Summary Report

on

Regulation

of the

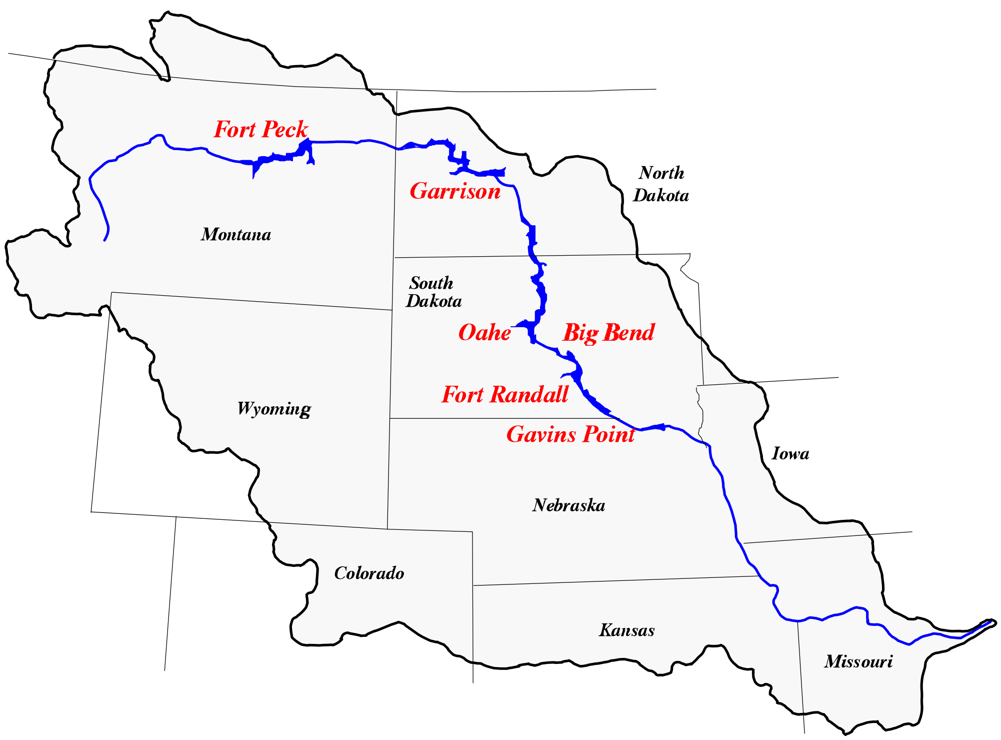
Missouri River Main Stem

Reservoir System

during the

1997 Flood

US Army
Corps of Engineers



Reservoir Control Center
Missouri River Region
Northwest Division
Corps of Engineers, US Army

May 1998

**SUMMARY REPORT ON
REGULATION OF THE MISSOURI RIVER MAIN STEM
RESERVOIR SYSTEM DURING THE 1997 FLOOD**

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Introduction

The Missouri river main stem reservoir system, authorized by the 1944 Flood Control Act, consists of six projects constructed on the Missouri River. Locations of the six main stem projects, as well as major tributary reservoirs in the basin, where regulation is coordinated and integrated with main stem regulation, are shown on **Figure 1**. **Figure 2** shows the storage distribution by project in which 88 percent of the total storage lies in the upper three larger projects and a profile of the system from Fort Peck to Sioux City. The main stem projects are operated for the congressionally authorized purposes of; flood control, irrigation, navigation, hydroelectric power generation, water supply, water quality, recreation, and fish and wildlife enhancement as shown on bottom of **Figure 2.** Pertinent data describing each main stem project and the system as a whole are given on **Figure 3**.

Flood season runoff from the drainage area controlled by the Missouri river main stem system during 1997 exceeded that occurring in any previous year during a century of record keeping. In the process of regulating the unprecedented 1997 runoff, Fort Randall (Lake Francis Case) reached a new record high pool level. Record high system releases were also made in order to evacuate the 1997 flood inflows.

Fort Peck, the most upstream main stem project, has been in operation since the late 1930s. The main stem reservoirs have been regulated together as a system since 1954, but the system did not fill to normal operating levels until 1967. Maximum reservoir levels and average daily releases experienced at each of the main stem projects since full operation began prior to 1997 as well as during 1997 are given below:

Missouri River Main Stem Reservoirs
Maximum Elevations and Releases

	Maximum Elevation, ft. msl			Maximum Average Daily Release, cfs		
Project	**Prior to 1997**		**1997**	**Prior to 1997**		**1997**
Fort Peck	2251.6	1975	2250.3	35,400	1975	22,300
Garrison	1854.8	1975	1854.4	65,200	1975	59,100
Oahe	1618.7	1996	1618.6	57,500	1975	59,300
Big Bend	1422.1	1991	1421.3	69,200	1975	74,300
Ft. Randall	1367.9	1995	1372.2	60,600	1975	67,500
Gavins Point	1210.7	1960	1208.1	61,100	1975	70,100

System storage climbed to 71.7 million acre feet (maf) on July 13, approaching the record 72.1 maf set in 1975. A graph of 1997 main stem storage accumulation is shown on **Figure 4**. The main stem system total storage capacity is currently 73.4 maf. When the storage crested, 1.7 maf (11%) of the total flood storage remained vacant. Total storage capacity continues to decline due to the accumulation of sediment. The main stem total storage capacity has been reduced by 1.2 maf since 1975, based upon the storage tables that were in use in 1975 and in 1997 for each of the reservoirs. The storage losses have generally been in the multipurpose-carryover and inactive storage zones of the reservoirs and not within the specified flood control zones.

All maximum release rates given previously are below the flow rates which occurred frequently prior to operation of the system and below those that would have occurred on numerous occasions since operation of the main stem dams began if it were not for the flood control provided by upstream reservoirs. However, continuation of relatively low outflows for more than 30 years of system operation has adversely affected the downstream channel capacity and has encouraged encroachment upon the downstream floodway. Very expensive developments currently exist and are expanding, along the river between projects and downstream from the main stem system. Examples of this can be seen in Bismarck, ND., Pierre, SD. and above Sioux City, IA., and also in other various locations between the projects.

Another significant impact has been the continued deterioration of channel capacity due to a lack of infrequent high flows that occurred prior to the construction of the main stem reservoirs. Examples of locations in which reductions in channel capacity have occurred are: the river reach near Bismarck, along the Pierre-Fort Pierre waterfront, near the mouth of the Niobrara river, and downstream from the mouth of the Platte river in Nebraska. The higher project releases have increased downstream channel capacities slightly in recent years due to the much above normal releases for extended periods but capacities still remain far below pre-project levels and those used for project design.

Chronological Report of Basin Hydrology and System Regulation:

A chronological history of the regulation performed prior to and during the 1997 flood event is presented below. This history includes; existing conditions, runoff prospects, operational outlook, and actual reservoir regulation operations performed.

1996 Basin Hydrology and System Regulation Summary

Total runoff into the reservoir system during 1996 was the seventh largest of the 100-year record. System releases were scheduled throughout the summer and fall months at rates sufficient to evacuate the accumulated storage prior to the upcoming 1997 flood runoff season. Releases were maintained above 50,000 cfs throughout the fall period as was accomplished in 1995. System storage was reduced as needed for complete evacuation of the annual flood control storage zone. System storage was 57.8 maf at the end of December in spite of the unseasonably high project inflows that continued throughout the fall and early winter period of 1996.

1997 Basin Hydrology and System Regulation Summary

Reservoir elevations, system storage, project releases and runoff, both forecasted and measured, for 1997 are summarized in the tables that follow. Monthly descriptions of basin conditions and system operations follow the tables beginning with January 1997.

Missouri River Main Stem System
1997 End-of-Month Reservoir Conditions

	Fort Peck		Garrison		Oahe		Fort Randall		System	
	Elev	Chg	Elev	Chg	Elev	Chg	Elev	Chg	Storage	Chg
Dec-96	2236.0		1838.9		1607.5		1345.6		57,785	
Jan-97	2235.4	-0.6	1838.0	-0.9	1607.7	0.2	1350.4	4.8	57,744	-41
Feb-97	2235.5	0.1	1839.4	1.4	1609.9	2.2	1356.4	6.0	59,377	1,633
Mar-97	2237.4	1.9	1844.4	5.0	1617.9	8.0	1362.2	5.8	64,609	5,232
Apr-97	2239.6	2.2	1847.5	3.1	1617.9	0.0	1370.8	8.6	67,129	2,520
May-97	2242.9	3.3	1847.8	0.3	1617.6	-0.3	1368.9	-1.9	67,616	487
Jun-97	2248.6	5.7	1853.7	5.9	1617.8	0.2	1368.5	-0.4	71,155	3,539
Jul-97	2250.1	1.5	1852.2	-1.5	1618.3	0.5	1368.7	0.2	71,158	3
Aug-97	2247.7	-2.5	1849.9	-2.3	1617.1	-1.2	1365.8	-2.9	69,080	-2,078
Sep-97	2244.5	-3.2	1846.9	-3.0	1616.5	-0.5	1357.1	-8.7	66,230	-2,850
Oct-97	2240.8	-3.6	1843.4	-3.5	1615.3	-1.3	1347.8	-9.3	62,947	-3,283
Nov-97	2237.3	-3.6	1841.4	-2.1	1612.4	-2.9	1337.4	-10.4	59,824	-3,123
Dec-97	2236.2	-1.1	1840.7	-0.6	1609.8	-2.6	1343.4	6.0	58,893	-931

(highlighted) = Record End of Month Elevation

Missouri River Main Stem System
Average Monthly Project Releases
In 1000 cubic feet per second

	Fort Peck	Garrison	Oahe	Ft. Randall	Gavins Point
Jan	12.7	22.9	24.5	21.0	24.9
Feb	13.3	21.1	19.3	22.5	30.3
Mar	7.3	16.0	23.1	28.0	35.6
Apr	3.2	16.2	53.0	46.4	50.3
May	8.3	31.1	43.7	53.7	59.5
Jun	13.2	42.5	44.8	54.6	60.0
Jul	9.8	57.3	56.6	57.9	61.5
Aug	18.0	49.9	54.5	60.7	64.4
Sep	20.1	46.5	48.5	61.7	65.4
Oct	21.6	49.4	53.9	65.4	68.2
Nov	21.1	42.3	56.1	66.7	70.0
Dec	10.7	21.9	36.1	32.4	37.1

(highlighted) = Record high for month

Missouri River Main Stem System
Annual Runoff Forecasts and Actual Monthly Runoff
Above Sioux City, Iowa

	Forecast (kaf)	Normal	Actual (kaf)	Normal (kaf)	% Normal
Jan-97	29,205	119%	1519	730	208%
Feb-97	33,388	136%	2954	1020	290%
Mar-97	35,492	144%	7262	2840	256%
Apr-97	38,532	157%	8686	2880	302%
May-97	42,469	173%	6023	3240	186%
Jun-97	44,517	181%	9652	5350	180%
Jul-97	46,799	190%	5194	3140	165%
Aug-97	47,570	193%	2768	1290	215%
Sep-97	49,013	199%	1483	1170	127%
Oct-97	48,736	198%	1395	1180	118%
Nov-97	48,501	197%	1258	1050	120%
Dec-97	48,501	197%	1524	710	215%
1997 Total			49,718	24,600	202%

(highlighted) = record high for month

January 1997

Mountain snowpack, on January 1, 1997, was 181 percent of normal above Fort Peck and 169 percent in the reach from Fort Peck to Garrison. Heavy snowpack existed on the plains across eastern Montana and the Dakotas. The runoff forecast upstream from Sioux City, Iowa, for 1997 based on the existing plains and mountain snowpacks was 29.2 maf, already at this early date 4 ½ maf above normal (119 percent of normal). The Calendar Year Runoff Forecast was based upon normal precipitation for the remainder of the year. The bottom of **Figure 4** indicates the Annual Calendar Year Runoff Forecast as computed each month during 1997 by the RCC.

The plan for system regulation included a system release of less than 40,000 cfs later in the year to orderly evacuate the water from flood storage by the spring of 1998. System storage was expected to crest at about 64 maf, which was less than the maximum storage reached in either 1995 or 1996.

Runoff during the month continued to be much above normal and, in fact, turned out to be a record high for the month of January. In recognition o the high runoff and the forecast of continued above normal system inflow, system releases for the month averaged 24,900 cfs. This was the second highest January release of record, the largest was 25,900 cfs which occurred in 1987 as a flood storage evacuation measure.

February 1997

On February 1, the mountain snowpack in the upper Missouri river was 155 percent of normal above Fort Peck and 159 percent in the reach from Fort Peck to Garrison Dam**.** **Figure 5** shows the 1997 mountain snowpack accumulation for the two reaches. Total snowfall accumulation on the upper plains continued to be quite heavy. The plains snowpack ranged from less than 6 inches in eastern Montana to as much as 36 inches in eastern North and South Dakota.

"The white residue of a brutal midwestern winter has set the stage for another high water year in the Missouri River basin," was the way the Corps press release described the month of February. The forecast for annual runoff was raised to 33.4 maf, 136 percent of normal and equal to a runoff that would be expected in only one year in 10. This was a very high runoff forecast for so early in the year.

The RCC was very aggressive in releasing water to prepare the reservoirs to capture the large volume of expected runoff that was yet to come. Releases from Gavins Point Dam were at 29,000 cfs at the beginning of the month and averaged a record 30,300 cfs for the month, exceeding the historic record set just 1 year earlier by 26%. By months-end, the release had been increased to 37,000 cfs. The normal release rate in February is 17,000 cfs. Ice in the river and the potential for significant flooding downstream from the main stem projects limited the releases from being even higher.

System storage at the beginning of the month was 57.7 maf, down slightly from December and very near the goal of 57.4 maf on March 1.

Early melting of part of the plains snowpack poured record amounts of water into the Missouri river reservoirs in February, but still over 85 percent of the flood storage remained available to capture the large runoff. The system gained 1.6 maf during the month, 1.2 maf of that in the last 10 days of the month, in spite of the record high system releases. The Ft. Randall pool rose 6.0 feet and Oahe climbed 2.2 feet. Total runoff upstream from Sioux City was nearly 3 maf for the month , almost 3 times normal, and the second highest of record exceeded only by the February runoff in 1996. Runoff in the reaches upstream from Ft. Randall and Gavins Point set new records based upon the 100-year historic period**.** **Figure 6** depicts the actual monthly runoff at Sioux City for 1997 as well as the annual runoff from 1989 through 1997.

March 1997

On March 3, the mountain snowpack was near a record 139 percent of normal above Fort Peck and 147 percent in the reach from Fort Peck to Garrison Dam. A major plains snowpack remained. . The extent and magnitude of the plains snowpack from water equivalent data acquired by Omaha District Corps of Engineers staff during a mid-March snow survey are shown on **Figure 7**. The runoff forecast for 1997 was raised to 35.5 maf, 144 percent of normal and if the forecast verified, it would be comparable to the largest runoffs of the 100-year historic record including 1996.

The National Weather Service forecasted record flooding for the James and Vermillion river basins and major flooding on the Big Sioux river basin in eastern North and South Dakota which was an indicator as to the seriousness of the heavy plains snow pack. It was anticipated at the beginning of the month, that releases from the main stem reservoirs would be reduced to minimize the potential for downstream flooding when the remainder of the plains snowpack melted. Model studies based upon the current runoff forecast showed a need to increase system releases by mid-summer to about 50,000 cfs in order to evacuate the expected accumulated storage to the base of flood control by the following spring.

As a result of the rapid melt of the plains snowpack, runoff upstream from Sioux City totaled 7.3 maf during the month, two and one-half times normal and very near the historic maximum. Actual runoff in the Oahe reach did set a new record, while the reaches downstream from Oahe approached their historic maximums.

System releases were adjusted up and down during the month in response to large downstream streamflows. But the aggressive release schedule was maintained in order to retain sufficent flood control storage to contain the remainder of the plains snowmelt plus the runoff expected from the much above normal mountain snowpack that was yet to melt and make its way to the projects.

System releases began the month at 36,000 cfs and ended the month at 42,000 cfs with reductions during the month to as low as 24,000 cfs to control downstream flooding. Releases averaged 35,600 cfs for the month and like February, broke the record set in 1996. Fort Peck and Garrison releases were reduced to prevent overfilling at Oahe and Fort Randall. Garrison releases were reduced to a record low 4,100 cfs on March 25. In spite of low Garrison releases, inflows into Oahe climbed to 162,000 cfs late in the month. The Oahe pool climbed six feet during the last 10 days of March, entering into its exclusive flood control pool on March 28. System storage increases approached 500,000 maf per day during the last days of March. **Figure 8** indicates average monthly releases during 1997 for the major flood control projects as well as Gavins Point system releases during 1996 and 1997.

The melting plains snowpack poured tremendous amounts of water into the Missouri river reservoirs in March, resulting in a record end-of-month storage of 64.6 maf. The Oahe and Ft. Randall pools climbed 8.0 and 5.8 feet respectively during the month. Oahe climbed into its exclusive flood control pool late in the month and the Ft. Randall pool approached the base of its exclusive pool. Releases from Oahe Dam were increased from 25,000 cubic feet per second (cfs) to over 57,000 cfs by the end of March to stem the rise of the Lake Oahe pool. It was necessary to utilize some of the vacant flood storage at Ft. Randall temporarily to accomplish a reduction in Oahe pool. The Lake Oahe elevation was 1617.9 feet msl and the reservoir's flood storage capacity was 82 percent full on March 31.

Record flooding on the James and upper Big Sioux river basins in eastern North and South Dakota occurred in late March and early April. In response, releases from Gavins Point Dam were reduced from 42,000 cfs to 38,000 cfs to minimize downstream flooding to the extent possible while still considering the expected future inflows into the main stem system.

April 1997

At the beginning of April, the mountain snowpack was 131 percent of normal above Fort Peck Dam and 136 percent in the reach from Fort Peck to Garrison Dam. The annual runoff forecast was raised an additional 3 maf to 38.5 maf, 157 percent of normal on 1 April. If the forecast were to verify, it would be the second largest runoff in the 100-year historic record and Gavins Point releases during both the summer and fall would have to be comparable to levels experienced during each of the past two years.

Blizzard conditions in early April dumped several inches of unwanted water in the form of snow across parts of North and South Dakota. The additional snowmelt combined with rain, poured huge amounts of water into the Missouri River reservoirs. Total runoff upstream from Sioux City for April was 8.7 maf, three times normal and the second largest runoff in 100 years of record, exceeded only in 1952. The runoff in the reach from Gavins Point Dam to Sioux City contributed 2.4 maf, 40% greater than the previous record high in 1984 and 7 times greater than average. System storage increased an additional 2.5 maf and ended the month at a record 67.1 maf.

System releases were increased during the month from a low of 38,000 cfs early in the month to 58,000 cfs by month's end, averaging 50,300 cfs for the month. Release increases were timed to follow the flow crests on the James and Big Sioux rivers to minimize downstream flooding. Flows at Sioux City approached 100,000 cfs early in the month as the record plains snowpack quickly melted due to very warm temperatures. The flows at Sioux City exceeded the Gavins Point release by as much as 60,000 cfs during the month. Flood stages were exceeded on the Missouri river from the Platte river in Nebraska to the mouth near St. Louis. The stages downstream from the Platte river to Kansas City rose above flood stage early in the month climbing to more than three feet over flood stage. Stages remained above flood stage for the remainder of the month causing significant flooding and interior drainage problems during the planting season.

The Ft. Randall pool rose from 1362.2 to 1370.8 feet msl during the month, exceeding the previous April record high pool by 7 ½ feet and the all time previous record high pool by 3.0 feet. Oahe releases were reduced by mid-April after Lake Oahe crested, to help check the rising Lake Francis Case. Ft. Randall climbed into its exclusive flood control pool during the first week of the month and reached record high levels by the second week. It climbed to elevation 1370 by the 14th of the month. The exclusive flood control zone at Ft. Randall extends from elevation 1365 to 1375 ft. The Ft. Randall pool had climbed into the exclusive flood control pool only two times previously, most recently in 1995. The Ft. Randall pool was held near 1370 feet the last half of the month at the request of the Omaha District. The stable pool elevation was requested during rip-rap placement so additional erosion would not occur in an area that was eroded by wave action as the pool was rising. Oahe remained in its exclusive flood control pool throughout the month, ranging from 1617.1 to 1618.6 feet msl and ended the month at 1617.6 ft. The extremely cold temperatures, which began early in the month and extended through mid-month, reduced plains snowmelt runoff and allowed the necessary time to transfer a significant amount of water stored in the Oahe exclusive flood control zone downstream into Ft. Randall. Temperatures warmed later in the month, increasing inflows to as high as 99,000 cfs. However by then, storage space was available in Oahe to capture the added runoff due to the melting of the snow from the blizzard that occurred during the first part of the the month. **Figure 9** indicates the 1997 lake elevations from January through October for the major storage reservoirs relative to the top of that project's spillway gates (top of exclusive flood control zone).

