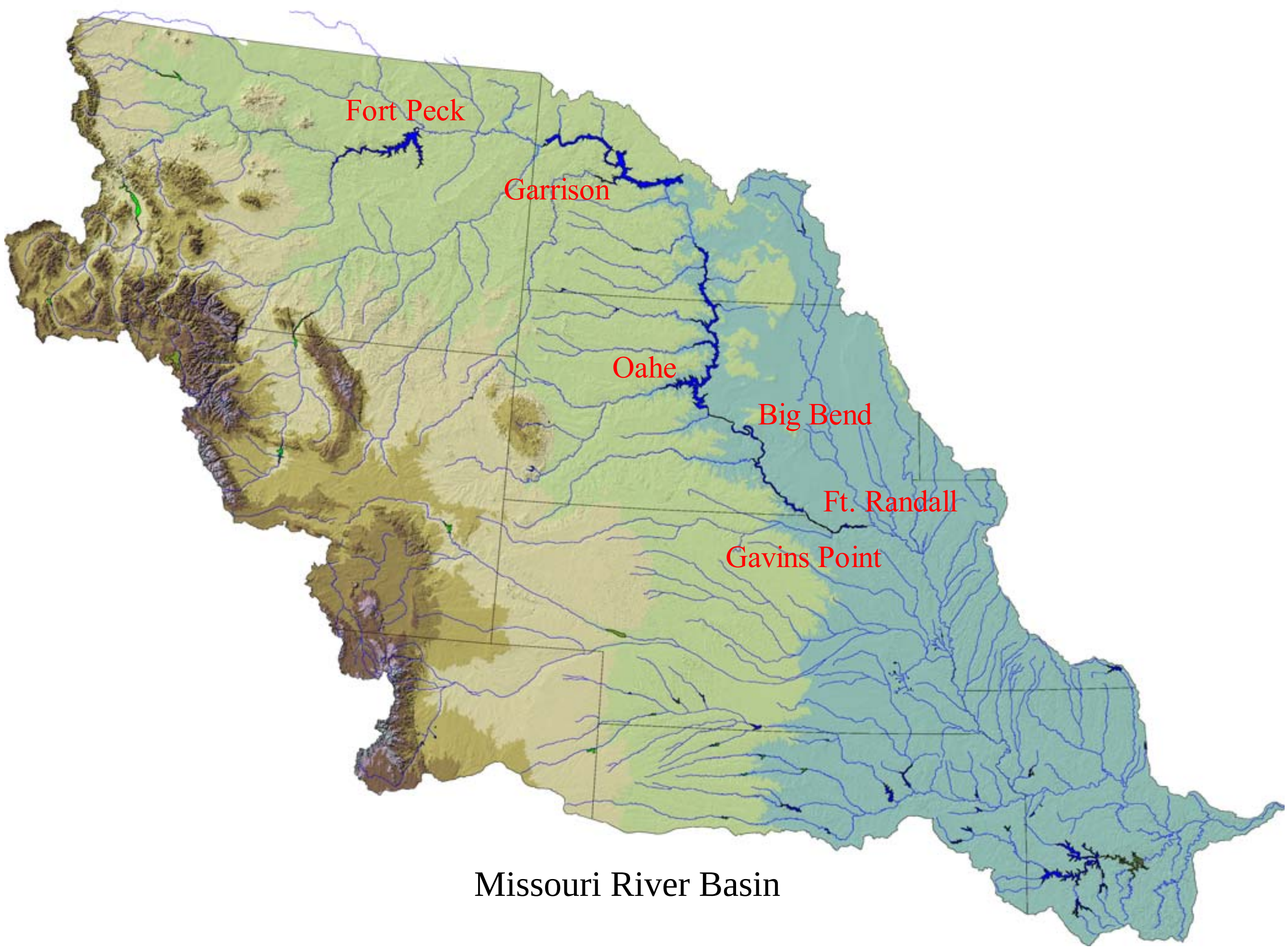
US Army Corps of Engineers

Northwestern Division

Missouri River Mainstem Reservoir System

Missouri River Stage Trends

RCC Technical Report A-04



Missouri River Basin

Reservoir Control Center
U. S Army Corps of Engineers
Northwestern Division - Missouri River Basin
Omaha, Nebraska

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MISSOURI RIVER STAGE TRENDS

Table of Contents

LIST OF FIGURES

Figure No.

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 collection of systematic and continuous discharge records by the 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 not to exceed 2 feet between Omaha and the mouth, and possibly as much as 1 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 1 foot. Since publication of that report, the main stem reservoirs have been completed and have 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, and February 2000.

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 main stem 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 main stem 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 cfs 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 continued annual submission of Missouri River flow measurement data and rating curves by each District. 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 Missouri River Main Stem 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 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 on line 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 main stem 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 on line. 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 project for this update.

GARRISON

In 1946, construction of the Garrison project was initiated. Dam closure was made in 1953, with power plant operation on line in 1956. Since 1956, outflows from Garrison have generally been through the power facilities, having a maximum capacity of about 38,000 cfs. Exceptions occurred in 1975 when outflows of 65,000 cfs were required for over 1 month and in 1997 when releases averaged 57,300 cfs during the month of July. ***Figure 1*** shows tailwater rating curves developed at 5-year intervals beginning in 1955 and extending through 2000, as well as the curve from the most recent survey in 2003. As illustrated by those curves, a lowering is shown at each 5-year update interval with each curve dropping about 1 to 2 feet until about

1980. From 1980 to 1995, the total shift was approximately 1 foot. The tailwater rating curves for 2000 and 2003 indicate an increased rate of degradation following the three high runoff volume years of 1995, 1996, and 1997. The rate of degradation has significantly lessened from 2000 to 2003, which were years of low runoff volume. This figure also shows an increased rate of tailwater lowering for discharges in excess of 20,000 cfs. 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 cfs 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.

OAHE

Diversion and closure of Oahe were completed in 1958 following ten years of construction. In April 1962, the first power unit came on line with all units operational in July 1966. Tailwater rating curves developed at 5-year intervals beginning in 1965 and extending through 2000, as well as the curve from the most recent survey in 2003, are compared on ***Figure 3***. As shown on those curves, there has generally been about 1 foot or less change in tailwater stages over the years. 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 m.s.l. 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. Time trend plots for discharges ranging from 10,000 cfs to 50,000 cfs are shown on ***Figure 4***.

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 on line in 1956. As shown on ***Figure 5***, a lowering of the tailwater stage of about 5 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 1-foot shift in the gage datum. During 1994, it was determined that the tailwater gage at Fort Randall has been recording water surface elevations 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 cfs 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 2003, the degradation increased almost a foot in the 30,000 to 45,000 cfs range.

GAVINS POINT

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 2 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. 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.

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. Since that time, there has been only a small decrease in tailwater stage at the projects, however 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. The total decrease in tailwater stage at these projects ranges from about 1 foot at Oahe to about 11 feet at Gavins Point; Garrison and Fort Randall tailwaters have experienced 10 and 8 feet of total degradation, respectively.

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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 regimen. Although the average annual discharge at Sioux City has not changed appreciably, maximum flood peaks have been significantly reduced, low flows increased and the distribution of the annual runoff 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 quite clearly on ***Figure 10***, the predominant stage trend at Sioux City has been downward. At normal full-service discharge levels, this downward shift of 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 from those experienced in the 1960's and early 1970's and appeared to be stabilizing for normal flow levels.

Stage reductions at Sioux City have caused numerous problems at marinas and dock facilities. These problems were magnified during the 6-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 2.5 to 3 feet below the river levels experienced during normal navigation releases from Gavins Point Dam. During the drought years 1987 to early 1993, the stage trends at Sioux City rose about a foot due to the less than normal flows. High flows, 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 has resulted in a sharp reduction in Sioux City stages. The data for 2003 indicates that since 1995, an additional 3 feet of stage reduction has occurred at Sioux City.

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 5 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 a foot or two. At below normal discharges, 10,000 to 20,000 cfs, stages rose a couple 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 4 to 5 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 5 feet by the mid-1950's. Between the mid-1950's and mid-1960's the stages recovered approximately 4 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 4 feet by the mid-1950's. Stages had risen to their former high level by the mid-1970's and rose another 2 feet by 1993 before falling back with the high flows of the late 1990's.

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 have demonstrated a consistent rise since 1950. The stages for flows of 30,000 to 40,000 cfs reflect a more gradual increase in stage.

The channel capacity of the Missouri River at flood stage at Nebraska City has been reduced from about 150,000 cfs to perhaps 80,000 cfs. An overall rise in stage of 5 to 6 feet has occurred for a discharge of 100,000 cfs. Based on 1994 data, the flood of 1993 reduced stages roughly 1 foot at Nebraska City for 70,000 and 100,000 cfs. These flood induced stage decreases appear to have returned to pre-1993 trends based on observations through 2003.

Most of the flood plain of the Missouri 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 increasing river stages at above normal flow levels. The sediment load provided by the Platte River is not removed by scouring flow as it was during pre-reservoir conditions.

ST. JOSEPH

Stages at St. Joseph for 20,000 and 40,000 cfs have remained relatively constant except for an upward trend in the rating curve of about 2 feet in 1952 when the 1952 flood caused the St. Joseph cutoff, upstream of the gage. In the early 1970's, stages for these discharges declined 1 to 2 feet. Since the flood of 1993, stages have lowered about 1.5 feet for discharges of 20,000 and 40,000 cfs as shown by the data through 1999 on ***Figure 13***. The stage trends for 70,000 and 100,000 cfs have been generally upward. At 70,000 cfs, the overall rise in the Missouri River stage has been about 2 to 3 feet since the 1940's and about 4 feet at 100,000 cfs. The stage at 70,000 cfs has been relatively constant over the past 30 years. The stage for a 100,000 cfs discharge has increased steadily since the early 1940's. Similar to Missouri River reach near Nebraska City, 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 7 to 9 feet lower than those experienced in the 1930's for 20,000 and 40,000 cfs, and 4 to 6 feet lower at 70,000 and 100,000 cfs. Kansas City stages for 40,000 and 70,000 cfs recovered 1 to 2 feet during the drought years of 1987 to early 1993, but then declined dramatically following the 1993 flood with little recovery since. Stage estimates for 2003 indicate a 1 to 2 foot drop in stages from the 1993 pre-flood conditions. Stages at 100,000 cfs have been relatively stable since the late 1950's. Stage observations in 1995 indicated a recovery to the pre-1993 trend following the dramatic shift after the 1993 flood.

At a discharge of 200,000 cfs, as shown on ***Figure 15***, stages have been slightly rising since the 1950's with a 2-foot stage increase experienced since 1950. 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 4 to 5 feet since the early 50's for discharges at and above 300,000 cfs.

WAVERLY

At the Waverly, Missouri gage, stages are generally 3 to 5 feet higher at the 200,000, 100,000, and 70,000 cfs discharge levels than those experienced during the 1930's. At 40,000 cfs, stages have risen about 2 to 3 feet since the 1930's. The river stage for a Missouri River discharge of 20,000 cfs has been nearly constant between about 1950 and 1990 with an indication of a slight rise and fall since then. Following the 1993 flood, 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 cfs and above. The upward trend appears to be continuing although the data at discharges in this range are sparse and highly variable.

BOONVILLE

At the Boonville, Missouri gage stages have remained relatively constant at this station for flows between 40,000 cfs and 100,000 cfs. Short term variations of plus or minus 1 foot over a 4 to 5 year period have been observed, but these changes are minor compared to changes at other stations on the river. The data available for the higher discharges of 200,000 cfs and 300,000 cfs demonstrate an upward trend of 2 to 4 feet has occurred at this station since 1960. ***Figure 18*** and ***Figure 19*** show the historical stage trends at Boonville.

HERMANN

At Hermann, Missouri an overall upward stage shift of about 1 to 3 feet was observed 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. At the 300,000 cfs discharge level, a 3-foot increase in stage has been noted prior to the 1993 flood. Post-1993 flood recovery data have demonstrated an erratic but downward trend. The data available for 400,000 cfs and 500,000 cfs indicate an upward shift of approximately 4 to 5 feet. ***Figure 20*** and ***Figure 21*** show the stage trends at Hermann.

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, including all the coarser fractions of the river sediment load. Delta formation in the headwaters area of the reservoir can extend upstream from the reservoir and can cause the reservoir backwater effect to progress upstream, increasing river stages. Headwaters areas of several of the main stem reservoir projects have been experiencing aggradation problems. These problems include increased water surface elevations, increased duration of flooding, and higher groundwater levels. Stage trends at several of the problem areas are discussed in the following paragraphs.

WILLISTON

The Garrison 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 increase rate that appears to be ongoing to the present. In the reach associated with the City of Williston, the rate has recently been in the order of one foot rise per seven to eight years. For the reach associated with the Buford-Trenton Irrigation District upstream from Williston, the rate is about one foot per six to seven years.

