MISSOURI RIVER
MAIN STEM RESERVOIR SYSTEM
RESERVOIR REGULATION MANUAL

MASTER MANUAL

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
OMAHA, NEBRASKA
1979

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In 7 Volumes

Volume 1

MASTER MANUAL

Volume 1	Master Manual
Volume 2	Fort Peck (Fort Peck Reservoir)
Volume 3	Garrison (Lake Sakakawea)
Volume 4	Oahe (Lake Oahe)
Volume 5	Big Bend (Lake Sharpe)
Volume 6	Fort Randall (Lake Francis Case)
Volume 7	Gavins Point (Lewis and Clark Lake)

PREPARED BY
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TABLE OF CONTENTS

SECTION I - AUTHORIZATION AND SCOPE

SECTION II - DESCRIPTION OF MISSOURI RIVER BASIN AND MISSOURI RIVER

TABLES

PLATES

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, N. Dak.	Near Pierre, S. Dak.	21 mi. upstream Chamberlain, S.D.	Near Lake Andes, S. Dak.	Near Yankton, S. Dak.		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, 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. Mont.	178. ending near Trenton, N.D.	231. ending near Bismarck. N.D.	80. ending near Pierre, S.D.	107. ending at Big Bend Dam	25. ending near Niobrara, Nebr.	755 Miles	4
5	Shoreline — Miles (3)	1520 (*El. 2234*)	1340 (*El. 1837.5*)	2250 (*El. 1607.5*)	200 (*EL. 1420*)	540 (*El. 1350*)	90 (*El. 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	137,00 (*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 — Cal. 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, Elev. ft. 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 feet	11
12	Damming Height. feet (5)	220	180	200	78	140	45	863 feet	12
13	Maximum Height. feet (5)	250.5	210	245	95	165	74		13
14	Max. Base width, total & w/o Berms, feet	3500:2700	3400; 2050	3500:1500	1200:700	4300:1250	850.450		14
15	Abutment Formations (*Under Dam & Embankment*)	Bearpaw shale and Glacial Till	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 fill	Rolled earth fill & shale berms	Rolled earth, shale, chalk fill	Rolled earth fill & chalk berms	Rolled earth & chalk fill		16
17	Fill quantity, cu. yds.	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 (*Cu. yds.*)	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, 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 Type of Gates	16--40'x25' Vertical Lift Gates	28-40'x29' Tainter	8-50'x23.5' Tainter	8-40'x38' Tainter	21-40'x29' Tainter	14-40 x30' 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, 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 249.000 acres	1854 msl 383.000 acres	1620 msl 371.000 acres	1423 msl 61.000 acres	1375 msl 102,000 acres	1210 msl 32,000 acres	1.198.000 acres	26
27	Max. Nor. Op. Pool Elev. & Area	2246 msl 240.000 acres	1850 msl 368.000 acres	1617 msl 356.000 acres	1422 msl 60.000 acres	1365 msl 95,000 acres	1208 msl 30,000 acres	1.146.000 acres	27
28	Base Flood Control Elev. & Area	2234 msl 212.000 acres	1837.5 msl 315.000 acres	1607.5 msl 313.000 acres	1420 msl 57.000 acres	1350 msl 78,000 acres	1204.5 msl 26,000 acres	1.001.000 acres	28
29	Min. Oper. Pool Elev. & Area	2160 msl 92.000 acres	1775 msl 129.000 acres	1540 msl 118.000 acres	1415 msl 51.000 acres	1320 msl 42,000 acres	1204.5 msl 26,000 acres	458.000 acres	29
	Stor. Allocation. Elev & Cap.								
30	Exclusive Flood Control	2250-2246 1.000.000 a.f.	1854-1850 1.500,000 a.f (10)	1620-1617 1.100.000 a.f.	1423-1422 60,000 a.f.	1375-1365 1,000.000 a.f.	1210-1208 62,000 a.f.	4.722.000 a.f.	30
31	Flood Control & Multiple Use	2246-2234 2.700,000 a.f.	1850-1837.5 4,300,000 a.f. (10)	1617-1607.5 3.200.000 a.f.	1422-1420 117,000 a.f.	1365-1350 1.300.000 a.f.	1208-1204.5 97,000 a.f.	11.714.000 a f.	31
32	Carryover Multiple Use	2234-2160 10.900.000 a.f.	1837.5-1775 13.400.000 a.f. (10)	1607.5-1540 13.700.000 a.f.		1350-1320 1.700,000 a.f.		39.700.000 a f	32
33	Inactive	2160-2030 4.300,000 a.f.	1775-1673 5.000.000 a.f.	1540-1415 5.500.000 a.f.	1420-1345 1.730.000 a.f.	1320-1240 1,600.000 a.f.	*1204.5-1160* *358,000 a.f.*	*18.488.000 a.f*	33
34	*Gross*	*2250 2030* *18.900.000 a.f.*	*1854-1673* 24.200.000 a.f. (10)	1620-1415 23.500.000 a.f.	1423-1345 1.907.000 a.f.	1375-1240 5.600.000 a.f.	1210-1160 517,000 a.f.	74.624.000 a f	34
35	Reservoir filling initiated	November 1937	December 1953	August 1958	November 1963	January 1953	August 1955		35
36	Initially reached Min. Oper. Pool	27 May 1942	7 August 1955	3 April 1962	25 March 1964	24 November 1953	22 December 1955		36
37	Est. Annual Sediment Inflow	17,500 a.f. 1080 yrs	38.100 a.f. 640 yrs	32,300 a.f. 730 yrs	4.400 a.f. 430 yrs	16.600 a.f. 370 yrs	2,500 a.f. 210 yrs	111,400 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" dia. (*No's. 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'x8.5' high (*net opening*) in each control shaft	1-18'x24.5' Tainter gate per conduit for fine regulation	1-13'x22' per conduit, vertical lift; 4 cable suspension and 2 hydraulic suspension (*fine regulation*)		2-11'x23' per conduit, vertical lift, cable suspension, also one vert. lift fine regulating gate at d s. end of tunnel #10			41
42	Entrance Invert Elevation	2095	1672	1425	1385 (12)	1229	1180 (12)		42
43	Avg. Discharge Cap. per conduit & total	Elev. 2250 22,500 cfs—45,000 cfs	Elev. 1854 30,400 cfs-98,000 cfs	Elev. 1520 18,500 cfs-111,000 cfs		Elev. 1375 32.000 cfs-128.000 cfs			43
44	Present Tailwater Elev. (*msl*)	2032—2036 5,000—35,000 cfs	1672-1680 15,000-60,000 cfs	1423-1428 25,000-55,000 cfs	1351-1355 (11) 25,000-100,000 cfs	1230-1239 5,000-60,000 cfs	1158-1165 15,000-60,000 cfs		44
	POWER FACILITIES AND DATA								
45	Avg. Gross Head avail. in ft. (13)	193	154	185	69	115	45	761 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	1,829	From 3,280 to 4,005		1.074		55,083 feet	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, 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	Disch. Cap. at Rated Head-cfs	PH#1 units 1&3 170', 2-140' 8,800 cfs, PH#2-2-170'-7,200 cfs	150' 38,000 cfs	185' 54,000 cfs	67' 103,000 cfs	112' 44,500 cfs	48' 36,000 cfs		50
51	Generator Rating, kw	2-43,500; 1-18,250; 2-40,000	3-80,000; 2-95,000	85,000	58.500	40.000	33,333		51
52	Plant capacity, kw	185,000	430,000	595,000	468.000	320,000	100,000	2,098,000 kw	52
53	Dependable capacity, kw (9)	173,000	367,000	470,000	538.000	285,000	67,000	1,900,000 kw	53
54	Average Annual Energy Million kwh (13)	1,019	2,270	2,604	952	1,715	651	9,211	54
55	Initial Gen., First & 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 January 1979 Completed project	$156,600.000	$294,800,000	$345.200,000	$107,000,000	$197,400,000	$48.100,000	$1,149,100,000	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 turbins.
(8) Length from upstream face of intake to downstream face of outlet or to spiral case.
(9) Based on 4th year of drought drawdown. (From study 2-76-1975)
(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) Based on study 2-76-1975.

Corps of Engineers, U.S. Army
Compiled by
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MISSOURI RIVER BASIN
MAIN STEM RESERVOIR SYSTEM
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IN 7 VOLUMES - VOLUME NO. 1

MASTER MANUAL

SECTION I - AUTHORIZATION AND SCOPE

1-1. Authorization. This manual has been prepared as directed in ER 1110-2-240 and in accordance with pertinent sections of EM 1110-2-3600, "Reservoir Regulation."

1-2. Scope. The Missouri River Main Stem System of reservoirs consists of six reservoirs, Fort Peck, Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point, constructed by the Corps of Engineers on the main stem of the Missouri River for flood control, navigation, irrigation, power, water supply, water quality control, recreation, and fish and wildlife.

1-3. In order to achieve the multi-purpose benefits for which the main stem reservoirs were authorized and constructed, they must be operated as a hydraulically and electrically integrated system. Therefore, this master manual presents the basic objectives and the plans for their optimum fulfillment, with supporting basic data. The individual project manuals serve as supplements to this manual and present aspects of project usage not common to the system as a whole, including more detail on the incremental drainage areas regarding hydrology, hydrologic networks, forecasting, and stream flow. With the inherent flexibility of operation of the main stem reservoir system, with the benefits which will be gained from further actual operating experience, and with possible changing emphasis on service to various functions as the result of economic growth, it may be found necessary to revise the plans presented herein from time to time in the future.

1-4. The manual is being prepared in 7 volumes as follows:

Volume	Project
1	Master Manual
2	Fort Peck Reservoir
3	Garrison Reservoir
4	Oahe Reservoir
5	Big Bend Reservoir
6	Fort Randall Reservoir
7	Gavins Point Reservoir

SECTION II - DESCRIPTION OF MISSOURI RIVER BASIN AND MISSOURI RIVER

II-A. Basin Geography.

2-1. Areal Extent. The Missouri River is formed by the confluence of the Gallatin, Madison, and Jefferson Rivers in southwestern Montana, near the town of Three Forks, and flows generally east and south about 2,316 miles to join the Mississippi River just upstream from St. Louis, Missouri. The Missouri River basin has an area of 529,350 square miles, including about 9,700 square miles in Canada. That part within the United States extends over one-sixth of the Nation's area, exclusive of Alaska and Hawaii. It includes all of Nebraska, most of Montana, Wyoming, North Dakota, and South Dakota, about half of Kansas and Missouri, and smaller parts of Iowa, Colorado, and Minnesota.

2-2. Topography. The Rocky Mountains form the basin's western boundary. They have an exceptionally rugged topography, with many peaks surpassing 14,000 feet in elevation. The mountains extend over an area of 56,000 square miles. The area contains many valleys, but the peaks and mountain spurs dominate the area.

2-3. Sloping eastward from the Rocky Mountains, the Great Plains form the heartland of the basin. This broad belt of highlands covers approximately 370,000 square miles. The eastern boundary lies along the 1,500-foot contour. The western boundary at the foot of the Rocky Mountains averages about 5,500 feet in elevation. West-to-east slopes average about 10 feet to the mile. South and west of the Missouri River, the surface mantle and topography have been developed largely by erosion of a fluvial plain extending eastward from the mountains. North and east of the Missouri River, and even extending south of the river in some places, the Great Plains have been affected by continental glaciation. Here, the topography was shaped primarily by erosion of the glacial drift and till. Within the Great Plains, there are isolated mountainous areas developed by erosion of dome-like uplifts. Principal among these are the Black Hills of western South Dakota and northeastern Wyoming, extending over an elliptical area 60 miles wide and 125 miles long.

2-4. The Central Lowlands border the Great Plains to the east, and often there is no perceptible line of demarcation between them. Roughly, the Central Lowlands extend from a line between Jamestown, North Dakota, and Salina, Kansas, eastward to the drainage divide between the Missouri and Mississippi Rivers. This entire area of

90,000 square miles has been developed by erosion of a mantle of glacial drift and till. The northern portion is covered by the coarser drift material, while the finer till is dominant in the southern portion.

2-5. In the southeastern part of the basin, in southern Missouri, an area of about 11,000 square miles of the basin lies in the Ozark Plateau. The topography here, developed by erosion of the Ozark uplift, is hilly to mountainous. Sedimentary formations in great depth underlie the moderate uplift, and only sedimentary rocks are left exposed. The basic surface material is limestone, and cavernous channels with spring flows abound in the area. Plate 1 is a basin map showing the physiographic features discussed above.

2-6. Land Use[1/]. Of the basin's total land area in the United States of about 328 million acres, agriculture uses about 95 percent, while the remainder is devoted to recreation, fish and wildlife, transportation, and built-up areas. Well over half of the total, 180 million acres, is pasture and range grassland devoted primarily to grazing. Cropland comprises nearly 104 million acres, or 32 percent of all lands basinwide, but the proportion ranges from as high as 71 percent in eastern Nebraska and western Iowa to as low as 7 percent in the Yellowstone River basin. Irrigated lands in the basin aggregate 7.4 million acres, with about 6.9 million acres intensively cropped and about 0.5 million acres in irrigated pasture. Forest and woodland areas, most of which are grazed, total about 28 million acres, about 9 percent of the basin area. Transportation, urban development, and related uses now require 8 million acres of land. Water areas aggregate 3.9 million acres. Although they represent only 1.2 percent of the basin area, the rivers, lakes, reservoirs, farm ponds, and other bodies of water involved are extremely important to the basin's economy.

2-7. Missouri River Slopes. With a total fall of 3,630 feet, the slope of the Missouri River averages 1.5 feet per mile, ranging from 4.3 feet per mile for the reach from Three Forks, Montana (head of the river) to above the falls at Great Falls, 3.7 feet per mile from below the falls to Zortman (near the head of Fort Peck Reservoir), 1.1 feet per mile from Zortman to the Yellowstone River, and an average of 0.9 of a foot per mile from the Yellowstone River to the mouth. While having no appreciable effect on the average stream slope, the length of the Missouri River has decreased over the period of historical record.

