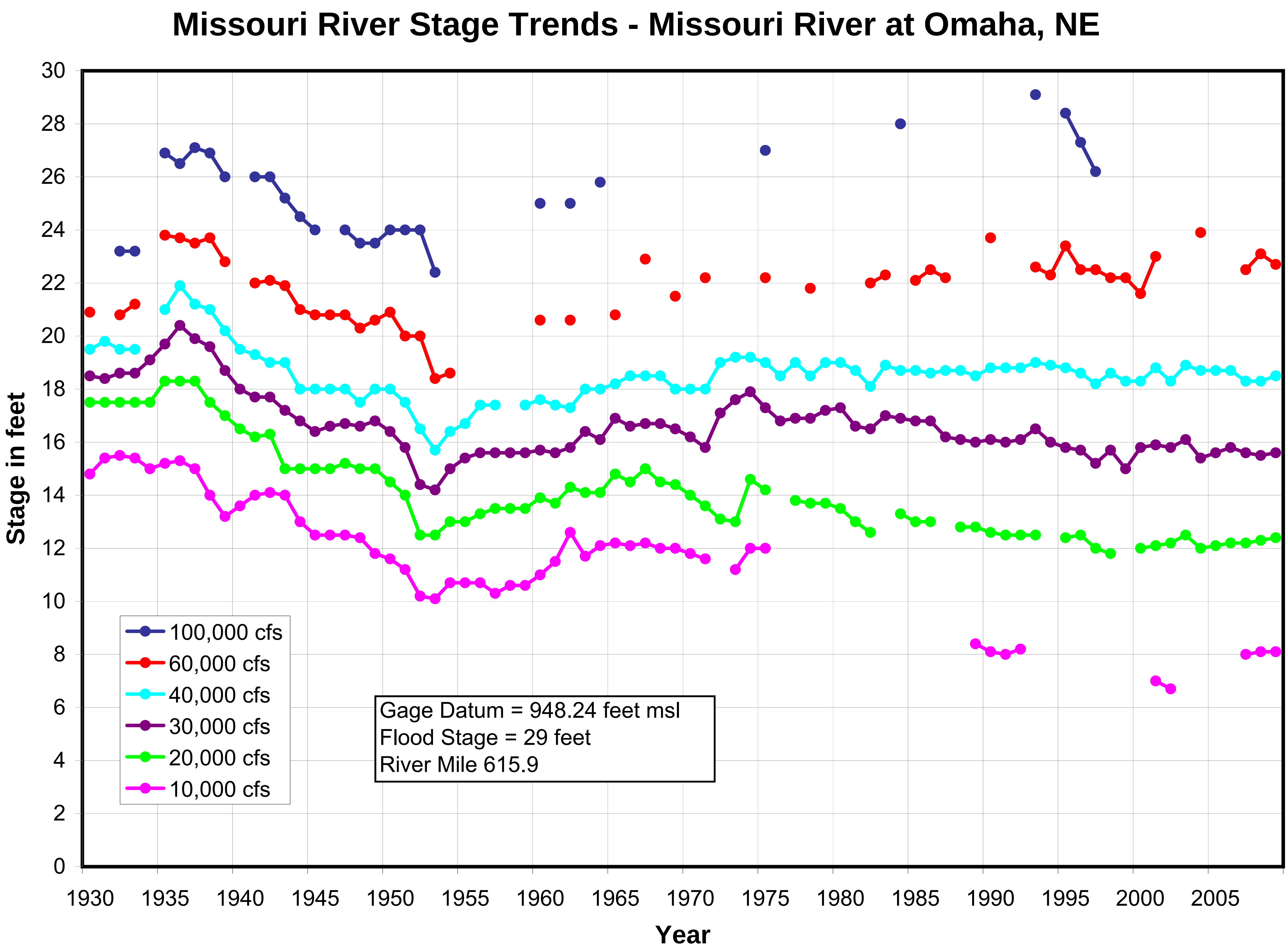
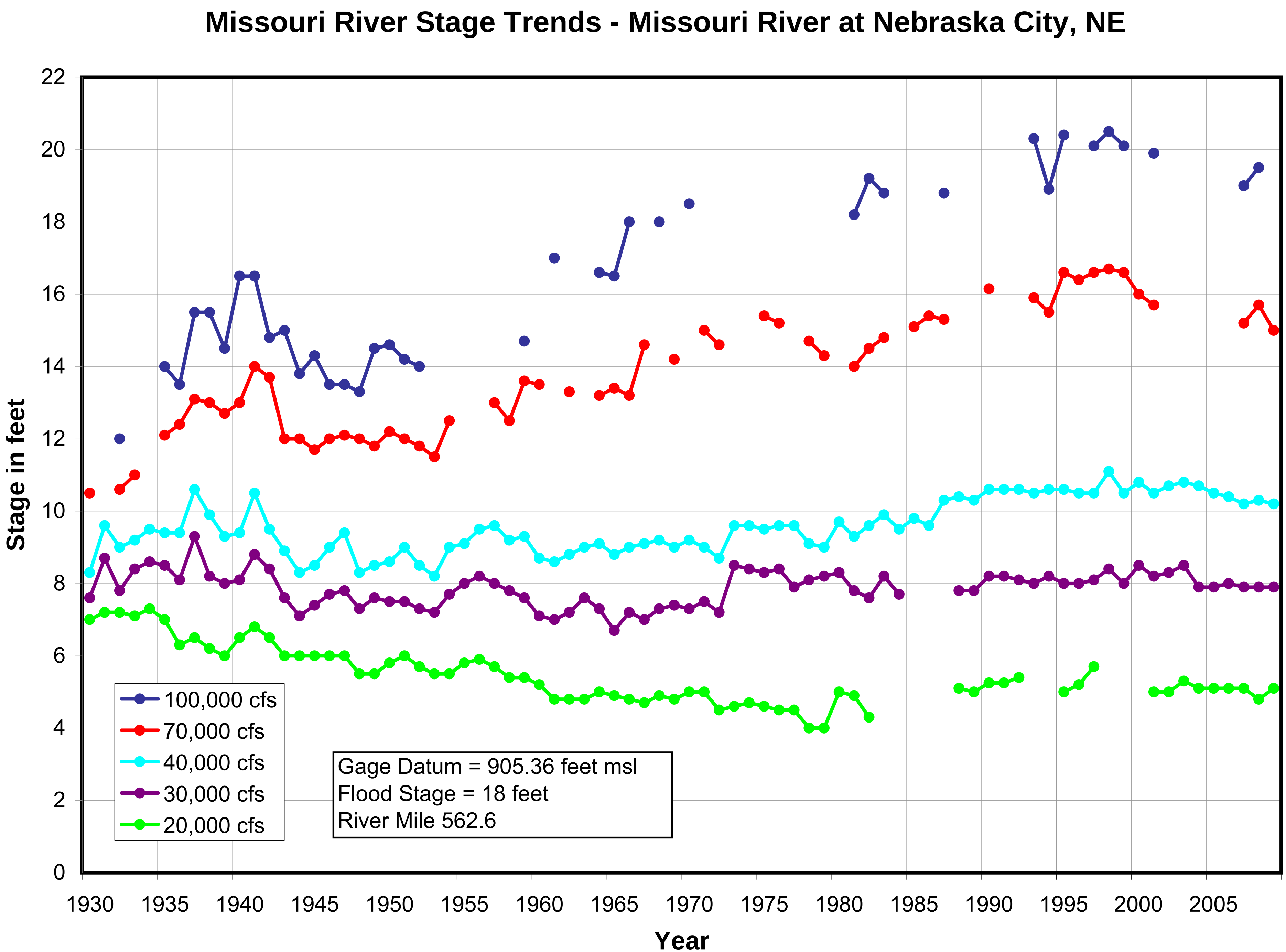