Garrison releases averaged 16,200 cfs and Fort Peck averaged a record low 3,200 cfs in April to retain as much vacant storage as possible in the downstream Oahe and Ft. Randall projects due to their unseasonably high levels. Garrison releases were stepped from 10,000 to 20,000 cfs during the second and third weeks of the month. The Fort Peck pool began the month at 2237.5 ft. msl and ended the month at 2239.6 ft msl nearly 6 feet above average.

May 1997

On May 1, the mountain snowpack was estimated at 135 percent of normal above Fort Peck Dam and 136 percent in the reach from Fort Peck to Garrison. The mountain snow accumulation usually peaks around mid-April.

As a result of the large actual April runoff and the mountain snowpack runoff estimate, the forecast for annual runoff was increased to 42.5 maf on May 1, an increase of 4 maf from April's forecast. The 42.5 maf runoff if verified would be the largest runoff since record keeping began in 1898. The previous record runoff above Sioux City, Iowa, was 40.6 maf in 1978. If this forecast were to verify, Gavins Point releases during the summer and fall would continue in the 55,000 to 60,000 cfs range.

Releases from Gavins Point averaged 59,600 cfs during May, 16,000 cfs higher than the previous monthly maximum which occurred in May 1971. Releases were increased from 58,000 cfs to 60,000 cfs early in the month following a drop in downstream tributary flows as the runoff from the last of the plains snowpack subsided.

Fort Peck releases were increased from 3,000 to 12,000 cfs by mid-month while the Garrison releases were adjusted to 40,000 cfs. Both pools were climbing slightly but the melt of the mountain snow pack was just beginning. Concern centered on the unprecedented pool levels being experienced currently at both Oahe and Ft. Randall. The large amount of accumulated system storage precluded system release reductions for downstream flood control. Storage space in the main stem system would be at a premium once the mountain snowpack runoff was captured.

Despite relatively dry conditions across much of the Missouri river basin, inflows into the reservoirs continued to be much above normal. Runoff during May was 6.0 maf, 186 percent of normal and the fourth highest on record. Runoff for the first 5 months totaled 26.4 maf, a whopping 247 percent of normal. The 1997 runoff exceeded the record January through May inflow in 1952 by 14 percent.

System storage ended the month at a record high 67.6 maf, an increase of one-half maf. The previous high was 66.8 maf in 1979. The relatively small system storage gain during May was credited to the aggressive system release schedule. The lakes behind Garrison, Oahe, and Ft. Randall dams ended the month at record May levels. Lake Francis Case exceeded its previous high pool elevation by 4.3 feet.

The Missouri river flow downstream from the system continued to be much above normal throughout the month. The Missouri River downstream from the Platte river in Nebraska remained above flood stage during the entire month. The James river flows declined during the month but remained well above average. The Big Sioux river flows continued to be much above normal throughout the month. No significant rainfalls occurred downstream from Gavins Point during May which greatly reduced the amount of flood damage experienced by the high system releases.

June 1997

On the first of June, the annual runoff forecast was increased an additional 2 maf to 44.5 maf , due to the remaining mountain snowpack and the persistent high runoff in all the reaches above Sioux City. If the forecast were to verify, the Gavins Point releases for the summer and fall would continue to be near 60,000 cfs. The much above normal temperatures caused the mountain snowpack to melt faster than normal which resulted in only half of the peak water equivalent amounts remaining on June 1.

Rapidly melting mountain snow pumped extraordinary amounts of water into the Missouri river reservoirs during June. Runoff in June was 180% of normal and the third highest in a century of record keeping. Storage in the big lakes was pushed to a June record high 71.1 maf. Runoff into the reservoirs during the first six months of the year totaled 36.1 maf, 225% of normal and one and a half times the amount that usually occurs in an entire year.

Unseasonably warm temperatures caused the mountain snow to melt much quicker than normal. This mountain snowmelt runoff raised the pool levels of Fort Peck and Garrison nearly six feet during the month. By capturing the high flows, the main stem dams significantly reduced peak river stages from Montana to Missouri. The lakes behind both Garrison and Ft. Randall dams ended the month at record June levels. The four large storage projects on the main stem system, Fort Peck, Garrison, Oahe and Ft. Randall were all in their exclusive flood control zones at the same time for the first time during the 1997 runoff event.

The lake behind Garrison Dam climbed two feet during the first two weeks of the month, reaching the base of its exclusive flood control zone on June 14. It continued a rapid rise during the last half of the month to very near the top of its exclusive flood control pool. It ended the month at elevation 1853.7 ft., only 0.3 feet below full pool. Inflows climbed to 100,000 cfs by mid-month. The project releases were increased from 40,000 to 50,000 cfs during the month as it became apparent that the volume of inflow was going to be record or near record.

Heavy rain fell in western North Dakota and eastern Montana very late in the month. Widespread areas reported 2 to 3 inches of rain with embedded rainfall reports of 4 to 5 inches. Williston, ND reported 4.54 inches, an unusually large amount of rainfall for this time of year. Prior to the rain, inflows into the reservoirs had dropped dramatically and storage gains were only modest. Lake Sakakawea was forecast to crest about one foot below the top of the exclusive flood control pool with the expected inflow from mountain snowmelt and normal precipitation. The very large rain event, however, caused early July inflows to increase dramatically and Lake Sakakawea gained 0.6 feet on the first day of July, rising to 0.3 feet above the top of the exclusive flood control pool.

River stages downstream from the reservoir system dropped only slightly during the month as tributary streams gradually fell. Missouri river stages downstream from the Platte river in Nebraska continued to be above flood stage throughout most of the month. A late month storm caused the river to again climb to about 2 to 3 feet above flood stage for a short period.

July 1997

The forecast for annual runoff was raised an additional 2.3 maf on 1 July, to 46.8 maf as a result of the large June runoff and the outlook for continued high inflows through July.

Above normal rainfall in July combined with the last of the melting mountain snow pushed 1997runoff to another record in the Missouri river basin. Runoff for July totaled 5.2 maf, 165 percent of normal and the eleventh highest in 100 years. System storage crested at 71.7 maf on July 13. The Fort Peck pool crested during the fourth week in July. Lake Sakakawea reached its maximum level on 1 July. Lake Oahe remained about one foot into its exclusive flood control pool throughout the month. Lake Francis Case remained nearly level with three to four feet of its 10 foot exclusive flood control pool filled.

It was necessary to further increase the Garrison releases early in July as a result of a rainstorm that dumped even greater inflows into the upper reservoirs. A sudden increase in the inflows into Garrison caused unexpected storage gains and the need for a regulation change. The releases were increased from 50,000 to 59,000 cfs by July 10. That release rate was maintained until July 28. This flow was near bankfull capacity through Bismarck with only a slight amount of channel buffer remaining for a downstream rainfall event that could easily exceed channel capacity and flood a major part of Bismarck. The pool was hovering near its full pool elevation of 1854 ft. The pool crested at 1854.37 ft. on July 1, and remained slightly above elevation 1854 for 13 days during the month. Water overtopped the spillway gates during a short period of the month. It should be noted that the USBR tributary reservoirs were regulated to help stem the rise at Lake Sakakawea during this period. The delayed evacuation of accumulated storage in the USBR projects on the Yellowstone and Upper Missouri resulted in reduced releases from Garrison and a delay in release increases from Fort Peck. The effect was that greater flood damages were prevented downstream because of the coordinated USBR and Corps of Engineers reservoir operations.

The Fort Peck pool climbed to the top of its exclusive pool (2250 feet msl) on July 15. It hovered near that elevation throughout the remainder of the month. Because of downstream constraints (the extremely high level of Lake Sakakawea) releases were not increased significantly from the 7,000 cfs rate until late July, ending the month at 14,000 cfs**.** **Figure 10** depicts the 1997 minimum and peak lake elevations for the major main stem flood control reservoirs. Also shown on the top of **Figure 10** is the total system storage at various times during 1997 related to the historic maximum and minimums. **Figures 11 through 13** show the individual main stem projects elevations, actual inflows and outflows for all of 1997.

System releases from Gavins Point averaged a record 61,500 cfs during the month, compared to an average July release of 33,700 cfs. The previous record was 52,600 cfs in 1975.

August 1997

Due to the extremely large July runoff, Gavins Point releases were increased to 65,000 cubic feet per second (cfs) during the first week in August. Plans were to continue the record releases through the summer and fall in order to evacuate the stored flood waters. The updated August 1, forecast for annual runoff was raised another 0.8 maf to 47.6 maf.

Runoff in the upper Missouri river basin during August was more than double the normal rate, slowing the evacuation of excess water in the big reservoirs. The 2.8 maf of runoff in August was 215 percent of normal, the second highest on record. System storage declined by 2.1 maf to 69.1 maf leaving nearly 12 maf of water to be evacuated. The Fort Peck, Garrison and Ft. Randall pools dropped more than 2 feet while Oahe fell only a foot. Garrison dropped out of its exclusive flood control pool on August 30, the first of the four larger main stem projects to have that storage zone evacuated.

River stages downstream from the system remained high but nearly steady. For example, the river stage at Nebraska City remained between 1 and 2 feet below flood stage throughout the month. No major rain storm events occurred during the month with the exception of a modest increase in the Platte river flows due to added rainfall runoff. The lack of downstream tributary runoff was similar to the other large evacuation years of 1975 and 1978, where downstream rainfall events were not significant.

September 1997

The September 1, annual runoff forecast was raised an additional 1.5 maf to 49 maf (198 percent of normal). System storage at the end of September was 66.2 maf the second highest since the system filled in 1967, exceeded only by 0.6 maf in 1975.

Reservoir inflows continued to decline and storage losses increased to average about 100,000 acre-feet per day. Fort Peck fell from its exclusive flood control pool on the 16th of September, Oahe on the 13th, and Ft. Randall on the 6th. System releases were further increased to 68,000 cfs late in the month, as it became apparent that the total flood storage accumulated could not be evacuated by March 1st with the current release schedule.

October 1997

The reservoirs continued to decline but because of greater than expected runoff into the system, releases were increased to a record 70,000 cfs on October 26 to meet the operational objective of having system storage at 57.1 maf on March 1, 1998. The fall stage shift on the Missouri river occurred on schedule, which resulted in very little stage increase for the 2,000 cfs increase in release. System storage was at 63.0 maf at the end of October, the third highest since the system was filled in 1967 but, 1.0 maf less than the record set in 1975.

November - 1997

The reservoirs continued to decline as the system release of 70,000 cfs was maintained during the entire month. By month's end, the system storage stood at 59.9 maf, the 11th highest in the 30-year operational history. The November inflow into the system was very close to average, which when combined with the record 70,000 cfs system release helped to significantly reduce the accumulated storage. Garrison's releases were reduced from 50,000 cfs beginning in mid-month to near the winter rate of 20,000 cfs by the end of the month. Main Stem system storage ended the month at 59.8 maf, 3.8 maf greater than average.

<u>December - 1997</u>

System releases were reduced at a rate of 3,000 cfs per day from the 70,000 cfs rate beginning December 1, until a release of 28,000 cfs was reached near mid-December. The winter release rate of 25,000 cfs was never reached during December, because the air temperatures along the river were warm enough so that the potential for ice jam flooding was at a minimum. The calendar year runoff for 1997 was 49.7 maf, 202 percent of normal. December runoff was 215 percent of normal, the second highest of record, due to the extremely warm temperatures. System storage evacuation progressed and ended the month at 58.9 maf., 3.4 maf greater than average. **Figure 14** shows the Gavins Point releases compared to previous records and the two previous largest runoff years of 1975 and 1978. Also shown on **Figure 14** are the releases and unregulated flows for 1996 through July 1997 for the upper three main stem projects and Gavins Point. The unregulated flows shown, exceed 250,000 cfs. **Figures 15 through 17** show the actual and natural flows for Bismarck, Sioux City, Omaha, Nebraska City, Kansas City and Boonville. **Figure 18** shows the peak stage reductions as a result of the main stem operations in 1997 for both the spring and summer flood events. Also shown on **Figure 18** is the flood damages prevented by the main stem dams during 1997, 5.2 Billion dollars, the largest year of damages prevented since the system became operational in 1967. The flood of 1997 was unlike many high peak years that normally have high sustained flows for only a few days. Without the main stem dams, the flood of 1997 would have been a bluff to bluff flood over the Missouri river flood plain. The runoff volume was so large it would have not only filled all the valley storage as it moved downstream but would have lasted many days causing the most destructive type of flooding.

Operational Problems/Constraints

Many concerns regarding project operations were identified during the 1997 flood event. A runoff that tested the flood control capability of the Missouri river main stem system even greater than that experienced in 1975, the record system storage event, resulted in the surfacing of numerous concerns regarding the main stem project's ability to be regulated to meet the operational objectives of the Missouri River Main Stem Master Water Control Manual.

The following concerns/constraints were identified as significant during the 1997 event:

- The tainter gates at Garrison Dam have not been reinforced like the other main stem projects. There was concern that the gates could or should not be opened if water was above the top of the gates. One option proposed was to open the gates as much as required to prevent any overtopping by the pool, including adjusting the gates to protect against wind setup and waves. It was determined that the gates should remain closed even if up to a foot of water was to be spilled over them to insure that river stages downstream were not increased significantly. The operation selected was the plan described in the water control manual. The low lying areas in the city of Bismarck, North Dakota, were being threatened by high river levels and the potential for significant uncontrolled runoff, between Garrison Dam and Bismarck was greatest during the time the downstream channel was nearly filled and the basin was saturated from recent rains. Increasing releases to result in a Bismarck stage of 16.0 feet (flood stage) would have been required if the pool elevation forecast exceeded 1855 feet m.s.l.

- Line loading relief was frequently required of WAPA by MAPP, forcing rapid and unexpected reductions in the powerplant releases at some projects. This resulted in the requirement for project personnel to quickly adjust flood control tunnel or spillway releases to compensate for the power plant release reduction and thereby maintain a near steady downstream flow. Quick adjustments had to be made because the downstream channels were near bankfull in order to move the larger volume of water in the least damaging manner and additional channel capacity did not exist to make up additional discharge at a later time. Fort Peck, Garrison, Oahe, and Fort Randall were all affected. Another concern was that significantly lowering releases in a short period of time would result in a larger amount of erosion from bank sloughing in the downstream channel.

- Bank erosion is frequently a problem during high releases. The Corps was requested by congressional interests to minimize the time that Garrison releases remained above 50,000 cfs. The effectiveness of this in reducing bank erosion is not known, but it is known that bank erosion is aggravated by high river flows. However, because of the reduction in higher flows over the operational history of the project, in general, bank erosion has been less since the system was constructed than that experienced prior to the main stem system operations.

- The flooding of private land near the mouth of the Niobrara river was again a problem in 1997. High river stages persisted although the high flows of recent years has increased the channel capacity so that a release of 60,000 cfs from Ft. Randall in 1997 resulted in a water surface similar to that of a 50,000 cfs release just two years earlier. Also, construction of a new Missouri river bridge in this area resulted in additional concerns and considerations.

- In anticipation of high flows in the Pierre-Fort Pierre waterfronts, emergency advance measures were taken to protect low-lying areas along the river channel. The downstream channel was protected to 80,000 cfs even though a release of greater than 60,000 was not required. The potential for a larger release was definitely there however.

- Flood control tunnel gates at Ft. Randall do not permit releases to be adjusted other than at full gate. This year, as in recent years, when the spillway gates can no longer be used to augment power plant releases because of the low lake level, spills will be at full gate opening. The power plant discharge and associated generation are reduced to provide the desired total project release. This lack of regulation flexibility results in a significant loss of hydropower production from the main stem dams.

- At Oahe Dam, the Pierre Shale abutments contain numerous faults and bentonite seams which present slope slide concerns. It was recommended that the pool elevation not be permitted to climb above elevation 1620 because of embankment concerns. This could be a very significant restriction if heavy rainfall were to occur in the upstream project area during similar type of event to that of 1997 and the pool would be above elevation 1620 for more than a month due to subsequent rainfall runoff events.

- The tainter gates at Oahe dam were a concern with several maximum pool levels contemplated before a position was taken to allow the pool to rise to 1620. The final consensus was that the pool could rise up to a maximum of 1621 for a very short period of time, from an unexpected rainfall event or a large wind. But that the lake would be drawn down by the RCC as quickly as possible (0.1 to 0.2 feet per day) to prevent any prolonged storage at this level for safety of the project.

- Persistent high river stages downstream from the mouth of the Platte River in Nebraska negatively affects agricultural planting and can damage existing crops. Interior drainage was impeded due to the high Missouri River stages preventing local drainage. Many acres could not be planted and some areas that did get planted did not produce a crop or experienced poor yields because of the high groundwater. It is estimated that some 88,000 acres of farmland were affected from Omaha to St. Joseph in 1997.

Summary

This was an extraordinary large runoff year, a new record. Historically, 40.7 maf was the largest runoff in 99 years of record with 37.2 maf being the next largest. This years runoff was double a normal runoff and will exceed the past record runoff by nearly 25 percent. Based upon a frequency analysis of annual runoff, the 1997 volume has near a 200-year chance of occurrence. The frequency curve is shown as **Figure 19.**

The high runoff was the result of an unprecedented heavy plains snowpack concurrent with a near record mountain snowpack. The melt sequence was more rapid than normal due to much above normal temperatures during the melt period, sometimes in the 80 degree range, which, without a doubt, significantly increased the total volume of runoff. Also, some significant rains occurred into the main stem system during the system storage peaking period in late June and early July.

It was fortunate that heavy downstream rains did not occur during the major evacuation period when high release rates were required. These releases used almost all the available channel capacity. Only small river rises were experienced from rainfall events during the summer and fall period so that river stages, although high, did not increase significantly. The potential certainly did exist for dramatic flooding downstream from the system if heavy rainfall had occurred. The 1997 situation was similar to that in 1975 when the previous record high, main stem system releases were made, with very little rainfall below the system.

The impacts of the very large runoff were minimized, to the extent possible, by significantly increasing system releases very early to maintain sufficient storage to contain the large mountain snowpack runoff that was expected. Record high releases began in February, exceeding past records set just one year earlier by 26 percent. In the months that followed, previous maximum releases were exceeded by from 7 to 37 percent. Releases nearly doubled an average release for the February through December period. The higher sustained releases slowly increased downstream channel capacity over time, so the over affects of the increases were made less by gradually stepping up release amounts.

Maximum reservoir regulation benefits were attained because the flood control pools at Fort Peck and Garrison were totally filled without having to make high damaging releases from either project. The Oahe pool neared its historic maximum level leaving only 1.4 feet of vacated flood control storage available. The Ft. Randall pool elevation exceeded its previous maximum level by 4.3 feet, leaving only 2.8 feet of vacated flood control storage space. Garrison was also near its historic peak and exceeded the top of its exclusive flood control zone as did Fort Peck. The relative elevation of these projects from the top of spillway gates is shown on Figure 9. Only a small portion of vacated flood control storage space remained in the main stem system for an extended period of time. The greatest concern was at Oahe and Ft. Randall because the early spring runoff raised these pools to such a high level so early in the season. The early anticipation of a very large runoff and the implementing of unprecedented high releases early in the year played a large role in preventing major flood damages in the river between projects and downstream from the main stem system.

More than $5.2 billion in damages were prevented during 1997 as a result of the Missouri River main stem system operation. A News Release published by the Corps on September 17, 1997, describing these benefits is shown on Plate 5.

Conclusions

There are numerous lessons learned from the operation of the main stem system during 1997. In some cases, these are simply reminders of what has been learned in previous high runoff years. These are:

- Some project features do not function as designed. Examples of these include: concerns over the operation of the spillway and flood control tunnels at Fort Peck, no fine regulation gate in a flood control tunnel at Ft. Randall and concerns when reservoirs pools reach high levels such as those experienced in 1997, especially Garrison and Oahe. The project features that cannot be used as designed should be identified and vigorous steps taken to complete repairs or make other appropriate adjustments.

- The water control staff needs to be realistic and do the best possible job in preparing runoff forecasts. Following the development of regulation plans for the forecasted conditions that exist at the time, the system must be operated patiently by following the water control plans and temptations to over-react should be resisted. The main stem system is the largest system of reservoirs in the United States and unique in terms of its large flood storage capability versus basin runoff. Significant actions need to be well planned and then followed. The relative size of the system precludes the necessity for quick reactions to changing conditions. This large system size does allow time for reasonable alternatives to be evaluated by individuals familiar with main stem system reservoir operations.   Over the years, a set of forecast models and analysis tools have been developed in the RCC to simulate operation the main stem system during various runoff scenarios. These are the tools must be used to evaluate the system during critical conditions. The individual main stem water control manuals show some results of the modeling tools, but during a major significant event such as 1997 many operational objectives must be met and utilization of the system model is required, employing a full range of possible inflows and outflows to bracket expected conditions and optimize the regulation for all authorized purposes.