1/ Data from June 1969 Comprehensive Framework Study, Missouri River Basin, Land Resources Availability Appendix.

Surveys made in 1890 indicated that the total length from source to mouth was 2,546 miles. In 1941, this total length was measured as 2,464 miles, while in 1965 a further examination revealed a total length of 2,316 miles. Some of this reduction in river mileage has resulted from channel rectification below Sioux City in connection with the Missouri River bank stabilization and navigation project. Since 1890, the mileage below Sioux City has decreased by about 75 miles. Additional shortening of the river length has resulted from inundation of the meandering channel by construction of the main stem reservoirs.

2-8. Drainage Pattern. The drainage pattern of the Missouri basin and the locations of the Corps' civil work projects are shown on Plate 2. Outstanding among the Missouri's tributaries are the Yellowstone River which drains an area of over 70,000 square miles and joins the Missouri River near the Montana-North Dakota boundary, the Platte River with a 90,000 square mile drainage area which enters the Missouri in eastern Nebraska, and the Kansas River which empties into the main stem in eastern Kansas and drains an area of about 60,000 square miles. The most prominent feature of the drainage pattern of the upper and middle portions of the Basin is that every major tributary, with the exception of the Milk River, is a right bank tributary flowing to the east or to the northeast. Only in the extreme lower basin, below the mouth of the Kansas River, is a fair balance reached between left and right bank tributaries. The direction of flow of the major tributaries is of particular importance from the standpoint of potential concentration of flows from storms that typically move in an easterly direction. It is also important in another respect on the Yellowstone River, since early spring temperatures in the headwaters of the Yellowstone and its tributaries are normally from 8° to 12° F. higher than along the northernmost reach of the Missouri near Williston. This ordinarily results in ice breakup on the Yellowstone prior to the time the ice goes out on the main stem, thereby contributing to ice jam floods.

II-B. Climatology.

2-9. General. The broad range in latitude, longitude, and elevation of the Missouri River Basin and its location near the geographical center of the North American Continent result in a wide variation in climatic conditions. The climate of the basin is produced largely by interactions of three great air masses that have their origins over the Gulf of Mexico, the northern Pacific Ocean, and the northern polar regions. They regularly invade and pass over the basin throughout the year, with the Gulf air tending to dominate the weather in summer and the polar air dominating it in winter. This seasonal domination by the air masses, and the frontal activity caused by their collisions, produce the general weather regimens found within the basin. As is typical of a continental-interior plains area, the variations from normal climatic conditions from season to season and from year to year are very great. The outstanding climatic aberration in the basin was the severe plains area drought of the 1930's when excessive summer temperatures and subnormal precipitation continued for more than a decade.

2-10. Precipitation. Normal average annual precipitation ranges from as low as 8 to 10 inches just east of the Rocky Mountains to about 40 inches in the southeastern part of the basin and in parts of the Rocky Mountains. The pattern of normal annual precipitation over the basin is shown on Plate 3. Prolonged droughts of several years' duration and frequent shorter periods of deficient moisture, interspersed with periods of abundant precipitation, are characteristic of the plains area.

2-11. Deep cyclones and accompanying frontal systems, moving from the southern great plains states toward the northeast, can cause widespread precipitation over the basin during all seasons of the year due to the resulting influx of moist maritime tropical air from the Gulf of Mexico. Cyclonic activity over the basin is at a maximum during the late winter and early spring months and decreases to a minimum during the late summer and early fall months. The moisture-carrying ability of an air mass is dependent upon the temperature of the mass and is normally at a maximum at mid-summer and at a minimum in mid-winter. The combination of moderate cyclonic activity and increased air mass moisture content which occurs during the spring and early summer months results in the normal seasonal precipitation maximum being observed throughout the basin at this time.

2-12. Precipitation during the late summer and fall months is usually of the short-duration thunderstorm type with small centers of high intensity, although widespread general rains occasionally occur, especially in the lower basin. Winter precipitation usually results from the passage of well-developed low-pressure systems and active fronts. This precipitation occurs in the form of snow in the northern and central portions of the basin; however, in the lower basin states it may occur as either rain or snow or a mixture of both. Winter precipitation depths are in general considerably less than at other seasons of the year, due to the decreased moisture-carrying ability of the colder air masses and due to the barrier imposed by the Rocky Mountains to the westerly circulation which generally prevails through this season.

2-13. Precipitation during the period from November through March is generally in the form of snow. Normally the basin has fairly frequent light winter snows, interspersed with a few heavy storms. The average annual snowfall over the plains increases from south to north. It ranges from 20 inches in the lower basin, to 30 inches in the eastern Dakotas and to near 50 inches in the high plains areas in the west. High elevation stations in the Black Hills and in the Rockies along the western edge of the basin receive in excess of 100 inches of snowfall. Following the winter season, snow depths up to 6 feet, with a water equivalent of 2 feet, are not uncommon at mountain locations. Snow does not usually progressively accumulate over the plains, but is melted by intervening thaws. However, there have been exceptions over the northern plains when snow accumulated on the ground by the end of winter had a water equivalent of 6 inches or more in some years.

2-14. Temperature. Because of its mid-continent location, the basin experiences temperatures noted for fluctuations and extremes. Winters are relatively long and cold over much of the basin, while summers are fair and hot. Spring is normally cool, humid, and windy, while autumn is normally cool, dry, and fair. Temperature extremes range from winter lows of -60° F. in Montana to summer highs of 120° F. in Nebraska, Kansas, and Missouri. The basin regularly experiences temperatures about 100° F. in summer and below 0° F. in winter over most of its area.

2-15. Evaporation. Average annual lake evaporation in the Missouri Basin varies from less than 2 feet in the western mountains to over 6 feet in the plains area of western Kansas. Evaporation from the main stem reservoirs averages about 3 feet annually. With small lakes whose surface temperatures approximate air temperatures, most evaporation occurs during the April-October period. However, due to the large size of the main stem projects, there is a considerable time lag between air temperatures and surface water temperatures. Also, since precipitation is normally at a maximum during the April-June period over the main stem reservoirs, net evaporation (evaporation less precipitation) is concentrated almost entirely in the July-December period. Normal annual net evaporation averages about 20 inches for the reservoir system as a whole, ranging from about 25 inches at Fort Peck to 17 inches at Gavins Point. A basin map showing average annual net lake evaporation is shown on Plate 4.

2-16. Storm Potentialities. Approximately 130 Missouri Basin storms have been studied in the Corps of Engineers' Storm Study Program; of these, 28 percent have occurred in the basin above Yankton and 72 percent below. None of the individual storms have been sufficiently extensive to encompass the entire basin. June has had the greatest number of occurrences, 38 percent of the total. If surface dewpoint temperatures are used as an index to the amount of moisture in the warm air mass from which the precipitation falls, records indicate that moisture charges during the major storms of record are all generally near the maximum of record. The source of moisture for all major storms in the basin is the Gulf of Mexico. Based on moisture potentialities alone, major storms would be most probable in late July or early August since it is at this time that normal and maximum recorded air mass moisture is the greatest. However, major storms throughout the basin result almost exclusively from conditions accompanying frontal systems, and since frontal passages are more numerous and more severe in May and June than in the dead of summer, major storms occur more frequently in late spring and early summer than at the time of maximum moisture charges in late July or early August.

2-17. Major storms do not provide a complete index to the probability of flood flows within the basin. Minor storms also may satisfy the infiltration capacities which exist in the basin, resulting in any additional rainfall contributing much larger volumes to streamflow than would have been the case if the ground had been relatively dry prior to the later storm. Because of this, a sequence of lesser storms, which may occur at any time of the year over portions of the basin, can also result in severe flooding. During winter months, continued minor storms in the upper basin often result in sufficient snow accumulation to cause the greatest flows of the year at the time the accumulation melts and appears as streamflow.

II-C. Runoff of the Missouri River.

2-18. Streamflow Records. The collection of systematic and continuous discharge records by the Geological Survey (in cooperation with the States, the Corps of Engineers, and other agencies) over most of the Missouri River basin is of rather recent origin. However, discharge records for stations on the Missouri River at Craig, Cascade, and Fort Benton, Montana, are available since 1890, 1902, and 1910, respectively, and for the Yellowstone River at Glendive, Montana, since 1903. Some records were obtained on the Missouri River at Williston, North Dakota, during 1905-07, at Bismarck, North Dakota, during 1904-05, and at Kansas City, Missouri, during 1905-06. Aside from these, streamflow measurements at the present stations on the main stem of the river were not started until 1928. However, daily stage records for many of the main stem stations began in the 1870's. Systematic and continuous streamflow measurements at scattered tributary locations began much earlier than on the main stem with some tributary records beginning in the early 1900's and in a few instances prior to 1900.

2-19. During planning studies of the main stem reservoir system in the 1940's, it was considered essential to extend the Missouri River discharge data beyond the 1928-to-date record period then available. Accordingly, comprehensive studies were made and monthly streamflow data developed for selected stations through the period extending from 1898 to the initiation of the expanded streamflow measurement program in 1928. Inasmuch as water use for all purposes has expanded significantly since settlement of the basin first began, it was also considered necessary to adjust the records to represent a common level of water resource development in order that the flow data would be directly comparable from year to year. While any development level would have been satisfactory, the 1949 level was selected, prior to the accelerated resource development that has occurred in recent years. Records accumulated since that time are also adjusted to the 1949 level for comparability purposes.

2-20. Tributary Streamflow Characteristics. Streams emanating from the Rocky Mountains are fed by snowmelt; they are clear flowing, and have steep gradients and cobble-lined channels. Stream valleys often are narrow in the mountain areas and widen out as they emerge from the mountains onto the outwash plains. As shown on Plate 5, mean annual unit runoff from the mountainous areas is high, exceeding 20 inches in some areas along the Continental Divide. Flood flows in this area are generally associated with the snowmelt period occurring in May and June. Occasionally, summer rainfall floods with high, sharp peaks occur in the foothills areas.

2-21. Streams flowing across the plains areas of Montana, Wyoming, and Colorado have variable characteristics. The larger streams with tributaries originating in the mountain areas carry sustained spring and summer flows from mountain snowmelt, and they have moderately broad alluvial valleys. Streams originating locally often are wide, sandy-bottomed, and intermittent, and they are subject to high-peak rainfall floods. Mean annual runoff from this upper plains area is low and variable, ranging from one-quarter to one-half of an inch.

2-22. Streams in the plains region of the Dakotas, Nebraska, and Kansas, with the exception of the Nebraska sandhills area, generally have flat gradients and broad valleys. Except for the Platte River, most of the streams originate in the area and are fed by plains snowmelt in the early spring and occasional rainfall runoff throughout the warm season. Streamflow is erratic. Stream channels are small for the size of the drainage areas involved, and flood potentials are high. When major rainstorms occur in the tributary area, streams are forced out of their banks onto the broad flood plains. Mean annual runoff is low, ranging from as little as a quarter inch to 2 inches. In many of these streams, there may be no flow during drought periods. The streams generally are turbid, and they carry large suspended sediment loads during periods of high flow.

2-23. Streams originating in the Nebraska sandhills, such as the Loup and Niobrara Rivers, are steady flowing, with much of the flow attributable to ground-water accretions. Floods are rare, and they have relatively low peaks. Only a very small part of the sandhills area contributes direct-flow runoff. The streams carry heavy loads of sand sediments, although they are relatively low in silt and collodial sediments. Runoff, as measured streamflow, is higher than generally found in the adjoining plains areas, ranging up to 4 inches.

2-24. Streams in the region east of the Missouri River have variable characteristics. Those in the Dakotas, such as the Big Sioux and James Rivers, are meandering streams with extremely flat gradients and very small channel capacities in relation to the areas drained. Drainage areas generally are covered with glacial drift, they are extremely flat, and they contain many pothole lakes and marshes. Rainfall in the spring often combines with the annual thaw to produce floods that exceed channel capacities and spread onto the broad flood plains. In late summer and fall, flows often drop to zero for extended periods. Streams in the eastern border region of Nebraska, Iowa, Missouri, and Kansas drain hard-soiled, hilly lands with relatively steep gradients and narrow valleys. Channels are deep and U-shaped. Flooding caused by high rainfall storms is frequent. Average annual runoff is high, ranging from 2 to 8 inches. Streamflow is generally turbid because of high concentrations of suspended sediments. Streamflow is somewhat more stable than in the plains area to the west, but in many streams it often approaches zero in late summer and fall.

2-25. Streams in the Ozark Highlands of Missouri resemble mountain streams with their clear, dependable base flows. Much of the area is underlain by limestone, and there are cavernous underground springs. The hilly terrain produces high-peak runoff, which contributes to frequent high-peak floods of large volume. Average annual runoff is high, ranging from 10 to 14 inches. High flows generally are experienced every year during the months of March, April, May, and June, after which flows recede, often to less than 15 percent of their average, during August, September, and October. Drainage areas are well timbered, and sediment yields are generally small.

2-26. Missouri River Flow Characteristics. Unregulated Missouri River flows usually followed a definite and characteristic annual pattern as illustrated by the monthly distribution of streamflows presented on Plate 6. Average flows, in general, increased from January to June and then decreased to December. Maximum and minimum monthly mean flows at Sioux City are 187,000 cfs in April 1952 and 3,700 cfs in January 1940. At Kansas City, corresponding flows are 301,000 cfs in June 1908 and 5,000 cfs in January 1940. The "with reservoirs" graph on Plate 6 also illustrates the major changes in the monthly streamflow distribution which have occurred as a result of reservoir control. Although the general pattern of summer flows being higher than winter flows still prevails, reservoir operations serve to reduce summer flows in most years and to use the water stored in this process to increase flows during the low water periods of fall and winter. The distribution of flows illustrates the two major flood periods of the upper Missouri basin, the "March rise" and the "June rise," as described below.