Missouri River Stage Trends - Missouri River at Omaha, NE
Stage in feet
Year
100,000 cfs
60,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
Gage Datum = 948.24 feet msl
Flood Stage = 29 feet
River Mile 615.9

Figure 11

Figure 12


Missouri River Stage Trends - Missouri River at Nebraska City, NE
Stage in feet
0
2
4
6
8
10
12
14
16
18
20
22
Year
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
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

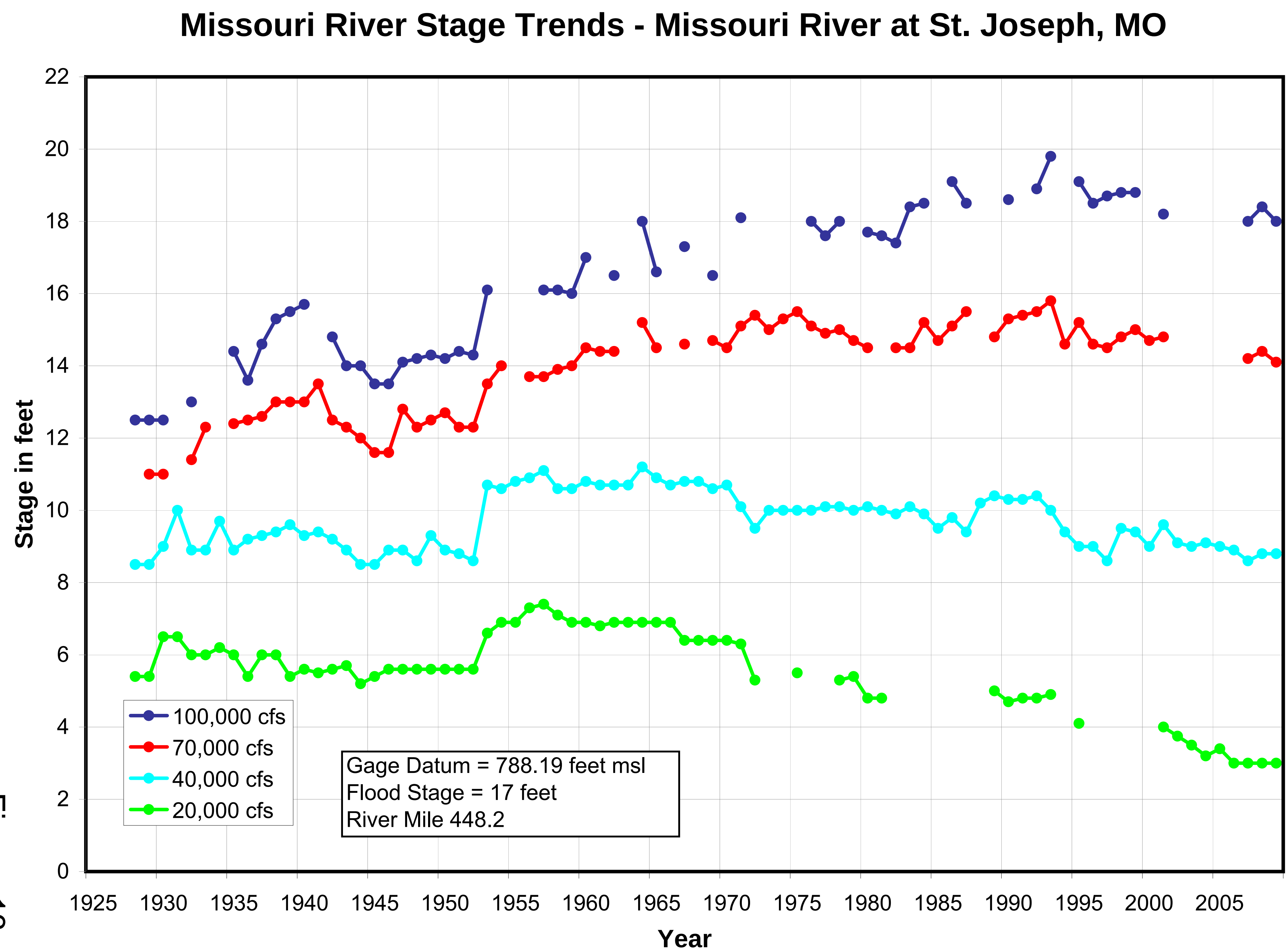
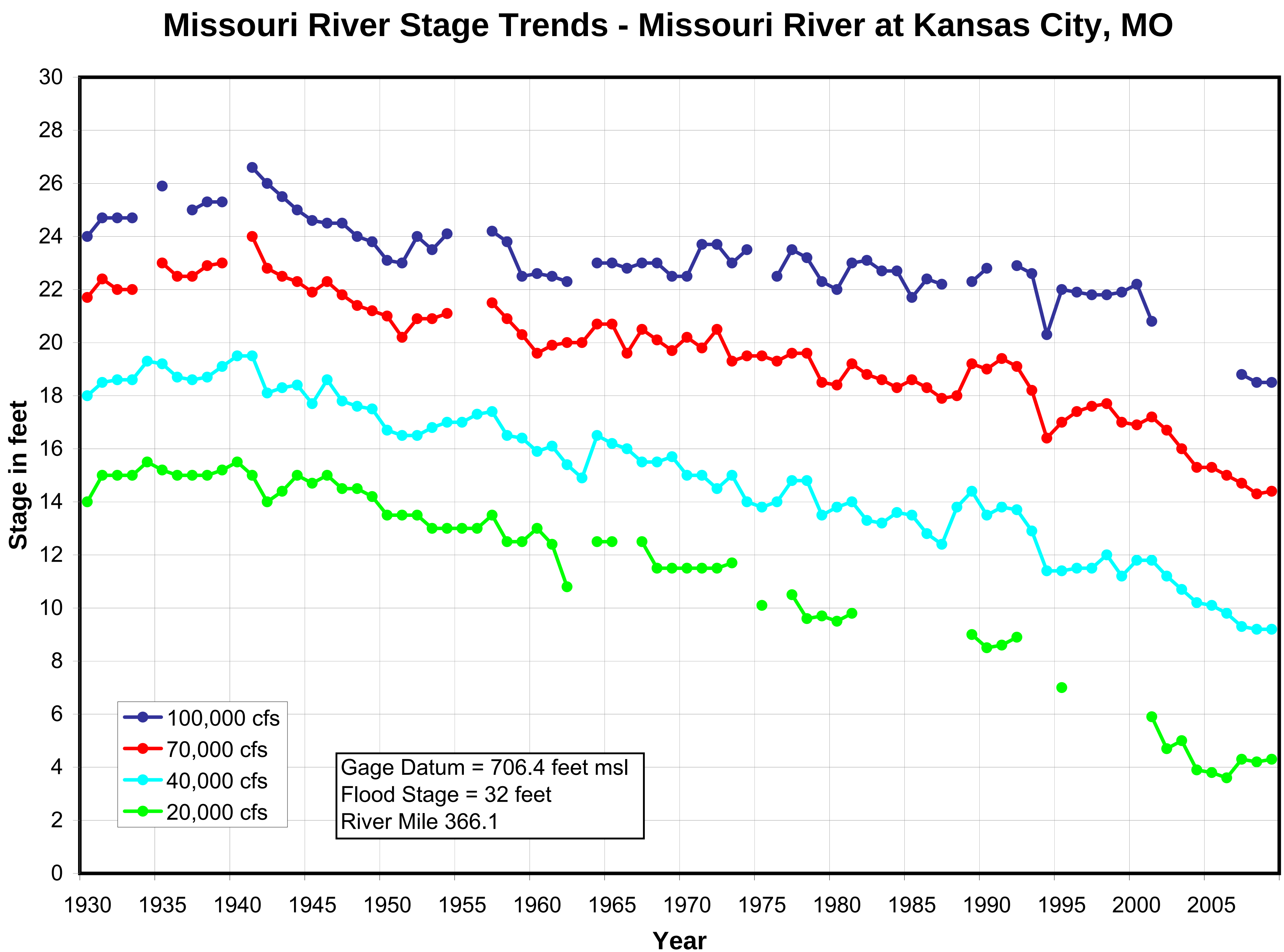