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 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 4 feet of sediment deposition has been measured on the Missouri River from 1969 to 1987 or about 0.2 feet per year.

BISMARCK

Bismarck, located in the Oahe headwaters area, is the only station on the Missouri River within the main stem reservoir 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, except for discharges of 30,000 cfs or greater, which have exhibited an upward trend of from 1 to 2 feet. 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 1 to 2 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 area. Sediments deposited from the Bad River which enters the headwater area at Fort Pierre, have averaged over 3 million tons per year and have caused 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 2 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 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 during periods of low reservoir elevation. 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 for a steady discharge of 35,000 cfs obtained in 1994 from upstream of Verdel, Nebraska to below the mouth of the Niobrara River was higher than a water surface profile obtained in the mid-1980's with a discharge of 44,000 cfs which, in turn, was higher than a the profile with a discharge of 60,000 cfs in 1975.

A study was completed by the Corps and published in September of 1992 “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 3 to 5 feet downstream of the confluence of the Niobrara and 2 feet upstream of the confluence between 1954 and 1984. This change in channel depth has caused increase in stage of about 6 feet downstream from the confluence for a discharge of 20,000 cfs. This increase has been 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 3 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 Verdel, located approximately 5 miles upstream from the confluence of the Niobrara, river stages have increased by about 4 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 1 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. 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 main stem reservoir system. However, the impacts became very obvious during the drought years 1987 through early 1993 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 a good communications effort to alert those affected to what is happening and how to adapt to the situation. Positive impacts include the greater flood protection provided to those adjacent to the river due to lower stages for some flows.

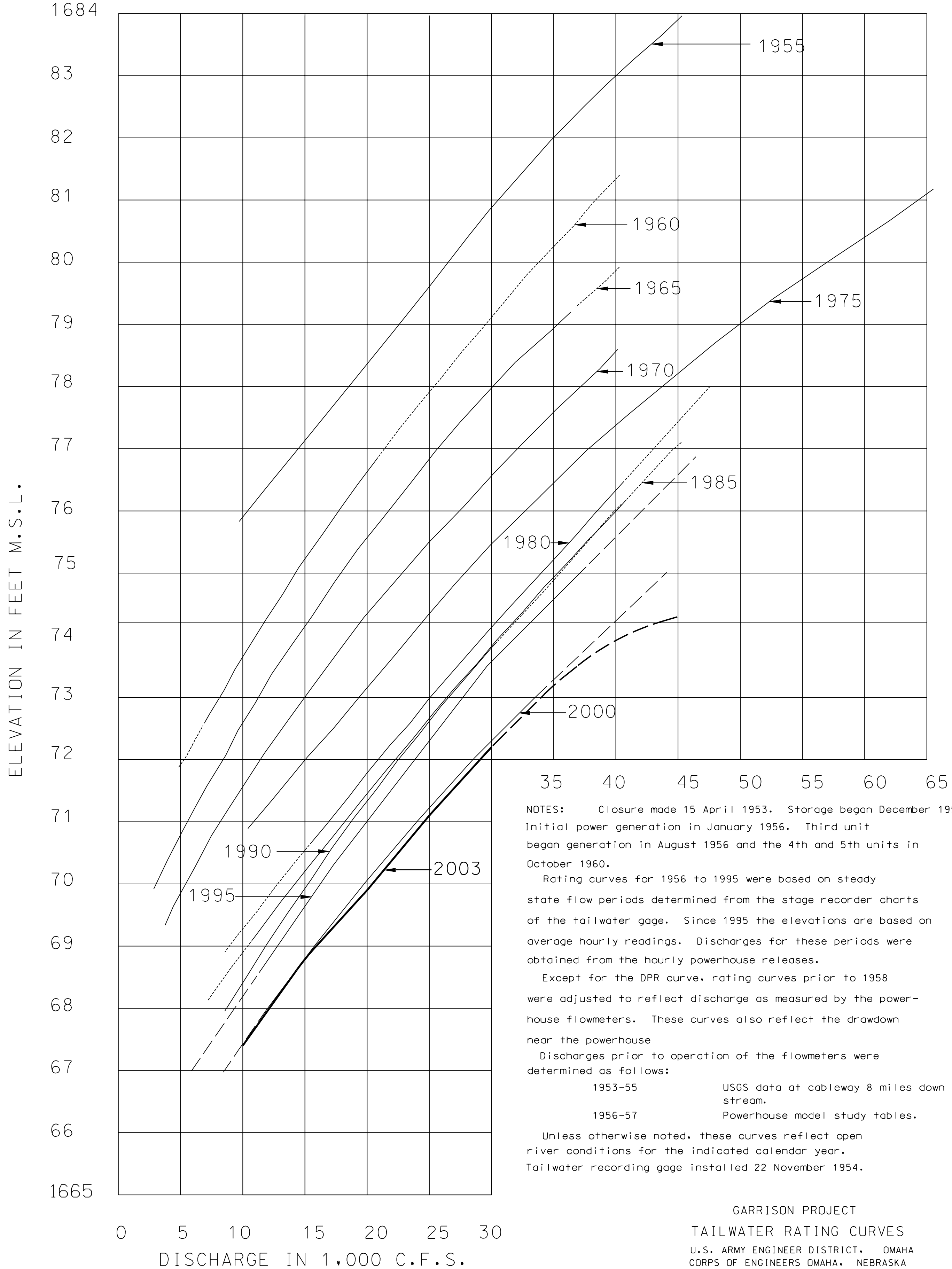
In the tailwater areas, downstream from the projects, decreases in tailwater stage have generally been experienced, with the most noticeable stage reductions occurring at the Garrison, Fort Randall and Gavins Point projects. At these projects the tailwater stage has decreased by about 7 to 10 feet since closure of the dams. In the period from 1980 through 1995, the rate of tailwater degradation had become more stable. The Garrison, Fort Randall, and Gavins Point Project tailwater trends show a marked increase in the rate of degradation with the high system releases experienced during the 1995 through 1998 period. An exception to the tailwater stage reduction is occurring below Oahe, where the tailwater stages have increased by less than 1 foot.

Upward stage shifts are apparent for the higher discharges at all stations located along the navigation channel or in headwater areas, although at Kansas City the upward trend is only evident at flows exceeding 200,000 cfs. 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 main stem 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 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 2 to 6 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 reanalysis of the reference plane to which these structures are built and maintained is periodically required.

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.



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.