2-27. In the upper portions of the basin, winter is characterized by frozen streams, progressive accumulation of snow in the mountain areas, and intermittent snows and thaws in the plains area where the season usually ends with a "spotty" snow cover of relatively low water content, and a considerable amount of water in ice storage in the stream channels. Runoff in this period, which usually extends from late November into March, is quite low. In the lower basin, milder temperatures prevail during the winter months and considerable precipitation may occur in the form of rain or snow which melts rapidly and which contributes immediately to streamflow. This may occasionally result in substantial flows in this region, although due to the relatively light amounts of precipitation which usually occur in this season, winter runoff is usually quite low. Intermittent freeze-up and breakup of ice on both the main stem and the tributaries is common in the lower basin.

2-28. Early spring is marked by rapid melting of snow and ice accumulations in the northern plains area, usually in March or April, accompanied ordinarily by very little rainfall. This causes the characteristic early spring ice breakup and increase in streamflow known as the "early spring" or "March" rise. Flood crests in the upstream reaches are flashy, particularly when associated with relatively sudden releases of ice jams. Ice jams are particularly severe in the Dakotas and on the Yellowstone River in Montana. The highest peak discharges and stages of record on the main stem from above the mouth of the Kansas through the Dakotas have resulted from spring breakup floods of this type. Snowmelt in the mountains usually begins in this period, but contributes little to runoff until later in the year. Flood flows originating in the upper basin are sometimes augmented by rainfall in the lower basin to produce large flows in the lower reaches.

2-29. Late spring and early summer are characterized by extensive general rains accompanied occasionally by severe local rainstorms and rapid melting of snow in the mountains. Peak runoff from these sources usually occurs in late May, June, or the first part of July. This results in the characteristic "late spring" or "June" rise, with crest discharges above Sioux City (except in the headwaters) usually less and volumes of runoff usually greater than during the early spring rise. A short interlude of moderately low discharges usually is experienced between the early spring and late spring rises. Occasionally runoff from severe rainstorms in the upper plains area synchronizes with the high runoff from snowmelt and general rainfall in the mountains during this period. Through the lower basin, runoff from rainstorms during the months of May, June, and July often augment the late spring flows originating in the upper basin, thereby resulting in the greatest flows of the year through these reaches. Lower basin storms alone have also resulted in very severe flooding below Sioux City during these months.

2-30. Late summer and autumn are generally characterized by diminishing general rainfall, fairly frequent widely scattered intense local rainstorms, and occasional severe storms. Flow in the upper river ordinarily decreases rapidly in late July from the previous high rates, and thereafter decreases gradually, with occasional rises, to the low flows which prevail in winter. There are no records of great storms in this period having produced floods on the upper Missouri River anywhere near the magnitude of the fairly frequent early spring or late spring floods, although very severe floods have occurred on tributaries during this period. Runoff originating in the lower basin also usually decreases, although during this season several large floods have occurred on the lower Missouri River.

2-31. Of particular interest to reservoir operation is the relationship of the characteristic cycle of Missouri River flows above Sioux City to conditions on the lower Missouri and Mississippi Rivers. High stages on the Mississippi, particularly below the Ohio, may be expected any time from January through July, with the greatest floods of actual record having occurred in February and April-May. On the lower Missouri, high flows have occurred in winter, but the main flood season extends from April to July, the greatest flood of record having occurred in July. Therefore, it is apparent that discharges from the upper basin during the early spring and late spring flood periods may contribute substantially to lower Missouri and Mississippi River floods. From August to December, both the lower Missouri and Mississippi are usually characterized by low discharges, much the same as the upper Missouri; however, large storms or a sequence of lesser storms over the lower Missouri and Mississippi during this period have occasionally resulted in severe flooding.

2-32. Missouri River Floods. Regulation provided by the main stem system of reservoirs, augmented by upstream tributary reservoir storage, has virtually eliminated flood flows on the Missouri River from Fort Peck Dam downstream to the mouth of the Platte River below Omaha, Nebraska. Many instances of above-bankfull flows were experienced through this reach prior to main stem reservoir regulation. Since regulation of these projects commenced, there would have been many more flood occurrences were it not for the upstream regulation. Below the mouth of the Platte River the incremental drainage area is of sufficient size that above-bankfull stages can continue to be expected as a result of flood runoff from major storms over the tributary areas, although significant stage reductions due to main stem regulation will usually occur. All floods experienced in the upper basin except one have occurred in the March-July season with snowmelt as an important flood component. The one exception occurred in 1923 when a large September rainstorm in southern Montana and northern Wyoming resulted in an early October Missouri River flood. Estimated crest discharges during this flood exceeded 100,000 cfs at Pierre, South Dakota, and all upstream locations to the mouth of the Yellowstone River. In the lower Missouri River basin, floods have tended to follow the same seasonal pattern observed in the upper basin; however, damaging floods have occasionally occurred prior to or following the normal March-July flood season, due mainly to rainfall over the downstream drainage areas. Crest stage and discharge data for past major Missouri River floods are summarized in Table 1 while significant flood occurrences, with specific causative factors, are discussed in following paragraphs.

2-33. Flood of 1844. This flood, of near legendary proportions, is generally conceded to be the greatest known in the lower Missouri River basin. From stage records at Kansas City and St. Louis, Missouri, high water marks at Manhattan and Topeka, Kansas, Boonville and Hermann, Missouri, and the precipitation records at Ft. Leavenworth, Ft. Scott, and Jefferson Barracks, the flood has been traced and the events leading to it have been reconstructed. These events do not differ from those which are now recognized as being conducive to major lower basin flooding; that is, prolonged periods of antecedent rainfall saturating the basin, followed by sequential bursts of intense storm rainfall. From 10 May-6 June 1944, Ft. Leavenworth had 5.77 inches of rainfall and Ft. Scott had 14.34 inches (4.5 inches approximates the normal for a similar period and location). This antecedent rainfall apparently saturated the Kansas basin sufficiently that most of the 4 to 8 inches of additional rainfall which fell in numerous bursts between 7-14 June probably became direct runoff. Firm stage heights and discharge measurements are not available for this historical event, but the maximum stages and discharges shown on Table 1 are believed to be reasonable estimates and have been accepted by most hydrologic investigators.

Table 1

CREST STAGE AND DISCHARGE DATA FOR MAJOR FLOODS
ON THE
MAIN STEM OF THE MISSOURI RIVER

Station	Miles Above Mouth	Flood Stage Feet	1952 Floods			1951 Floods			1943 Floods			1903 Flood			1881 Flood			1844 Flood			Highest of Record		
			Date	Stage Feet	Discharge c.f.s.	Date	Stage Feet	Discharge c.f.s.	Date	Stage Feet	Discharge c.f.s.	Date	Stage Feet	Discharge c.f.s.	Date	Stage Feet	Discharge c.f.s.	Date	Stage Feet	Discharge c.f.s.	Date	Stage Feet	Discharge c.f.s.
Williston	1650.2	20	April 1	17.8	170,000	April 8	16.8	110,000	March 28	19.8											March 28,1943	19.8	
Albowoods (a)	1504.0	17	April 5	25.2	360,000	April 6	16.0		March 30 March 31	- 21.1	204,000 241,000										April 4,1930 April 5,1952	- 25.2	231,000 360,000
Garrison (b)	1455.0	1690	April 5	1701.8	348,000	April 11 April 7	- 1693.6	94,000 130,000	April	1696.3											March 27 ,1947 April 15,1952	1704.0	348,000
Bismarck	1377.8	19	April 6	27.9	500,000	April 4	16.3		April 1	22.7					March 30	31.6					March 30,1881 April 6,1952	31.6	500,000
Mobridge	1250.6	16	April 9	25.1	435,000	April 5 April 4	 14.8	130,000 195,000	April 3 March 28	- 19.6	282,000										April 9,1952	25.1	435,000
Pierre	1117.0	15	April 10	25.4	440,000	April 8	12.3	127,000	April 5 April 6	- 19.6	282,000 281,000	June 25	9.8		April	23.0	259,000(g)				April 10,1952	25.4	440,000
Chamberlain	1012.9	18	April 11	25.6	440,000	April 8	11.5	113,000	April 7	19.3	(e)										April 11,1952	25.6	440,000
Fort Randall(b)	922.0	1250	April 12	1258.9	447,000	April 8	1246.3	134,000	April 8	1252.6											April 12,1952	1258.9	447,000
Yankton	840.4	12	April 13,14	15.5	480,000	March [illegible]	11.9	134,000	April 9	13.6	-				April 5	30.5					April 5, 1881	30.5	
Sioux City	760.0	16	April 14	24.3	441,000	April 8	13.0	152,000	April 8 April 10	- 18.7	282,000 212,000	July10&11	12.3		April 23	22.5	362,000(g)				April 13,14 52 April 14,1952	 24.3	480,000 441,000
Decatur (b)	715.7		April 15	23.3	(e)	April 9	16.6	(e)	April 11	20.5	(e)										April 15,1952	23.3	
Blair	670.4	19	April 17	23.5	(e)	April 11	19.0	(e)	April 12	21.4	(e)				April 24	19.7					April 17,1952	23.5	
Omaha	632.0	19	April 18	30.2	396,000	April 11	18.2	152,000	April 13	22.4	-	June 1	14.4		April 25	24.6	370,000(g)				April 18,1952	30.2	396,000
Plattsmouth (b)	607.5	952.5	April 18	961.4	(e)	April 11,12	954.5	(e)	April 12 April 14	- 957.6	200,000 (e)	June 1	11.2		April 25	957.9					April 18,1952	961.4	
Nebraska City	579.3	18	April 18	27.7	414,000	June 2	18.5		April 14	19.9	181,000				April 27	18.1	380,000(g)				April 18,1952	27.7	414,000
Brownville (b)	552.0	15	April 17	29.8	(e)	March 29 June 3	 21.5	163,000 (e)	April 16	19.9	(e)										April 17,1952	29.8	
Rulo	514.4	17	April 22	25.6	358,000	June 3	21.0	175,000	April 17	20.2	(e)										April 22,1952	25.6	358,000
St. Joseph	460.3	17	April 22	26.8	397,000	May 3	19.9	198,000	June 18	18.5		June 2	20.5	252,000(c)	April 29	27.2	370,000(g)	June	24.5	350,000(c)	April 29,1881	27.2	
Leavenworth (b)	408.2	19	April 23	27.6	(e)	July 8	20.8	(e)	April 18 June 19	- 23.1	134,000 (e)				April 30	23.1					April 22,1952 April 23,1952	 27.6	397,000
Kansas City	377.5	22	April 24	30.6	400,000	July 14	36.2	573,000	June 19	29.1		June 2	35.0	548,000(c)	April 30	27.8	373,000(d)	June 16	38.0	625,000(c)	June 16,1844	38.0	625,000(c)
Napoleon (b)	332.4	17	April 24	24.6	(e)	July 14	26.8	(e)	June 18 June 19	 22.4	336,000 (e)										July 14,1951	26.8	
Waverly	297.2	18	April 24	28.1	369,000	July 14	28.2		June 18	24.4											July 14,1951	28.2	
Glasgow (b)	226.8	25	April 27	32.1	358,000	July 16 July 17	 36.7	549,000 550,000	June 19 June 21	- 33.3	310,000 (e)	June 5	32.7(c)		May 3	28.2(c)					July 16,1951 July 17,1951	 36.7	549,000 550,000
Boonville	196.7	21	April 27	27.7	360,000	July 17	32.8	550,000	June 22	28.8	366,000	June 6	30.9	612,000(c)	May 3	23.3		June 21	32.7	710,000(c)	July 17,1951	32.8	
Jefferson City (b)	143.0	23	April 27	26.1	(e)	July 18	34.2	(e)	June 23	30.1	(e)	June 6	33.5		May 4	26.3(c)					June 21,1844 July 18,1951	 34.2	710,000(c)
Gasconade (b)	103.9	22	April 27,28	29.2	(e)	July 19	35.4	(e)	May 21	34.2	(e)										July 19,1951	35.4	
Hermann	96.9	21	April 28	27.1	368,000	July 19	33.3	618,000	May 21	31.1	550,000	June 6,7	29.5	676,000(d)	May 4	23.7		June	35.6	892,000(d)	June 1844	35.6	892,000(d)
Washington (b)	66.8	20	April 28	34.4	(e)	July 19	31.0	(e)	May 22	28.6	(e)										July 19,1951	31.0	
St. Charles	28.1	25	April 29	31.8	(e)	July 20	37.3	(e)	May 22	36.6	(e)	June 8	36.8	730,000(c)	May 5	31.6		June 27	40.1	900,000(c)	June 27,1844	40.1	900,000(c)

Stages are from gage read'ngs reported by the U.S.W.B. unless otherwise noted. Discharge values are those reported or published by the U.S.G.S unless otherwise noted. Discharge values are given for the floods of 1903, 1881 and 1844 where such estimates are available.

(a) U.S.G.S. Gage.
(b) C.E. Gage.
(c) Data from 308 Report.
(d) Estimated by Kansas City District
(e) Stages only, discharge not obtained at this station.
(g) Estimated by Omaha District

2-34. There is some evidence to indicate that the basin above the main stem reservoirs probably contributed a relatively small part of the 1844 crest flow at St. Joseph. A downbound French steamboat captain reported grounding difficulties in the Dakotas with no report of high water until he reported the evidences of a great flood below the mouth of the Platte River. There is further evidence of a large contribution from the Platte in that a wagon train, westward bound on the Oregon Trail, reported a delay while waiting the passage of a great flood before fording the Platte River.