Missouri River Stage Trends - Missouri River at St. Joseph, MO
Stage in feet
0
2
4
6
8
10
12
14
16
18
20
22
Year
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 788.19 feet msl
Flood Stage = 17 feet
River Mile 448.2

Figure 13

Figure 14


Missouri River Stage Trends - Missouri River at Kansas City, MO
Stage in feet
Year
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
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

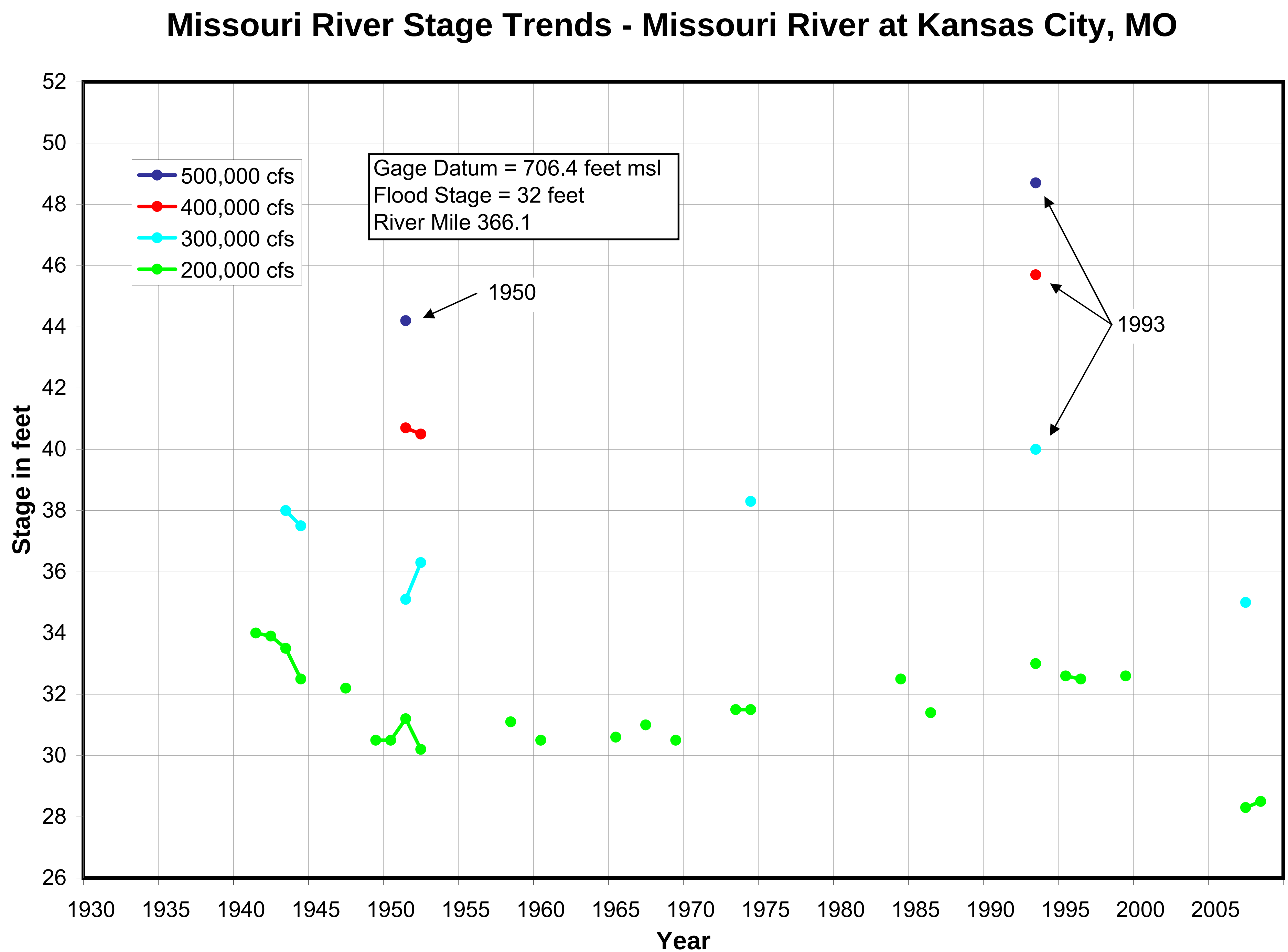
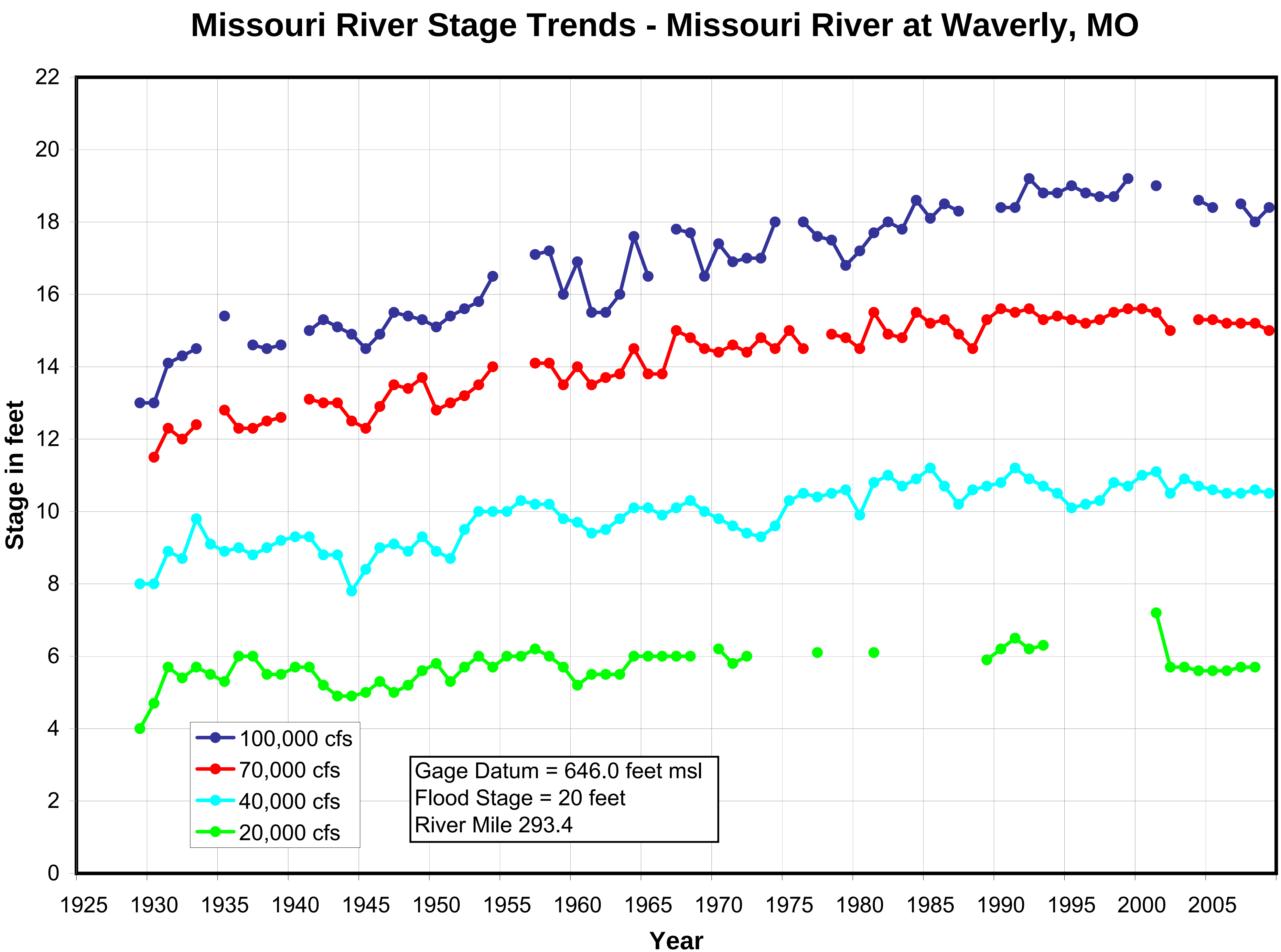

Missouri River Stage Trends - Missouri River at Kansas City, MO
500,000 cfs
400,000 cfs
300,000 cfs
200,000 cfs
Gage Datum = 706.4 feet msl
Flood Stage = 32 feet
River Mile 366.1
1950
1993
Stage in feet
52
50
48
46
44
42
40
38
36
34
32
30
28
26
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

Figure 15



Missouri River Stage Trends - Missouri River at Waverly, MO
Stage in feet
0
2
4
6
8
10
12
14
16
18
20
22
Year
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
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 16