- The project storage capacity needs to be utilized during a large significant event such as 1997. In order to maximize project purposes and benefits such as downstream flood control, the storage space must be used during major events. The last few years of extremely high runoffs have resulted in major flood damages prevented because of the projects' storage capability being used according to the water control plan. If features are constructed within the flood pools they must be sacrificed during significant flood events. Likewise, features located inappropriately in downstream channels or flood plains are likely to be flooded. We need to both plan and explain this thoroughly to the widest possible audience. The system operational constraints mentioned earlier must be removed if possible, to allow the system to function as designed.

- The team concept of working towards reasonable solutions during significant events worked well in 1997. The foundation for the team decision was; the RCC runoff forecast , system reservoir modeling and project release guidance provided by the RCC staff. Other Missouri River Region team personnel offered guidance and decision support on specific items beyond the RCC water management staff's expertise. Omaha District staff provided valuable plains snow water equivalent data used for the calendar year runoff forecast, which formed the basis for the early release decisions. Omaha District staff also, provided valuable streamflow information during the 1997 used in the RCC forecasting models, so that existing channel capacity could be utilized as much as possible.

- Public confidence in the Corps of Engineers remained high, because of a clear explanation of the expected release and pool rises provided by the RCC staff. The distribution of this information to the public was provided in a concise up-front manner, which also helped alleviate rumors. The close association of the RCC staff with the public affairs office was crucial, as was also the interaction with emergency management.

- The Omaha District Operations Division staff did an excellent job of operating the main stem projects and keeping the RCC notified of current field conditions that could affect the operation of the dams. Also they sought out the correct information on project release and pool elevation plans directly from the RCC and dealt with the public on a one on one basis to provide the correct information, which alleviated most rumors and major concerns.

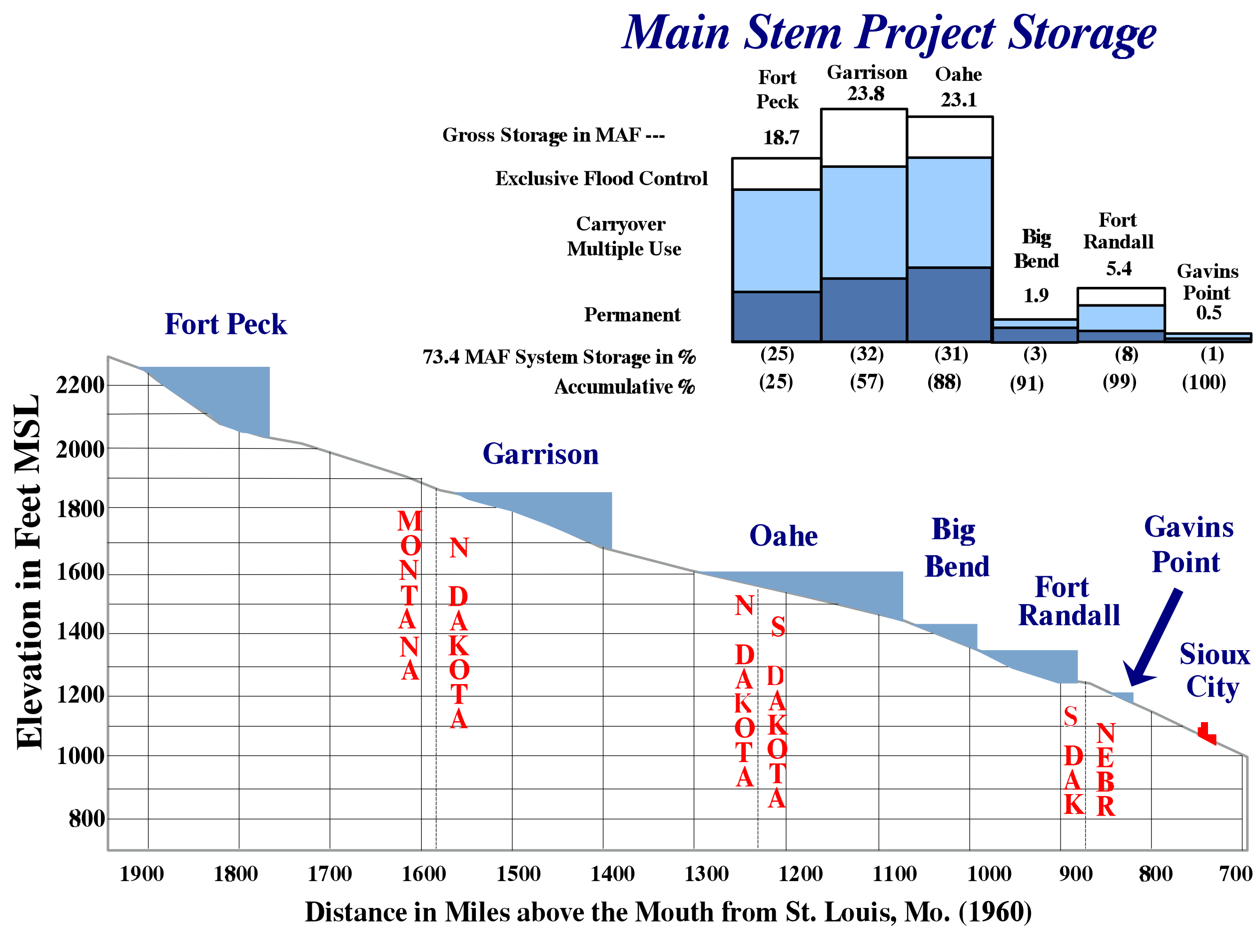
- The Special Dam Safety Committee meeting held at Missouri River Region served to identify all operational restrictions with the main stem dams and provided a forum for the RCC to brief the more technical members of the Committee on the operational considerations and plans during a critical period. This meeting was very beneficial for everyone in attendance. This committee needs to annually inform the water management staff regulating the main stem system of the constraints and concerns on main stem project operations during the following season. This could best be utilized prior to the preparation of the Draft annual operating plan in August.

- The ability for the public to keep self-informed by observing the real-time data available on the RCC Water Management homepage over the internet cannot be over emphazied. This tool may have provided the greatest benefit in terms of both informing the public, who were then prepared to ask very meaningful fully informed questions, and allowing the RCC staff extra time during a very long significant event, to accomplish the increased water management tasks.

- The forecasting procedure for the plains snowpack part of the annual runoff needs to be evaluated. The historic data is sparse and difficult to interpret in its present format. During the 1997 runoff event, the major significant historic Missouri River basin plains snowmelt events were converted from paper map to digital format using GIS coverages. An attempt was made to compare the 1997 plains snowpack to other significant historic years primarily 1969 by subtracting GIS raster files for the coverage area. This information was then compared to historic runoff by reach and used to prepare an improved March – April runoff forecast for 1997. The digital data need to be placed into GIS polygon coverages by river basin so that greater precision can be gained in the main stem plains snowmelt forecast. Also a new analysis of this area needs to be undertaken with the improved way of analyzing and displaying historic data so that a better technique can be developed for forecasting the April and May runoff in years with a significant plains snowpack. This effort has been initiated within the Reservoir Regulation Team of the RCC. The need for ground truthed plains snowpack data as early as possible inorder to prepare an adequate runoff forecast as early as possible should not be underestimated, and was the key for initiating releases at the higher rates so that enough space was left to contain the mountain snowpack melt. Future efforts to reduce this component of the budget, although it is only needed on the average of once every eight years, should be thwarted. The funding has to be there when there is a need or the main stem system will not be operated effectively. Floods of very large magnitude such as a Spillway Design Flood at Garrison Dam require the pool be drawn down seven feet, elevation 1830, prior to the spring snowmelt beginning. This will require obtaining plains snowmelt data in early February so large releases in the 50,000 cfs range can be initiated by mid-February further indicating the importance of this data and timeliness required for main stem operations.

Missouri River Basin
Tiber Dam
Bull Hook Dam
Havre
Great Falls
Fort Peck Dam
Wolf Point
Williston
Garrison Dam
Helena
Canyon Ferry Dam
Montana
North Dakota
Dickinson
Pipestem Dam
Bismarck*
Jamestown Dam
Jamestown
Miles City
Billings
Heart Butte Dam
Bowman Haley Dam
Shadehill Dam
Clark Canyon Dam
Yellowtail Dam
Mobridge
Aberdeen
Yellowstone Lake
South Dakota
Oahe Dam
Keyhole Dam
Wyoming
Pierre*
Huron
Rapid City
Pactola Dam
Cedar Canyon Dam
Big Bend Dam
Minnesota
Boysen Dam
Cold Brook Dam
Cottonwood Springs Dam
Sioux Falls
Casper
Fort Randall Dam
Gavins Point Dam
Valentine
Glendo Dam
Sioux City
N
W
E
S
Norfolk
Kingsley Dam
Nebraska
Iowa
Cheyenne*
North Platte
Papio Creeks (4)
Omaha
Grand Island
Lincoln*
Rathbun Dam
Colorado
Enders Dam
Medicine Creek Dam
Salt Creeks (10)
Trenton Dam
Red Willow Dam
Harlan County Dam
Missouri
Kelly Road Dam (2)
Denver*
Bear Creek Dam
Cherry Creek Dam
Chatfield Dam
Norton Dam
Lovewell Dam
St. Joseph
Bonny Dam
Kirwin Dam
Long Branch Dam
Webster Dam
Glen Elder Dam
Tuttle Creek Dam
Smithville Dam
Perry Dam
Kansas
Milford Dam
Topeka*
Kansas City
Blue Springs Dam
Longview Dam
Cedar Bluff Dam
Wilson Dam
Salina
Pomona Dam
Clinton Dam
Jefferson City*
Kanopolis Dam
Hillsdale Dam
Melvern Dam
Harry S Truman Dam
Bagnell Dam
Pomme De Terre Dam
Stockton Dam
Corps Projects
USBR Authorized Flood Control Projects
Other Non-Federal Projects
Army Corps of Engineers
Northwest Division
Missouri River Region
Reservoir Control Center
100
0
100
200
300
Statute Miles

Figure 1



Profile of Missouri River Main Stem Reservoir System

Congressionally Authorized Project Purposes

- **Flood Control**
- **Navigation**
- **Hydroelectric Power**
- **Irrigation**
- **Water Supply and Water Quality**
- **Recreation**
- **Fish and Wildlife**
  - **Endangered Species**

Figure 2

Summary of Engineering Data - Missouri River Main Stem Reservoirs

Item No.	Subject	Fort Peck Lake	Garrison Dam - Lake Sakakawea	Oahe Dam - Lake Oahe	Big Bend Dam - Lake Sharpe	Fort Randall Dam - Lake Francis Case	Gavins Point Dam - Lewis & Clark Lake	Total	Item No.
1	Location of Dam	Near Glasgow, Montana	Near Garrison, ND	Near Pierre, SD	21 miles upstream Chamberlain,	Near Lake Andes, SD	Near Yankton, SD		1
2	River Mile - 1960 Mileage	Mile 1771.5	Mile 1389.9	Mile 1072.3	Mile 987.4	Mile 880.0	Mile 811.1		2
3	Total & incremental drainage areas in square miles	57,500	181,400 (2) 123,900	243,490 (1) 62,090	249,330 (1) 5,840	263,480 (1) 14,150	279,480 (1) 16,000		3
4	Approximate length of full reservoir (in valley miles)	134, ending near Zortman, MT	178, ending near Trenton, ND	231, ending near Bismarck, ND	80, ending near Pierre, SD	107, ending at Big Bend Dam	25, ending near Niobrara, NE	755 miles	4
5	Shoreline in miles (3)	1520 (elevation 2234)	1340 (elevation 1837.5)	2250 (elevation 1607.5)	200 (elevation 1420)	540 (elevation 1350)	90 (elevation 1204.5)	5,940 miles	5
6	Average total & incremental inflow in cfs	10,200	25,600 15,400	28,900 3,300	28,900	30,000 1,100	32,000 2,000		6
7	Max. discharge of record near damsite in cfs	137,000 (June 1953)	348,000 (April 1952)	440,000 (April 1952)	440,000 (April 1952)	447,000 (April 1952)	480,000 (April 1952)		7
8	Construction started - calendar yr.	1933	1946	1948	1959	1946	1952		8
9	In operation (4) cal. yr.	1940	1955	1962	1964	1953	1955		9
	Dam and Embankment								
10	Top of dam elevation in feet msl	2280.5	1875	1660	1440	1395	1234		10
11	Length of dam in feet	21,026 (excluding spillway)	11,300 (including spillway)	9,300 (excluding spillway)	10,570 (including spillway)	10,700 (including spillway)	8,700 (including spillway)	71,596	11
12	Damming height in feet (5)	220	180	200	78	140	45	863 feet	12
13	Maximum height in feet (5)	250.5	210	245	95	165	74		13
14	Max. base width, total & w/o berms in feet	3500, 2700	3400, 2050	3500, 1500	1200, 700	4300, 1250	850, 450		14
15	Abutment formations (under dam & embankment)	Bearpaw shale and glacial fill	Fort Union clay shale	Pierre shale	Pierre shale & Niobrara chalk	Niobrara chalk	Niobrara chalk & Carlile shale		15
16	Type of fill	Hydraulic & rolled earth fill	Rolled earth filled	Rolled earth fill & shale berms	Rolled earth, shale, chalk fill	Rolled earth fill & chalk berms	Rolled earth & chalk fill		16
17	Fill quantity, cubic yards	125,628,000	66,500,000	55,000,000 & 37,000,000	17,000,000	28,000,000 & 22,000,000	7,000,000	358,128,000 cu. yds	17
18	Volume of concrete (cubic yards)	1,200,000	1,500,000	1,045,000	540,000	961,000	308,000	5,554,000 cu. yds.	18
19	Date of Closure	24 June 1937	15 April 1953	3 August 1958	24 July 1963	20 July 1952	31 July 1955		19
	Spillway Data								
20	Location	Right bank - remote	Left bank - adjacent	Right bank - remote	Left bank - adjacent	Left bank - adjacent	Right bank - adjacent		20
21	Crest elevation in feet msl	2225	1825	1596.5	1385	1346	1180		21
22	Width (including piers) in feet	820 gated	1336 gated	456 gated	376 gated	1000 gated	664 gated		22
23	No., size and types of gates	16 - 40' x 25' vertical lift gates	28 - 40' x 29' Tainter	8 - 50' x 23.5' Tainter	8 - 40' x 38' Tainter	21 - 40' x 29' Tainter	14 - 40' x 30' Tainter		23
24	Design discharge capacity, cfs	275,000 at elev 2253.3	827,000 at elev 1858.5	304,000 at elev 1644.4	390,000 at elev 1433.6	620,000 at elev 1379.3	584,000 at elev 1221.4		24
25	Discharge capacity at maximum operating pool in cfs	230,000	660,000	80,000	270,000	508,000	345,000		25
	Reservoir Data (6)								
26	Max. operating pool elev & area	2250 msl 246,000 acres	1854 msl 380,000 acres	1620 msl 374,000 acres	1423 msl 61,000 acres	1375 msl 102,000 acres	1210 msl 31,000 acres	1,194,000 acres	26
27	Max. normal op pool elev & area	2246 msl 240,000 acres	1850 msl 364,000 acres	1617 msl 360,000 acres	1422 msl 60,000 acres	1365 msl 95,000 acres	1208 msl 28,000 acres	1,147,000 acres	27
28	Base flood control elev & area	2234 msl 212,000 acres	1837.5 msl 307,000 acres	1607.5 msl 312,000 acres	1420 msl 57,000 acres	1350 msl 77,000 acres	1204.5 msl 24,000 acres	989,000 acres	28
29	Min. op. pool elev. & area	2160 msl 90,000 acres	1775 msl 128,000 acres	1540 msl 117,000 acres	1415 msl 51,000 acres	1320 msl 38,000 acres	1204.5 msl 24,000 acres	450,000 acres	29
	Storage allocation & capacity								
30	Exclusive flood control	2250-2246 975,000 a.f.	1854-1850 1,489,000 a.f.	1620-1617 1,102,000 a.f.	1423-1422 60,000 a.f.	1375-1365 985,000 a.f.	1210-1208 59,000 a.f.	4,670,000 a.f.	30
31	Flood control & multiple use	2246-2234 2,717,000 a.f.	1850-1837.5 4,222,000 a.f.	1617-1607.5 3,201,000 a.f.	1422-1420 117,000 a.f.	1365-1350 1,309,000 a.f.	1208-1204.5 90,000 a.f.	11,656,000 a.f.	31
32	Carryover multiple use	2234-2160 10,785,000 a.f.	1837.5-1775 13,130,000 a.f.	1607.5-1540 13,461,000 a.f.		1350-1320 1,607,000 a.f.		38,983,000 a.f.	32
33	Permanent	2160-2030 4,211,000 a.f.	1775-1673 4,980,000 a.f.	1540-1415 5,373,000 a.f.	1420-1345 1,682,000 a.f.	1320-1240 1,517,000 a.f.	1204.5-1160 321,000 a.f.	18,084,000 a.f.	33
34	Gross	2250-2030 18,688,000 a.f.	1854-1673 23,821,000 a.f.	1620-1415 23,137,000 a.f.	1423-1345 1,859,000 a.f.	1375-1240 5,418,000 a.f.	1210-1160 470,000 a.f.	73,393,000 a.f.	34
35	Reservoir filling initiated	November 1937	December 1953	August 1958	November 1963	January 1953	August 1955		35
36	Initially reached min. operating pool	27 May 1942	7 August 1955	3 April 1962	25 March 1964	24 November 1953	22 December 1955		36
37	Estimated annual sediment inflow	18,100 a.f. 1030 yrs.	25,900 a.f. 920 yrs.	19,800 a.f. 1170 yrs.	4,300 a.f. 430 yrs.	18,300 a.f. 250 yrs.	2,600 a.f. 180 yrs.	92,500 a.f.	37
	Outlet Works Data								
38	Location	Right bank	Right Bank	Right Bank		Left Bank			38
39	Number and size of conduits	2 - 24' 8" diameter (nos. 3 & 4)	1 - 26' dia. and 2 - 22' dia.	6 - 19.75' dia. upstream, 18.25' dia. downstream	None (7)	4 - 22' diameter	None (7)		39
40	Length of conduits in feet (8)	No. 3 - 6,615, No. 4 - 7,240	1529	3496 to 3659		1013			40
41	No., size, and type of service gates	1 - 28' dia. cylindrical gate 6 ports, 7.6' x 8.5' high (net opening) in each control shaft	1 - 18' x 24.5' Tainter gate per conduit for fine regulation	1 - 13' x 22' per conduit, vertical lift, 4 cable suspension and 2 hydraulic suspension (fine regulation)		2 - 11' x 23' per conduit, vertical lift, cable suspension			41
42	Entrance invert elevation (msl)	2095	1672	1425	1385 (12)	1229	1180 (12)		42
43	Avg. discharge capacity per conduit & total	Elev. 2250 22,500 cfs - 45,000 cfs	Elev. 1854 30,400 cfs - 98,000 cfs	Elev. 1620 18,500 cfs - 111,000 cfs		Elev 1375 32,000 cfs - 128,000 cfs			43
44	Present tailwater elevation (ft msl)	2032-2036 5,000 - 35,000 cfs	1670-1680 15,000- 60,000	1423-1428 20,000-55,000 c	1351-1355(11) 25,000-100,000	1228-1239 5,000-60,000 cf	1155-1163 15,000-60,000 cfs		44
	Power Facilities and Data								
45	Avg. gross head avail in feet (15)	194	161	174	70	117	48	764 feet	45
46	Number and size of conduits	No. 1-24'8" dia., No. 2-22'4" dia.	5 - 29' dia., 25' penstocks	7 - 24' dia., imbedded penstocks	None: direct intake	8 - 28' dia., 22' penstocks	None: direct intake		46
47	Length of conduits in feet (8)	No. 1 - 5,653, No. 2 - 6,355	1829	From 3,280 to 4,005		1,074		55,083	47
48	Surge tanks	PH#1: 3-40' dia., PH#2: 2-65' dia.	65' dia. - 2 per penstock	70' dia., 2 per penstock	None	59' dia, 2 per alternate penstock	None		48
49	No., type and speed of turbines	5 Francis, PH#1-2: 128.5 rpm, 1-164 rpm , PH#2-2: 128.6 rpm	5 Francis, 90 rpm	7 Francis, 100 rpm	8 Fixed blade, 81.8 rpm	8 Francis, 85.7 rpm	3 Kaplan, 75 rpm	36 units	49
									50
50	Disch. cap. at rated head in cfs	PH#1, units 1&3 170', 2-140' 8,800 cfs, PH#2-4&5 170'-7,200 cfs	150' 38,000 cfs	185' 54,000 cfs	67' 103,000 cfs	112' 44,500 cfs	48' 36,000 cfs		
51	Generator nameplate rating in kW	1&3: 43,500; 2: 18,250; 4&5: 40,000	3 - 109,250, 2 - 95,000	112,290	3 - 67,276, 5 - 58,500	40,000	44,100		51
52	Plant capacity in kW	185,250	517,750	786,030	494,320	320,000	132,300	2,435,650 kw	52
53	Dependable capacity in kW (9)	181,000	388,000	534,000	497,000	293,000	74,000	1,967,000 kw	53
54	Avg annual energy, million kWh (13)	1,170	2,472	2,898	1,052	1,846	749	10,034 million kWh	54
55	Initial generation, first and last unit	July 1943 - June 1961	January 1956 - October 1960	April 1962 - June 1963	October 1964 - July 1966	March 1954 - January 1956	September 1956 - January 1957	July 1943 - July 1966	55
56	Estimated cost September 1992 Completed project (14)	$158,428,000	$299,938,000	$346,521,000	$107,498,000	$199,066,000	$49,617,000	$1,161,068,000	56