2-35. Floods of 1881. The floods of March-April 1881 are the second greatest floods of record on the Missouri River in the Dakotas, and the "June" rise in 1881 was one of the largest of the late spring rises. The flood year 1881 had the greatest total cumulative volumes of record on the Missouri River between Bismarck, North Dakota, and St. Joseph, Missouri. Following a wet year in 1880, the winter of 1880-81 was marked by below-normal temperatures and heavy snows, resulting in the heaviest known snow blanket on the plains area by spring. Spring thaws and ice breakup began in the upper basin in late February and early March while the lower river was still frozen, resulting in huge ice gorges in the Dakotas. This first rise was checked by a short period of cold weather during which additional precipitation occurred, after which temperatures throughout the plains area rose to well above normal to complete the release of water from snow and ice. The estimated crest stages and discharges of the early spring-type 1881 flood at main stem locations are shown on Table 1. The crest stage of 18.5 feet above flood stage at Yankton is the highest known rise above flood stage on the Missouri River and 15 feet higher than any other known stage at that station. This extremely high stage resulted from a tremendous ice jam extending from below Yankton to Vermillion, filling the river channel for a distance of over 30 miles with solid ice rising in places to a height of over 30 feet above the surface of the water. The total flood volume in March and April 1881 has been estimated at approximately 15 million acre-feet at Pierre and almost 18 million acre-feet at Sioux City.

2-36. It is known from hydrologic records and gage heights along the Missouri River that the 1881 early spring flood was followed by one of the wettest summers of record. It is estimated that a crest mean daily discharge of 184,000 cfs occurred at Yankton on 14 June. It is also estimated that the total volume of flood runoff at Sioux City, Iowa, during the March-July 1881 period, was more than 40,000,000 acre-feet, which by far exceeds the volume of any other flood year of record at this location. The severe flood sequence, as reconstructed from available stage records, served as the primary basis for the design of flood control storage space in the main stem reservoir system.

2-37. Flood of 1903. The severe flood on the lower Missouri River in May and June 1903 resulted from conditions similar to those which caused the great flood of 1844. Rainfall through the lower basin during the first half of May was above normal, which saturated the soil and resulted in above normal tributary flows for that time of the year. From 16 to 31 May, rainfall occurred almost every day through the lower basin states of Iowa, Nebraska, Kansas, and Missouri. More intense bursts were observed from 21 to 23 May, and when heavy bursts again occurred from 28 to 30 May, the extreme flood developed. Rainfall for the month of May totaled over 17 inches at stations in Iowa, Nebraska, and Kansas. During the period 25 to 31 May, a total of 16.8 inches of rainfall occurred at Abilene, Kansas. Flood flows were of only moderate size in the upstream reaches, but below Omaha, Nebraska, the heavy rains resulted in the most damaging flood experienced to that time through the lower reaches of the Missouri River. Although stages were somewhat lower than in 1844, as shown in Table 1, increased development of the river valley resulted in greater damages. This flood was also especially severe on the lower Kansas River and its tributaries where at some locations, maximum recorded stages were established which have not been exceeded to this date.

2-38. Flood of 1908. The flood of June 1908 is the greatest ice-free flood known on the Missouri River through Montana and North Dakota. It resulted from general rains in May, climaxed by one of the region's greatest storms in June, accompanied by the mountain snowmelt runoff. Estimated crest discharges during this flood were 155,000 cfs at the Fort Peck dam site, 240,000 cfs at Williston, 225,000 cfs at Bismarck, 182,000 cfs at Pierre, and 187,000 cfs at Yankton. As the flood crest passed downstream, it coincided with runoff from heavy rainfall in the lower basin, which resulted in extensive damage through the downstream reaches although crest stages and discharges were not of record proportions.

2-39. Flood of 1927. Flooding occurred in April 1927 over the lower Missouri River basin largely as a result of rainfall runoff originating in this portion of the basin. Rainfall over the lower basin during March had been considerably above normal while April was the wettest month recorded for so early in the season in the lower basin states of Kansas and Missouri. The resulting flood was unique for a flood at this time of the year in that the upper basin made only minor contributions to crest stages and discharges on the lower Missouri and Mississippi Rivers.

2-40. In the upper Missouri basin the high altitude snow pack ranged from about normal to slightly above normal at the end of March, although snow cover over the plains area at this time was virtually nonexistent. During April, precipitation in the upper basin ranged from slightly above to much above normal. This was followed by an exceedingly wet May through all of the upper basin states. In addition to contributing directly to streamflow (maximum floods of record occurred on some tributary streams in South Dakota during May) the heavy April-May precipitation resulted in substantial snow accumulations in the mountainous areas of the basin. Missouri River flows at and above Sioux City, Iowa during the May-July period were notable for their large volume, high flat crests and large recession volumes. The 1927 calendar year runoff above Sioux City (37 million acre-feet when adjusted to the 1949 level of water resource development) is the greatest occurring since reliable records began in 1898. Fortunately, lower basin runoff during the late spring and summer of 1927 was only moderate and did not compound the flood flows originating from the upstream areas.

2-41. Floods of 1943. Above-normal precipitation during the winter of 1942-43, augmented by a heavy 4-day snowstorm in the middle of March over the Dakotas, resulted in a near-record snow cover by winter's end in both the northern plains and mountain regions. High temperatures occurring in late March and early April resulted in rapid melt of the plain's snow cover over ice-sheathed and frozen ground which, in turn, caused a great flood. The formation of ice jams and subsequent progressive release of the water impounded behind them contributed considerably to high crest discharges through North and South Dakota. Crest discharges above 200,000 cfs occurred from Williston to Omaha with peaks near 280,000 cfs from Bismarck to Yankton. As the April flood wave progressed downstream from Omaha, flattening occurred; however, serious damages extended to above Kansas City, with only minor flooding below that point. The total volume of runoff in March and April was comparatively small, amounting to only 7,300,000 acre-feet at Sioux City, during which period 1,800,000 acre-feet were impounded in Fort Peck Reservoir.

2-42. The March-April flood was followed closely by a flood which developed in the lower basin in May as a result of heavy rainfall over southeastern Kansas and the south and central portions of Missouri. Stages in May 1943 were higher than any since 1844 on the Mississippi at St. Louis, although the crest discharge of 840,000 cfs may have been exceeded in 1903. On the Missouri at Hermann, a crest discharge of 550,000 cfs occurred on 21 May. Crest stages and discharges along the Missouri River in 1943 are shown in Table 1.

2-43. During June and July 1943, relatively high discharges again prevailed on the Missouri River in the Dakotas as a result of the melt of the heavy mountain snow cover and above-normal rainfall in the upper basin. A total volume of about 8,200,000 acre-feet passed Sioux City during the 2-month period while 3,760,000 acre-feet were stored in Fort Peck Reservoir. During the same period, the lower basin states also experienced heavy rains which considerably augmented the flow originating upstream and resulted in extensive flooding from Rulo, Nebraska, to the mouth of the Missouri River. A crest of 236,000 cfs occurred at Kansas City on 18 June where the 2-month volume exceeded 15 million acre-feet.

2-44. Flood of 1944. The March-April period of 1944 was characterized by only moderate rises on the Missouri River above Bismarck at which point a crest flow of 136,000 cfs was observed. Heavier snow accumulations through southern North Dakota and South Dakota added materially to the flood volume and increased the crest at Sioux City to 180,000 cfs. Below Sioux City, the April 1944 flood is noteworthy because of the transmission of the flood wave down the river to synchronize progressively with runoff from general rains through the middle river and from heavy rains within the lower basin. This resulted in crest flows which exceeded any of recent record at many of the downstream stations and even the high discharges of 1943 were exceeded at Hermann and on the Mississippi at St. Louis.

2-45. June 1944 was one of the wettest months of record through the upper Missouri basin. The combination of excessive rainfall runoff with the melt of the mountain snow accumulation resulted in 10,500,000 acre-feet of flow past Sioux City with 2,400,000 acre-feet stored in Fort Peck Reservoir during the June-July period. This represented the greatest volume of runoff originating in the upper Missouri basin during a comparable late spring period since intensive stream gaging began in 1929.

2-46. Flood of 1947. In March and April of 1947, a flood was caused by a combination of ice jams and a relatively small amount of snowmelt runoff from streams draining portions of Montana, Wyoming, North Dakota, and western South Dakota. Although peak stages were generally less than those of the 1943 flood, peak discharges at locations in North Dakota exceeded 250,000 cfs and were the highest experienced up to that time, exceeding both the estimated 1881 and observed 1943 peaks.

2-47. High discharges again occurred in June and July 1947 in the Dakotas as a result of heavy rains and runoff from mountain snowmelt. Peak discharges increased progressively from 104,000 cfs at Bismarck to 171,000 cfs at Sioux City. In the lower Missouri River basin, the months of March through May of 1947 were all wetter than normal, with June being extremely wet throughout the basin. Runoff from this extraordinary series of excessive rains occurring in June was supplemented by the upstream rises to cause the highest stages since 1844 at several stations between Plattsmouth, Nebraska, and the mouth of the Missouri River and on the Mississippi River at St. Louis.

2-48. Flood of 1951. Prior to 1951, the 1844 flood had been the "great" lower basin flood. The estimated stages and discharges of that historical flood were generally accepted although somewhat discounted for lack of supporting data. A considerable amount of hydrologic data was assembled prior to, during, and after the rise and fall of the 1951 flood and these data lend support to the belief that major floods of the magnitude of the 1844 flood are possible. May and June 1951 precipitation over the Kansas basin was above normal by amounts of 2.66 and 5.58 inches, respectively. The intense rains on 9-13 July resulted in sustained and widespread flooding which was the greatest in recent years. Rainfall accumulated to 18.5 inches at the storm center during this 5-day period and averaged 8 inches over 30,000 square miles of eastern Kansas. Crest stages occurred on the Kansas River and its tributaries within a 4-day period, 11-14 July. The Missouri River at Kansas City, Missouri, crested on 14 July. Fortunately, the crest from the Kansas River coincided with relatively low flows from the upper Missouri River. At Kansas City, the Missouri River remained above flood stage until 21 July. The main stem crest passed the mouth of the Missouri River on 21 July and by the 1st of August, the lower river fell below flood stage. Peak discharge at the lowermost Kansas River station, Bonner Springs, Kansas, was 510,000 cfs on 13 July. On the Missouri River at Kansas City, the peak was 573,000 cfs and at Hermann, Missouri, the main stem crested at 618,000 cfs on 19 July. Other crest stages and discharges are shown in Table 1.

2-49. Flood of 1952. The flood of April 1952 in the Missouri River basin was of exceptional magnitude and severity on the Missouri River and most of the tributary streams which join the Missouri River at and above Sioux City, Iowa. On the Missouri River, flooding was continuous from the Yellowstone River to the mouth. In most of the reach between Williston, North Dakota, and the mouth of the Kansas River, a distance of about 1,250 river miles, this flood was the greatest of record, establishing record discharges throughout and record stages at all except a few isolated localities where previously established record stages, resulting from severe localized ice jams, were not surpassed. Flooding was general on all major tributaries of the Missouri River between and including the Milk River in Montana and the Floyd River in Iowa, with the exception of the Niobrara River. On many of these tributaries, stages and discharges approached previously established records and on some, new record stages and discharges were established.

2-50. Normal winters in the upper Missouri River basin include periods of warm weather sufficiently mild to permit intermittent thawing of the snow cover over appreciable areas. Of particular significance during the winter of 1951-1952 was the absence of such periods of thawing; instead, they were supplanted by unusually continuous low temperatures. At the end of March, one of the heaviest snow covers in the history of the upper plains was present. Snow surveys completed at the time of maximum snow accumulation on 20 March indicated a water content in the snow cover ranging from 2.4 inches over about 10,000 square miles in the Yellowstone River basin up to 3.6 inches over much of the Grand River basin in South Dakota. A water content of over 6 inches was present in the lower Grand and Moreau basins and on the eastern edge of the Big Sioux River basin. The water content of the 1951-1952 snow cover was approximately equalled over portions of the basin in previous years but not over nearly so extensive an area. For example, the snow cover over eastern South Dakota was nearly as great in 1950-1951 as it was in 1951-1952. Similarly, the snow cover over the right bank tributary basins in North Dakota and South Dakota was nearly as great, and over some localized areas even greater in 1949-1950 than it was in 1951-1952. The heavy snow cover of 1951-1952, however, extended over both of these areas and others as well, including the lower Yellowstone River basin in Montana.

2-51. Severe flooding along the Missouri River began late in March from rapid melting of snow cover in the lower Yellowstone, Little Missouri, and over the upstream portions of the Missouri River tributaries in the western Dakotas. With few exceptions, the peak outflows of the western Dakota tributaries were synchronized with the peak flow on the Missouri River. Coincidence of tributary outflows was in large part due to release of tributary water which had been ponded behind ice jams formed against the solid ice of the Missouri. Throughout North Dakota, movement of the flood waters downstream was hampered by successive ice jams which greatly increased stages and discharges. The Missouri River crested at Williston, North Dakota, on 1 April with a peak stage and discharge below previous highs of records. At Elbowoods, North Dakota, below the mouth of the Little Missouri River, the flood crested on 5 April, establishing a record stage 25.2 feet, and discharge of 360,000 cfs. The crest occurred on 6 April at Bismarck, North Dakota, establishing a record discharge of 500,000 cfs. This discharge was more than 75 percent higher than the previous record discharge but the record stage established in 1881 was not exceeded.