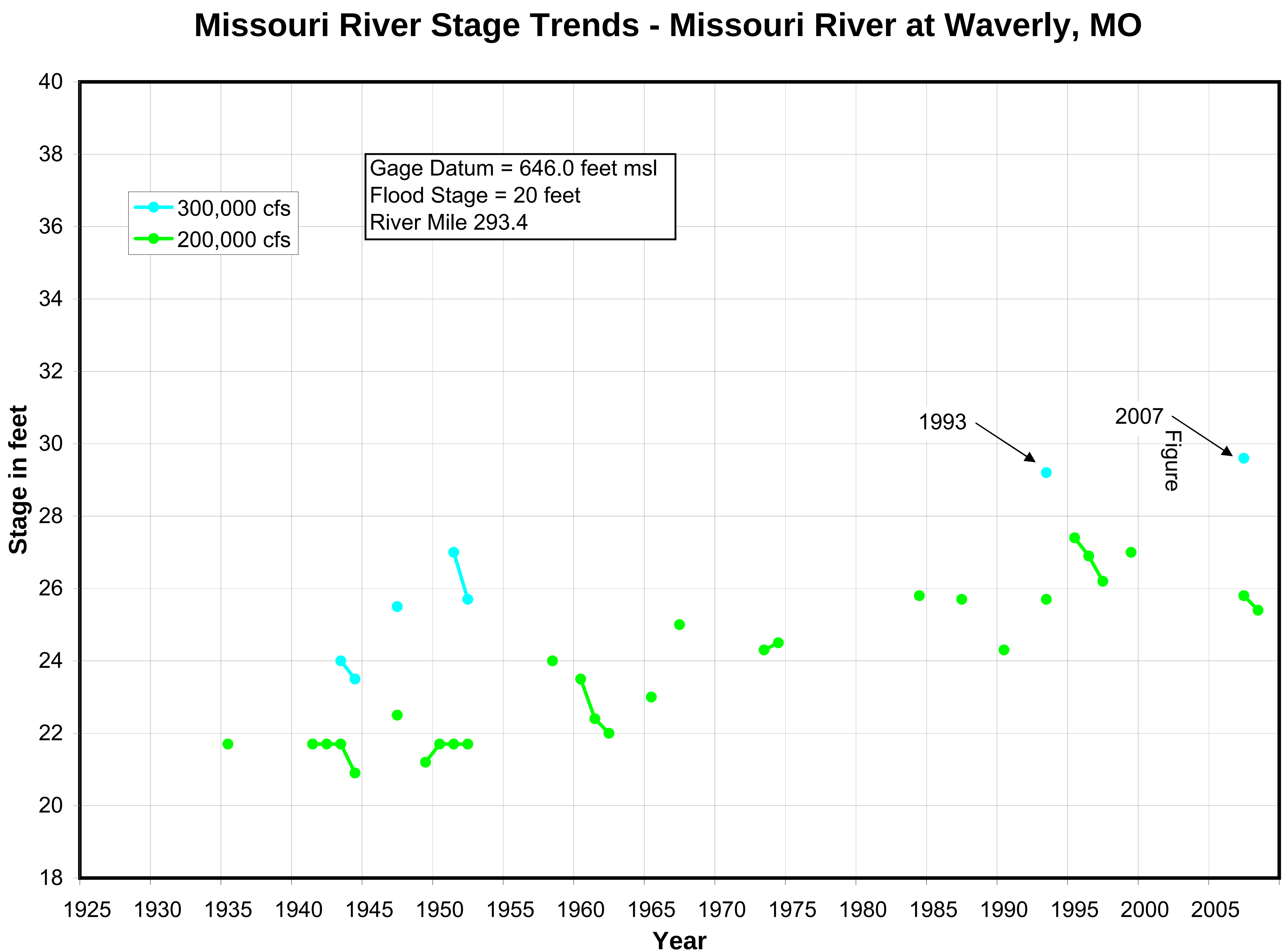
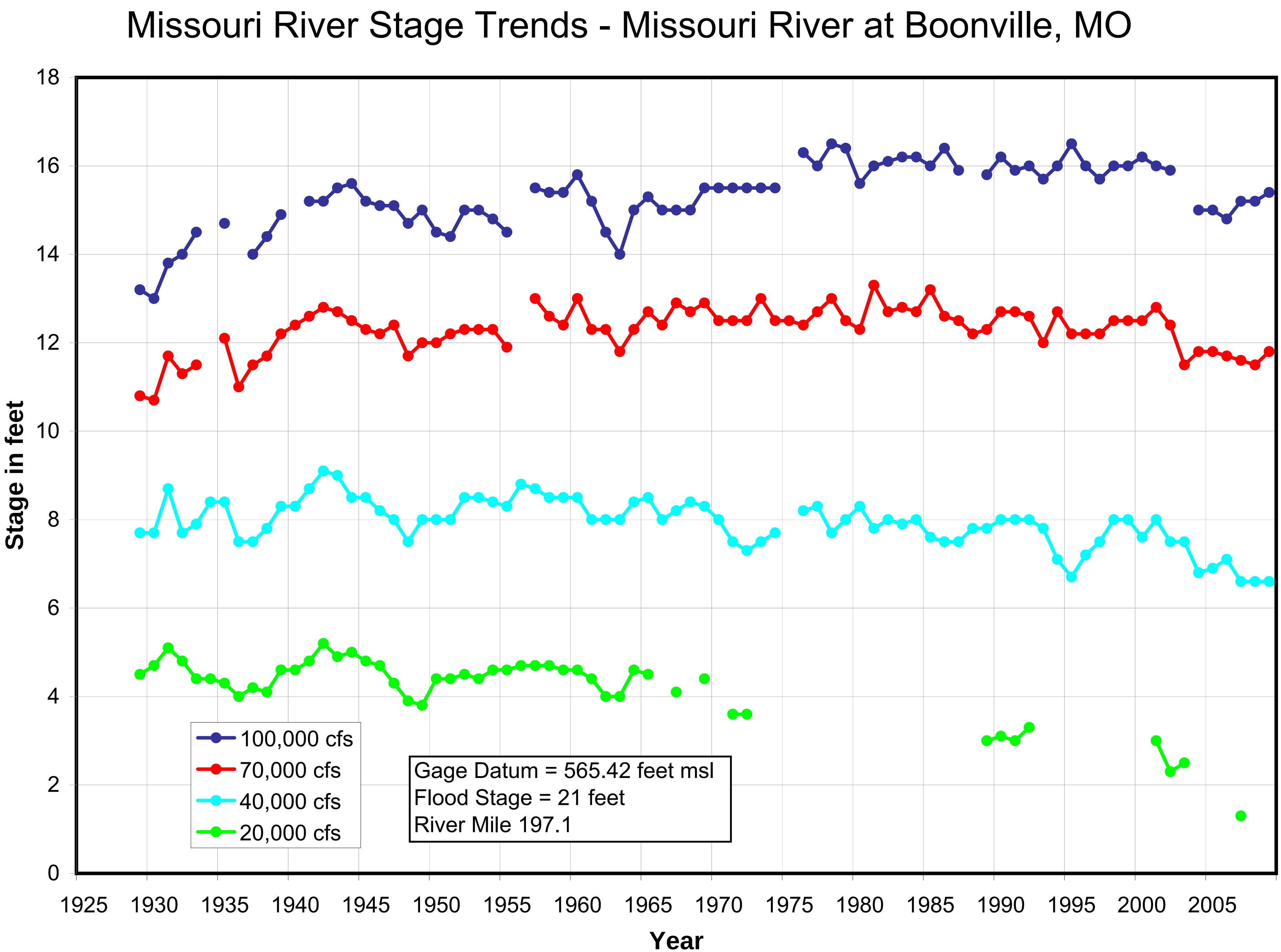