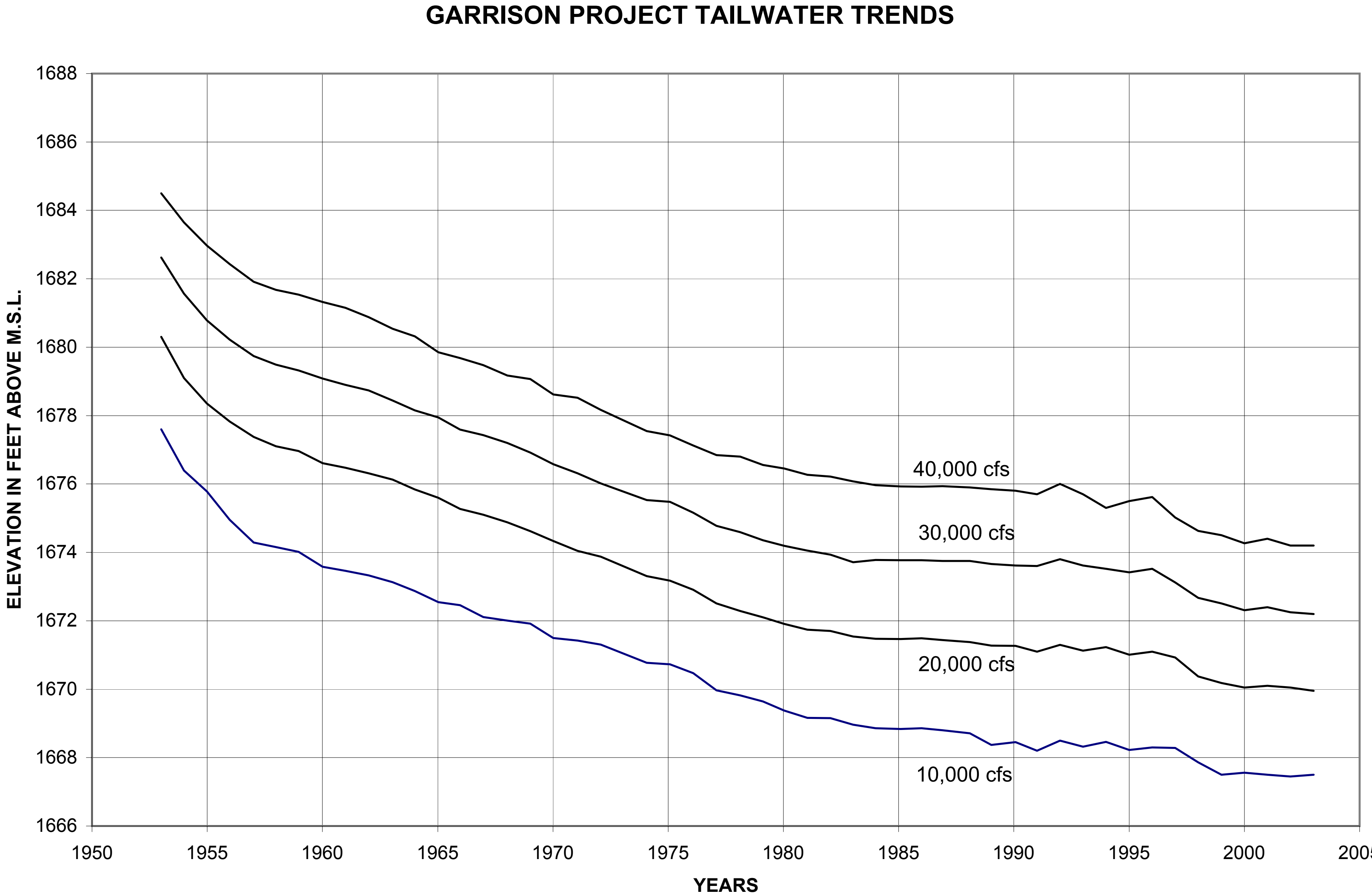
GARRISON PROJECT

TAILWATER RATING CURVES

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

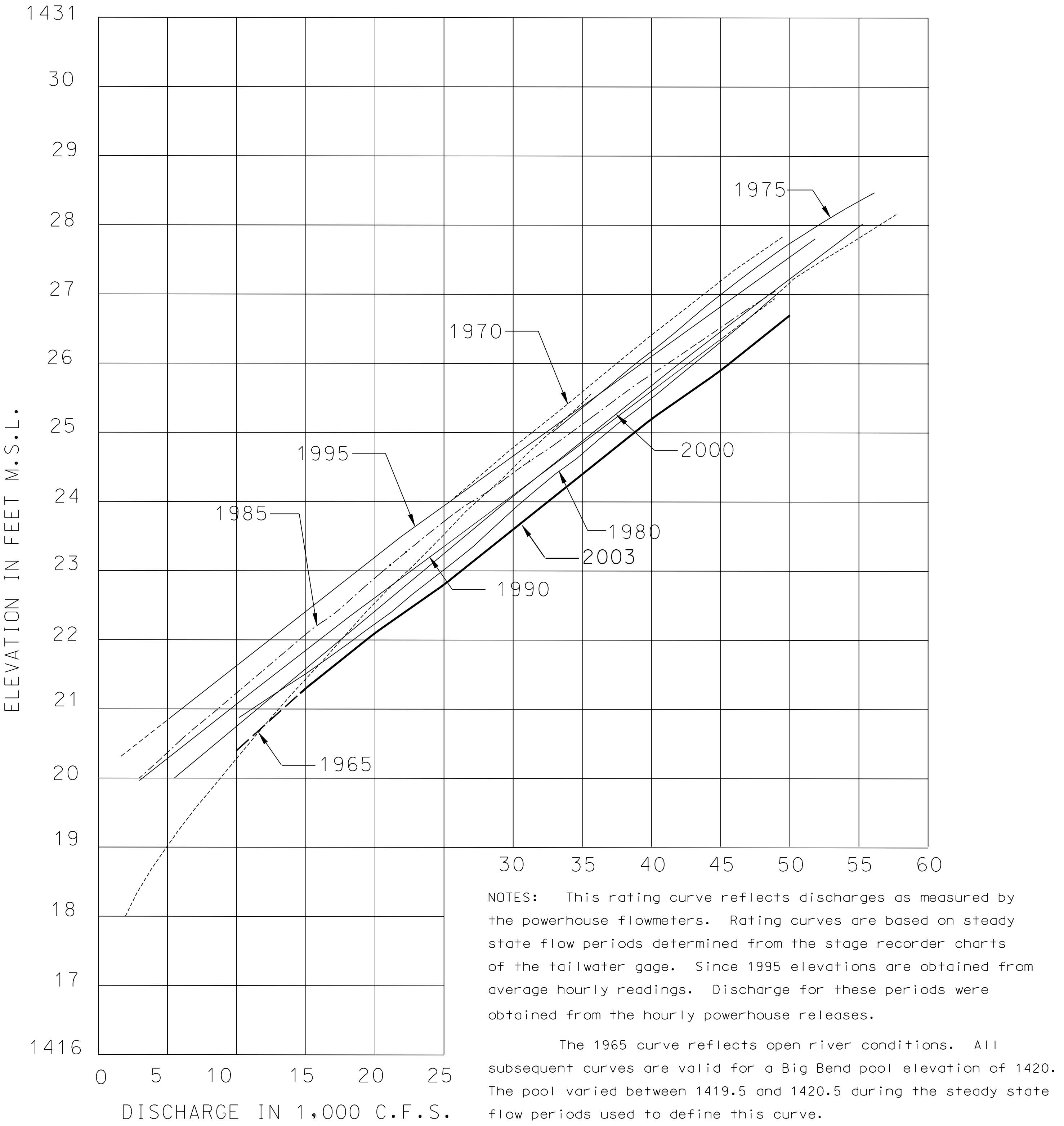
JANUARY 2004

Figure 1



January 2002

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

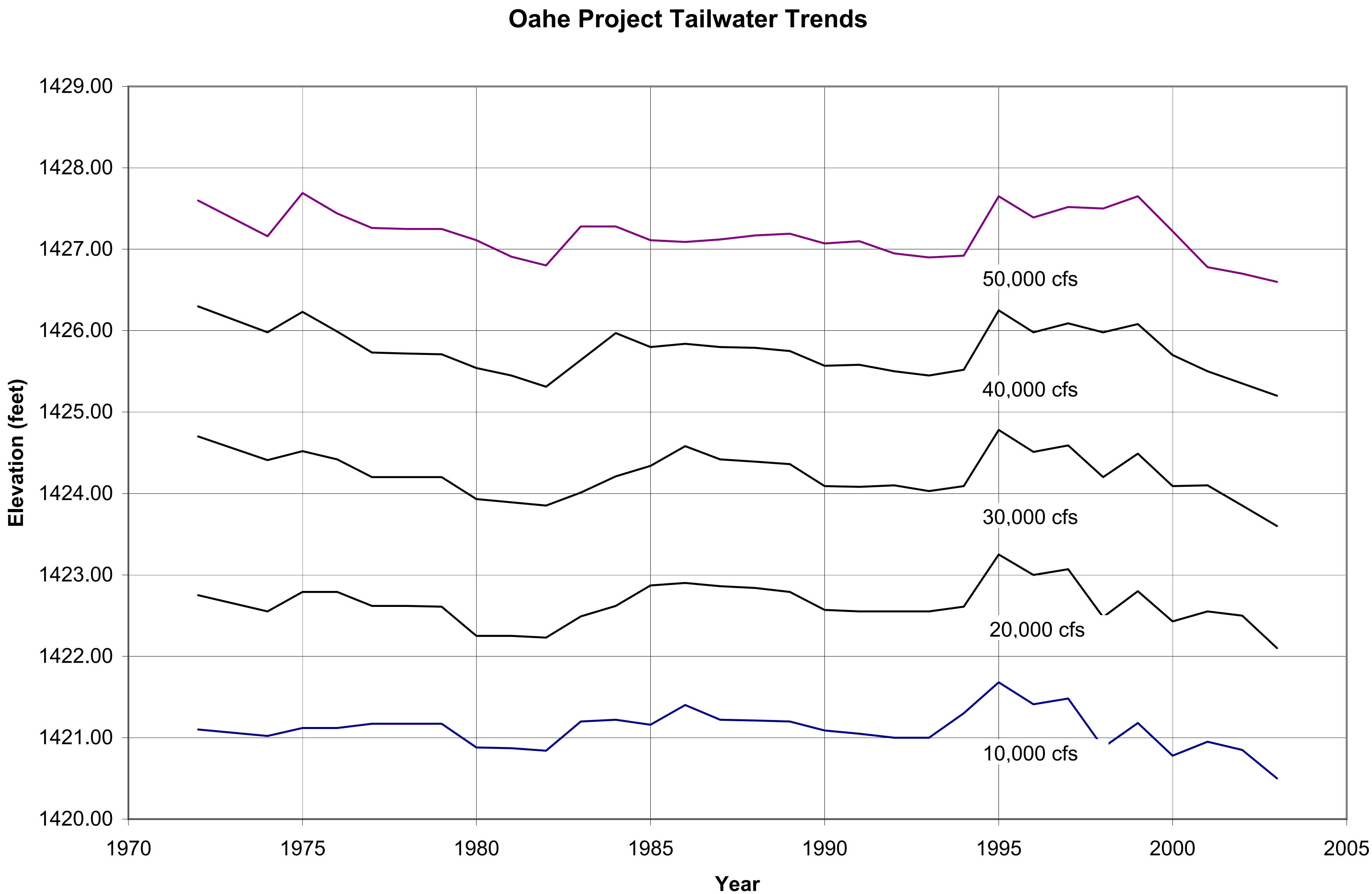
TAILWATER RATING CURVES

U.S. ARMY ENGINEER DISTRICT, OMAHA

CORPS OF ENGINEERS OMAHA, NEBRASKA

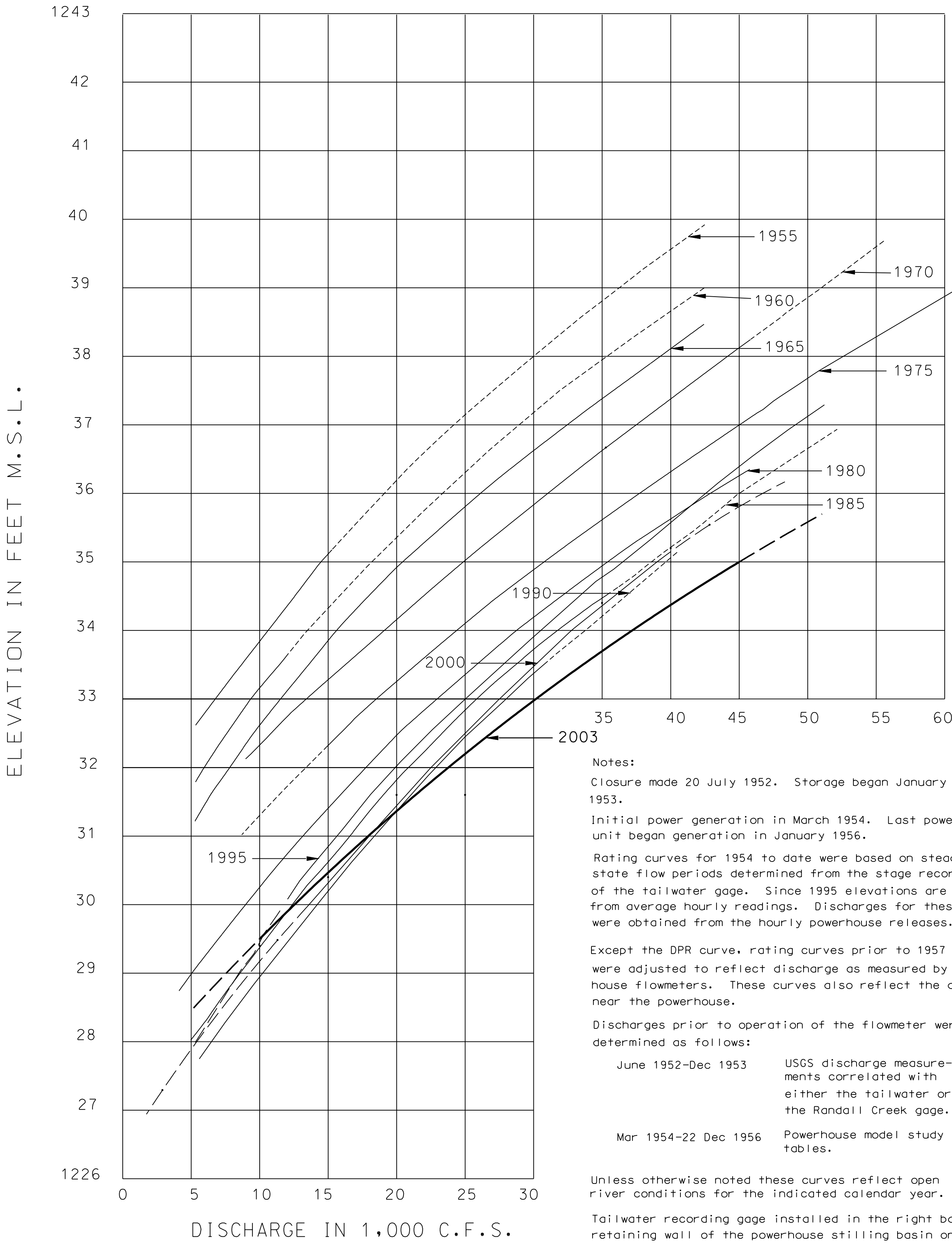
JANUARY 2004

Figure 3



January 2004

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 power-house 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 measure-ments 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.