2-52. The flood crest reached Mobridge, South Dakota, on 9 April, Pierre on 10 April, Chamberlain on 11 April, Yankton on 13 April, and Sioux City, Iowa on 14 April. The flood crest moved through most of

South Dakota with peak discharges of 440-450 cfs, increasing to 480,000 cfs at Yankton due to additional tributary inflow. Below Yankton, peak discharges reduced gradually downstream, but throughout South Dakota, past maximum recorded discharges were exceeded by as much as 72 percent. Past record stages were similarly exceeded at all stations in South Dakota except Yankton, where the record stage was established by the exceptionally severe ice jam below Yankton during the 1881 flood. Below Sioux City, the flood continued to establish new record stages and discharges as far downstream as the vicinity of St. Joseph, Missouri. The crest reached Omaha, Nebraska, on 18 April, Nebraska City on 18 April, Rulo on 22 April, and St. Joseph, Missouri on 23 April. The coincidence of the crest at Omaha and Nebraska City resulted from the valley storage provided by failure of major levee units which flattened the Omaha crest to less than that prevailing at Nebraska City on 18 April. At St. Joseph, the peak discharge exceeded the previous high discharge of record, but the record stage established during the 1881 flood, although approached, was not exceeded. Below St. Joseph, the flood did not equal previously established record stages or discharges. Throughout the entire reach from St. Joseph to the mouth, however, it continued to be a flood of major proportions. Crest stages and discharges occurring in the 1952 flood are tabulated in Table 1.

2-53. The flood of April 1952 was strictly a snow-melt flood, due entirely to runoff from melting of the winter's accumulation of ice and snow over the plains areas of the upper basin. The great magnitude of the flood was due to several factors; the unusual areal coverage of the accumulated snow cover, the high water content of the snow cover at the time melting began, the rapidity with which melting took place, the frozen conditions of the ground, and the presence of an ice layer beneath the snow cover which resulted in a very high percentage of the snow's water content reaching the stream channels. Rainfall over the basin prior to and during the flood period was light, and runoff therefrom did not add to the flood discharges.

2-54. Flood of 1960. The first major flood occurrence since integrated main stem system operations began in 1954 was the 1960 plains area snowmelt flood. Snow accumulations during the winter months prior to the flood were very large, particularly over the plains areas of South Dakota, western Iowa, Nebraska, and Kansas. Melt of this snow in late March and early April caused record high floods on some tributary streams in the area and general flooding along the Missouri River from the mouth of the Platte River in Nebraska downstream. Inflows to the main stem reservoir system were particularily large downstream from Oahe Dam and, in the process of controlling the flood, Gavins Point rose 0.7 of a foot into the surcharge pool.

Outflows from Fort Randall contributed less than 1,000 cfs; however, high inflows between Fort Randall and Gavins Point required outflows of 32,000 cfs from the downstream project.

2-55. System storage gains during late March and April were about 5 million acre-feet. Stages on the lower Missouri River were as much as 8 feet above established flood stage and resulting damages approximated 17 million dollars. However, without the regulation provided by the reservoirs, crest stages would have been about 5 feet higher throughout the flooded area. The unregulated crest flow at Gavins Point Dam was estimated to be 210,000 cfs, compared to the maximum release of 32,000 cfs. Flood damages prevented by reservoirs and local protective works were estimated to be in the $200 million range.

2-56. Floods of 1967. During June 1967, intense rains over the lower basin states of Nebraska, Kansas, and Missouri caused severe flooding along many Missouri River tributary streams and along the main stem of the Missouri River from the Platte River downstream to the mouth. Missouri River crest stages up to nearly 10 feet above flood stage occurred and over 500,000 acres of agricultural land were inundated. The failure of 171 local levees during the flood contributed to the flooding. During the last half of June, Missouri River stages were so high that navigation was halted to protect water-soaked local levees from the wakes caused by the tow boats.

2-57. In the Missouri River headwaters areas of Montana and Wyoming, mountain snows accumulated at a greater than normal rate until by early May 1967 many mountain snow courses were reporting record high accumulated water contents. During late May and continuing through June, heavy upper basin rains coincided with the melt of this mountain snow, resulting the third highest May-July runoff volume of record above Sioux City, Iowa. However, the control effected by the main stem eliminated all flood damage that otherwise would have occurred through the reach extending from Fort Peck Dam to the mouth of the Platte River. At Sioux City, the regulation effects resulted in a crest discharge reduction of almost 200,000 cfs. While total flood damages sustained along the river amounted to over $125 million, damages prevented by reservoirs and Federal levees were estimated at about $600 million, of which over $200 million was credited to the main stem reservoirs.

2-58. Flood of 1973. The Missouri River flood of 1973 was unusual in that it was a fall flood resulting from continuing heavy rain over the lower basin states during late September and October. Severe flooding, at many locations the worst experienced since the unprecedented 1951 flood, occurred along many tributary streams in

Kansas and Missouri. Tributary flood control reservoirs in this area accumlated large amounts of storage, in many cases exceeding the maximum storage levels previously recorded. Unusual for the season was the prolonged period the main stem of the Missouri River remained above flood stage, extending for 5 days at Kansas City, 19 days at Waverly, 22 days at Boonville, and 24 days at Hermann, Missouri. Crest stages were as much as 8.5 feet above flood stage. The main stem reservoir system added a few thousand cfs to the flood flows because runoff from the upper basin during this period was relatively small and flood storage was being evacuated.

2-59. Flood of 1975. Flood season runoff during 1975 from the drainage area controlled by the Missouri River main stem reservoir system exceeded that occurring in any previous year during the period of available record extending from 1898 to the present time. In the process of regulating this unprecedented runoff, three of the projects (Fort Peck, Garrison, and Oahe) exceeded previous maximum reservoir elevations, while sustained releases from all projects were at higher rates than any previous release. All maximum release rates were well 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 began if it were not for the control provided by upstream reservoirs. However, continuation of relatively low outflows through over 20 years of system operation has adversely affected the downstream channel capacity and encouraged encroachment upon the downstream floodway. Landowners have cleared and placed under cultivation low-lying areas adjacent to the river; areas that would have been frequently flooded prior to construction of the dams. Another effect has been a deterioration in the capability of the downstream channel to pass flows of a moderate magnitude. For example, at Bismarck, North Dakota, a stage of 13 feet reflected a flow of about 90,000 cfs prior to the construction of Garrison Dam; 1975 experience was that flows slightly in excess of 50,000 cfs resulted in a stage of this magnitude. Another effect of the low releases was the growth of the Niobrara delta below Fort Randall Dam that significantly reduced channel capacity through about a 10-mile reach of the Missouri River above the delta. Maintenance of relatively stable flows through the portions of the Missouri River above the Platte River also resulted in considerable recreational development, such as boat docking facilities in low lying areas adjacent to the channel. These effects are recognized in the regulation of the reservoirs; however, in large flood years such as occurred in 1975, problems associated with higher than normal releases occur.

2-60. In early 1975, it appeared that runoff above the reservoirs would be less than normal, due to a subnormal mountain snowpack. However, much above normal precipitation was the rule over Montana and North Dakota through July. The most severe event was the extremely heavy rainstorm of 18-19 June centered to the east of the continental divide in Montana where average depths exceeding 10 inches covered a 2,500 square mile area and an area of 10,000 square miles had an average rainfall exceeding 6 inches. Control provided by the reservoirs prevented any stages below the system from exceeding flood stage and $87 million in prevented damages was credited to the system. However there was considerable criticism directed to the Corps at the time the regulation was being performed. Since similar criticisms can be expected in the future if similar events recur, the main problems encountered during this flood are discussed in the paragraphs that follow.

2-61. A criticism of overall regulation in 1975 was that levels of the Fort Peck and Garrison reservoirs were allowed to rise too high. At the maximum elevation, Fort Peck reached 1.6 feet above the maximum operating level and into the surcharge zone provided for the control of extraordinary floods. Inundated lands were entirely those acquired by the Government for project purposes. Some roads across project lands were affected; however, no reports of any serious inconvenience were received. Shoreline erosion at a higher than normal reservoir level affected the shoreline to some extent, in all probability hastening and extending the beaching process that has been in progress since the project first began operation. The Garrison maximum level reached elevation 1854.8, 0.8 of a foot into the surcharge zone provided for control of extraordinary floods, but below the 1855 guide taking line for land acquisition. Although most of the land inundated had previously been acquired by the Government for project operation purposes, there were a number of tracts flooded that had not been purchased, due to faulty surveys or mapping at the time of initial land acquisition, or due to inadequate blocking-out. The majority of complaints relating to high lake levels were received from the headwaters' area of the Garrison project. Lands affected were Government-purchased lands affected by the backwater effects of both high lake levels and large inflow rates. These were lands leased to private individuals, subject to flooding if required for project operations. Complaints were also received of flooding on the Missouri River near the mouth of the Yellowstone, upstream of the taking line. However, this land was flooded by high river levels, rather than by the Garrison Reservoir. Studies are continuing in this reach to determine to what degree the headwater aggradation may have been a factor in this flooding.

2-62. Maintaining significantly lower levels in the upstream reservoirs would have required substantial increases in the outflow rates from these projects. After the time it became apparent that utilization of surcharge storage was probable, outflows were increased up to the maximum rate believed practicable without causing substantial lowland flooding through the immediate downstream areas. Increased releases from Garrison would also have transferred the problems downstream to the Oahe project where substantial areas purchased by the Government were also leased to private individuals, subject to flooding from project operation.

2-63. Admittedly, encroachment into the surcharge zone of any reservoir project reduces the effectiveness of the project for control of subsequent flood inflows that may occur. If the encroachment into this space provided in Fort Peck and Garrison had occurred early in the flood season prior to mountain snowmelt, it would have been much more serious and would have required greater project releases. However, actual encroachment was after it became evident that mountain snowmelt was essentially completed and the normal season of large runoff producing rains in upstream areas had passed. Maintaining relatively higher Fort Peck and Garrison reservoir levels than at downstream projects also served to maintain an increased overall flood control capability of the main stem system by providing additional flood control storage space in the downstream projects.

2-64. Another criticism of the 1975 regulation of the system was that higher than normal releases should have been initiated earlier in order that the maximum reservoir elevations and maximum release rates would have been at lower levels. This criticism did not recognize that prior to early May, runoff above the main stem reservoir system was forecasted to be in the sub-normal to normal range. The excess runoff resulted primarily from much above normal precipitation occurring in the April through early-July period. Additionally, after it became evident that above normal inflows could be anticipated, tributary inflows to downstream reaches of the Missouri River were high enough to require restrictions to system releases during June. Releasing at higher than normal rates early in the season at times that runoff forecasts cannot support such releases is inconsistent with all main stem reservoir functions other than the flood control function. All of these other functions depend upon the accumulation of storage rather than the availability of vacant storage space. Unnecessary drawdown of storage would subject the Corps to criticism from many varied interests, including power customers, navigators, recreationists, and irrigators.

2-65. Numerous individuals claimed that additional flood control storage space should be provided in order that system releases of the magnitude experienced during 1975 would not be required. However, high system releases were not required because of system storage inadequacies, but were due to the need to evacuate the large amount of storage accumulated within the system. In fact, at the crest storage level there still remained 2.5 million acre-feet of flood control storage space that was not utilized for the flood control function. System flood control procedures were originally designed to accomplish evacuation of all stored flood waters prior to the succeeding year's flood period. These procedures envisioned that releases of 50,000 cfs from Fort Peck and 100,000 cfs from the other reservoirs could be made, if necessary. The reduced channel capacities which have developed since construction of the main stem reservoirs tends to place a somewhat lower limit on permissible releases, except in case of emergencies. The maximum releases which were made during 1975 (35,000 cfs from Fort Peck, 65,000 cfs from Garrison, and 61,000 cfs from Fort Randall and Gavins Point) were well below the releases specified under reservoir design flood conditions when the projects were designed.

2-66. It was also claimed that main stem operations, particularly the high release rates, unduly increased bank erosion along the unstabilized portion of the Missouri River channel. However, bank erosion has always occurred extending back since the river first formed. Data available to the Corps indicates that average erosion rates through the unprotected areas since main stem projects began operation are less than during pre-project conditions, although this improvement is small in some reaches. Preliminary studies of 1975 erosion indicate that erosion rates were near the average rates which have occurred since the reservoirs were constructed.

2-67. Suggestions were received that more system storage should be evacuated during the winter season, thereby allowing a corresponding reduction in the summer release level. However, ice formation during the winter severely reduces channel capacity and past experience indicates that even with the moderate winter releases scheduled, stages well above flood stages are quite possible when ice formation occurs. Missouri River stages at one or more gaging stations along the river rose above flood stage in five of the six winters preceding 1975, although releases from Gavins Point were generally below the 20,000 cfs level.

2-68. Complaints were also received that man-made floods resulted from reservoir operations. Actual flooding associated with reservoir releases during 1975 were very minor with the exception of a 10-mile reach located upstream from the mouth of the Niobrara River. Except for this reach, all flooding was in low-lying areas that would have frequently been inundated (on an average of two or three times a year) prior to project operation. With no zoning restrictions along the river valley, encroachment into these flood prone areas has been general throughout the reach of the Missouri River where almost complete control is provided by the main stem reservoirs. When higher than normal outflows are required from the reservoirs, flooding of such flood plain lands and developments can be expected. The reach above the mouth of the Niobrara River is adversely affected by the growth of the delta in the Missouri River. Prior to project operation, large flood flows would periodically remove the delta material; however, since project operation began large flood flows have been eliminated. The delta has grown through the years and at the present time severely restricts the channel carrying capacity. The Court of Claims has ruled that the flooding associated with this delta restriction is the fault of the main stem reservoirs and negotiations are underway to acquire flooding easements.