Remarks

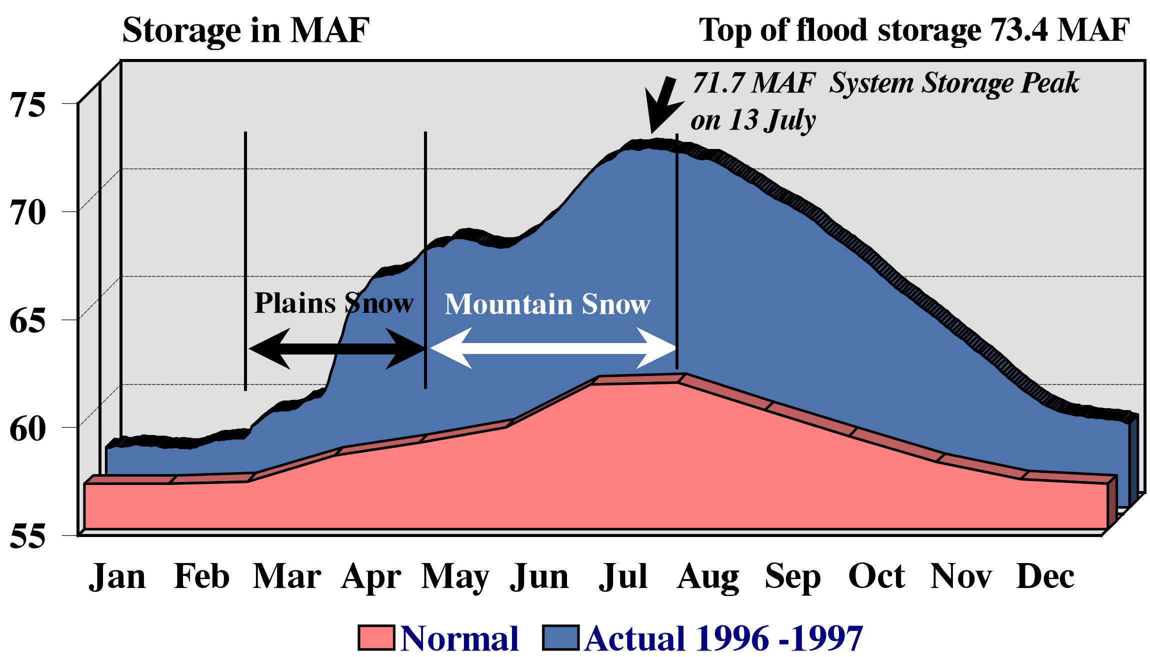
(1) Includes 4,280 square miles of non-contributing areas.
(2) Includes 1,350 square miles of non-contributing areas.
(3) With pool at base of flood control.
(4) Storage first available for regulation of flows.
(5) Damming height is height from low water to maximum operating pool. Maximum height is from average streambed to top of dam.
(6) Based on latest available storage data.
(7) River regulation is attained by flows over low-crested spillway and through turbines.
(8) Length from upstream face of outlet or to spiral case.
(9) Based on 8th year (1961) of drought drawdown (From study 8-83-1985).
(10) Storage volumes are exclusive of Snake Creek arm.
(11) Affected by level of Lake Francis case. Applicable to pool at elevation 1350.
(12) Spillway crest.
(13) 1967-1996 Average
(14) Source: Annual Report on Civil Works Activities of the Corps of Engineers. Extract Report Fiscal Year 1996.

Corps of Engineers, U.S. Army
Compiled by
Missouri River Division
May 1997

Figure 3

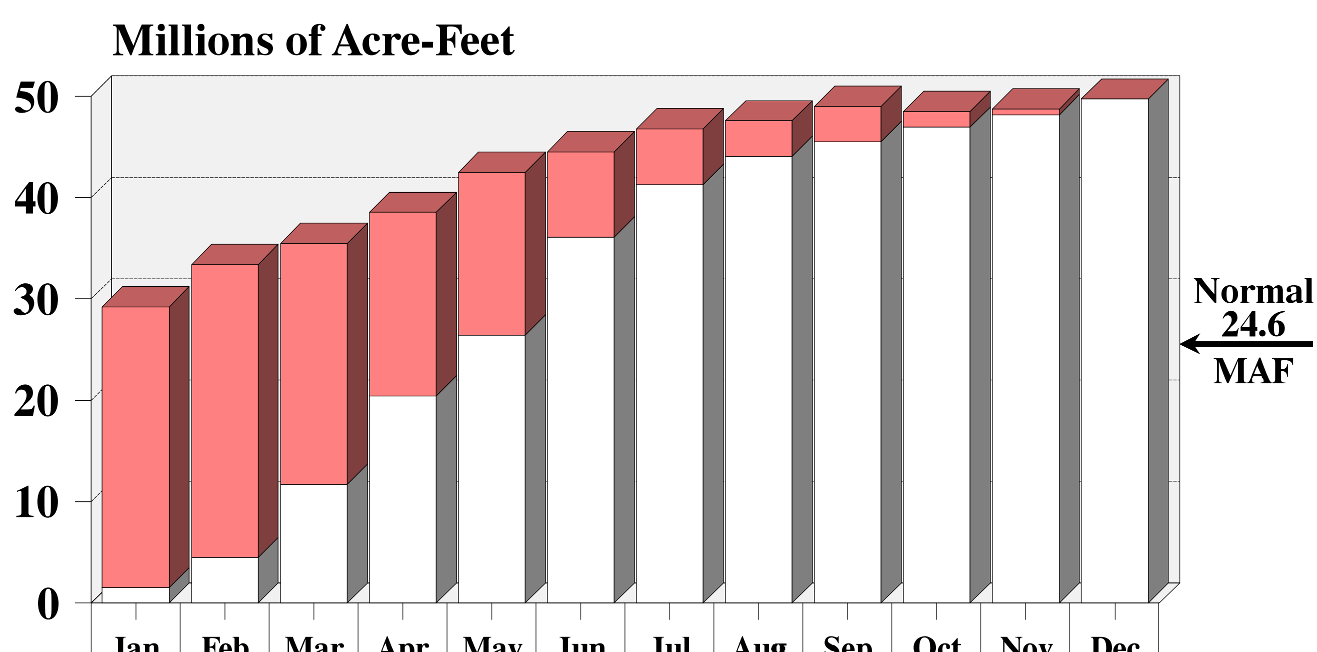
Missouri River Main Stem System

1997 System Storage vs Normal



Main Stem Annual Runoff for CY 1997

Forecasted vs Actual



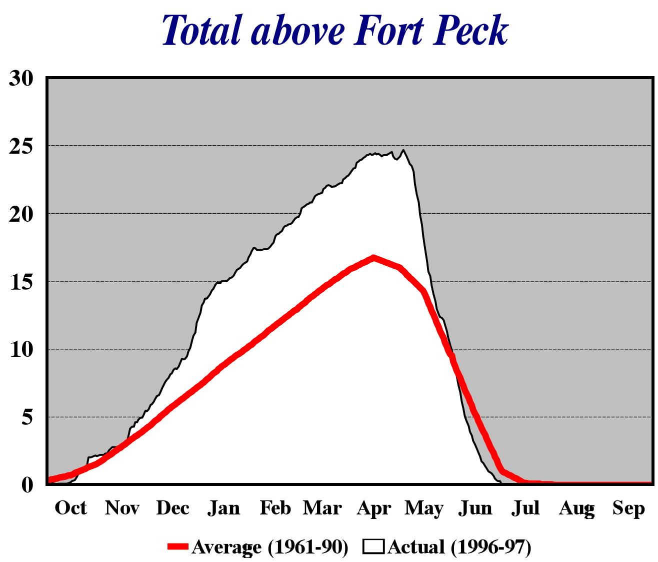
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forecst Increment	*27.7*	*28.9*	*23.8*	*18.1*	*16*	*8.4*	*5.5*	*3.5*	*3.5*	*1.6*	*0.5*	*0*
Actual Mthly Sum	*1.5*	*4.5*	*11.7*	*20.4*	*26.4*	*36.1*	*41.3*	*44.1*	*45.5*	*46.9*	*48.2*	*49.7*
1997 Forecst Total	*29.2*	*33.4*	*35.5*	*38.5*	*42.5*	*44.5*	*46.8*	*47.6*	*49*	*48.5*	*48.7*	*49.7*

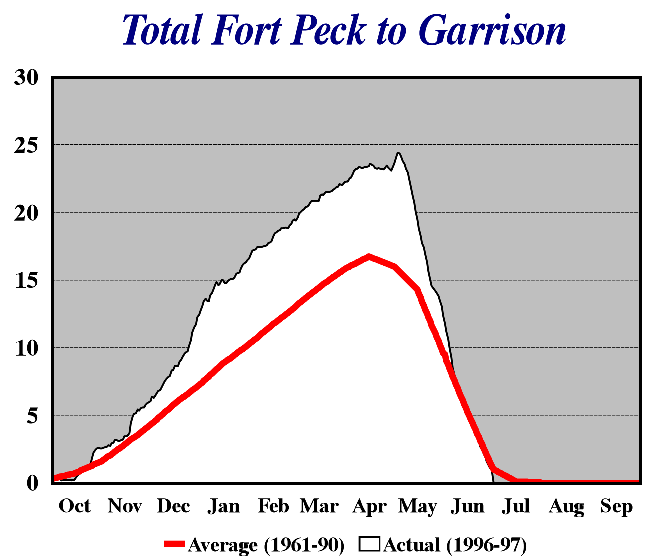
1997 Record Runoff = 49.7 MAF - 202 % of normal

Reservoir Control Center Forecasts
Adjusted to 1949 Level of Runoff

Figure 4

Missouri River Basin
1997 Mountain Snow Pack Water Content





Missouri River Basin
Mountain Snow Pack Water Content
1996 - 1997

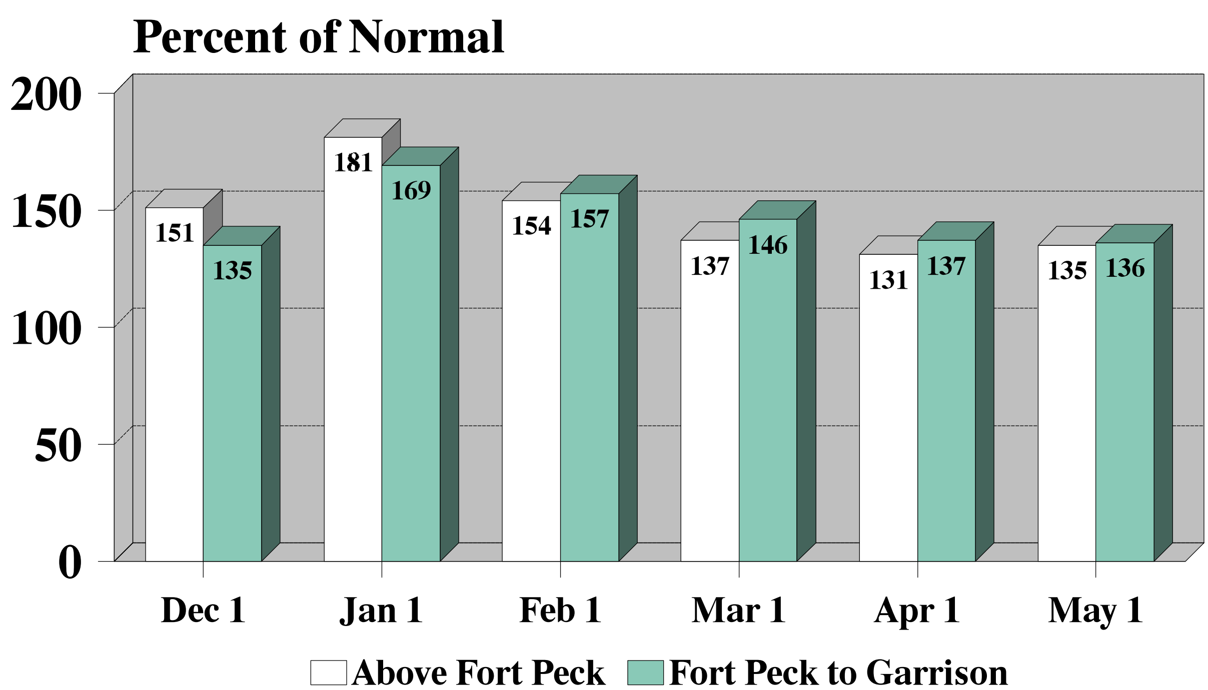
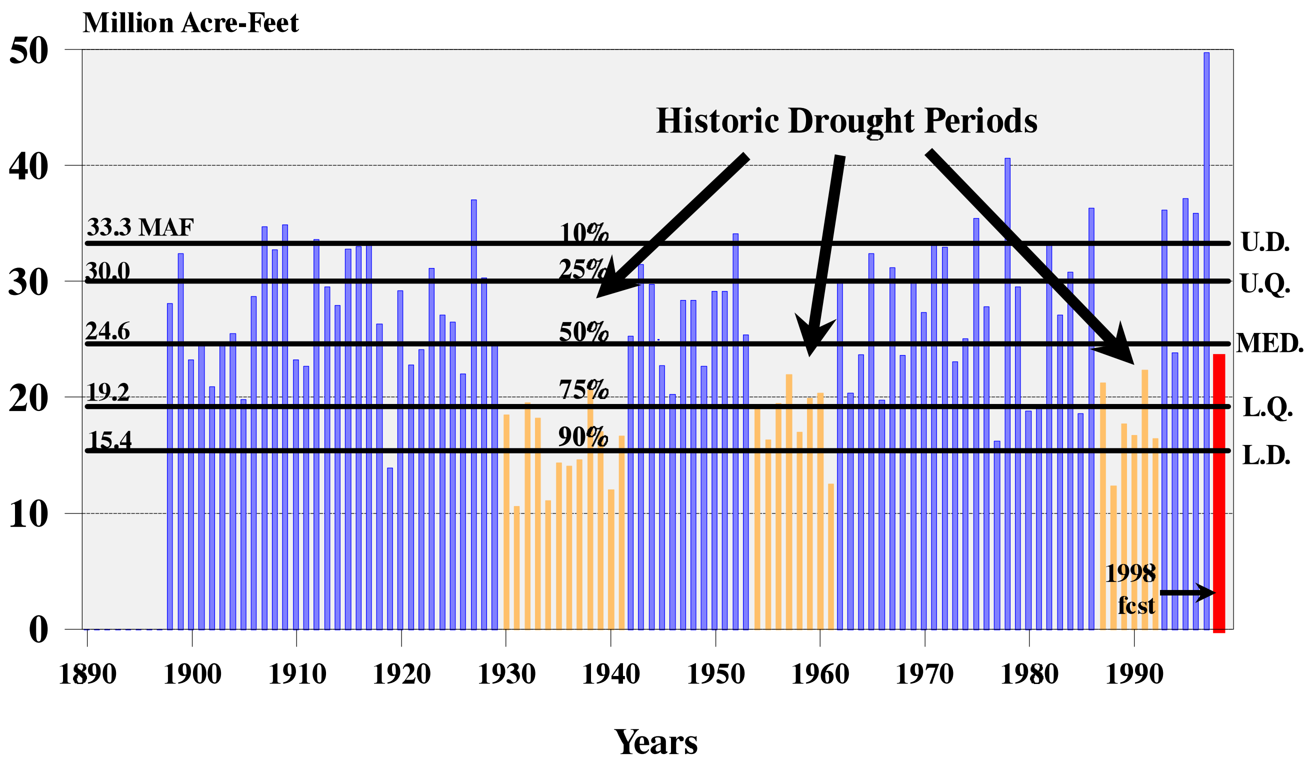


Figure 5

Missouri River Main Stem Annual Runoff above Sioux City, Iowa



1997 runoff = 49.7 maf - 202 % of normal (largest in 100 years of record keeping)