JANUARY 2004

Figure 5

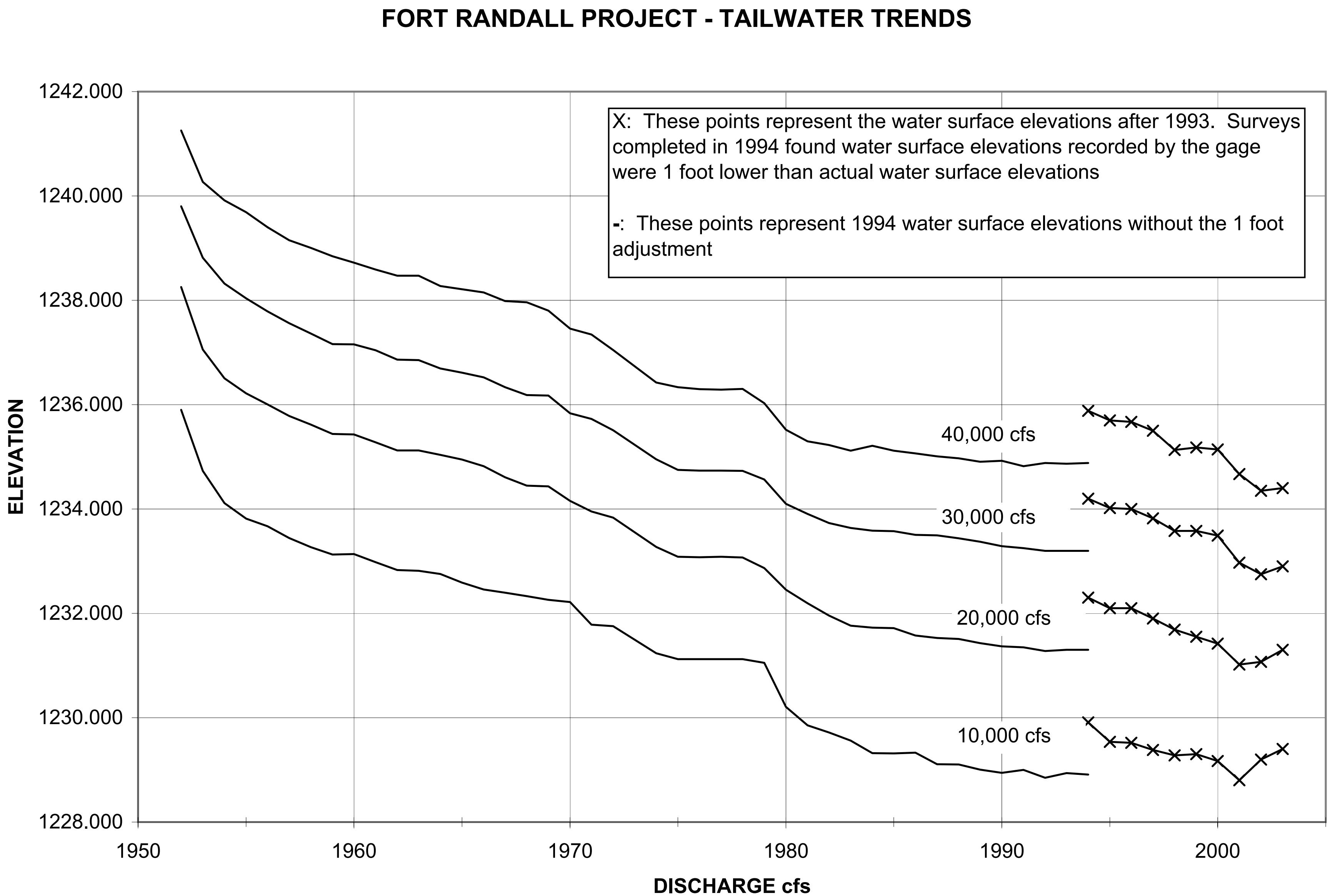
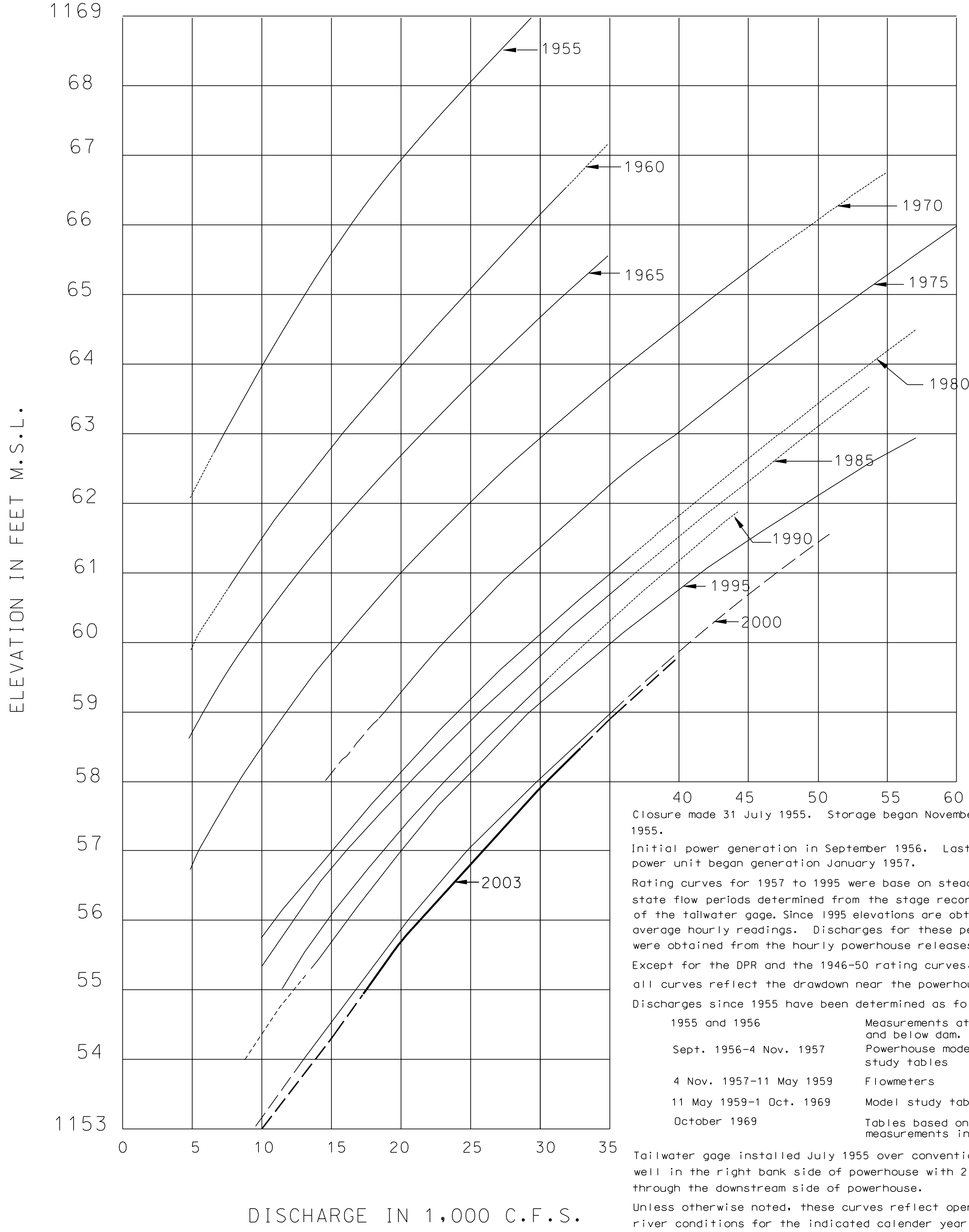


Figure 6

January 2004



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.

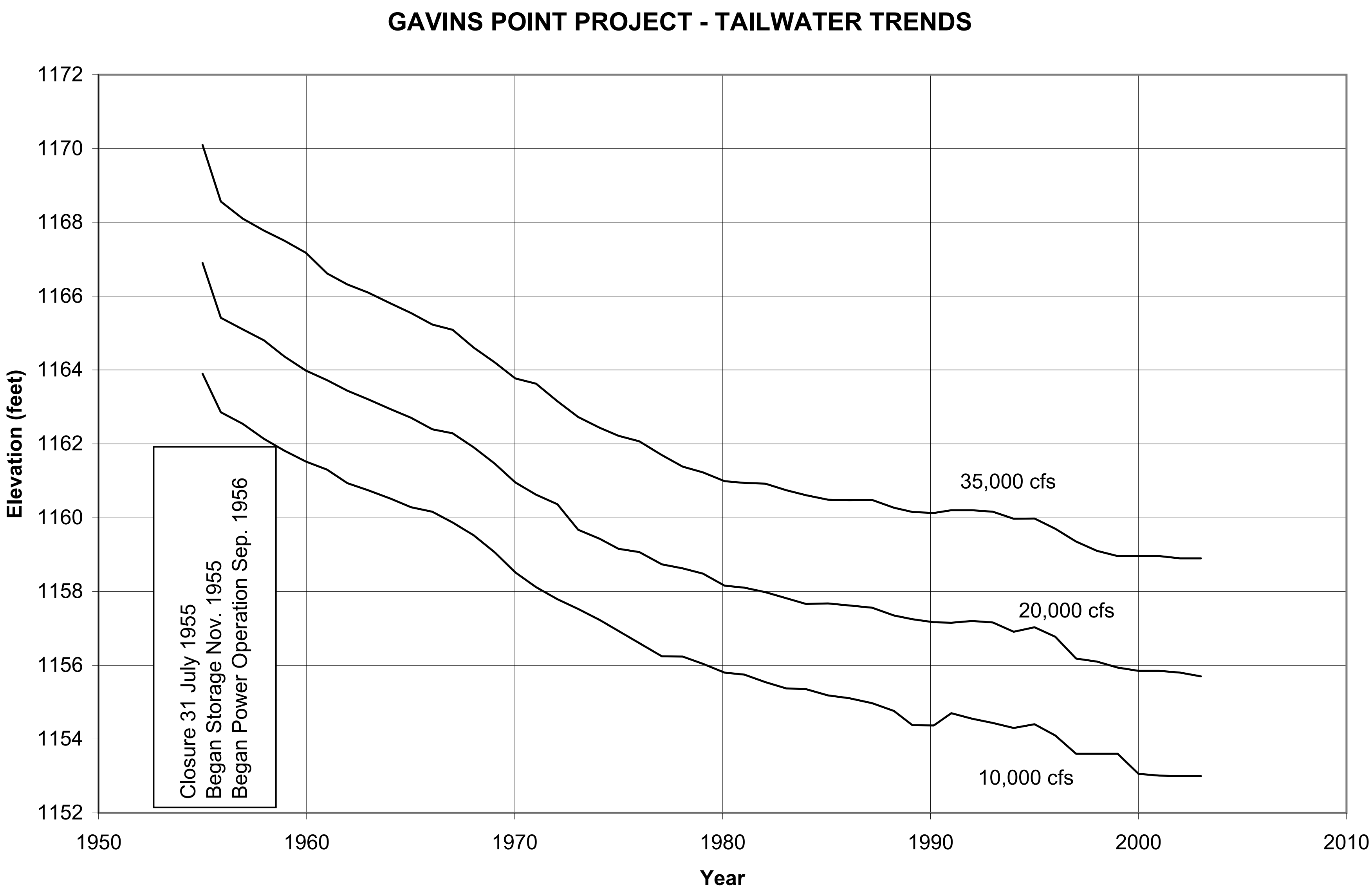
Unless otherwise noted, these curves reflect open river conditions for the indicated calender year.

GAVINS POINT PROJECT

TAILWATER RATING CURVES

U.S. ARMY ENGINEERS DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JANUARY 2004