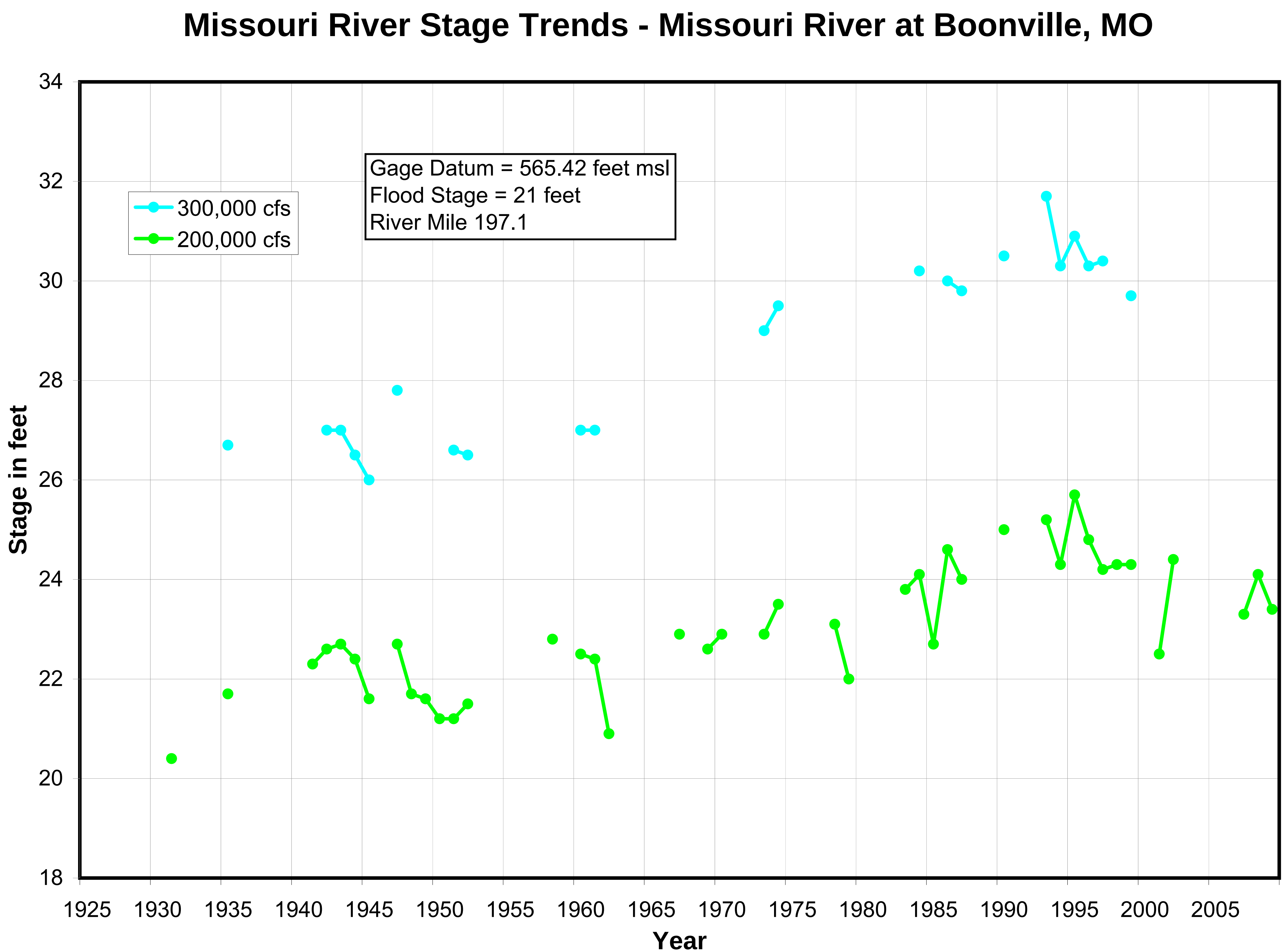