1997 Missouri River Monthly Runoff Above Sioux City, Iowa

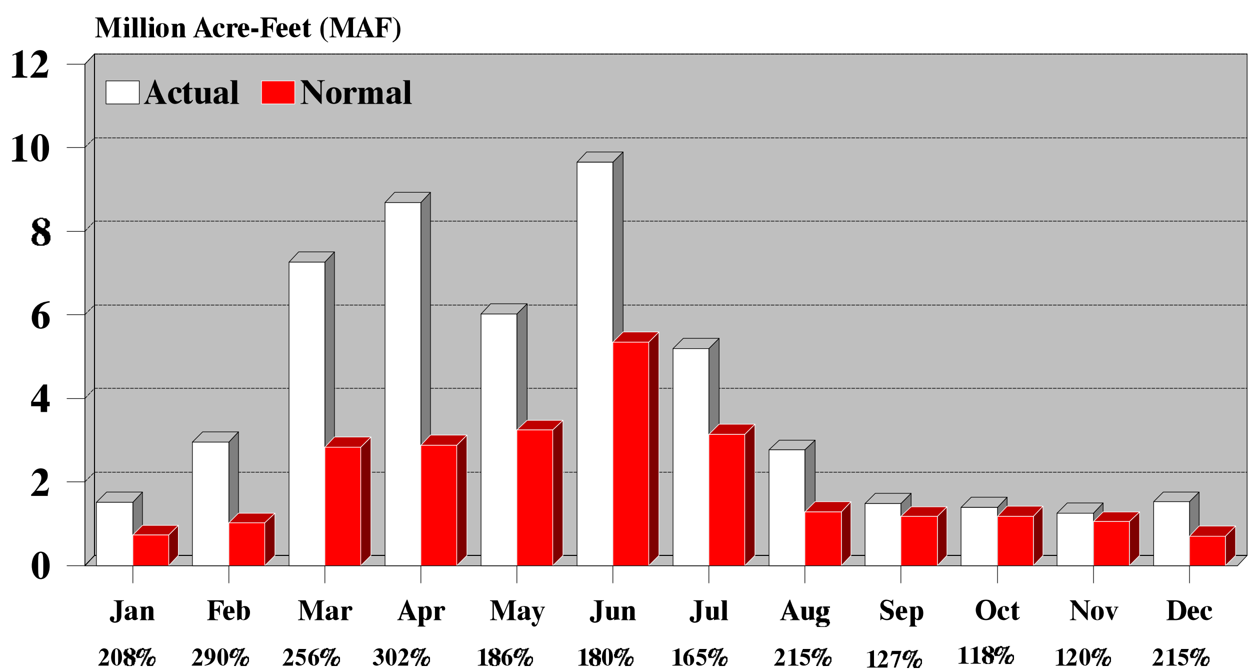


Figure 6

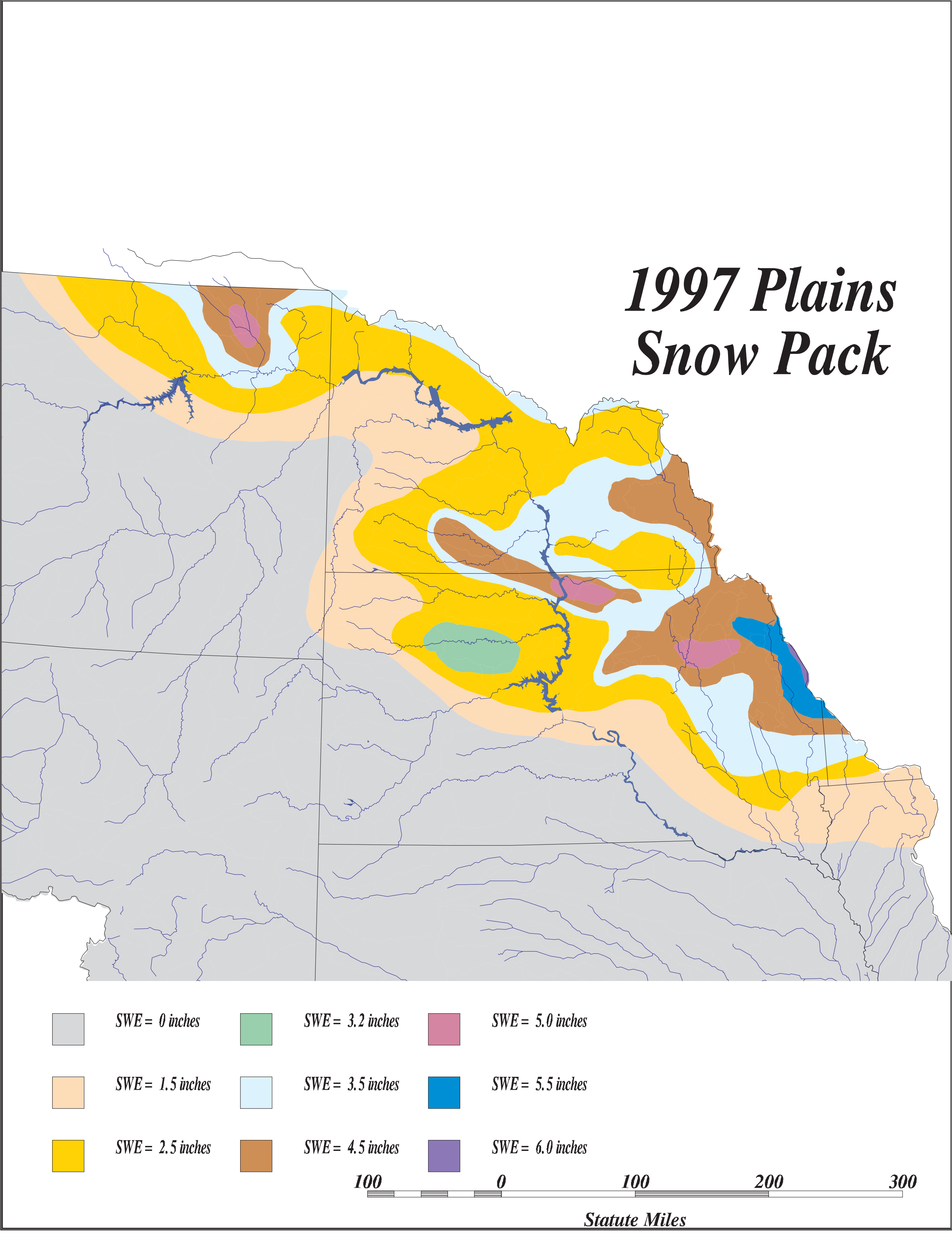
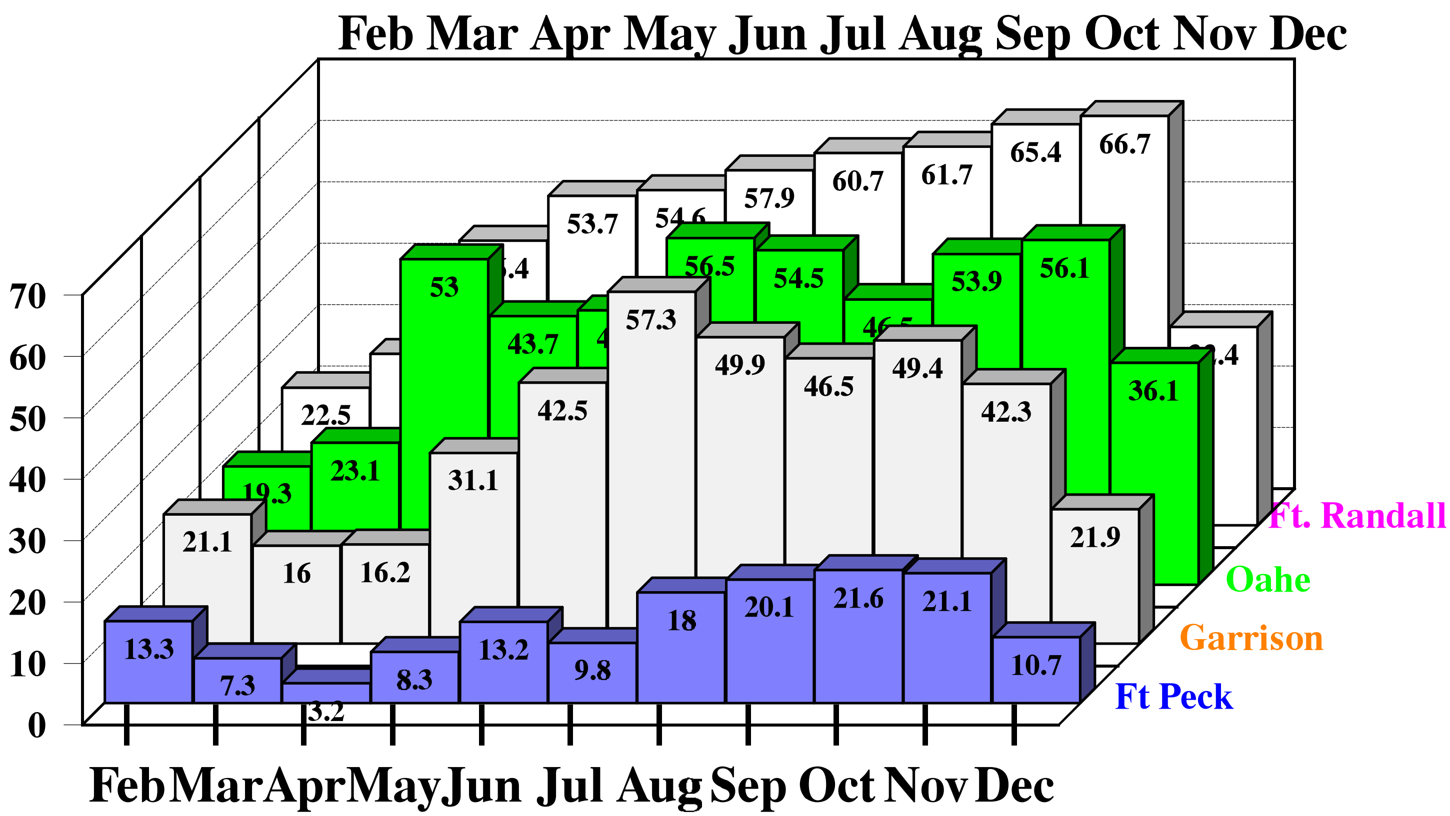
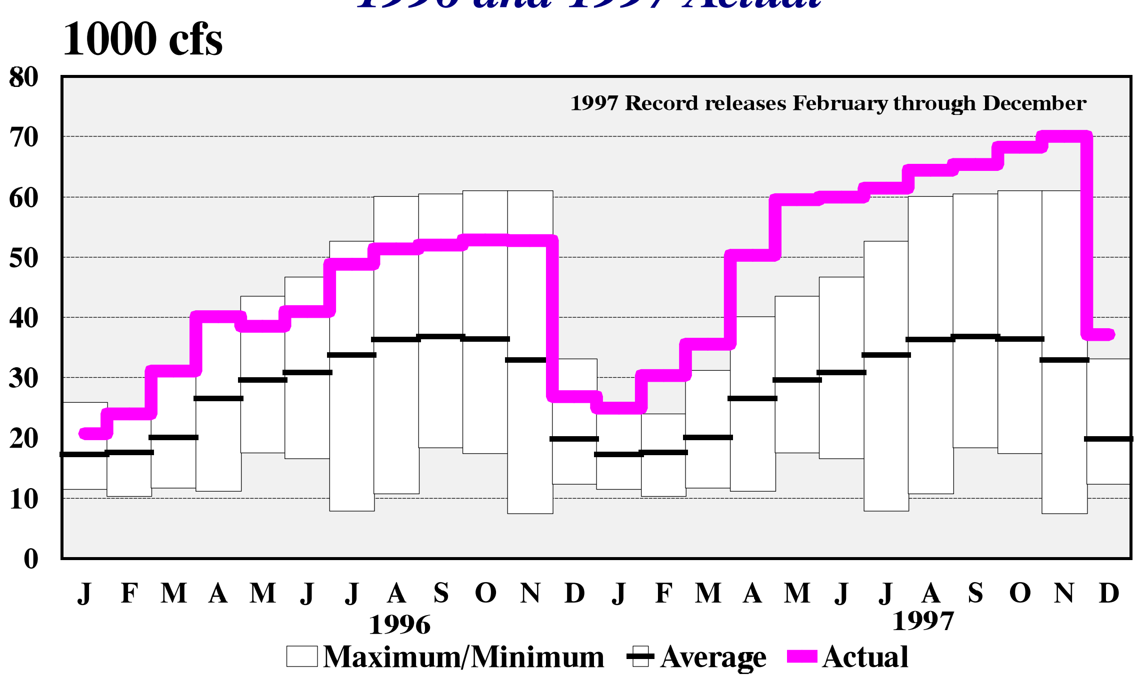

1997 Plains
Snow Pack
SWE = 0 inches
SWE = 1.5 inches
SWE = 2.5 inches
SWE = 3.2 inches
SWE = 3.5 inches
SWE = 4.5 inches
SWE = 5.0 inches
SWE = 5.5 inches
SWE = 6.0 inches
100
0
100
200
300
Statute Miles

Figure 7

Missouri River Main Stem
1997 Average Monthly Releases in 1000 cfs



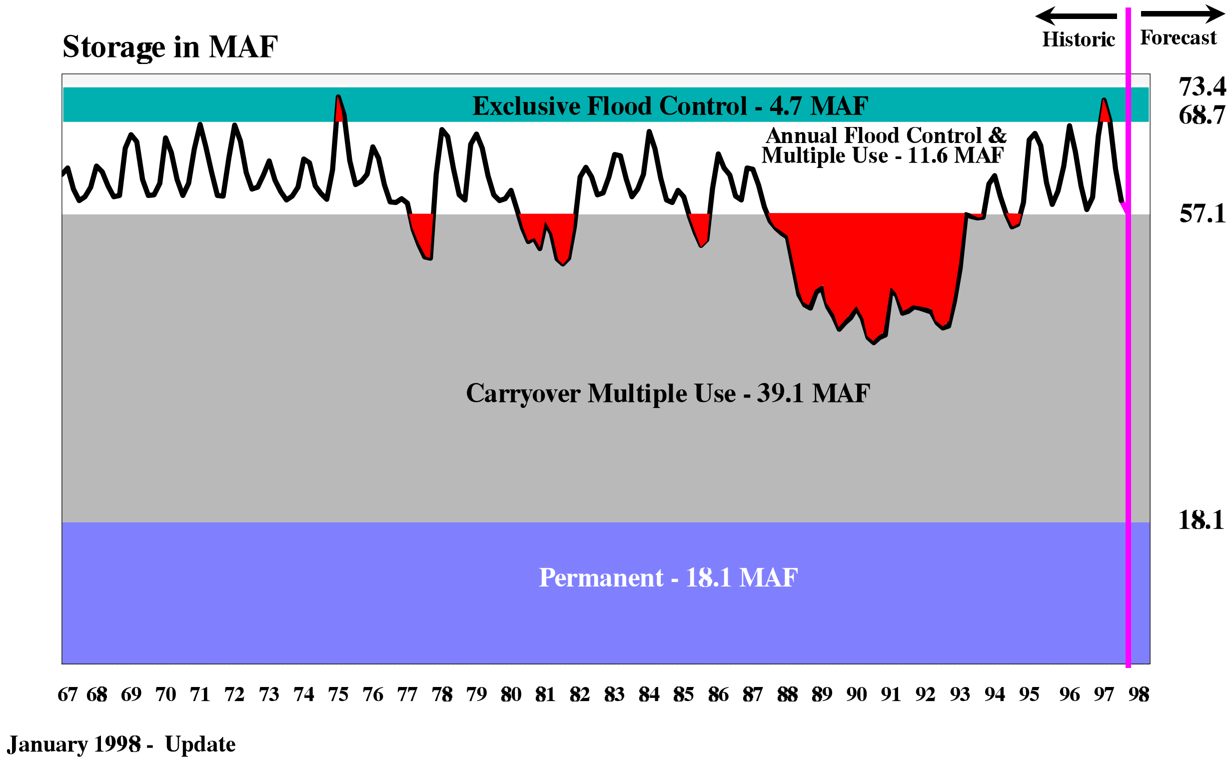
Gavins Point Average Monthly Releases
1996 and 1997 Actual



Max, Min, and Avg 1967-96

Figure 8

Missouri River Main Stem
System Storage 1967-1998



Missouri River Main Stem
1997 Project Lake Heights vs Top of Spillway Gates

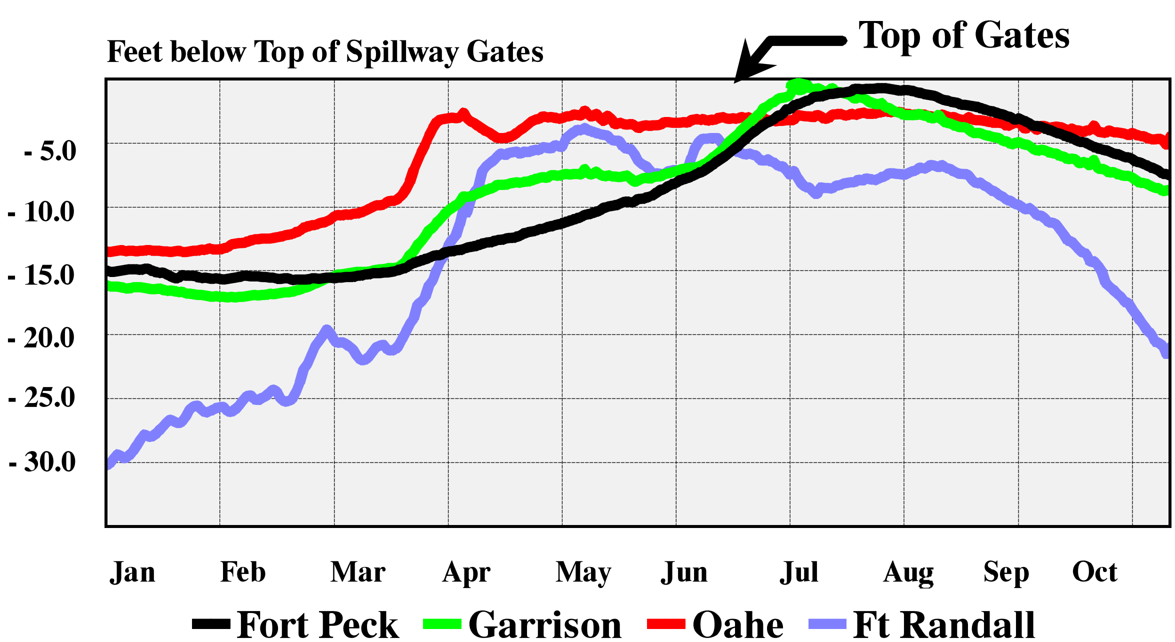
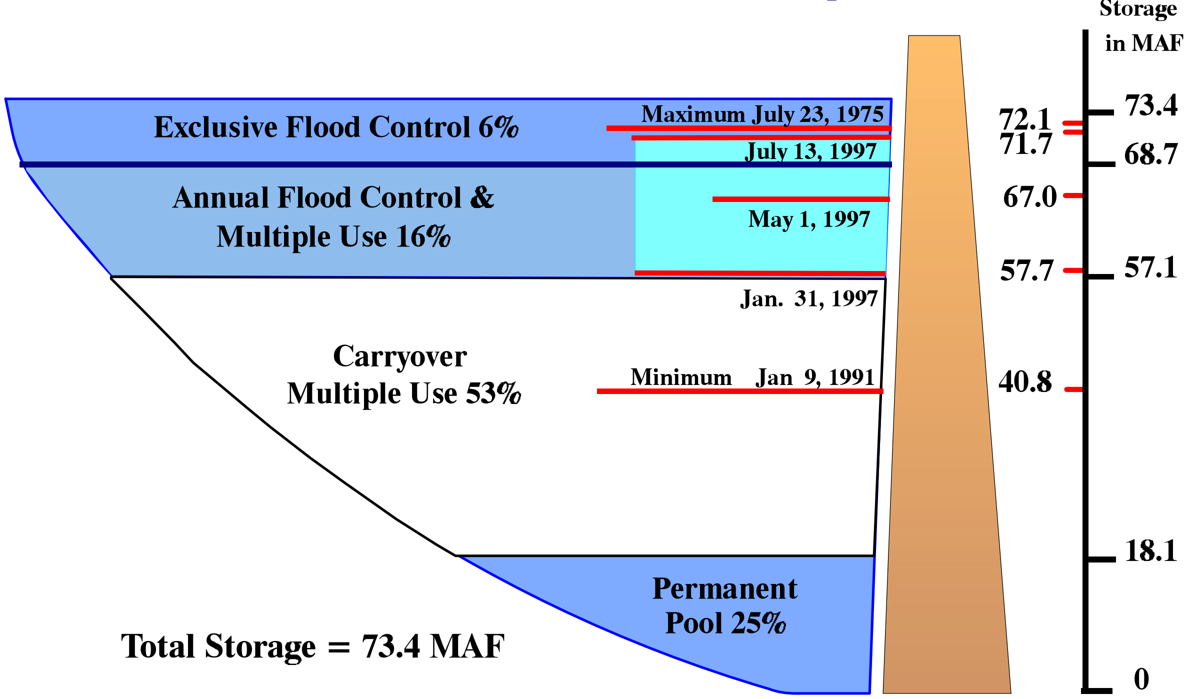


Figure 9

Missouri River Main Stem System Storage Allocations
Historic Max/Min and 1997 Storage



Missouri River Main Stem Reservoirs
1997 Minimum and Peak Lake Elevations

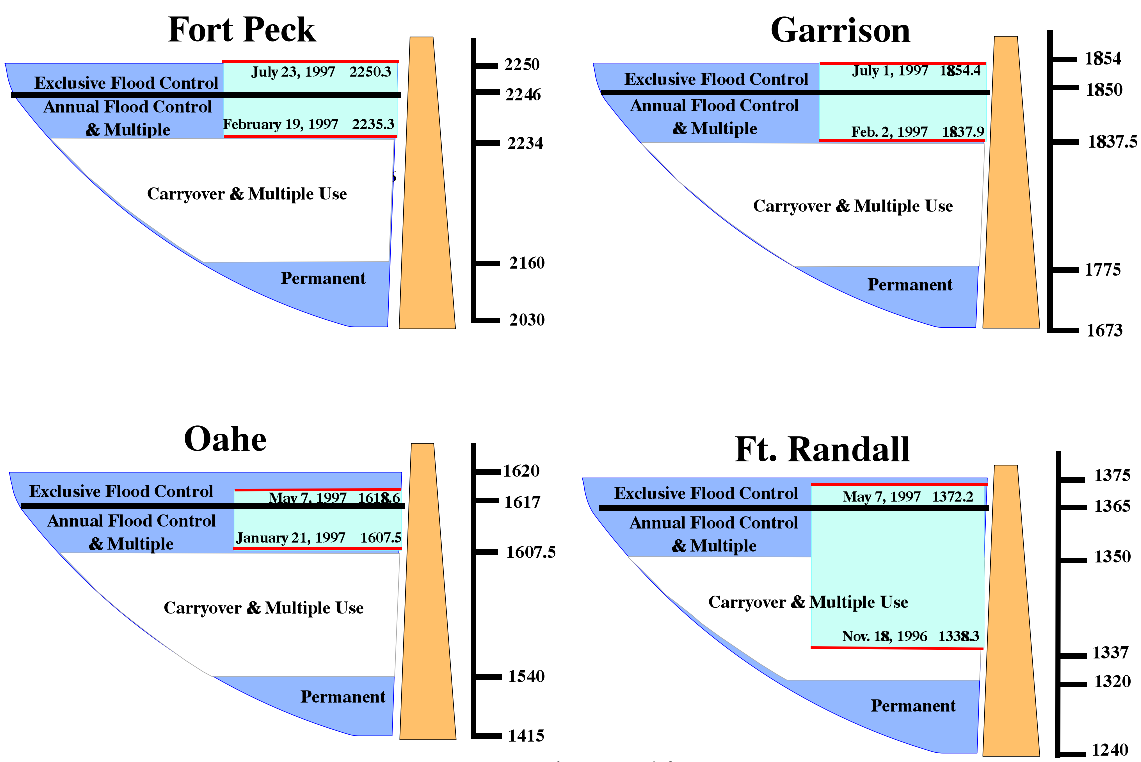
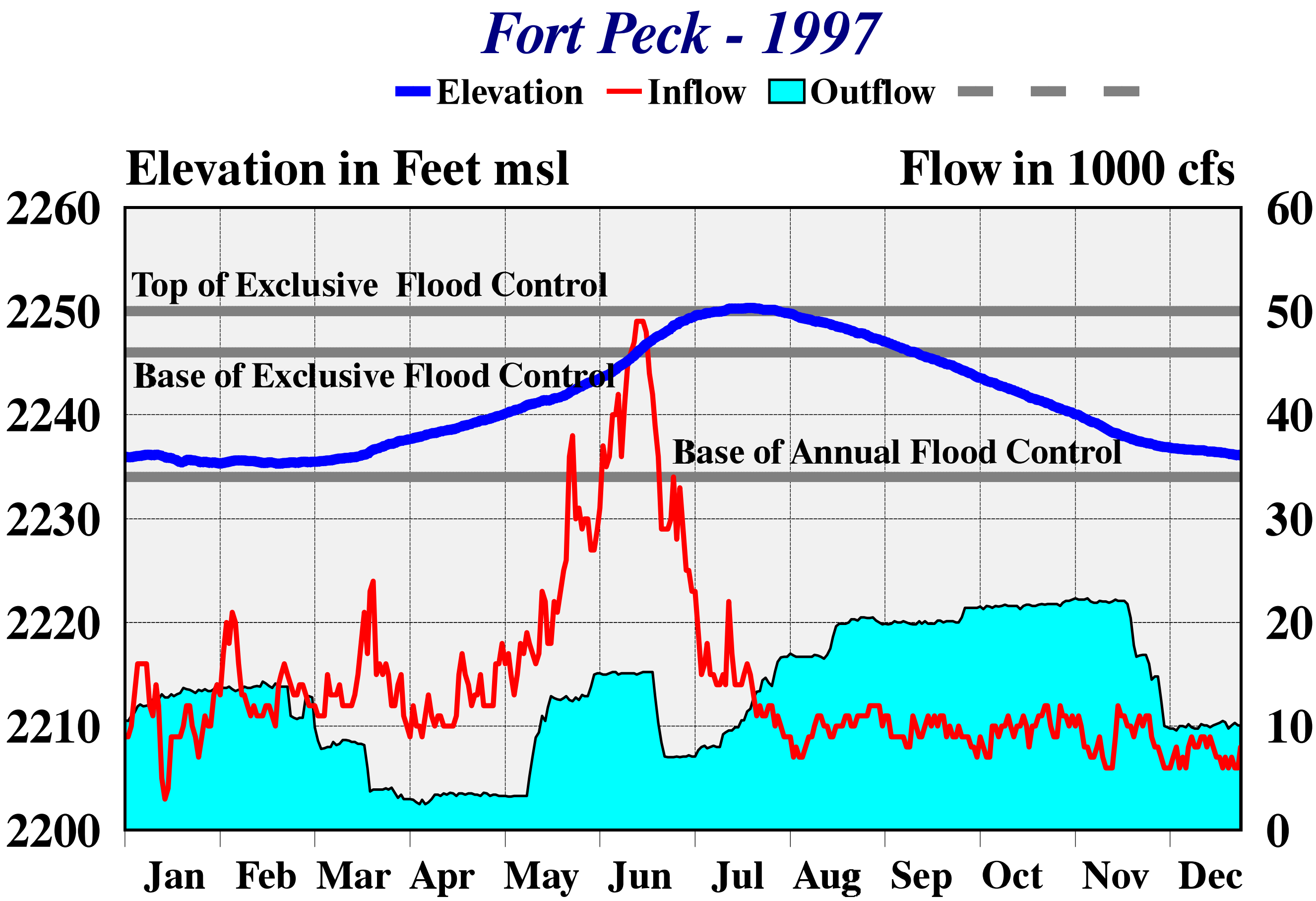