Figure 7



January 2004

Figure 8

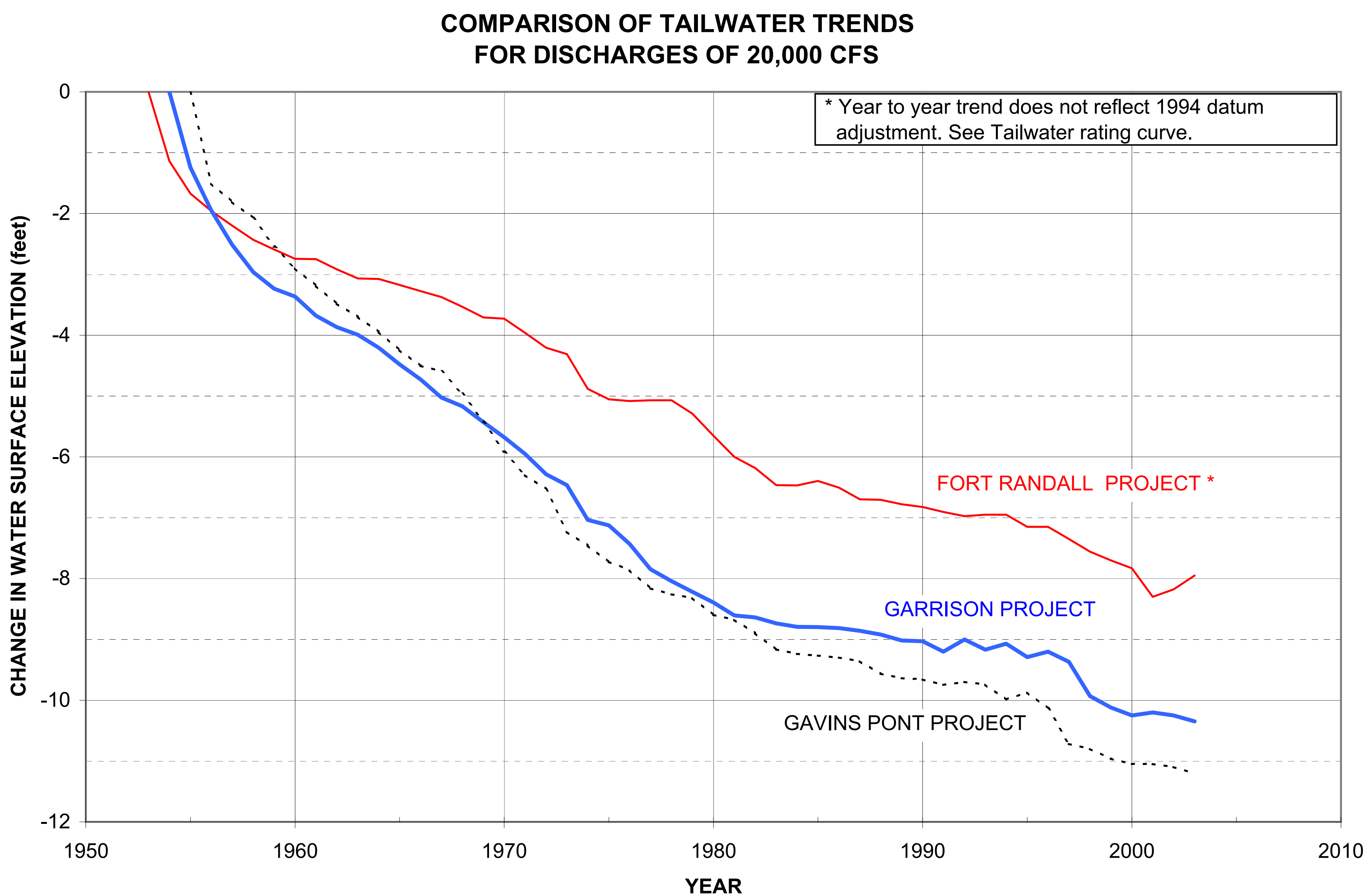


Figure 9

January 2004

Missouri River Stage Trends at Sioux City, Iowa

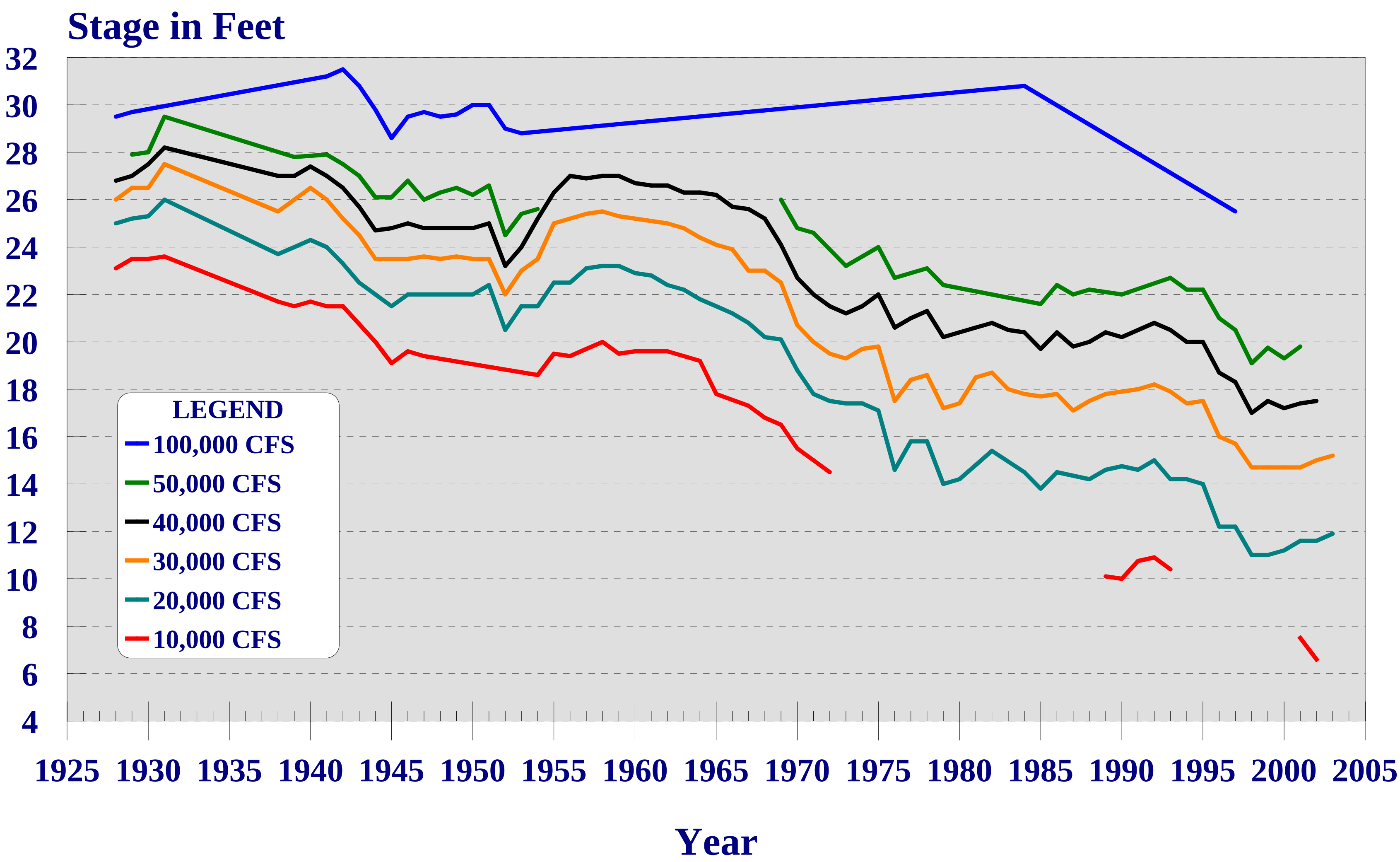


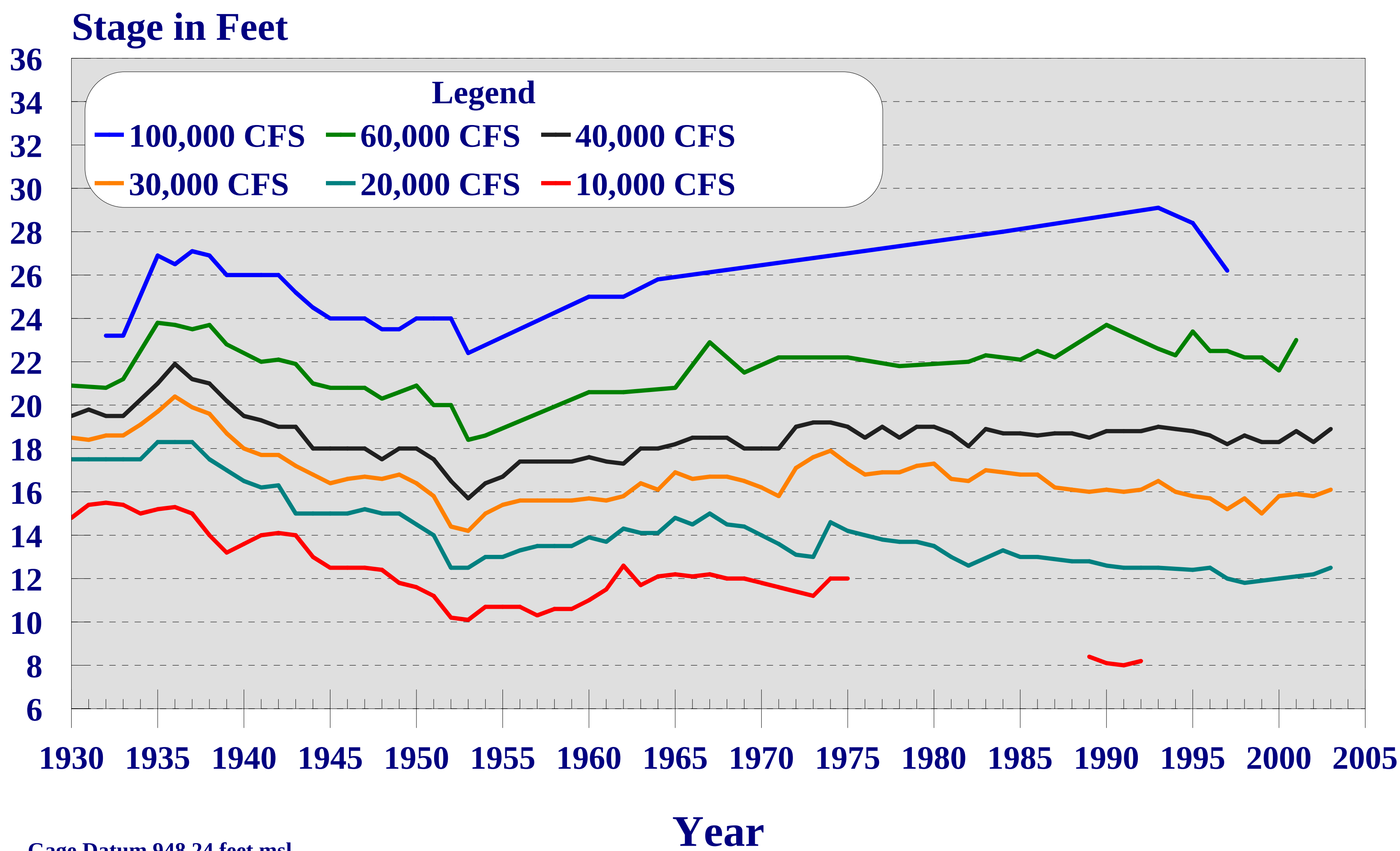
Figure 10

Gage Datum 1056.98 feet msl
Flood Stage 30 feet
River Mile 732.3

2003 Provisional Data

3/04

Missouri River Stage Trends
at Omaha, Nebraska

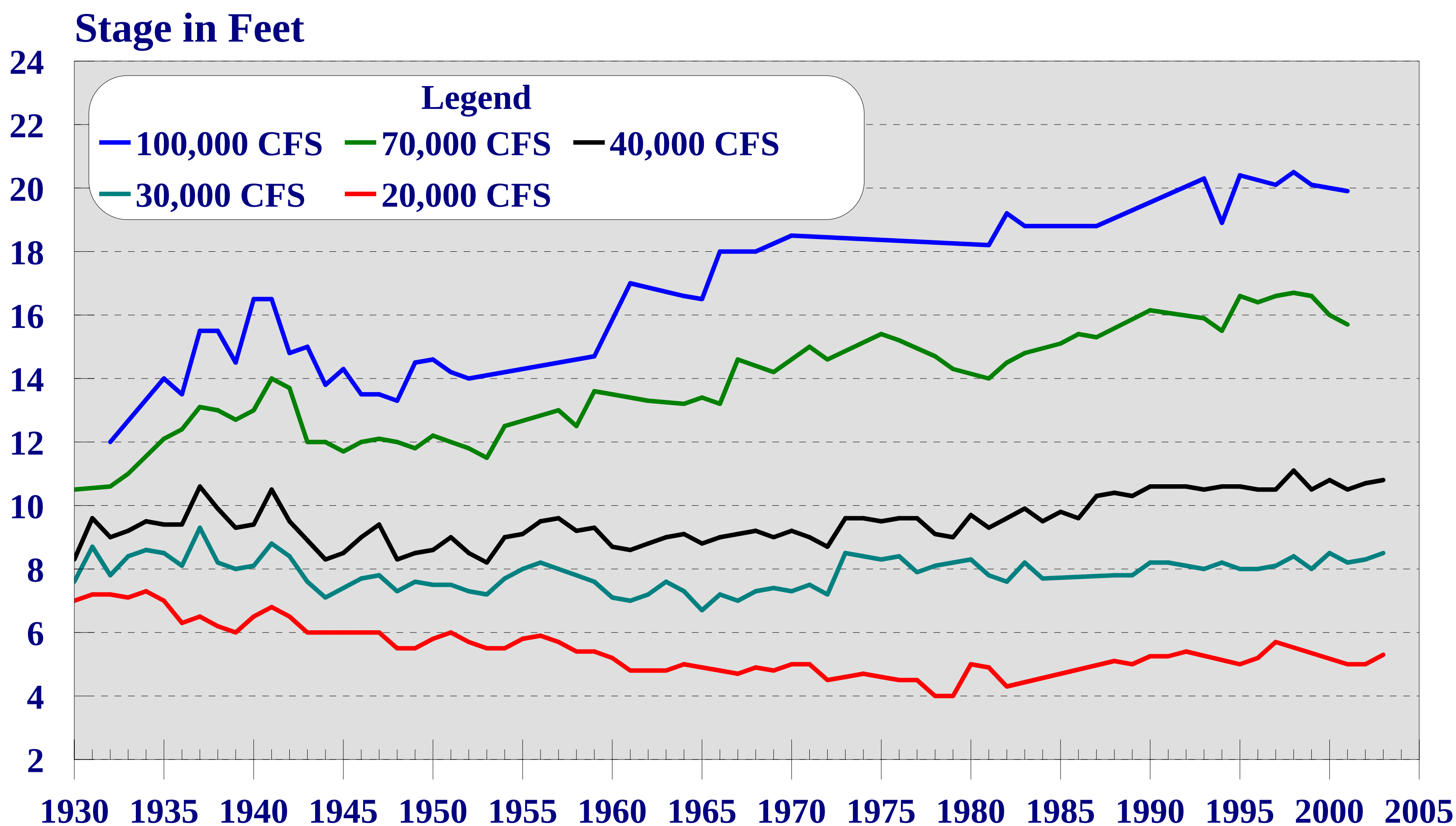


Gage Datum 948.24 feet msl
Flood Stage 29 feet
River Mile 615.9

Figure 11

3/04

Missouri River Stage Trends at Nebraska City, Nebraska