2-69. Water Quality. Water quality characteristics that are of greatest concern in the basin are: chemical constituents, which affect human health and plant and animal life; temperatures, which affect fisheries and the aquatic environment; biological organisms, which affect human health; and taste, odor, and floating materials, which affect the water's potability and the aesthetic quality of the environment. Historically, and aside from the biological and bacterial aspects of water quality, the basin's principal concern with water quality has been in connection with dissolved solids concentrations as these affect domestic, industrial, and irrigation uses of water. Tolerance of dissolved solids is partly dependent upon the particular purpose for which the water is to be used. For most uses, water with dissolved solids concentrations less than 500 milligrams per liter is considered excellent, that with 500 to 1,500 milligrams per liter is considered usable, and that with over 2,000 milligrams per liter is considered undesirable. By these standards, water quality of the Missouri River is generally considered to be excellent. The main stem reservoirs have a very stabilizing effect upon water quality parameters. Biologic quality and dissolved-oxygen quality have not been considered problems within the basin until recent years. As a result, there has not been a long-term systematic program for obtaining area-wide data, but it is known that problems do exist below several of the major cities and below industrialized areas on some of the smaller streams.

2-70. Sediment. In its natural state, the Missouri River transported a sediment load increasing from an average of 25 million tons per year in the vicinity of Fort Peck, Montana to 150 million tons per year at Yankton, South Dakota, 175 million tons per year at Omaha, Nebraska, and approximately 250 million tons per year at Hermann, Missouri, near its confluence with the Mississippi River. With the construction of each of the main stem dams, beginning with the closure of the Fort Peck Dam in 1936, the sediment entering each of the respective reservoirs was trapped. The flow released from the reservoirs was clear and essentially free from sediment, and the downstream load was derived from downstream tributary contributions and from material eroded from the bed and banks of the river. Currently, the river from the headwaters of the Fort Peck Reservoir to the Gavins Point Dam near Yankton, South Dakota, is almost fully controlled by the main stem dams. Beginning at Gavins Point, the lowermost dam, the main stem of the Missouri begins anew as a sediment-free stream. It begins immediately to derive a new load from erosion of the bed and banks and from tributary streams, but to date, the sediment transport in the river from the Gavins Point Dam to the mouth is but a small portion of its previous load. Analysis of the sediment transport in the Missouri River at Omaha shows that the load presently is composed of about 70 percent sand-size material whereas this fraction was only about 30 percent of the total prior to closure of the upstream dams and armoring of the channel bank below Sioux City, Iowa. Subsequent to closure of the Fort Randall Dam in 1952, the total suspended load at Omaha has been relatively consistent at approximately 25 million tons per year, versus the long-term average of 175 million tons per year. At the mouth of the Missouri River near St. Louis, the total suspended sediment load now is about one-half the load experienced prior to closure of the main stem and tributary dams.

II-D. Missouri River Channel Characteristics.

2-71. General. The maximum flow which may be passed without damage varies through the length of the Missouri River, and is dependent upon channel dimensions, the degree of encroachment upon the flood plain, and upon improvements such as levees and channel modifications. Capacities at specific locations also varies from season to season, especially in the middle and upper reaches where a decrease in capacity due to the formation of an ice cover is common through the winter and early spring months. In common with most streams, the capacity of the Missouri River channel usually increases progressively downstream, although instances occur where this trend is reversed.

2-72. Ice Formation. Above Sioux City, the main stem of the Missouri River and its tributaries can be expected to freeze over each year. An intermittent ice cover will also usually form on the Missouri River as far downstream as St. Joseph, Missouri. In the downstream reaches of the river below St. Joseph, an ice cover may occasionally form as a result of severe and extended cold temperatures. The time of formation and disintegration of the ice cover varies widely from year to year, but an ice cover may be expected over some reaches from early December to about mid-March. RCC Technical Report No. SS-N-71, "Missouri River Freeze and Breakup" November 1971, presents detailed historical data on this subject.

2-73. An ice cover greatly decreased the river conveyance at any given stage and consequently the channel capacities are materially reduced. The formation and breakup of the ice cover through any reach or series of reaches often causes ice jams. Very substantial volumes of water are stored temporarily by these ice jams, or by a solid ice cover, due to flow retardance by the ice. This phenomenon has a marked effect upon streamflow and river stages. Downstream flows and accompanying stages may be markedly reduced at the onset of the jam while stages just upstream or in the upstream portions of ice covered sections of the river may rise to damaging levels. The volume of ice in any particular reach of the river which may contribute to jamming is a function of the thickness of ice, the width of the river, and the length of the reach. With low stages, the river width, and consequently the ice volume within the reach, is reduced from what it would have been with higher stages. Most of the maximum stages of record in the upper Missouri River resulted from ice jams and occurred prior to regulation provided by the main stem reservoirs. These projects now act as a trap to flowing ice and reduce the possibility of severe ice jam formation in downstream areas, both during the period of ice formation and ice breakup.

2-74. In the downstream portions of the river, ice blocking or jamming is likely to occur during periods of extremely cold weather which results in ice formation on the river which up to that time had been essentially open. Large cakes of ice form and float downstream to a restricted reach where they lodge. The resulting blocks are fed by additional floating ice. Usually, such blocks in the downstream reaches are temporary in nature, and continue only until such time that temperatures moderate. On several occasions in recent years, blocks have formed in the Nebraska City-St. Joseph reach of the river and have caused stages to exceed established flood stage, in spite of low releases from the main stem reservoirs.

2-75. Ice cover forming on the Missouri River below Fort Peck and Garrison Dams has a marked effect upon the winter regulation of these projects. At the time the ice cover first forms, the downstream channel capacities are at a minimum. However, as the ice cover stabilizes, a progressive increase in the capacity occurs and prior to the end of the winter season, it is often possible to release at significantly greater rates while maintaining relatively constant downstream stages. This phenomenon is discussed in more detail in Section VIII of this manual and in two RCC Techincal Reports, "Freezing of the Missouri River Below Garrison Dam, February 1973," and "Freezing of the Missouri River Below Fort Peck Dam, July 1973."

2-76. Seasonal Variations in Stage-Discharge Relationships. The Missouri River is an alluvial stream with a movable sand bed; consequently, marked variations in the relationship between stages and corresponding discharges occur. While some of these variations may be more or less permanent in nature due to changes in channel regimen, there is strong evidence of seasonal shifts in this relationship, particularly in the reach extending from Sioux City, Iowa, to Kansas City, Missouri. Investigation indicates that this shift is related to water temperature and consequent bed configuration. In essence, the typical seasonal shift results in higher stages during the mid-summer months than during the early spring and fall months for similar rates of flow. Stage variations of over 2 feet may occur as a result of these seasonal rating curve shifts.

2-77. Channel Deterioration. At numerous locations along the Missouri River there is evidence of a permanent shift in the stage-discharge relationship. This warping generally is in the direction of reduced channel capacity for higher flows and has been very significant at some locations. For example, below Fort Randall Dam just upstream from the Niobrara River, land areas adjacent to the river channel are now being inundated with flows of 50,000 cfs that were dry with flows of over 150,000 cfs prior to the time the main stem system of reservoirs began operation. Many similar instances could be cited, although not as extreme as the above example. In general, the effects of these channel changes have been to reduce capacity and can be partly attributed to the control of flood flows by the reservoirs, thereby eliminating the scouring effect of the floods. However, some deterioration in channel capacity may have resulted from bank stabilization measures that have been constructed for navigation or erosion control purposes.

2-78. Conversely, at some locations there is evidence of significant degradation of the Missouri River channel. As expected, degradation has occurred downstream of the main stem power plants. In these cases, it is considered beneficial as increased power heads result. On the Missouri River below the main stem system, particularly at Sioux City, Iowa, river stages associated with low flows have decreased markedly since system operation first began in 1954. This degradation has had adverse effects upon recreation facilities constructed adjacent to the river channel, as well as on navigation docks.

2-79. Channel Capacities. A general summarization of present day open-water channel capacities through specific main stem reaches is given below:

a. Fort Peck Dam to Mouth of Yellowstone River. Damages begin with open water flows of 30,000 cfs; however, with flows ranging from 50,000 cfs in the upper portion to 70,000 cfs in the lower portion of the reach, damages are relatively minor and limited mainly to pasture and other unimproved lands. If stages at Wolf Point, Montana, and Culbertson, Montana, are maintained at or below 11 feet and 13 feet respectively, few complaints concerning the Fort Peck release level can be expected. During the winter season, the ice-covered channel capacity through the reach will allow releases of 10,000 cfs at the time of ice formation to over 15,000 cfs after the ice cover has stabilized, provided that significant tributary inflows do not coincide with reservoir outflows.

b. Garrison Dam to Oahe Reservoir. The main damage center in this reach is Bismarck, North Dakota. If Bismarck stages are not allowed to rise significantly above 13 feet, few complaints regarding high reservoir releases can be expected. At the time Garrison Dam was constructed, this represented an open water channel capacity of about 90,000 cfs; however, in 1975 after 20 years of reservoir operation, the channel had deteriorated to the extent that open water flows of about 50,000 cfs resulted in a stage of 13 feet. During 1975, releases of 65,000 cfs were made from Garrison with resulting stages at Bismarck above 14 feet. While this caused many complaints, actual resulting damages appeared quite minor. There has been a substantial amount of flood plain development at low levels in the Bismarck vicinity. Winter flows under an ice-cover of 20,000 cfs, when ice formation occurs, to over 35,000 cfs after the ice-cover stabilizes can be accommodated with a Bismarck stage near 13 feet.

c. Oahe Dam to Fort Randall Dam. Very little natural Missouri River channel remains in this reach and ice formation has not presented difficulties. It is believed that flows of 100,000 cfs can be accommodated without serious difficulty.

d. Fort Randall Dam to Gavins Point Reservoir. Since system operations began, a delta has formed at the mouth of the Niobrara River, a stream which enters the Missouri River just upstream from the Gavins Point Reservoir. Prior to system operations, large flood flows periodically removed the delta material; however, these large floods are now eliminated by upstream reservoir control. While this reach of the Missouri River was capable of passing flows in excess of 150,000 cfs prior to construction of the main stem projects, Fort Randall open water releases of 40,000 - 50,000 cfs now result in flood problems to adjacent property owners. The ice-covered channel capacity has probably been reduced to about 25,000 cfs. It appears quite probable that the channel capacity in the reach will be further reduced during future years. With the severely restricted channel capacity in this reach, inundation of some of the bottom lands adjacent to the channel will probably be necessary in most years that an above-normal water supply is available to the main stem.

e. Gavins Point Dam to Sioux City, Iowa. Prior to construction of the main stem reservoirs, the open water channel capacity through this reach of the Missouri River was well in excess of 100,000 cfs. There is evidence of channel deterioration due largely to encroachment in backwater areas and along old river meander chutes; however, this is offset by channel degradation and in 1975, flows of 65,000 cfs in this reach caused no flood damage. Capacity with a stabilized ice cover is believed to be in excess of 30,000 cfs.

f. Sioux City, Iowa to Omaha, Nebraska. Open water channel capacities in this reach prior to construction of the main stem reservoirs was in excess of 100,000 cfs. During recent years, there has been considerable encroachment on the channel area. Fixed boat docks have been constructed in numerous locations through this reach and low areas are now being cropped. Much of this development is on or adjacent to river stabilization structures and takes advantage of sand deposition encouraged by this stabilization. Flows of 65,000 cfs in 1975 resulted in inundation of some of the cropped land and interrupted access to some marinas constructed along the banks. Flows of up to 35,000 cfs with a stable ice-cover appear possible without flooding; however, during freezing and ice break-up periods, which can occur at any time during the winter season, flows in excess of 20,000 cfs could result in lowland inundation.

g. Omaha, Nebraska to Kansas City, Missouri. Deterioration of the channel capacity has occurred through this reach during the past 25 years. Recent experience indicates that mid-summer flows exceeding 90,000 cfs will result in river levels above flood stage at Nebraska City and Rulo, Nebraska, as well as at St. Joseph, Missouri. Complaints are received from adjacent landowners concerning waterlogging of cultivated fields with stages 2 or more feet below flood stage. During the winter months, stages in this reach have gone as much as 5 feet above flood stage due to ice jams, even though Gavins Point releases were limited to 20,000 cfs and there was little incremental inflow occurring below Gavins Point.

h. Kansas City, Missouri to Mouth of Missouri River. Open-water flows of about 150,000 cfs will cause only relatively minor agricultural damages in this reach; however, the established flood stage at Waverly, Missouri, has been exceeded when flows were greater than 115,000 cfs during recent years. Ice jams can cause flooding with flows of less than 30,000 cfs.

2-80. Stage-Discharge-Damage Curves. Rating and damage curves, relating stages at particular locations with open-river discharges and with damages through an adjacent reach along the Missouri River, are shown on Plates 7 through 11. Damage curves have been developed for both existing and natural conditions. This has been done to show the effect of protective levees which have been built in many reaches of the Missouri River below Sioux City, Iowa. Levees in place at the present time provide protection as indicated by the existing curves, while the natural curves indicate the damages which would result at any particular stage with complete levee failure or overtopping through the affected reach. A transitional zone on the existing damage curves exists through the elevations which define the freeboard on the levees in that the exact effects of stages above the selected design stages for a particular levee are not determinate. The timing, location, and manner of levee failures at these high elevations, the exact stage where the levees would be overtopped at various points through the reach, as well as the effects upon the reference gage of any failures or overtopping, cannot be definitely estimated in advance. This transitional zone, in which actual damages may vary from that presented, dependent upon circumstances at the time, extends downward from the upper point where the existing and natural curves meet through the freeboard range of the affected levees.

2-81. Water Travel Time. Plate 12 presents the usual time of travel of within-bank, open-water flows for the Missouri River and its major tributaries. It should be recognized, however, that these are general approximations that may be affected by many factors. For purposes of scheduling main stem system releases, approximate open water travel time from Gavins Point Dam are 1.5 days to Sioux City, 3 days to Omaha, 3.5 days to Nebraska City, 5.5 days to Kansas City, and 10 days to the mouth of the Missouri River.