Figure 10


Fort Peck - 1997
Elevation
Inflow
Outflow
Elevation in Feet msl
Flow in 1000 cfs
Top of Exclusive Flood Control
Base of Exclusive Flood Control
Base of Annual Flood Control
2260
2250
2240
2230
2220
2210
2200
60
50
40
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

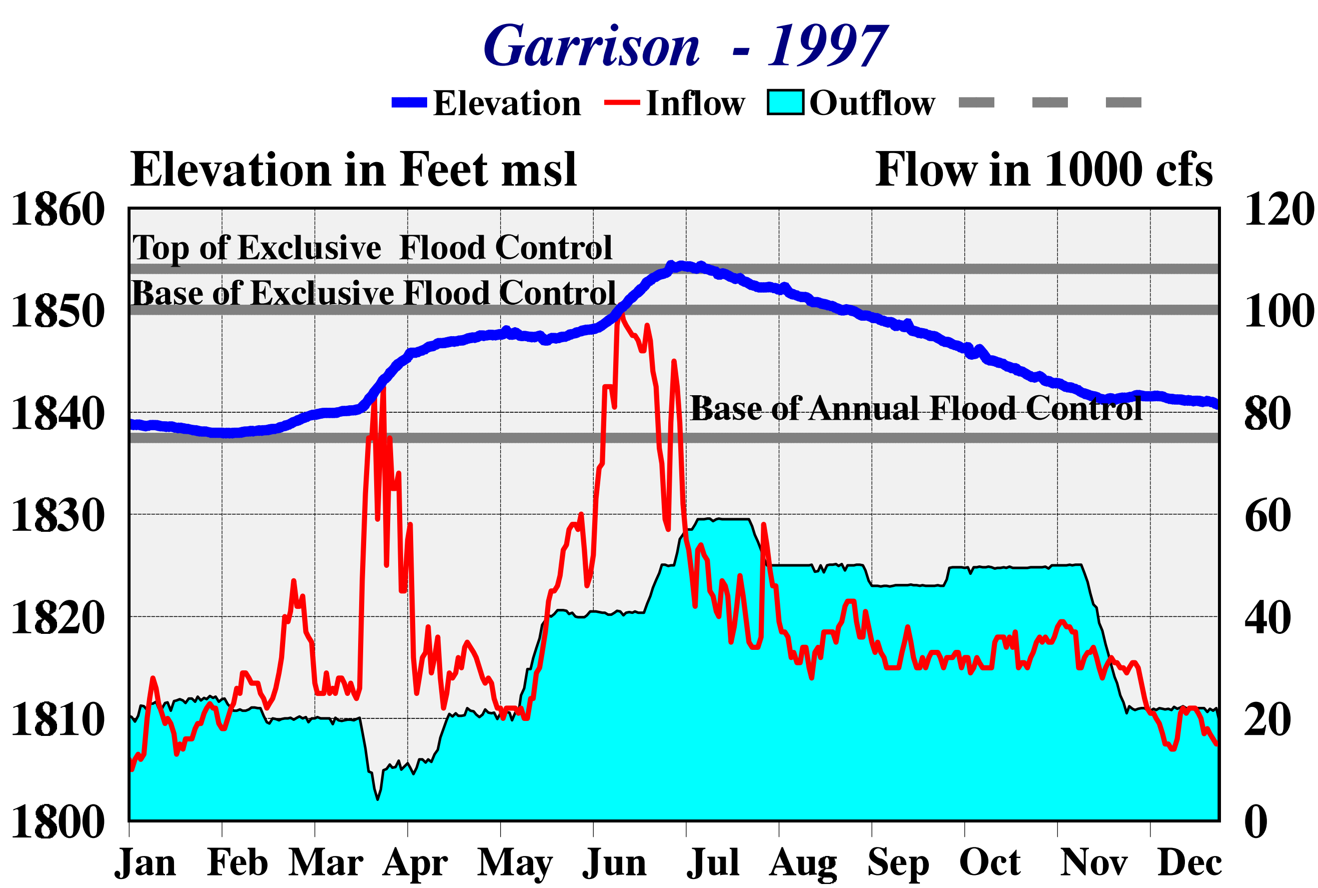
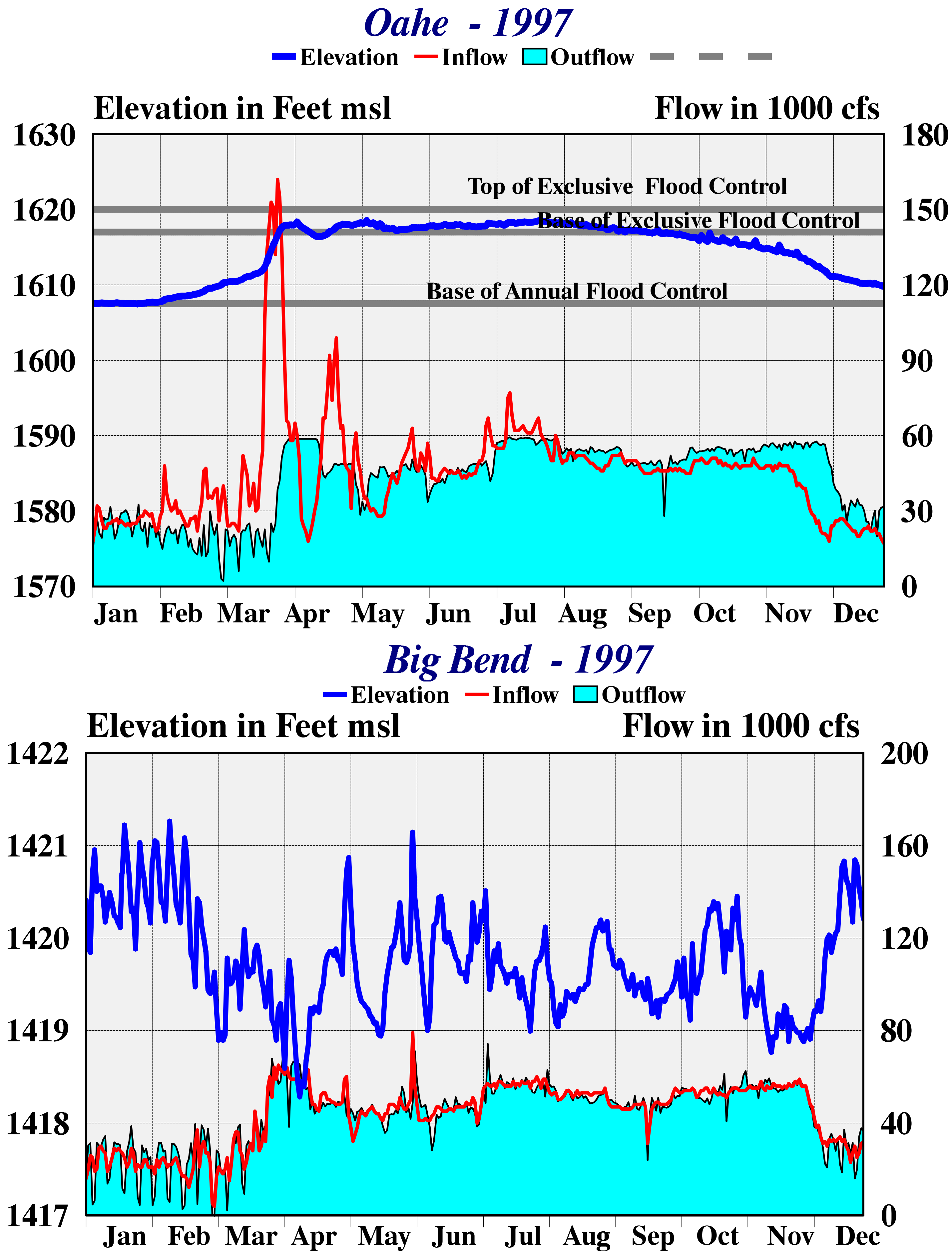
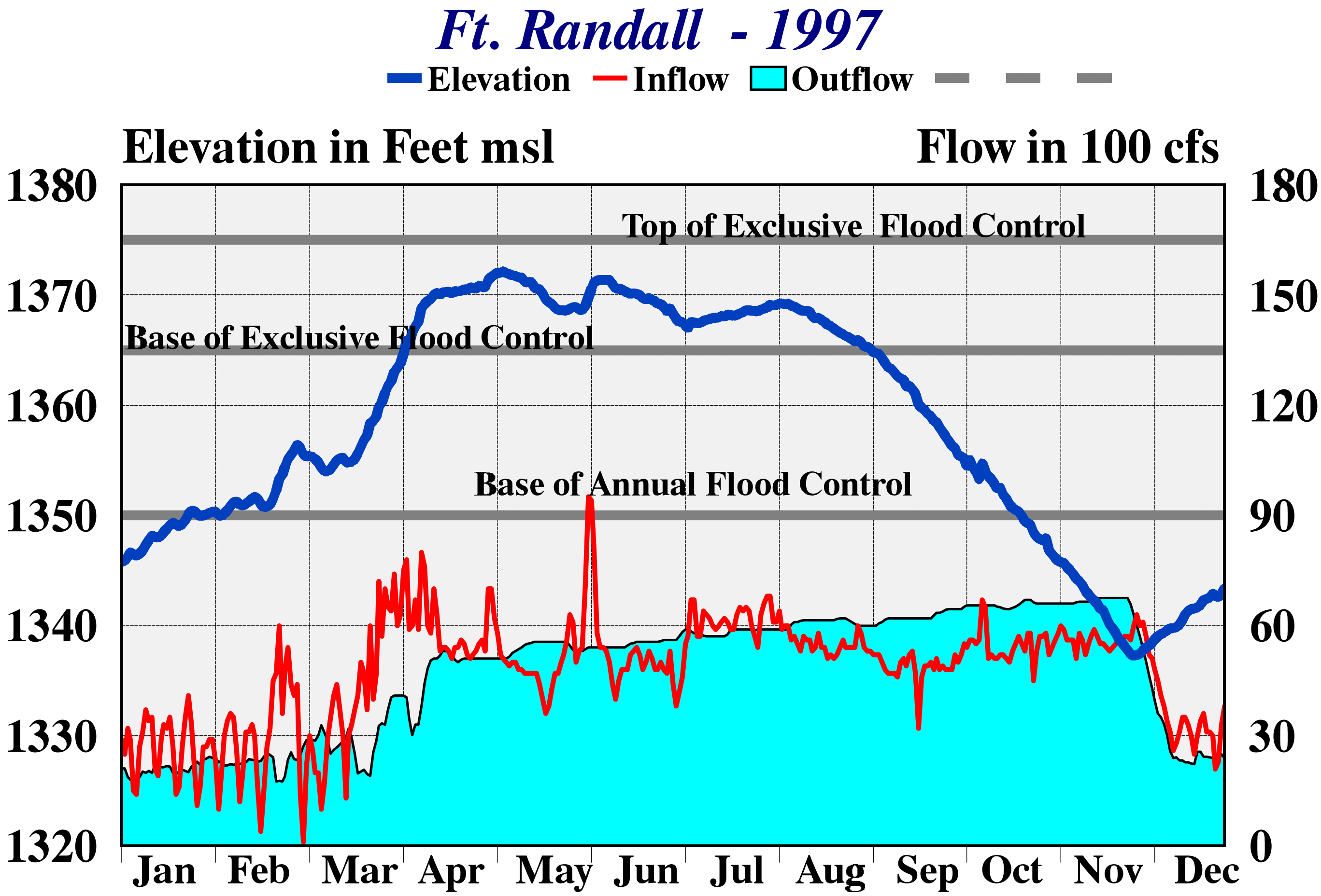
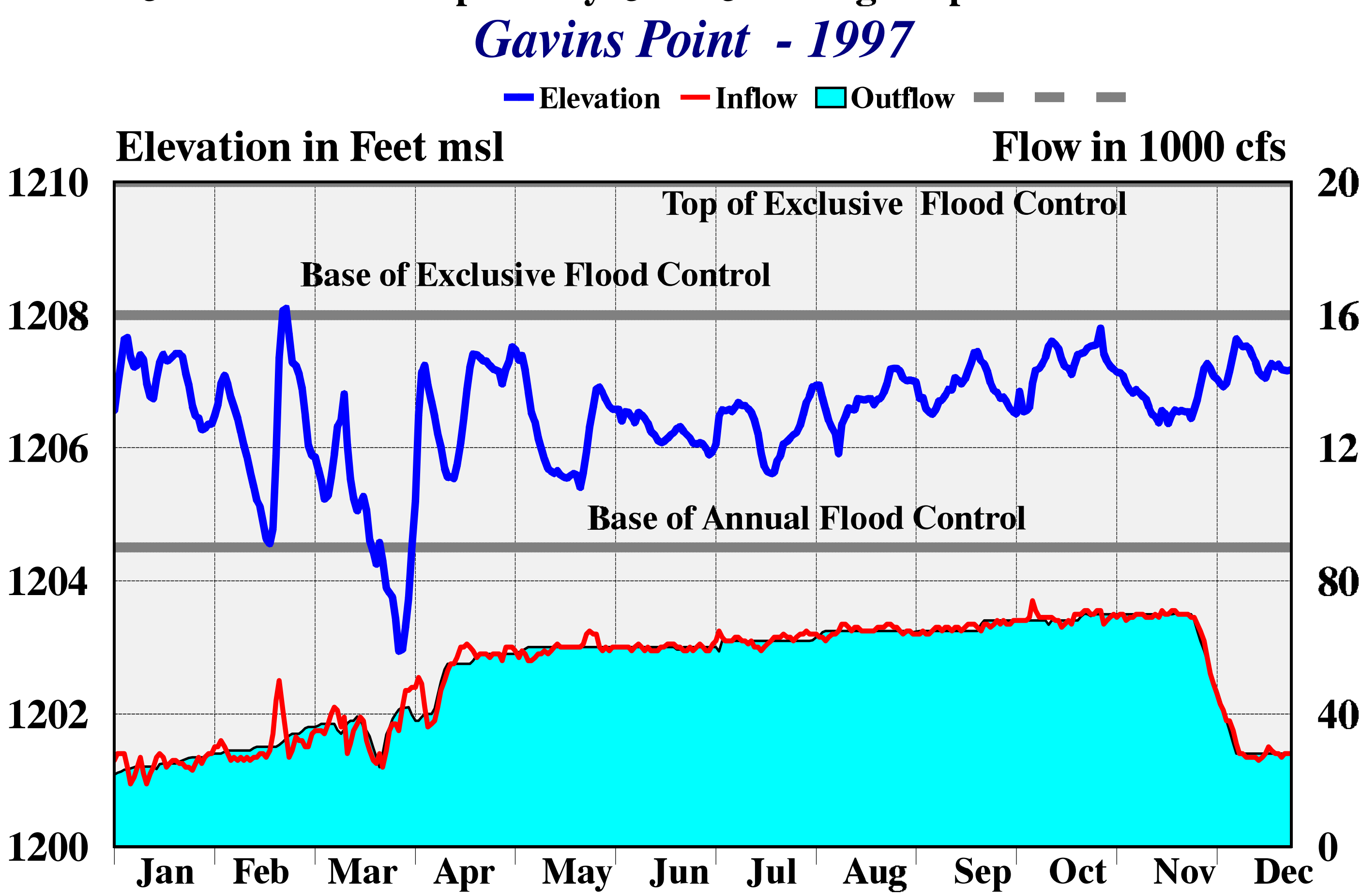

Garrison - 1997
Elevation
Inflow
Outflow
Elevation in Feet msl
Flow in 1000 cfs
Top of Exclusive Flood Control
Base of Exclusive Flood Control
Base of Annual Flood Control
1860
1850
1840
1830
1820
1810
1800
120
100
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Figure 11


Oahe - 1997
Elevation
Inflow
Outflow
Elevation in Feet msl
Flow in 1000 cfs
Top of Exclusive Flood Control
Base of Exclusive Flood Control
Base of Annual Flood Control
1630
1620
1610
1600
1590
1580
1570
180
150
120
90
60
30
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Big Bend - 1997
Elevation
Inflow
Outflow
Elevation in Feet msl
Flow in 1000 cfs
1422
1421
1420
1419
1418
1417
200
160
120
80
40
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Figure 12



Ft. Randall - 1997
Elevation
Inflow
Outflow
Elevation in Feet msl
Flow in 100 cfs
1380
1370
1360
1350
1340
1330
1320
180
150
120
90
60
30
0
Top of Exclusive Flood Control
Base of Exclusive Flood Control
Base of Annual Flood Control
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

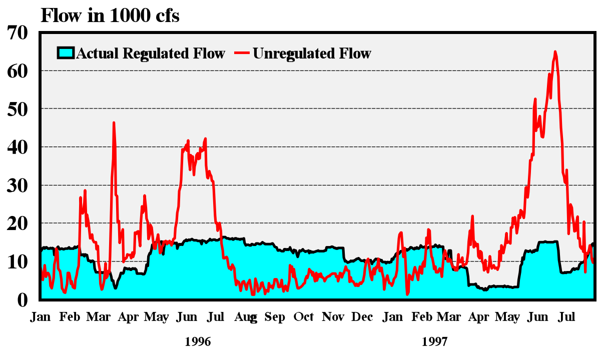


Gavins Point - 1997
Elevation
Inflow
Outflow
Elevation in Feet msl
Flow in 1000 cfs
1210
1208
1206
1204
1202
1200
20
16
12
80
40
0
Top of Exclusive Flood Control
Base of Exclusive Flood Control
Base of Annual Flood Control
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