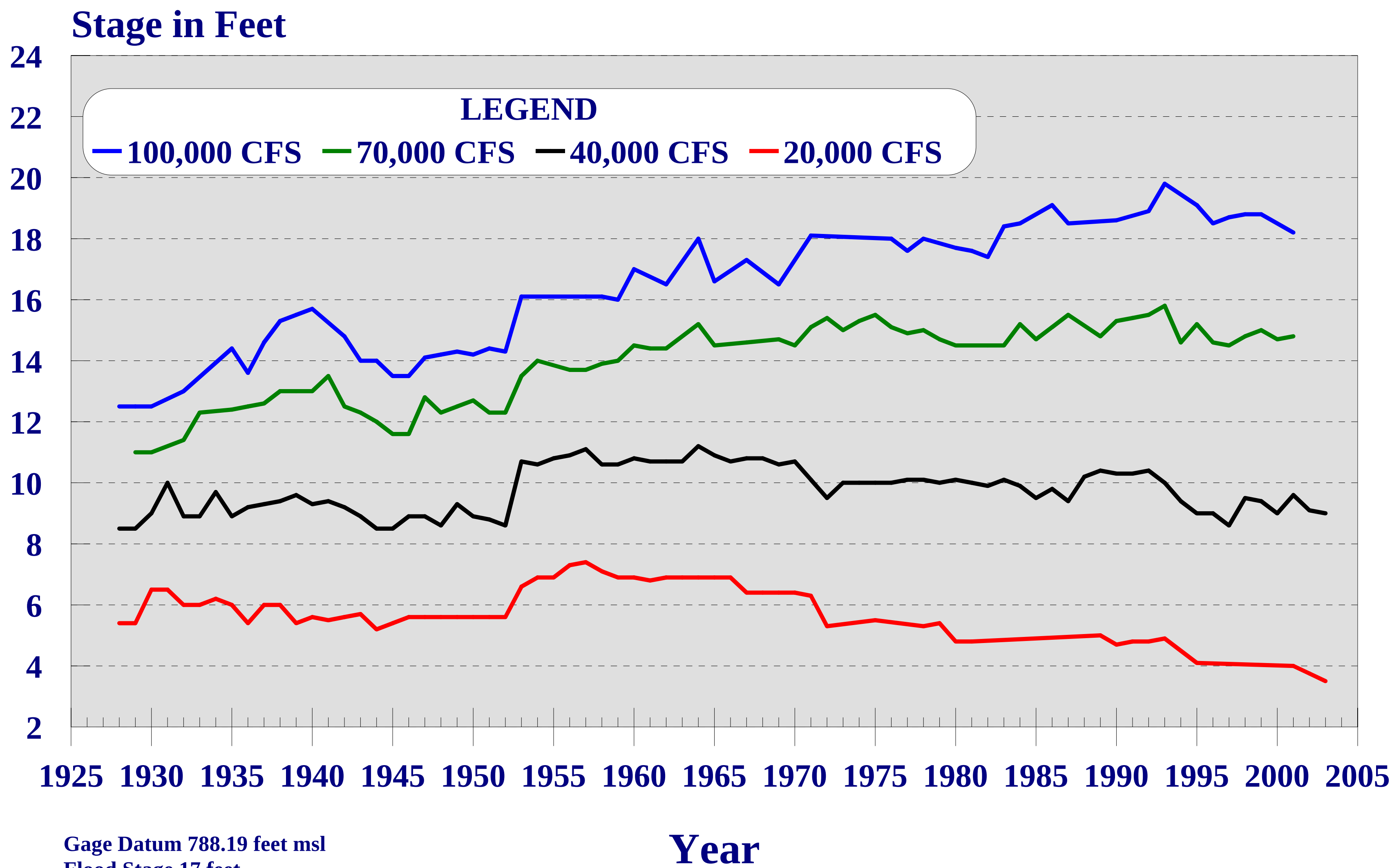


Gage Datum 905.36 feet msl
Flood Stage 18 feet
River Mile 562.6

Figure 12

3/04

Missouri River Stage Trends at St. Joseph, Missouri



Gage Datum 788.19 feet msl
Flood Stage 17 feet
River Mile 448.2

3/04

Figure 13

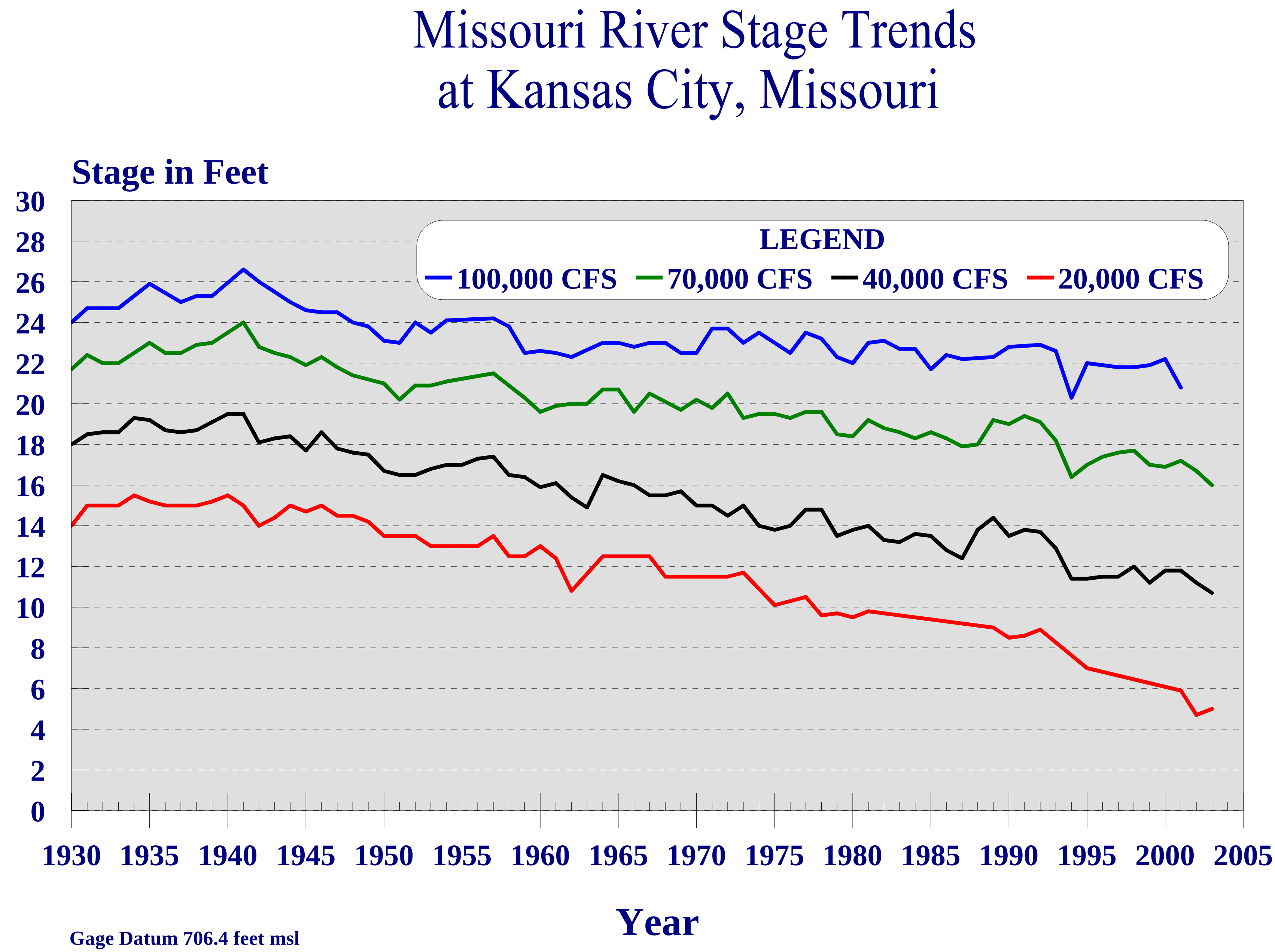


Figure 14

Gage Datum 706.4 feet msl
Flood Stage 32 feet
River Mile 366.1

2003 Provisional Data

3/04

Missouri River Stage Trends at Kansas City, Missouri

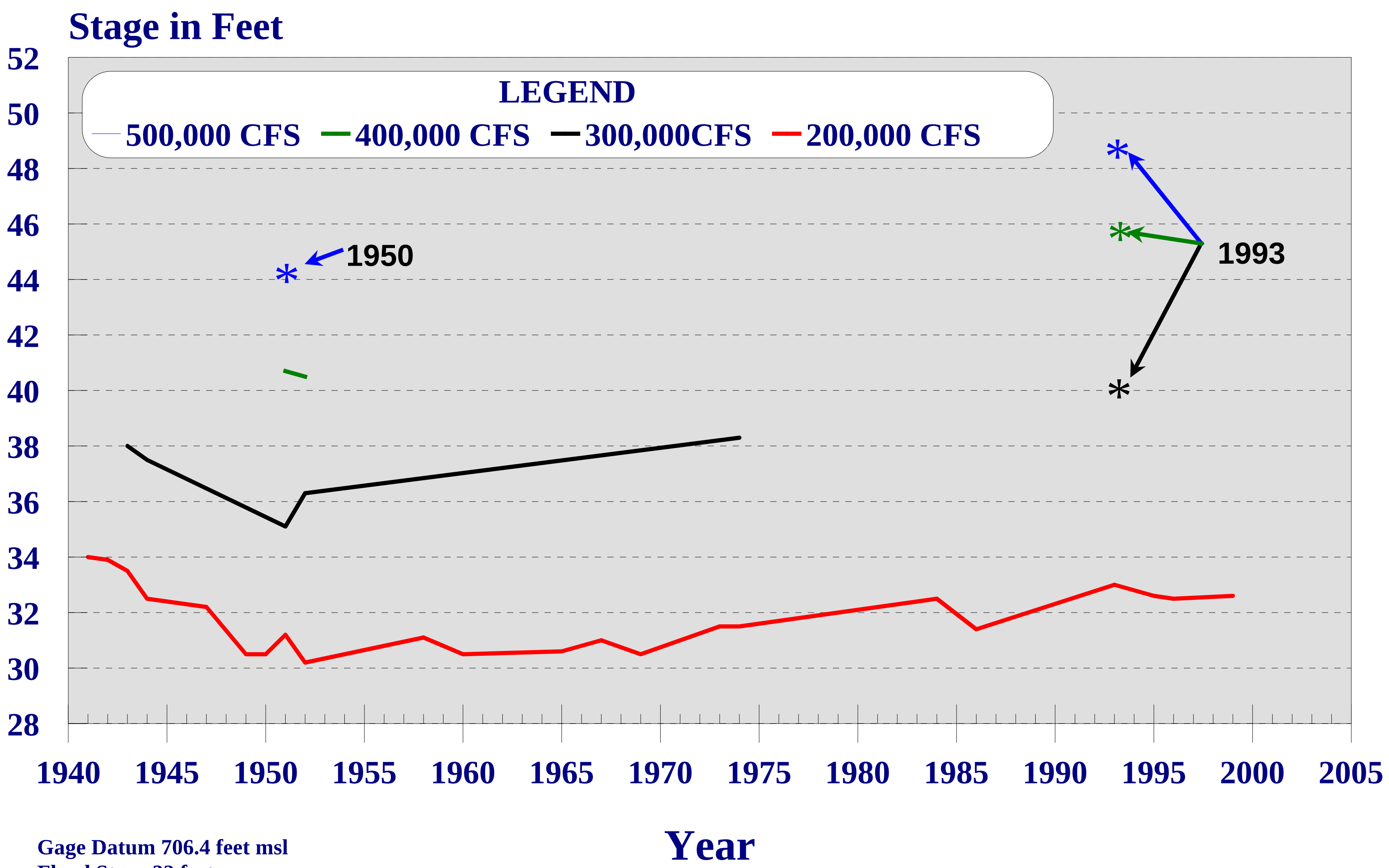
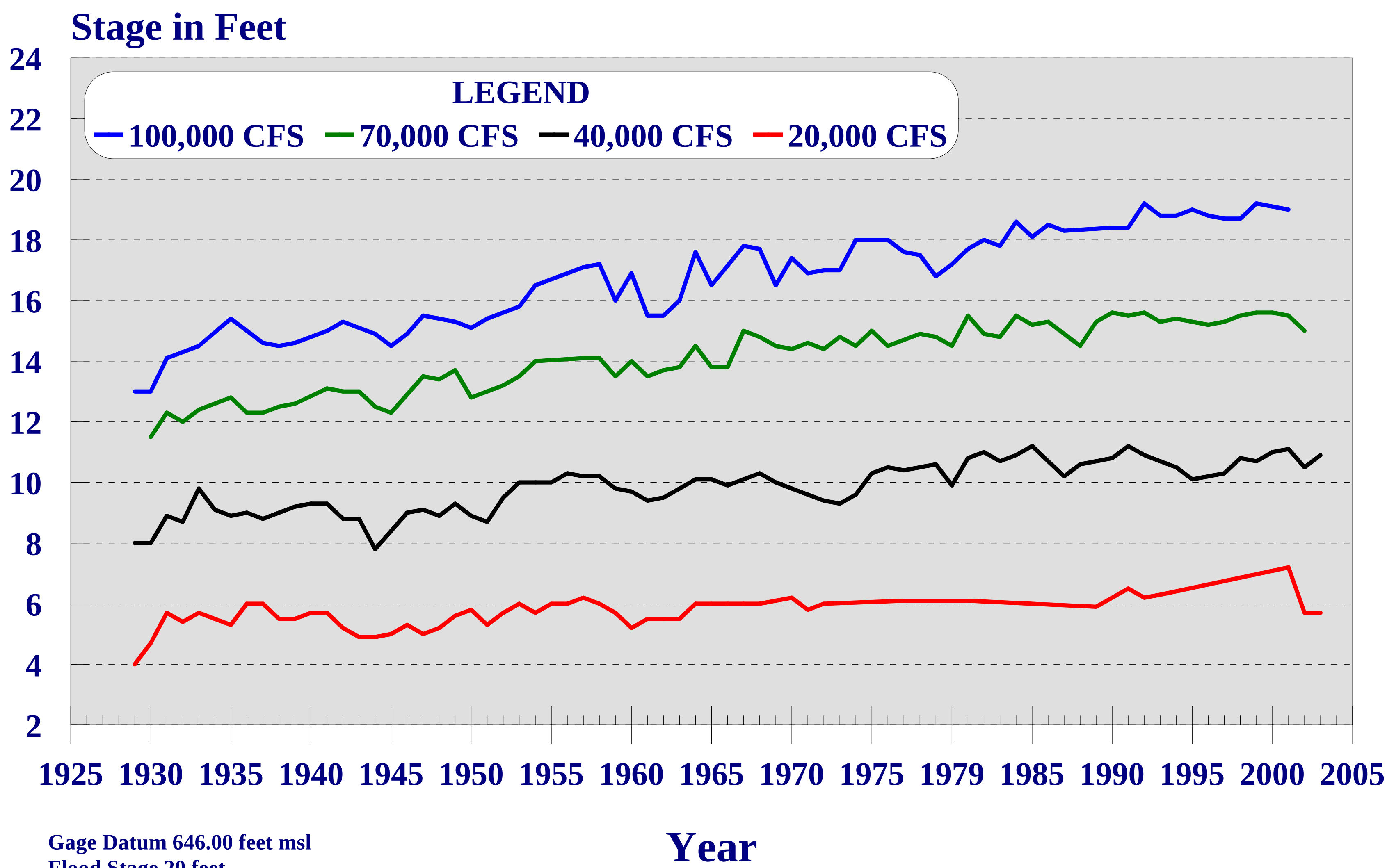