SECTION III - WATER RESOURCE DEVELOPMENT IN THE MISSOURI RIVER BASIN

III-A. Legislative History.

3-1. Early Development. The first Federal exploration and survey of the Missouri Basin was made by the two Corps of Engineers' officers, Captains Lewis and Clark, on their historic trip of 1804-1806, immediately following the Louisiana Purchase in 1803. Development of the basin's water resources began in the 1800's. The earliest efforts were single-purpose developments in response to specific needs, such as use of the rivers for water supply, irrigation, navigation, or mining. The first steamboat entered the river in 1819, and traffic developed rapidly to meet the needs of the expanding West. The first Federal development was initiated when Congress appropriated funds to the Corps of Engineers for a program of snag removal to aid navigation in 1824. Navigation of the Missouri River by steamboat reached a peak in about 1880 and dwindled to nothing by about 1890 because of the coming of the railroads. In 1884, at about the peak of steamboat traffic, the Congress created the Missouri River Commission within the Corps of Engineers for the purpose of river channel improvement and decreasing the transportation hazards. When the Commission ceased to exist in 1902, the Corps of Engineers resumed their normal activities in the basin.

3-2. Prior to 1865, streamflow in the Missouri River Basin was largely unused except for transportation by water and as a source of water supply. At about that time, the early settlers and homesteaders, their numbers swollen by uprooted Civil War survivors, began irrigation and mining ventures in substantial numbers. By the year 1900, streamflow depletions in the Missouri Basin, due to these private developments, had increased to about 3 million acre-feet per year. Prior to 1900, Congressional legislation dealing with water resource development other than navigation was primarily concerned with support and ecouragement of private development of water resources. This emphasis changed shortly after the turn of the century; and, within the overall scope of the history of basin water resources development, several aspects of Federal legislation merit specific mention.

3-3. The Reclamation Act of 1902. This Act authorized development of irrigation projects with Federal financing subject to partial repayment by irrigators and partial reimbursement from hydroelectric power revenues. The Act is limited in application to the 17 states west of the 98th Meridian. The fundamental purpose of the Act was to reclaim and foster settlement on undeveloped lands in the western states. Accordingly, a limitation of 160 acres was placed on the amount of individually-owned land that would be furnished irrigation water. The Reclamation Act has since been amended and expanded to permit water resources development for other beneficial purposes besides irrigation.

3-4. The River and Harbor Act of 1912. This Act authorized a 6-foot navigation channel in the Missouri River from the mouth to Kansas City, Missouri. Several subsequent Congressional acts modified this navigation project, the latest being the River and Harbor Act of 2 March 1945, which provided for works to secure a 9-foot deep by 300-foot wide channel from the mouth to Sioux City, Iowa.

3-5. The River and Harbor Act of 1927. Pursuant to this Act, the Corps of Engineers undertook the first comprehensive investigation and study ever made of the water resources and problems of the Missouri basin. The entire river system was examined to determine the water resources and the prospects of its development for flood control, navigation, irrigation and power. The reports of these investigations, the "308" Reports, are historic documents in the development of the Missouri basin.

In entering this broad field of investigation and report, many projects were conceived which did not appear to be feasible at that time or within the scope of national policy for Federal development, but which were subsequently adopted by the Corps of Engineers and the Bureau of Reclamation as integral parts of the present Missouri Basin Plan. Experience was gained and a fund of data collected in diversified fields which have made important contributions subsequently in the solution of basin problems.

3-6. The River and Harbor Act of 1935. The construction of Fort Peck Dam was commenced under Executive Order in October 1933 with funds provided by Congress for the relief of unemployment. The project was subsequently specifically authorized by Congress in the River and Harbor Act approved 30 August 1935, in accordance with the Chief of Engineers' recommendations included in House Document No. 238, 73rd Congress, 2nd Session. The Fort Peck Power Act of 1938 authorized construction of power facilities. The project was originally authorized primarily for improving navigation on the Missouri River, and incidental purposes of flood control and hydroelectric power production. It authorized the inclusion of power facilities, designated the Bureau of Reclamation as marketing agent for power generated, and made power rate schedules subject to the confirmation and approval of the Federal Power Commission.

3-7. The Flood Control Act of 1936. This act established the policy that (a) flood control on navigable waters or their tributaries is a proper activity of the Federal Government in cooperation with the states, and (b) the Chief of Engineers would have jurisdiction over, and supervision of, Federal investigations and improvements of rivers and other waterways for flood control and allied purposes. Subsequent flood control acts amended the 1936 Act to authorize Federal participation in more comprehensive water resources developments.

3-8. The Flood Control Act of 1938. Although this legislation resulted from studies of floods on the Mississippi River, and did not authorize a large number of projects to be built in the Missouri Basin, it recognized the Missouri Basin as having a general flood problem in the lower portion and as contributing significantly to the disastrous floods on the Mississippi. Accordingly, the Act authorized the Corps of Engineers to construct nine reservoirs in the lower part of the Missouri Basin for flood control. The 1938 Act adopted comprehensive plans for many basins, including the Missouri River Basin. This was the initial step toward the overall Missouri Basin Development Plan. The first expansion of this plan resulted from additional studies by the Corps of Engineers and appeared in the Flood Control Act of 1941, wherein levee protection along the Missouri River from Sioux City, Iowa, to Kansas City, and the Harlan County Reservoir on the Republican River in Nebraska were authorized.

3-9. The Flood Control Act of 1944. This Act approved a plan of development for the Missouri River Basin based upon a plan by the Corps of Engineers as presented in House Document No. 475, 78th Congress, Second Session, and a contemporary plan by the Bureau of Reclamation as presented in Senate Document No. 191, 78th Congress, Second Session, and based also on the coordination of these two plans as presented in Senate Document No. 247, 78th Congress, Second Session. Under this Act, the Corps of Engineers is responsible for development of projects on the main stem of the Missouri River. Tributary projects were made the responsibility of the Corps of Engineers if the dominant purpose were flood control. The Department of the Interior was designated as the marketing agent for all power, beyond project requirements, produced at Corps of Engineers' projects. The Department of the Interior subsequently designated the Bureau of Reclamation as the marketing agent for power generated by the main stem projects and the Southwestern Power Administration as the marketing agent for power generated at basin projects within the State of Missouri. Rate schedules for the sale of power are subject to confirmation and approval by the Federal Power Commission. Section 1(b) of the Act, sometimes referred to as the O'Mahoney-Millikin Amendment, provides that, for water rising in states wholly or partly west of the 98th

Meridian, use for navigation shall be subordinate to present or future beneficial comsumptive use in those states. Under the Act, approximately 100 tributary reservoirs were authorized in addition to the Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point Reservoirs on the Missouri River. The Fort Peck Project was authorized to be incorporated into the multi-purpose main stem reservoir system upon the availability of downstream main stem storage in other reservoirs.

3-10. The Watershed Protection and Flood Prevention Act of 1954. This Act extended Federal interest and financial participation to land stabilization and flood prevention measures on smaller watersheds. Thus, this Act served to supplement the policy for flood control measures on major streams established earlier. Subsequent amendments to the Act of 1954 increased the limitations on size of watershed eligible for improvement and on storage capacity of individual reservoirs. These amendments also authorized provision of storage for purposes other than flood prevention, within the overall storage limitation.

3-11. The 1958 Water Supply Act. In this Act, Congress recognized that the states and local interests have primary responsibility for developing water supplies for domestic, municipal, industrial, and other purposes; but it provided that the Federal Government should participate and cooperate by making provision for water supply in the construction, maintenance, and operation of Federal navigation, flood control, irrigation, or multiple-purpose projects. Accordingly, storage for water supply may be included in any Federally-constructed reservoir project, subject to consummation of certain assurances or agreements for non-Federal repayment of costs allocated to water supply.

3-12. Other Federal legislation of particular importance to land and water resources development in the basin includes the Fish and Wildlife Coordination Act of 1946, the Federal Water Pollution Control Act of 1956 and subsequent amendments, the Federal Water Projects Recreation Act of 1965, the Water Resources Planning Act of 1965, and the National Environmental Policy Act of 1969. Respectively, these Acts have established Federal policy concerning (1) preservation and enhancement of fish and wildlife resources in conjunction with Federal participation in water resource developments, (2) preservation of water quality through low-flow augmentation, (3) Federal participation in water-based outdoor recreation, (4) Federal participation in comprehensive river-basin planning for water-and-land resources development, and (5) actions to be taken relative to protecting and enhancing the quality of the human environment.

III-B Reservoirs.

3-13. General. In 1975, the Missouri River Basin contained about 100 multiple-purpose reservoirs and over 1,200 single-purpose reservoirs either completed or under construction. In the aggregate, these reservoirs provide a total of over 106 million acre-feet of storage capacity. The investment cost for this storage capacity exceeded $3 billion. Almost 99 percent of the total storage capacity serves multiple-purpose functions, although only about 95 percent of the total investment cost represents investment in multiple-purpose reservoirs. Purposes served by individual multiple-purpose reservoirs may include any combination of the purposes of flood control, municipal and industrial water supply, water quality control, irrigation, navigation, hydroelectric power, fish and wildlife enhancement, and recreation. In contrast, the function of most single-purpose reservoirs is either flood control or water supply. Pertinent data from the more important reservoirs in the basin, including all of the reservoirs in which the Corps has an operational responsibility, are listed in Table 2. Locations of the major reservoirs, as well as the locations of other water resource developments discussed subsequently herein, are shown on Plate 2.

3-14. Main Stem Reservoirs. The backbone of the Missouri River Basin reservoir system is formed by the six Missouri River main stem reservoirs, which were constructed by the Corps of Engineers. These reservoirs contain about 75 million acre-feet of storage capacity, which constitutes over 70 percent of the total storage in the basin's 1,300-plus reservoirs. These main stem projects contain 70 percent of the installed capacity in the basin's Federal hydroelectric power system, provide almost all of the reservoir support for navigation on the Missouri River, and contribute greatly to flood protection for over 2 million acres of land in the flood plain of the Missouri River. At normal pool levels, these reservoirs provide an aggregate water surface area of 1 million acres for recreation and fish and wildlife. Irrigation from these projects is currently limited to that accomplished by pumping by individual landowners, but Federal projects providing for irrigation of over 1.5 million acres of land are in various stages of planning, design, and construction.

3-15. Effects of Tributary Reservoirs on Main Stem Flows. Although it is relatively simple to approximate the effects of a single tributary reservoir upon specific streamflow occurrences, provided flow and storage data are available, such a process becomes exceedingly complex with the large number of such reservoirs existing in the basin. The problem becomes further complicated upon recognition of the many small projects in existence for which no hydrologic data are available.

TABLE 2
PERTINENT DATA FOR SELECTED MAJOR MISSOURI BASIN RESERVOIRS
(Including all reservoirs for which the Corps of Engineers has operational responsibility)