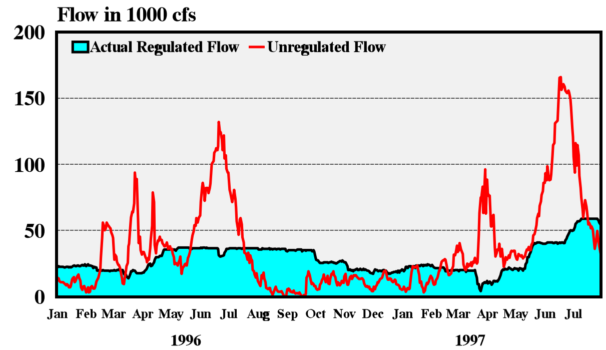
Figure 13

Missouri River Main Stem
Actual Release and Unregulated Flow

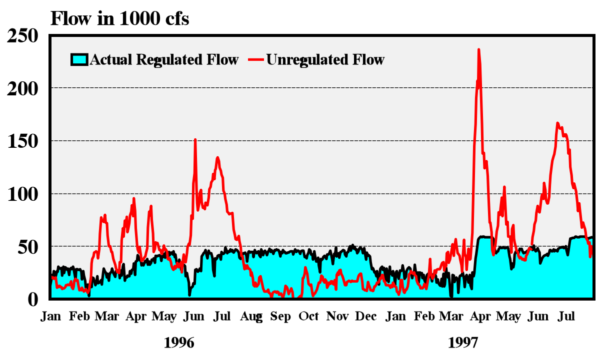
Fort Peck



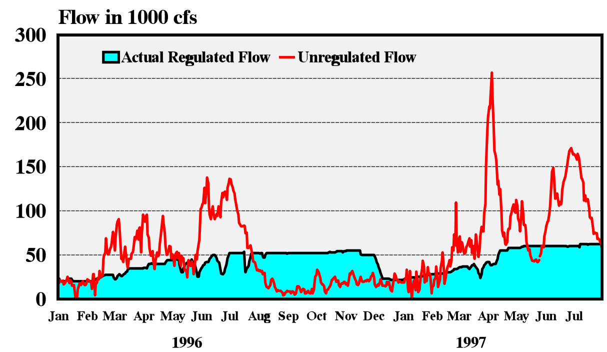
Garrison



Oahe



Gavins Point



Gavins Point Monthly Releases
1975, 1978 & 1997 vs. Average

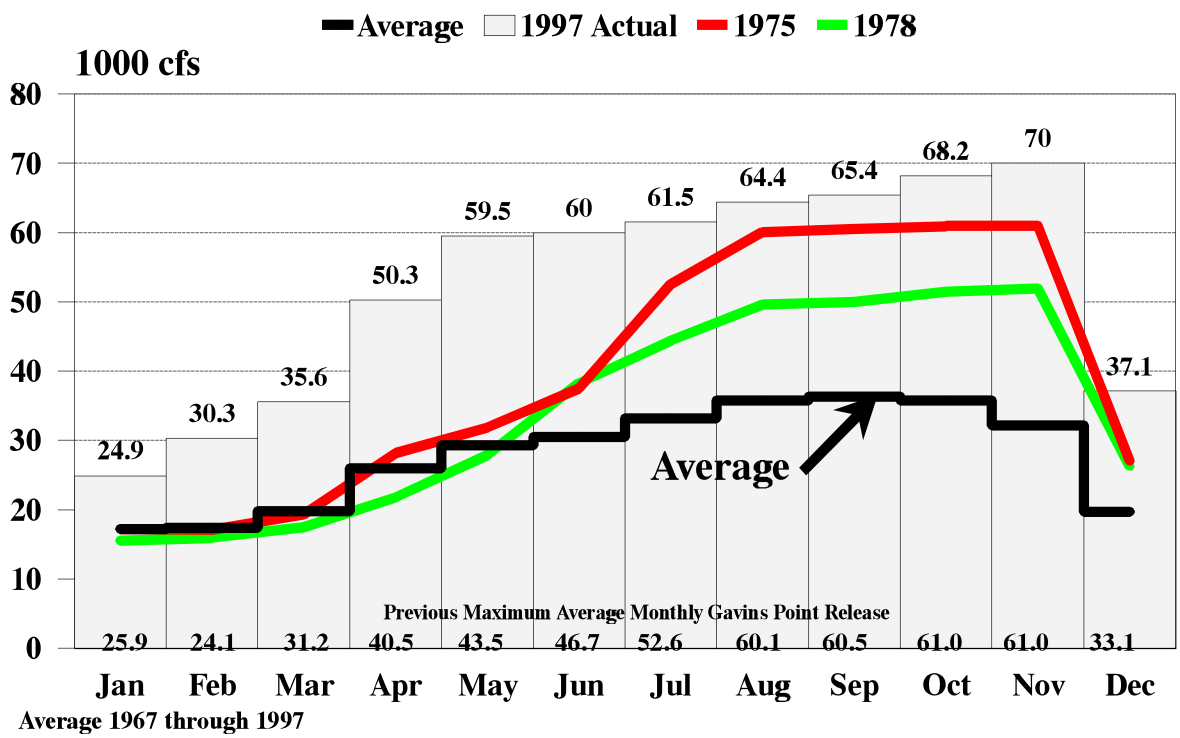
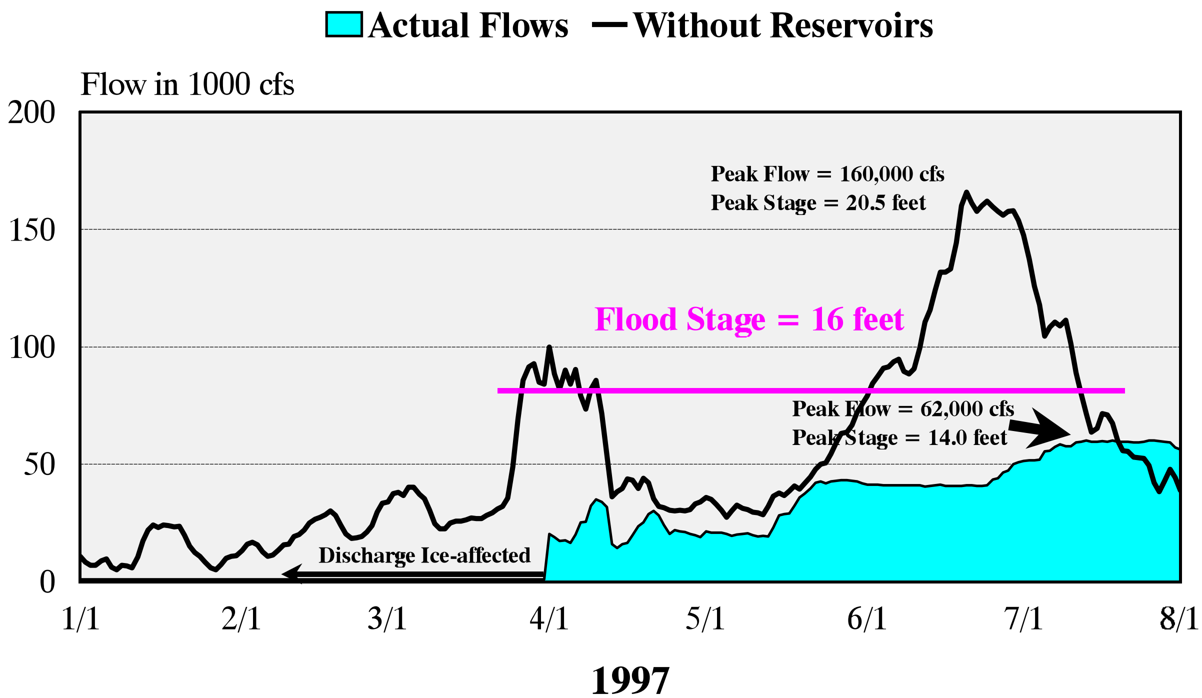


Figure 14

Missouri River at Bismarck, ND
Actual and Natural Flows for 1997



Missouri River at Sioux City, IA
Actual and Natural Flows for 1997

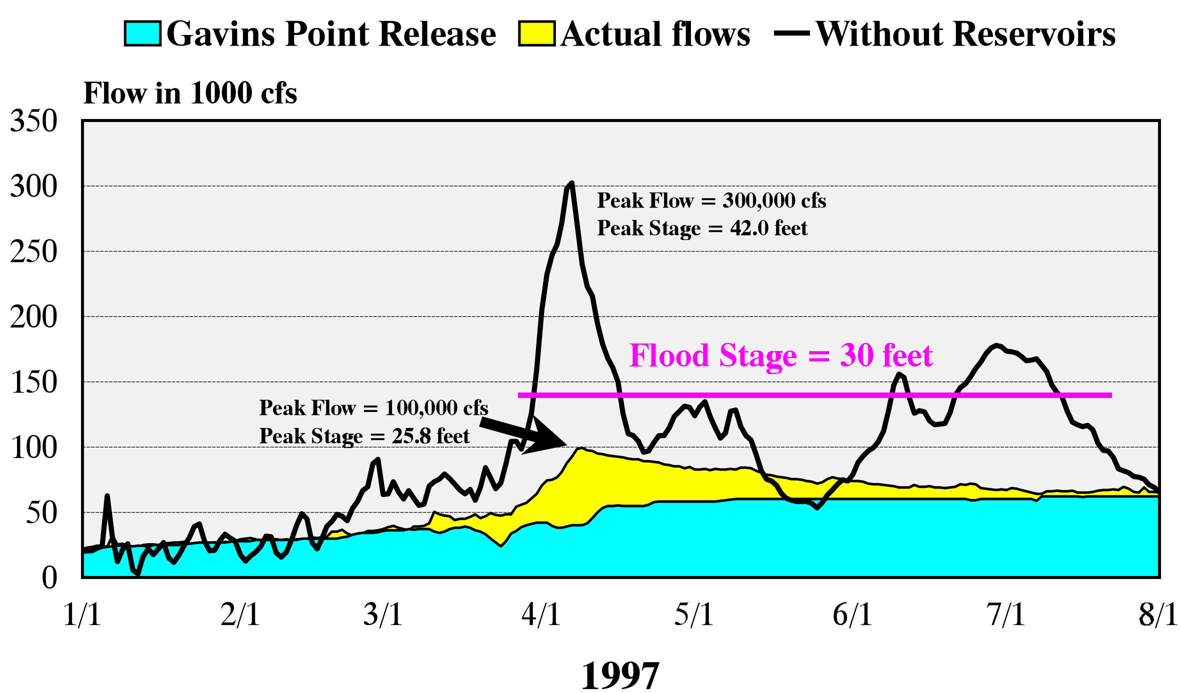
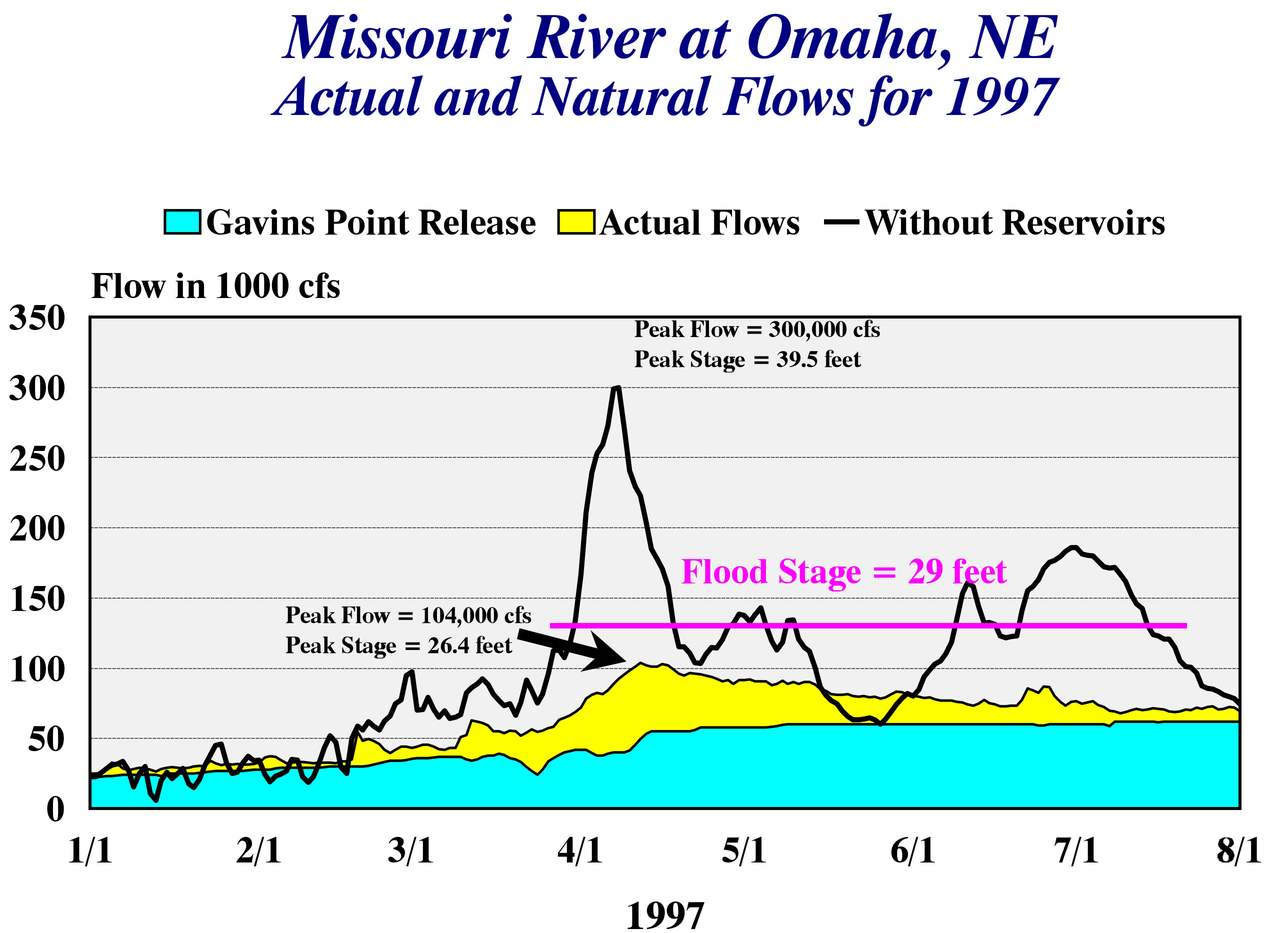


Figure 15


Missouri River at Omaha, NE
Actual and Natural Flows for 1997
Gavins Point Release
Actual Flows
Without Reservoirs
Flow in 1000 cfs
350
300
250
200
150
100
50
0
Peak Flow = 300,000 cfs
Peak Stage = 39.5 feet
Flood Stage = 29 feet
Peak Flow = 104,000 cfs
Peak Stage = 26.4 feet
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
1997

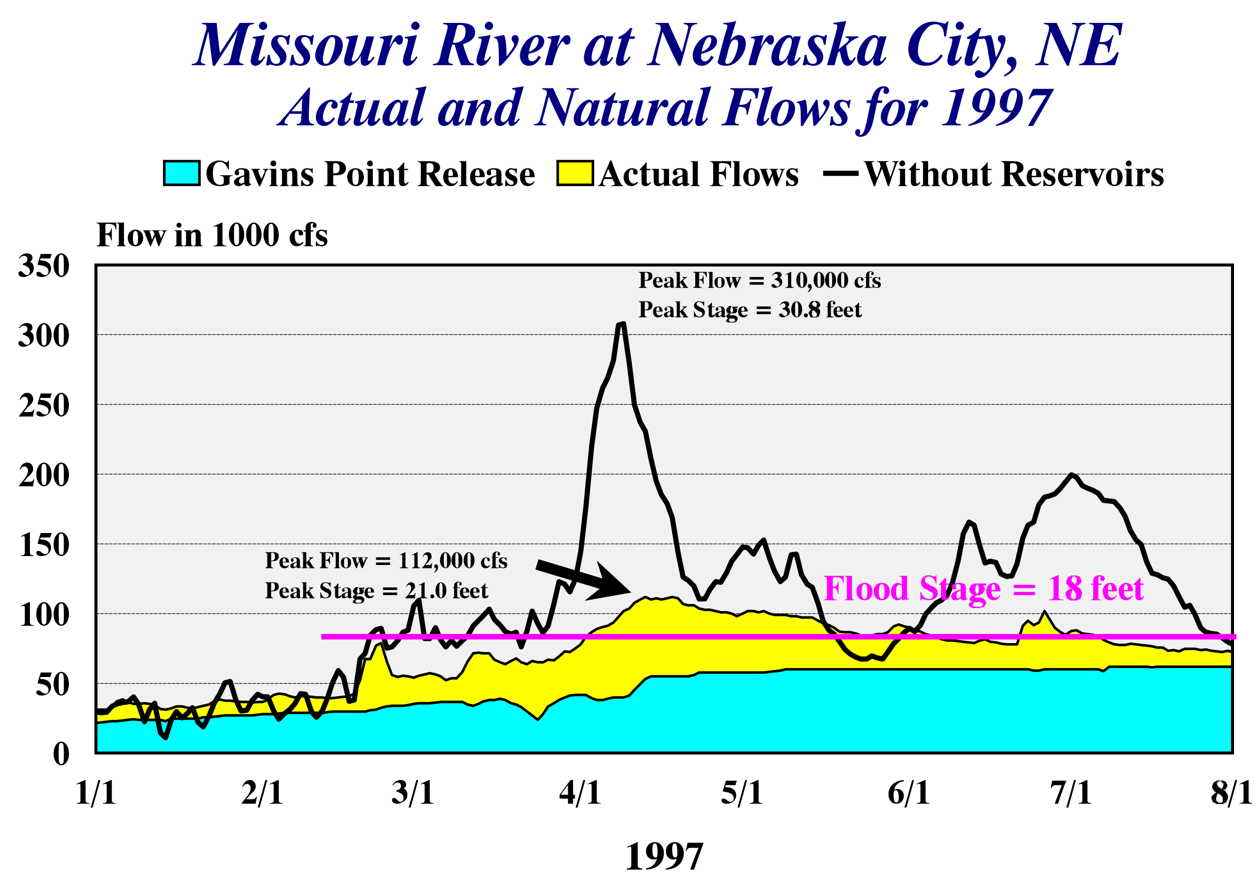
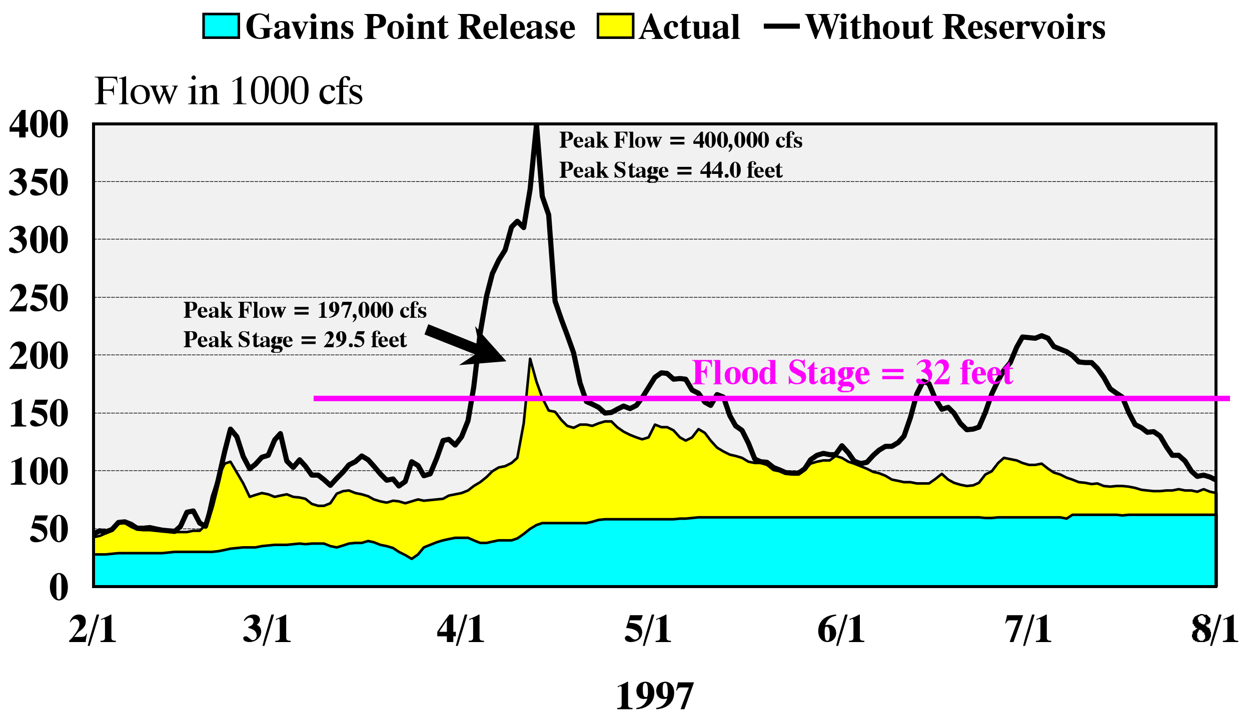