Figure 15

Gage Datum 706.4 feet msl
Flood Stage 32 feet
River Mile 366.1

3/04

Missouri River Stage Trends
at Waverly, Missouri

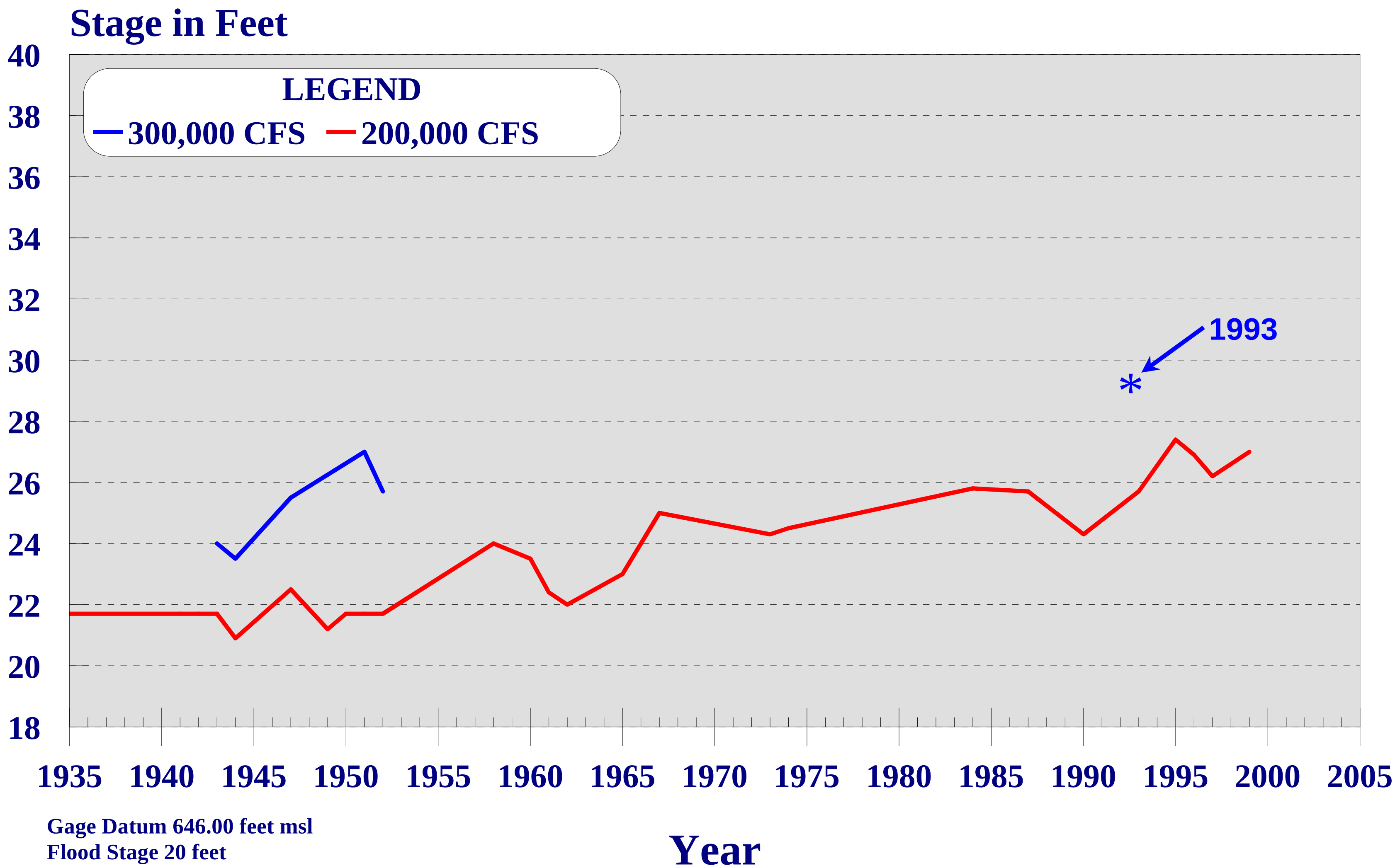


Gage Datum 646.00 feet msl
Flood Stage 20 feet
River Mile 293.4

Figure 16

3/04

Misssouri River Stage Trends
at Waverly, Missouri

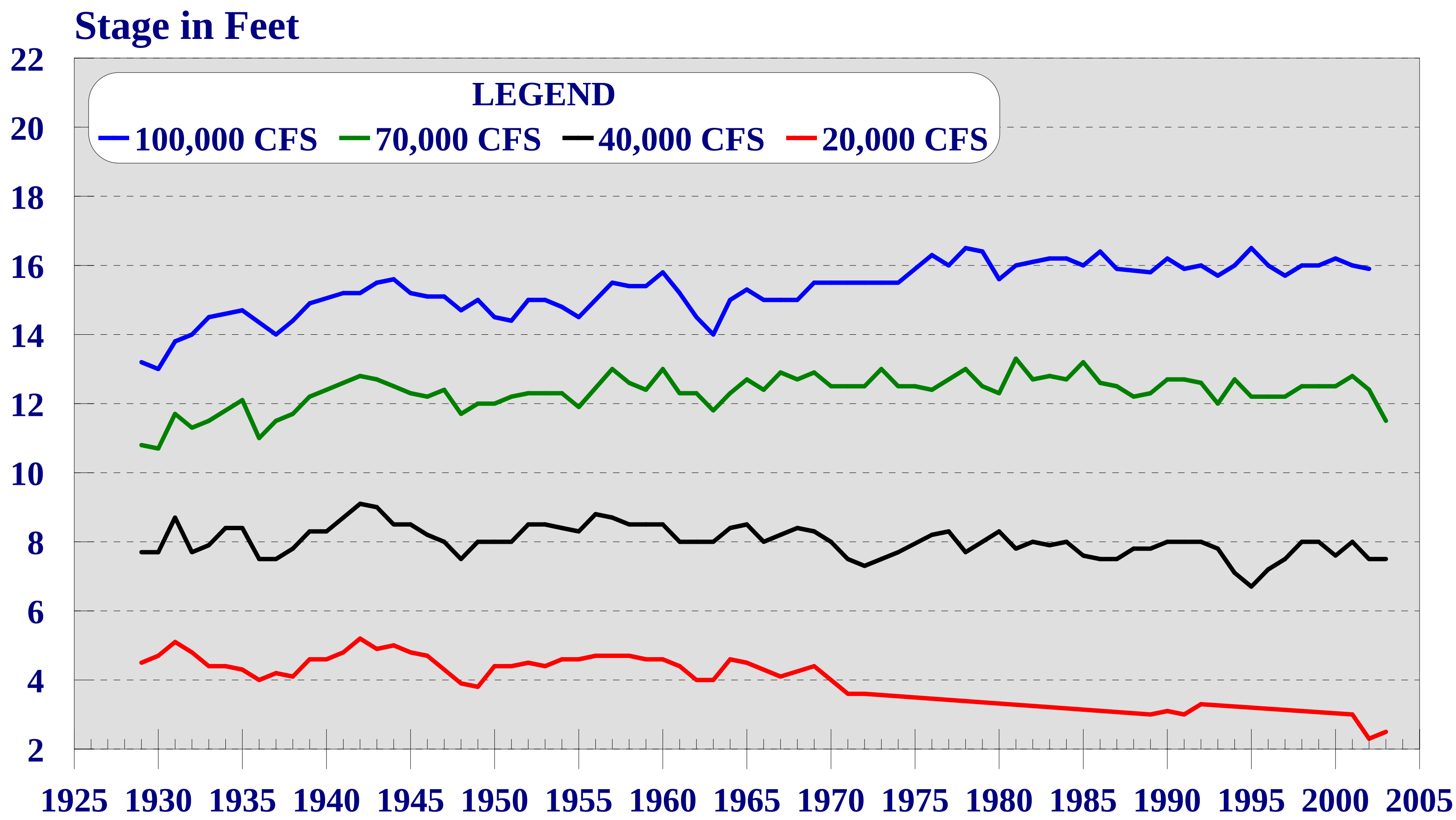


Gage Datum 646.00 feet msl
Flood Stage 20 feet
River Mile 293.4

3/04

Figure 17

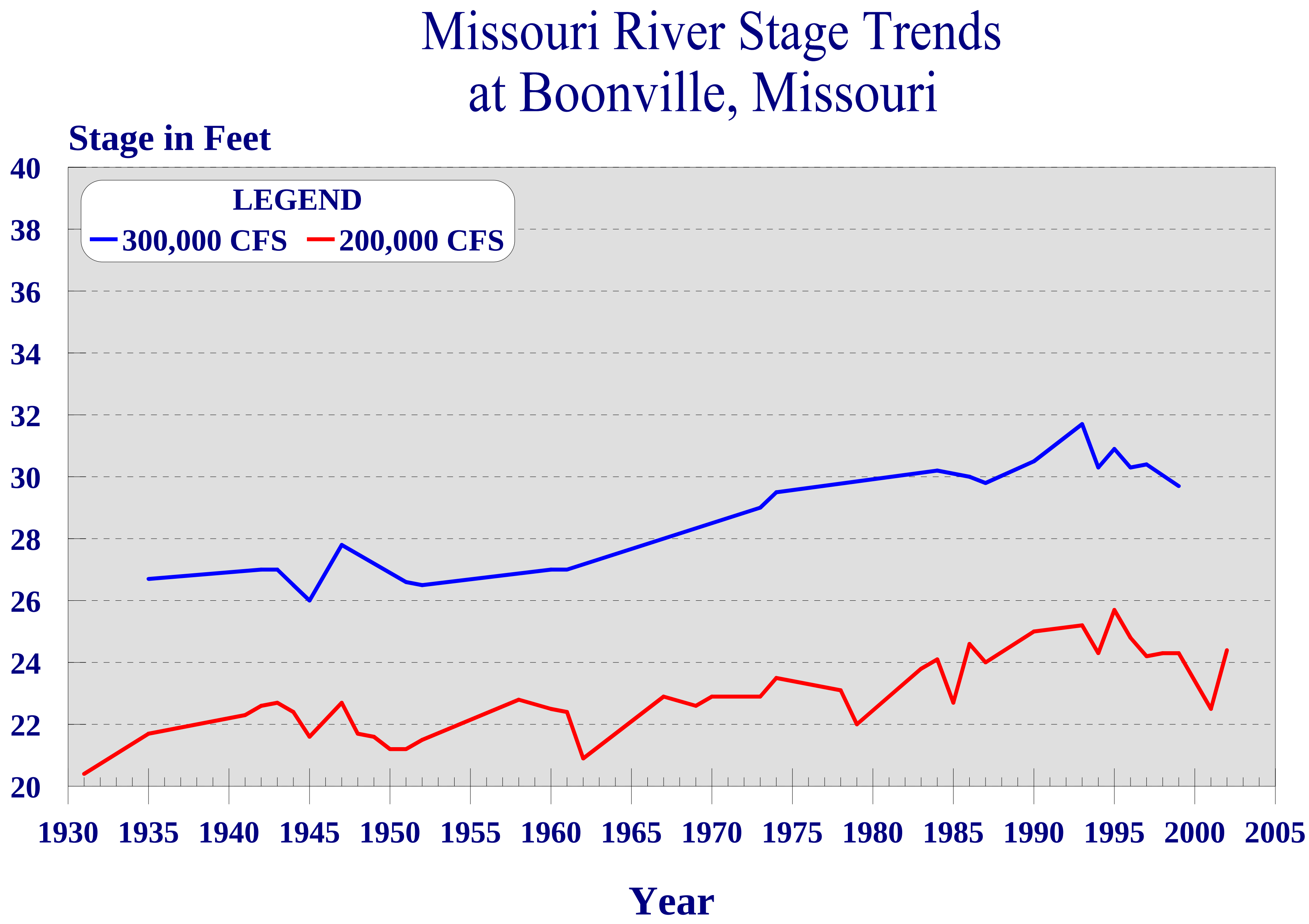
Missouri River Stage Trends
at Boonville, Missouri