Missouri River Stage Trends - Missouri River at Waverly, MO
Gage Datum = 646.0 feet msl
Flood Stage = 20 feet
River Mile 293.4
300,000 cfs
200,000 cfs
1993
2007
Figure
Stage in feet
Year
40
38
36
34
32
30
28
26
24
22
20
18
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

Figure 17

Figure 18

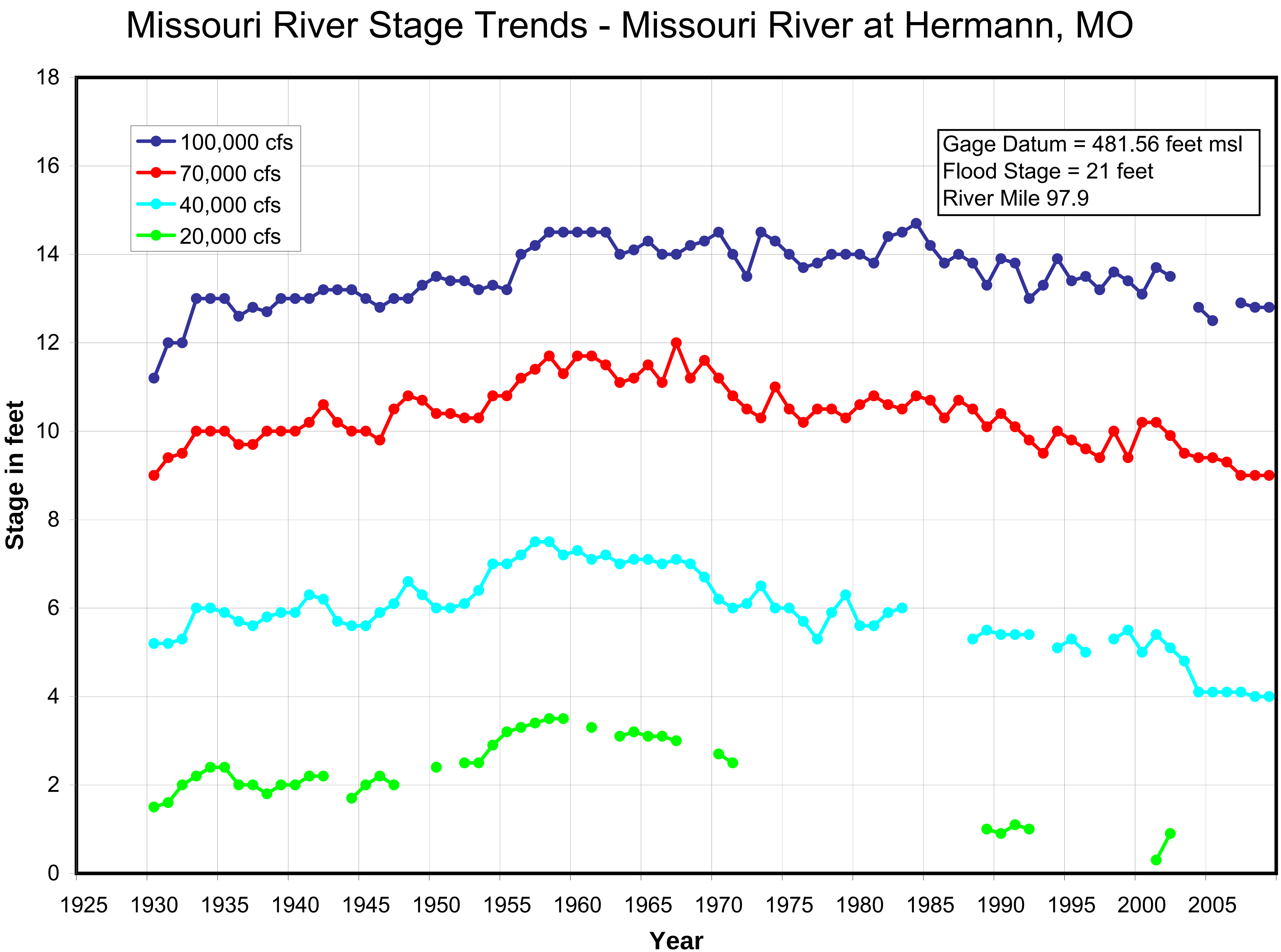

Missouri River Stage Trends - Missouri River at Boonville, MO
Stage in feet
Year
0
2
4
6
8
10
12
14
16
18
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
100,000 cfs
70,000 cfs
40,000 cfs
20,000 cfs
Gage Datum = 565.42 feet msl
Flood Stage = 21 feet
River Mile 197.1



Missouri River Stage Trends - Missouri River at Boonville, MO
Gage Datum = 565.42 feet msl
Flood Stage = 21 feet
River Mile 197.1
300,000 cfs
200,000 cfs
Stage in feet
Year
34
32
30
28
26
24
22
20
18
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

Figure 19

Figure 20



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
0
2
4
6
8
10
12
14
16
18
Year
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