Missouri River at Nebraska City, NE
Actual and Natural Flows for 1997
Gavins Point Release
Actual Flows
Without Reservoirs
Flow in 1000 cfs
350
300
250
200
150
100
50
0
Peak Flow = 310,000 cfs
Peak Stage = 30.8 feet
Peak Flow = 112,000 cfs
Peak Stage = 21.0 feet
Flood Stage = 18 feet
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
1997

Figure 16

Missouri River at Kansas City, MO
Actual and Natural Flows for 1997



Missouri River at Boonville, MO
Actual and Natural Flows for 1997

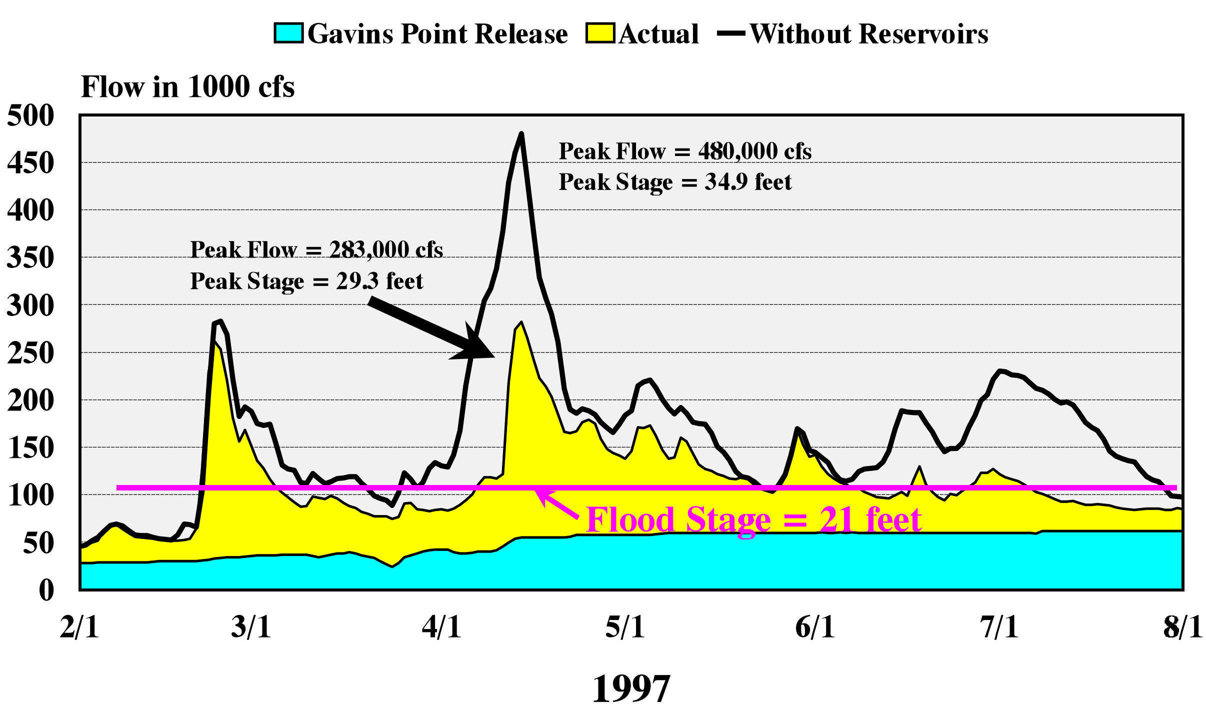
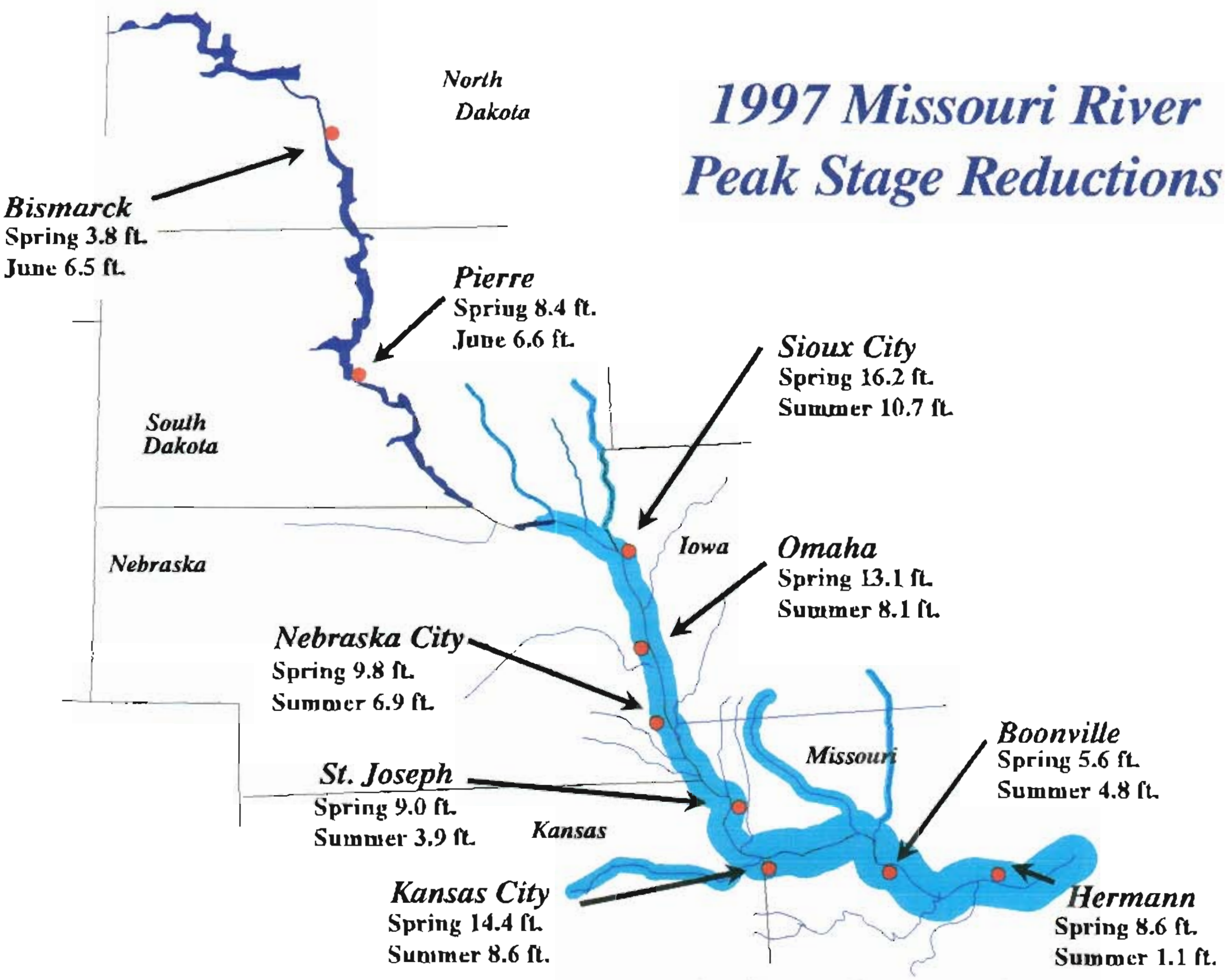


Figure 17


1997 Missouri River
Peak Stage Reductions
North
Dakota
Bismarck
Spring 3.8 ft.
June 6.5 ft.
Pierre
Spring 8.4 ft.
June 6.6 ft.
South
Dakota
Sioux City
Spring 16.2 ft.
Summer 10.7 ft.
Iowa
Omaha
Spring 13.1 ft.
Summer 8.1 ft.
Nebraska
Nebraska City
Spring 9.8 ft.
Summer 6.9 ft.
St. Joseph
Spring 9.0 ft.
Summer 3.9 ft.
Kansas
Missouri
Boonville
Spring 5.6 ft.
Summer 4.8 ft.
Kansas City
Spring 14.4 ft.
Summer 8.6 ft.
Hermann
Spring 8.6 ft.
Summer 1.1 ft.

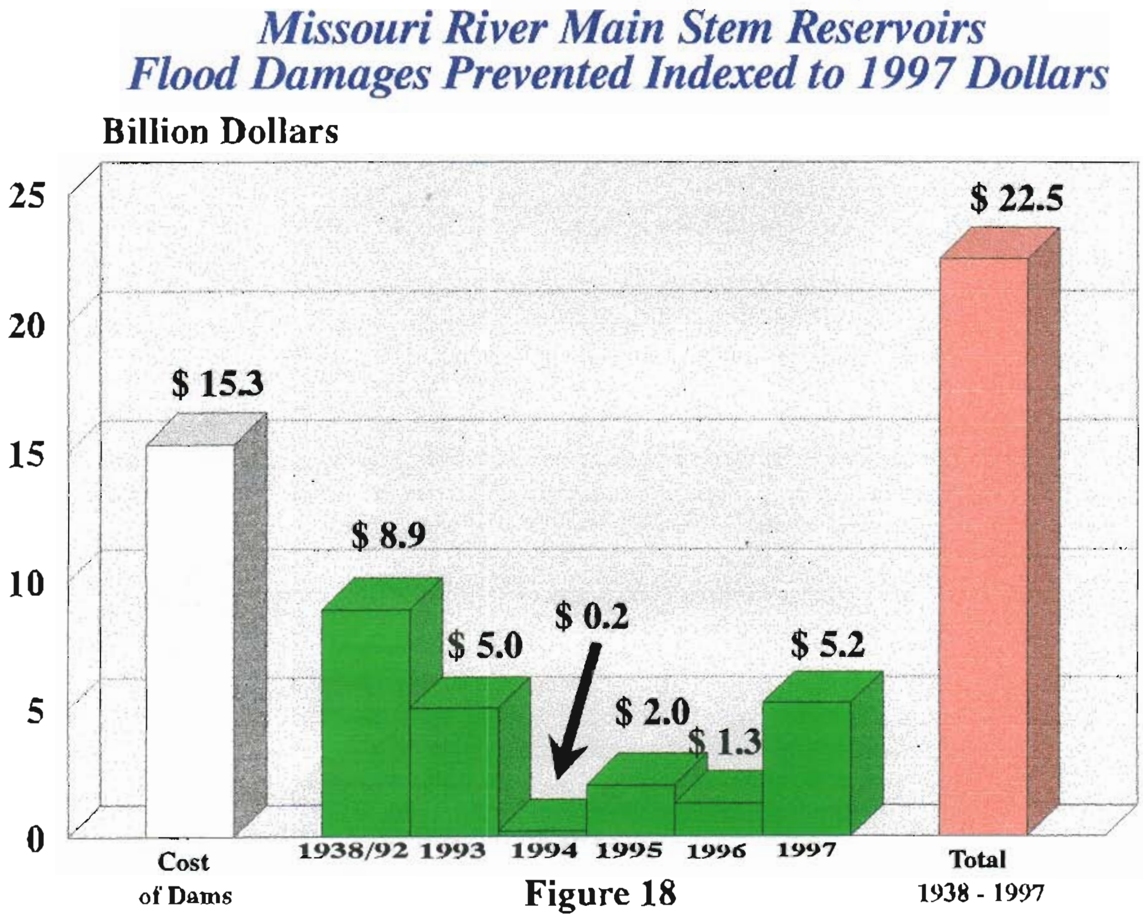

Missouri River Main Stem Reservoirs
Flood Damages Prevented Indexed to 1997 Dollars
Billion Dollars
25
20
15
10
5
0
$ 15.3
$ 8.9
$ 5.0
$ 0.2
$ 2.0
$ 1.3
$ 5.2
$ 22.5
Cost
of Dams
1938/92
1993
1994
1995
1996
1997
Total
1938 - 1997

Figure 18

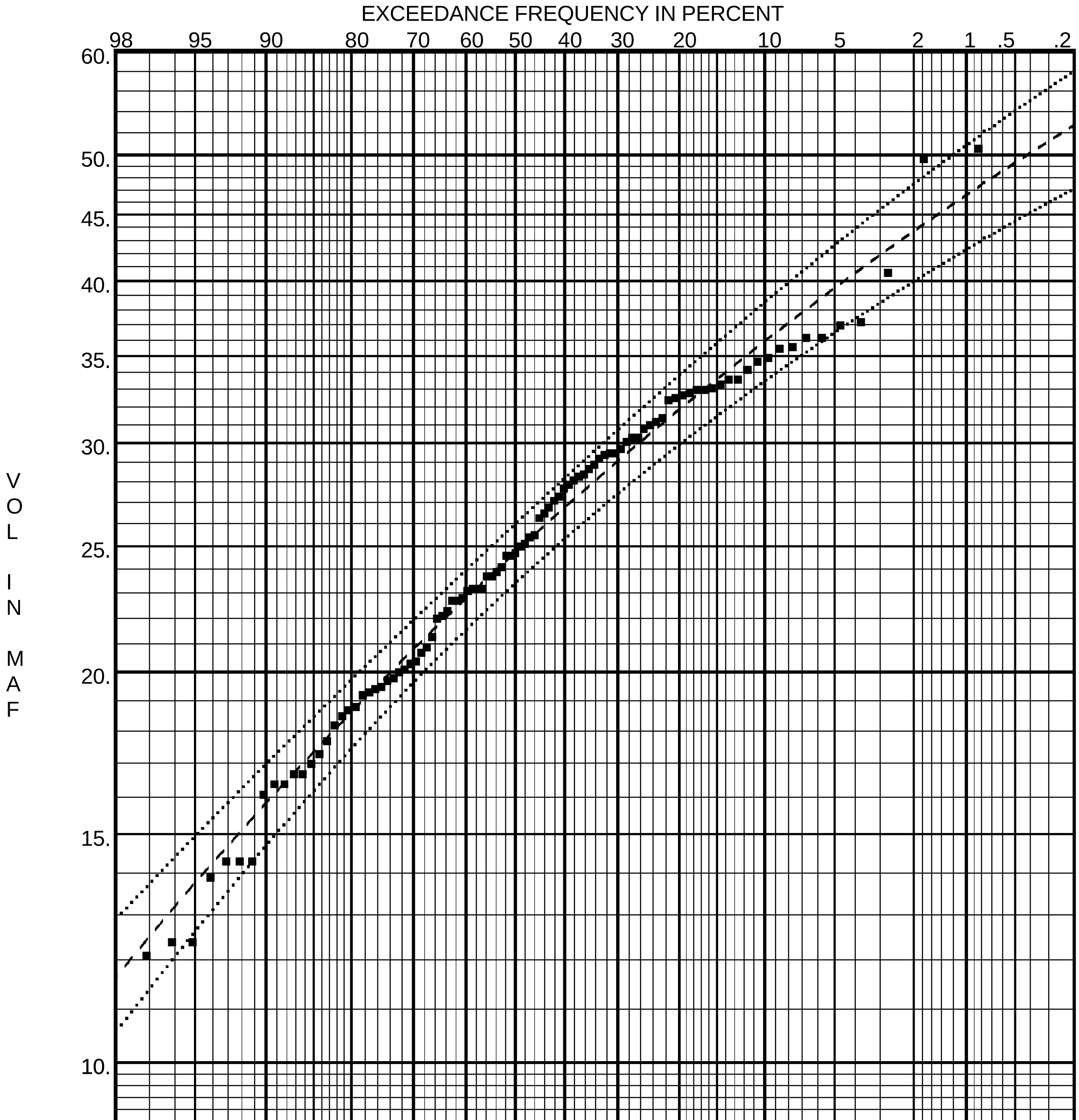
2-Jan-98

Missouri River Basin
Calendar Year 1997 Runoff
Historic and Forecasted

Values in 1000 Acre-Feet

Reach Above	Fort Peck	Garrison	Oahe	Fort Randall	Gavins Point	Sioux City	Summation above Gavins Point	Summation above Sioux City	Accumulated Summation above Sioux City
	(Historic)								
JAN 97	502	271	207	116	257	166	1,353	1,519	1,519
NORMAL	315	265	10	20	95	25	705	730	730
DEPARTURE	187	6	197	96	162	141	648	789	789
% OF NORM	159%	102%	2070%	580%	271%	664%	192%	208%	208%
FEB 97	588	660	548	586	438	134	2,820	2,954	4,473
NORMAL	360	350	70	40	120	80	940	1,020	1,750
DEPARTURE	228	310	478	546	318	54	1,880	1,934	2,723
% OF NORM	163%	189%	783%	1465%	365%	168%	300%	290%	256%
MAR 97	725	1,902	2,569	876	407	783	6,479	7,262	11,735
NORMAL	600	990	545	215	200	290	2,550	2,840	4,590
DEPARTURE	125	912	2,024	661	207	493	3,929	4,422	7,145
% OF NORM	121%	192%	471%	407%	204%	270%	254%	256%	256%
APR 97	620	1,987	2,865	478	360	2,376	6,310	8,686	20,421
NORMAL	670	1,120	480	140	170	300	2,580	2,880	7,470
DEPARTURE	-50	867	2,385	338	190	2,076	3,730	5,806	12,951
% OF NORM	93%	177%	597%	341%	212%	792%	245%	302%	273%
MAY 97	1,523	1,587	860	432	386	1,235	4,788	6,023	26,444
NORMAL	1,120	1,280	300	135	170	235	3,005	3,240	10,710
DEPARTURE	403	307	560	297	216	1,000	1,783	2,783	15,734
% OF NORM	136%	124%	287%	320%	227%	526%	159%	186%	247%
JUN 97	3,012	4,608	406	635	342	649	9,003	9,652	36,096
NORMAL	1,645	2,710	435	150	170	240	5,110	5,350	16,060
DEPARTURE	1,367	1,898	-29	485	172	409	3,893	4,302	20,036
% OF NORM	183%	170%	93%	423%	201%	270%	176%	180%	225%
JUL 97	1,187	2,954	295	118	280	360	4,834	5,194	41,290
NORMAL	820	1,790	165	60	125	180	2,960	3,140	19,200
DEPARTURE	367	1,164	130	58	155	180	1,874	2,054	22,090
% OF NORM	145%	165%	179%	197%	224%	200%	163%	165%	215%
AUG 97	553	1,296	119	205	294	301	2,467	2,768	44,058
NORMAL	350	615	60	45	110	110	1,180	1,290	20,490
DEPARTURE	203	681	59	160	184	191	1,287	1,478	23,568
% OF NORM	158%	211%	198%	456%	267%	274%	209%	215%	215%
SEP 97	448	552	37	66	240	140	1,343	1,483	45,541
NORMAL	340	480	115	45	105	85	1,085	1,170	21,660
DEPARTURE	108	72	-78	21	135	55	258	313	23,881
% OF NORM	132%	115%	32%	147%	229%	165%	124%	127%	210%
OCT 97	461	565	-47	58	201	157	1,238	1,395	46,936
NORMAL	395	525	70	10	115	65	1,115	1,180	22,840
DEPARTURE	66	40	-117	48	86	92	123	215	24,096
% OF NORM	117%	108%	-67%	580%	175%	242%	111%	118%	205%
NOV 97	479	565	-47	-49	173	137	1,121	1,258	48,194
NORMAL	390	410	65	10	115	60	990	1,050	23,890
DEPARTURE	89	155	-112	-59	58	77	131	208	24,304
% OF NORM	123%	138%	-72%	-490%	150%	228%	113%	120%	202%
DEC 97	362	494	56	223	318	71	1,453	1,524	49,718
NORMAL	330	250	-5	5	90	40	670	710	24,600
DEPARTURE	32	244	61	218	228	31	783	814	25,118
% OF NORM	110%	198%	1120%	4460%	353%	178%	217%	215%	202%
				Calendar Year Totals					
	10,460	17,441	7,868	3,744	3,696	6,509	43,209	49,718	
NORMAL	7,335	10,785	2,310	875	1,585	1,710	22,890	24,600	
DEPARTURE	3,125	6,656	5,558	2,869	2,111	4,799	20,319	25,118	
% OF NORM	143%	162%	341%	428%	233%	381%	189%	202%	

Figure 19



- - - Vol Frequency (with Exp. Prob.)
■ Weibull Plotting Positions
······· 5% and 95% Confidence Limits

FREQUENCY STATISTICS

Log Transform of VOL, MAF		Number of Events	
Mean	1.3841	HISTORIC EVENTS	1
Standard Deviation	.1378	HIGH OUTLIERS	0
Skew	-.4049	LOW OUTLIERS	0
Regional Skew	-.4000	ZERO OR MISSING	0
Adopted Skew	-.4000	SYSTEMATIC EVENTS	100

HISTORIC PERIOD(1881-1997) 117

Frequency Analysis
Missouri River Basin
Above Sioux City
Annual Runoff Volume
In Million Acre-Feet (MAF)
BASIN AREA = 314,617 sq mi
WATER YEARS IN RECORD
1881,1898-1997

Figure 20