Gage Datum 565.42 feet msl
Flood Stage 21 feet
River Mile 197.1

Figure 18

3/04

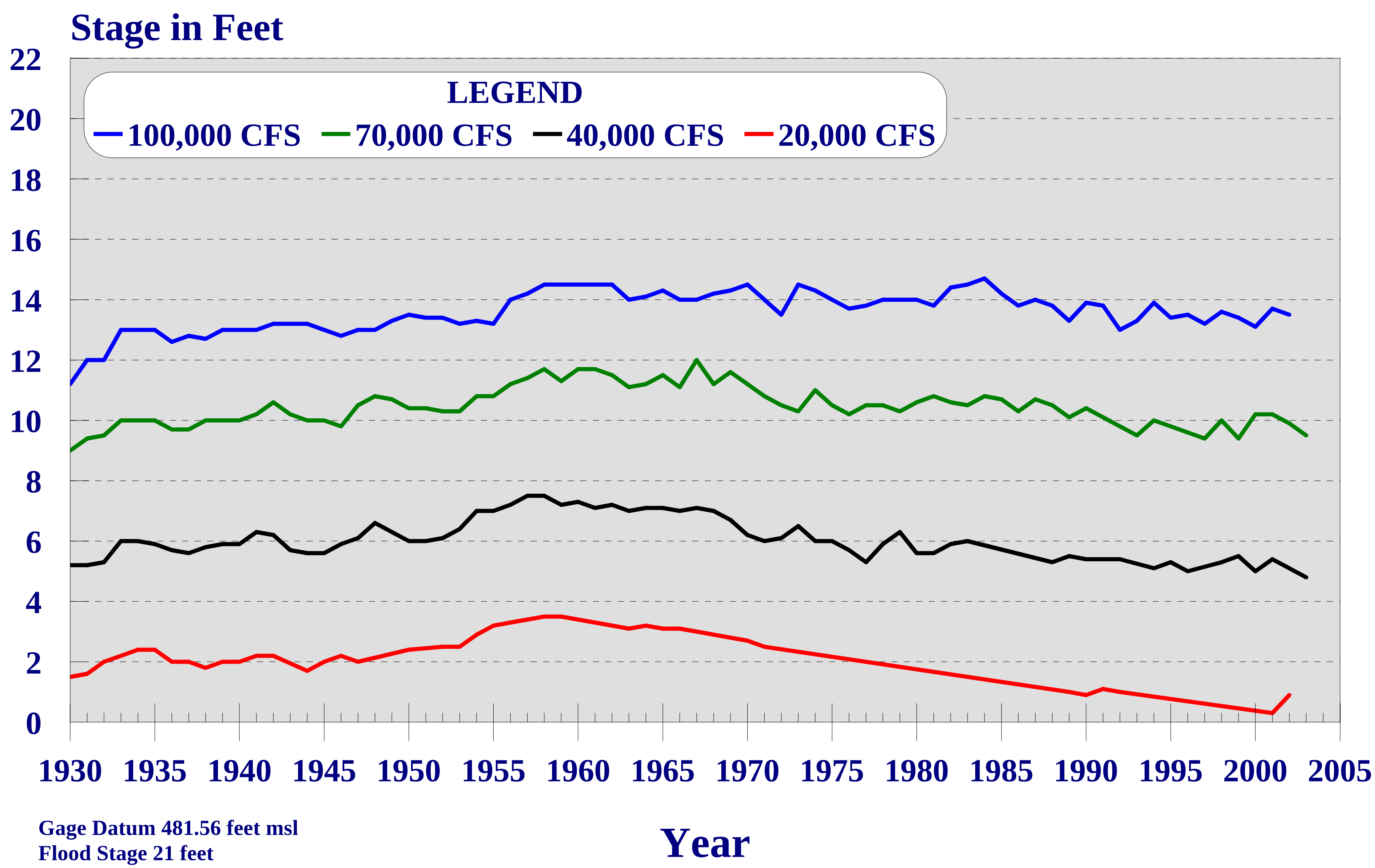


Gage Datum 565.42 feet msl
Flood Stage 21 feet
River Mile 197.1

3/04

Figure 19

Missouri River Stage Trends
at Hermann, Missouri



Gage Datum 481.56 feet msl
Flood Stage 21 feet
River Mile 97.9

Figure 20

3/04

Missouri River Stage Trends
at Hermann, Missouri

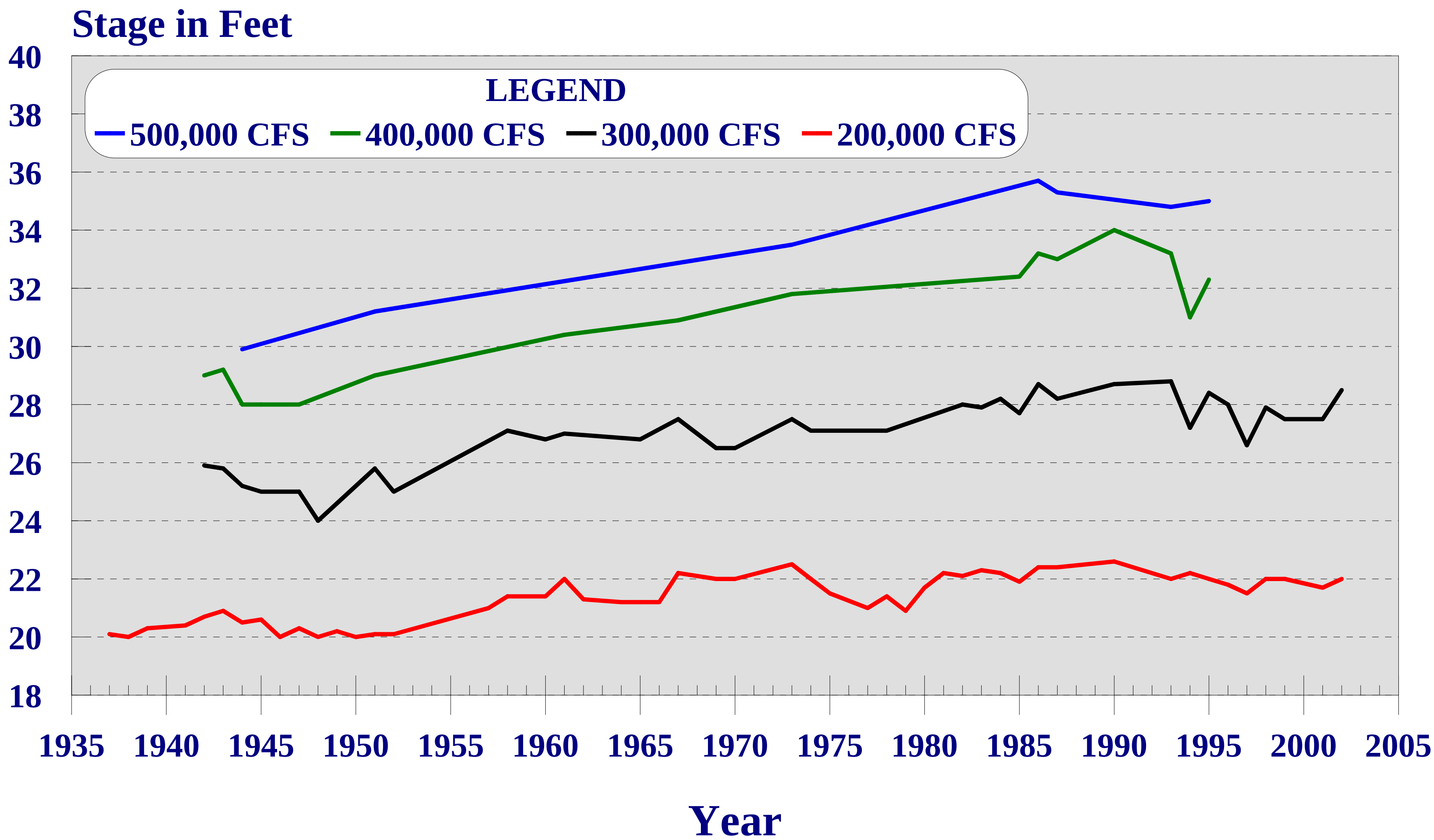
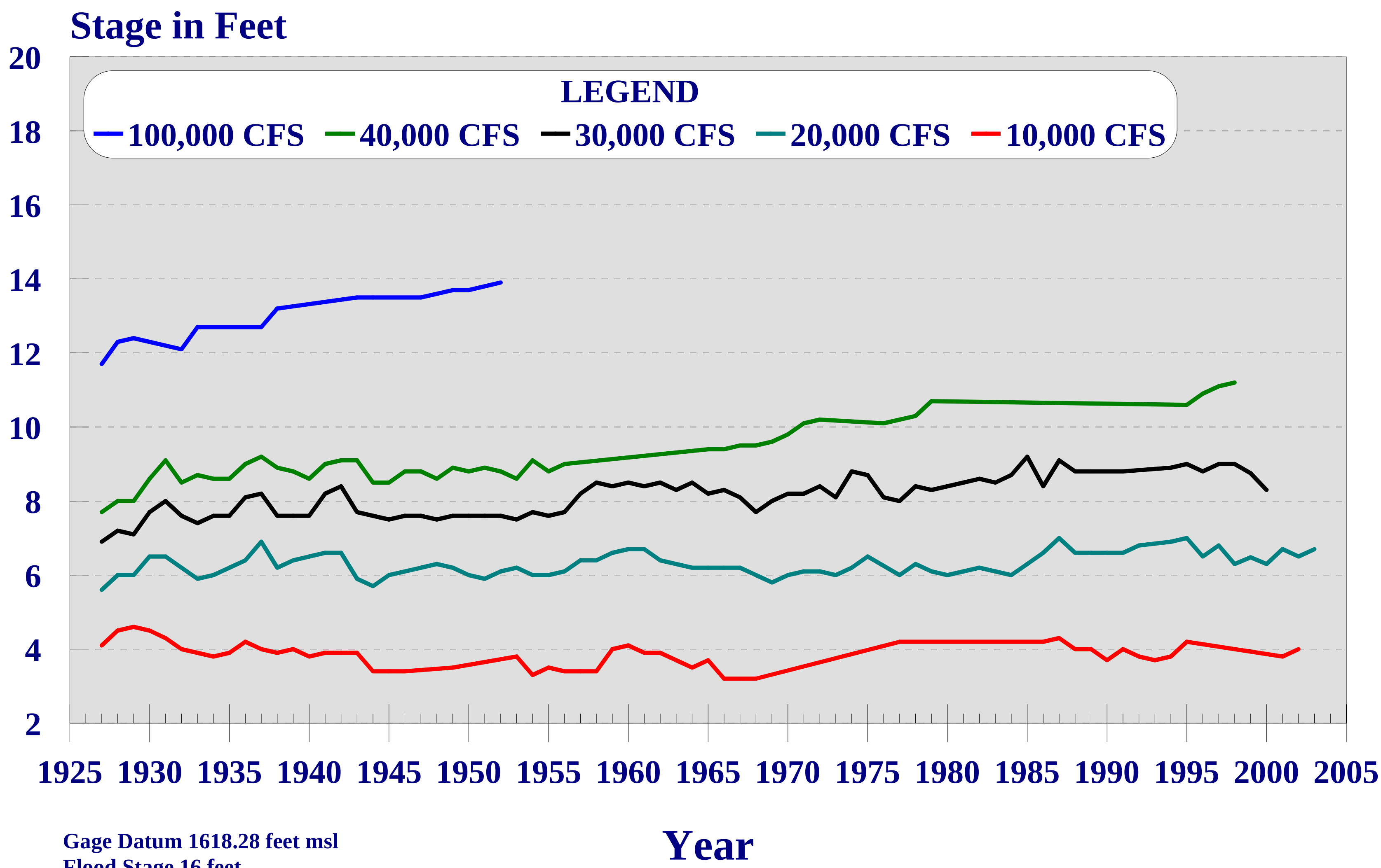


Figure 21

Gage Datum 481.56 feet msl
Flood Stage 21 feet
River Mile 97.9

3/04

Missouri River Stage Trends
at Bismarck, North Dakota



Gage Datum 1618.28 feet msl
Flood Stage 16 feet
River Mile 1314.5

Figure 22

3/04