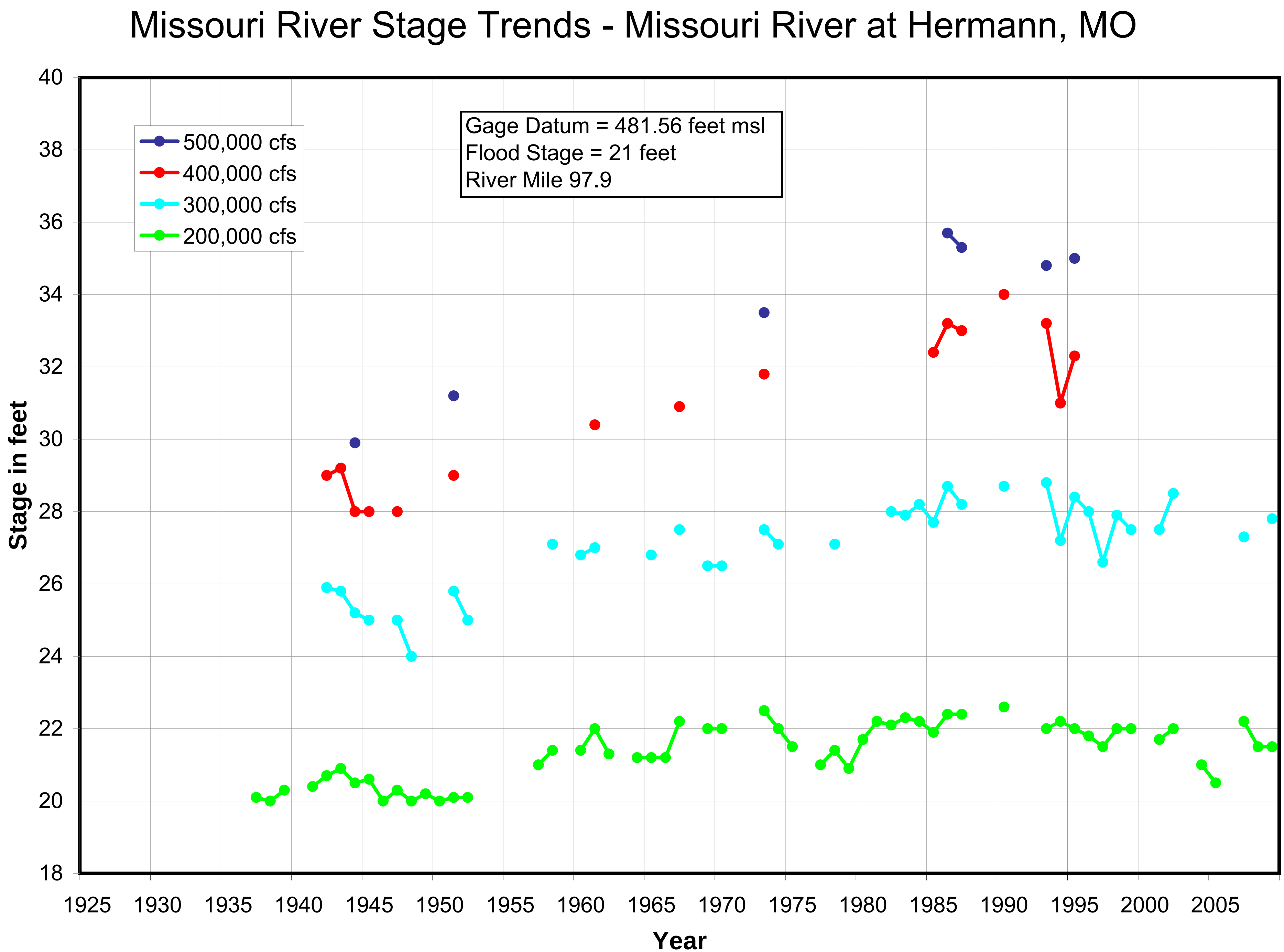
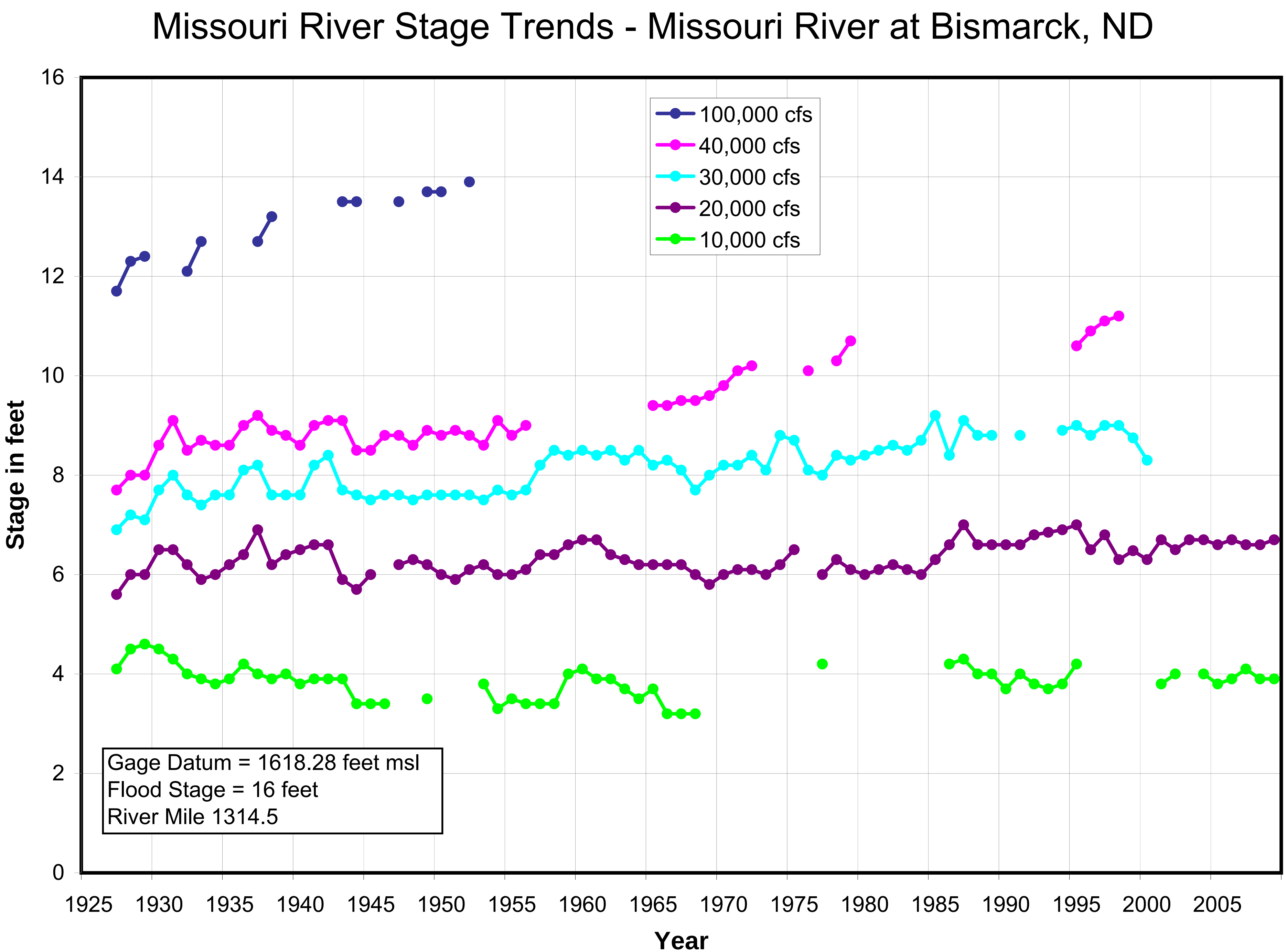

Missouri River Stage Trends - Missouri River at Hermann, MO
500,000 cfs
400,000 cfs
300,000 cfs
200,000 cfs
Gage Datum = 481.56 feet msl
Flood Stage = 21 feet
River Mile 97.9
Stage in feet
40
38
36
34
32
30
28
26
24
22
20
18
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

Figure 21

Figure 22



Missouri River Stage Trends - Missouri River at Bismarck, ND
100,000 cfs
40,000 cfs
30,000 cfs
20,000 cfs
10,000 cfs
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
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005