State, Dam and Stream	Agency (1)	Purposes Served (2)	Drainage Area Square Miles	Storage in 1,000 Acre-Feet						Power Installed Capacity KW	Manual or Report (5)	
				Total	Exclusive Flood Control (3)	Joint Use	Replacement	Multi-Purpose (3)	Inactive and Dead		Status (4)	Dated
COLORADO												
Bear Creek, Bear Creek	CE	F	236	28.6	26 6			1.9	0.1		A-P	Jan 78
Bonny, Republican River	USBR	F	1,435	170.1	128 8			39.2	2.1		A	Oct 69
Chatfield, So. Platte River	CE	F	3,018	235.0	211.2			23.8			A-P	Jan 73
Cherry Creek, Cherry Creek	CE	F	386	94.0	80.0			14.0			A	Oct 71
Kelly Road, Westerly Creek	CE	F	11	0.3	0.3						A	Jan 71
IOWA												
Rathbun, Chariton River	CE	F-N-W	549	551.7	346.3			205.4			A	May 74
KANSAS												
Cedar Bluff, Smoky Hill River	USBR	F-I-M	5,365	377.0	191.9			149.8	35.3		A	Sep 75
Clinton, Wakarusa River	CE	F-M	367	397.5	268.4			129.1			U	
Glen Elder, Solomon River	USBR	F-I-M	5,076	963.8	722.3			204.8	36.7		A	Jul 72
Kanopolis, Smoky Hill River	CE	F-I-M	7,860	425.6	370.4			55.2			A	Oct 71
Kirwin, N. Fork Solomon River	USBR	F-I	1,367	314.6	215.1			89.7	9.8		A	Feb 74
Lovewell, White Rock Creek	USBR	F-I	345	92.2	50.5			24.9	16.8		A	Apr 69
Melvern, Marais des Cygnes River	CE	F-W	349	363.0	209.0			154.0	26.0(6)		D	Jan 72
Milford, Republican River	CE	F-I-M-W	17,388	1173.1	757.7			415.4			A	Nov 71
Norton, Prairie Dog Creek	USBR	F-I-M	688	134.8	98.8			30.7	5.3		A	Aug 74
Perry, Delaware River	CE	F-N-W	1,117	770.0	527.0			243.0			A	Nov 73
Pomona, 110-Mile Creek	CE	F-M-W	322	247.4	176.8			70.6			A	Feb 73
Tuttle Creek, Big Blue River	CE	F-N-W	9,628	2367.0	1941.7			425.3	233.0(6)		A	Apr 74
Webster, S. Fork Solomon River	USBR	F-I	1,150	260.7	183.4			72.1	5.2		A	Jul 75
Wilson, Saline River	CE	F-I-N-W	1,917	778.5	530.7			247.8			A	Oct 71
MISSOURI												
Bagnell, Osage River	UEC	P	13,994	1973.0				1246.0	727.0	176,200	N	
Harry S. Truman, Osage River	CE	F-P	11,500	5209.3	4005.9			1203.4		160,000	U	
Long Branch, E. Fork Little Chariton	CE	F-M-W	109	65.0	30.4			34.6			U	
Pomme de Terre, Pomme de Terre Riv.	CE	F-N	611	648.8	407.2			241.6			A	Feb 72
Smithville, Little Platte River	CE	F-M-W	213	246.5	101.9			144.6			U	
Stockton, Sac River	CE	F-P	1,160	1666.7	779 6			887.1		45,200	A	Aug 73
Thomas Hill, Mid. Fk. Chariton Riv.	AEC	F	147	85.5	10.6			60.2	14.7		N	
MONTANA												
Bynum, Teton River	TCR	I	(7)	75.0				74.5	0.5		N	
Canyon Ferry, Missouri River	USBR	F-I-M-P	15,904	2050.9	104.3	349.8	449.3	713.0	434.5	50,000	A-P	Mar 72
Clark Canyon, Beaverhead River	USBR	F-I-M	2,320	257.1	79.1(10)	50.4		126.1	1.5		A	Aug 76
Deadman's Basin, Musselshell River	MDNR	I	(7)	76.8				72.2	4.6		N	
Fort Peck, Missouri River	CE	ALL	57,500	18900.0	1000.0	2700.0		10900.0	4300.0	185,000	A	Oct 76
Francis Lake, Dupuyer Creek	PCCR	I	(7)	116.9				111.9	5.0		N	
Fresno, Milk River	USBR	I	3,766	129.1				127.2	1.9		N	
Gibson, Sun River	USBR	I	575	104.8				104.8			N	
Hauser, Missouri River	MPC	P	16,876	98.2				51.4	46.8	17,000	N	
Hebgen Lake, Madison River	MPC	P	904	384.8				377.5	7.3	50	N	
Holter, Missouri River	MPC	P	17,149	240.4				81.9	158.5	50,000	N	
Madison, Madison River	MPC	P	2,181	42.0				41.0	1.0	9,400	N	
Nelson, Milk River	USBR	I	(7)	85.5				66.8	18.7		N	
Pishkin, Sun River	USBR	I	(7)	48.5				32.1	16.4		N	
Tiber, Marias River	USBR	F-I-M	4,850	1368.2	709.2(8)		690.0(9)	74.4	584.7		U	Dec 59
Yellowtail, Bighorn River	USBR	F-I-M-P	19,626	1375.0	259.0	250.0		363.7	502.3	250,000	A	Jan 74
Bull Hook, Bull Hook-Scott Coulee	CE	F	54	6.5	6.5						N	
NEBRASKA												
Enders, Frenchman Creek	USBR	F-I	786	74.5	30.0			34.5	10.0		A	Mar 73
Harlan County, Republican River	CE	F-I	13,556	840.6	498.0			342.6			A	Aug 73
Kingsley, North Platte, River	CNP	I-P	33,500	1948.0				1948.0			N	
Medicine Creek, Medicine Creek	USBR	F-I	642	89 3	52.2			27.6	9.5		A	Jun 74
Merritt, Snake Creek	USBR	I	640	74.5				72.9	1.6		N	
Minatare, North Platte River	USBR	I	(7)	62.2				60.8	1.4		N	
Red Willow, Red Willow Creek	USBR	F-I	310	86.6	48.9			27.3	10.4		A	Nov 69
Salt Creek, Salt Creek Tributaries	CE	F	216	191.5	139.8			51,7	36.4		A-P	Jun 67
Sherman, Owl Creek	USBR	I	(7)	69.1				54.8	14.3		N	
Trenton, Republican River	USBR	F-I	3,941	254.0	133.8			104.7	15.5		A	Oct 69
NORTH DAKOTA												
Bowman-Haley, N. Fork Grand River	CE	F-M	471	93.0	73.2			15.5	4.3		A-P	Jan 68
Garrison, Missouri River	CE	ALL	123,900	24100.0	1500.0	4300.0		13300.0	5000.0	430,000	A	Aug 78
Heart Butte, Heart River	USBR	F-I	1,710	225.5	150.0			68.7	6.8		A	Feb 51
Jamestown, James River	USBR	F-I-M	1,760	220.9	185.4	6.6		28.1	0.8		A	Nov 57
Pipestem, Pipestem Creek	CE	F	594	146.9	137.0			9.6	0.3		A-P	Jul 75
SOUTH DAKOTA												
Angostura, Cheyenne River	USBR	I	9,100	127.6				116.4	11.2		N	
Belle Fourche, Owl Creek	USBR	I	(7)	192.0				185.2	6.8		N	
Big Bend, Missouri River	CE	ALL	5,840	1907.0	60.0	117.0			1729.0	468,000	A	Dec 78
Cedar Canyon, Deadman's Gulch	CE	F	0.4	0.1	0.1						A	Jan 71
Cold Brook, Cold Brook, Fall River	CE	F	71	7.2	6.7			0.5			A	Aug 54
Cottonwood Spgs. Cottonwood Sp. Ck.	CE	F	26	8.4	7.7			0.2	0.4		A	Sep 73
Fort Randall, Missouri River	CE	ALL	14,150	5600.0	1000.0	1300.0		1700.0	1600.0	320,000	A	Feb 79
Gavins Point, Missouri River	CE	ALL	16,000	517.0	62.0	97.0			358.0	100,000	A	Mar 79
Oahe, Missouri River	CE.	ALL	62,090	23500.0	1100.0	3200.0		13700.0	5500.0	595,000	A	Sep 78
Pactola, Rapid Creek	USBR	F-I	319	99.0	43.0			55.0	1.0		A	Feb 77
Shadehill, Grand River	USBR	F-I	3,120	358.0	216.0			84.0	58.0		A	Nov 51
WYOMING												
Alcova, North Platte River	USBR	I-P	10,075	184.3				30.6	153.7	36,000	N	
Boysen, Bighorn River	USBR	F-I-M-P	7,700	952.4	150.0	146.1		403.8	252.1	15,000	A	Dec 66
Buffalo Bill, Shoshone River	USBR	I-P	1,498	424.0				375.8	48.2	11,000	N	
Bull Lake, Bull Lake Creek	USBR	I	210	152.5				151.8	0.7		N	
Glendo, North Platte River	USBR	F-I-P	14,330	795.2	271.9			458.5	64.8	24,000	A-P	Apr 70
Guernsey, North Platte River	USBR	I-P	15,008	45.2				45.2		4,800		
Keyhole, Belle Fourche River	USBR	F-I	1,950	340.1	140.2			190.4	9.5		A	Jun 69
Pathfinder, North Platte River	USBR	I-P	10,011	1015.9				984.7	31.2	48,000	N	
Seminoe, North Platte River	USBR	I-P	6,641	1017.3				985.6	31.7	32,400	N	
Tongue, Tongue River	MDNR	I	1,770	69.4				68.0	1.4		N	

FOOTNOTES:

(1) Symbols used

AEC	- Associated Electric Company, Springfield, Missouri
CE	- Corps of Engineers
CNP	- Central Nebraska Public Power & Irrigation District
MDNR	- Montana Department of Nat. Resources & Consv.
MPC	- Montana Power Company
PCCR	- Pondera County Canal & Reservoir Company
TCR	- Teton Cooperative Reservoir Company
UEC	- Union Electric Company
USBR	- U.S. Bureau of Reclamation

(2) Symbols used

F	- Flood control and detention
I	- Irrigation
M	- Municipal and industrial water
N	- Navigation
P	- Power
W	- Water quality control
ALL	- Indicates all purposes are served

Note: Recreational and fish and wildlife not shown since all projects generally serve these purposes

(3) Includes sediment when allocated to pool as noted by footnote (6)

(4) Symbols used

A	- Manual or report approved
D	- Draft completed
N	- No manual or report required
P	- Preliminary
U	- Construction not complete

(5) Reservoir Regulation Manual for Corps of Engineers Projects
Information Report for Bureau of Reclamation Projects

(6) Allocated to sediment

(7) Offstream reservoir

(8) All storage allocated to flood control temporarily suspended in 1966 pending spillway rehabilitation. The 709.2 value includes replacement storage.

(9) Temporarily unavailable pending spillway rehabilitation

(10) Includes replacement storage

Individually, these small projects have insignificant effects upon Missouri River flows; however, when considered in the aggregate, this effect may be very significant. Certain general conclusions, as given below, may be deduced relative to the effect upon streamflow of these projects which are not operated specifically for flood control.

a. On an annual or other long-term basis, the existence of tributary reservoir storage will result in a decrease in main stem streamflow. In addition to the consumptive use of water from the projects, nearly all are located in regions where the volume of evaporation from the reservoir will exceed the volume of precipitation which may fall directly on the pool.

b. During any flood season, the existence of upstream tributary storage will almost certainly reduce main stem flood volumes to some extent, the amount being dependent on antecedent conditions. Although specific flood control storage may not be allocated, these reservoirs are located in regions where flows are of a distinct seasonal nature. Operation to achieve the purposes for which the reservoirs were built results in storing water during periods of excess flows, which is then utilized later during periods of low runoff. This will reduce flood volumes and augment low flows.

c. Normally, the natural crest flows on the main stem will also be reduced by the existence of tributary reservoir storage, provided significant runoff contributing to the crest flows originates above the tributary projects. Reasons for this are those given in "b" above, in addition to the effects of the reservoir in smoothing and delaying sharp crests even if there was no appreciable vacant storage space remaining at the time of the crest. It is realized that in certain instances, a reservoir project can increase the size of the crest below the project over that which would be observed naturally, either by the speed up of travel time through the length of the reservoir or by delaying a portion of the runoff from a subarea and thus contributing to a major upstream crest on the main stream. With a single tributary reservoir, or only a few projects, such an increase in crests might occasionally be expected. However, with the large number of projects tributary to the main stem, the possibility of their aggregate effect being such as to increase main stem crest flows is very remote.

3-16. Regulation of Tributary Flood Control Storage Space. The Corps of Engineers is responsible for flood control regulation of all Federally-financed reservoirs with allocated flood control space. Many of these reservoirs will be regulated, insofar as practical, to prevent flood damages along both the tributary streams and the main stem downstream from the projects and for this reason, regulation will be coordinated with regulation of the main stem projects at times of large flood flows.

III-C Local Flood Protection.

3-17. Missouri River Agricultural Levees. The production of food is the major industry in the large agricultural region which makes up the Missouri Basin. More than one and one-half million acres of the most productive farm land contained within the basin, together with the associated livestock, equipment, farm buildings and other improvements, as well as numerous rural communities, are located on the flood plain of the Missouri River between Sioux City, Iowa, and the river's mouth. In addition, railroads, highways, bridges and municipal developments within the flood plain increase the necessity for adequate flood protection in the river bottom areas. Local interests have built many miles of levees, comprising about 500 non-Federal levee units through this reach of the river. These are listed in appropriate Flood Emergency Plans. However, most of these levees are inadequate to withstand major floods.

3-18. Federal levee construction in accordance with the 1941 and 1944 Flood Control Acts was started in 1947. The levees are designed to function as a team with main stem and tributary reservoirs. Neither the reservoirs alone nor the levees provide the desired degree of protection, but operating to supplement each other, they provide protection against floods equal to any of past record. The whole system of Federal levees is being constructed in individual units. They are generally being built of semicompacted earth fill with a top width of 10 feet, side slopes of 1 on 3, and a freeboard of 2 feet above the water surface of the design flood. Landside berms or seepage wells are provided where foundation conditions require such measures. Drainage structures extend through the levees to provide adequate internal drainage.

3-19. At the end of 1975 there were 29 Federal units either constructed or under construction. With the exception of two units between Kansas City and Boonville, all Federal levees now constructed are in the reach located between Omaha and Kansas City. While other units in addition to those presently constructed or under construction appear economically feasible, they presently are in an inactive status. Design discharges of these Federal levees range from 250,000 cfs at Omaha, 295,000 cfs at Nebraska City, 325,000 cfs at St. Joseph, 425,000 cfs at Kansas City, up to 620,000 cfs at Hermann near the mouth of the

Missouri River. Detailed locations of these levees, together with maps of protected areas, are given in the Project Maps, as published and revised annually by the District offices.

3-20. Missouri River Urban Protection Projects. Levee projects for the protection of large urban areas along the Missouri River have been constructed at Omaha, Council Bluffs, and the Kansas Citys. The Kansas Citys project was authorized by the 1936 Flood Control Act and modified and extended by the Acts of 1944 and 1954. The authorizations for the Omaha and Council Bluffs projects were included in the 1944 Act. The projects are designed to operate in conjunction with the main stem and tributary reservoirs to prevent flooding of these localities from the most severe flood events of record. In addition to the large projects, a short levee constructed by the Corps under Section 212 protects the town of New Haven, Missouri, from Missouri River floods. Design discharge of the Omaha-Council Bluffs project is 250,000 cfs, while levees in the Kansas City area are designed for Missouri River flows of 540,000 cfs.

3-21. Tributary Levee Projects. In addition to levee protection along the main stream of the Missouri River, the comprehensive plan for basin development includes many protection projects for localities in the upstream reaches of the river or on tributary streams. Some of the projects are designed to provide protection in combination with flood control reservoirs constructed upstream from the affected locality. Description of each of these projects is beyond the scope of this manual and reference is made to individual project manuals or tributary reservoir manuals for descriptions of these projects.

III-D Other Functional Development.

3-22. Irrigation. Irrigation is the largest single user of water in the Missouri Basin. As of 1965, about 7.4 million acres of irrigated land, including 6.9 million acres of cropland and 0.5 million acres of pasture, required an annual farm delivery in excess of 14 million acre-feet of water. Of this total, about 5.8 million acres are served by group irrigation systems. These systems have an aggregate reservoir storage capacity of nearly 9 million acre-feet and about 42,000 miles of group-delivery canals. About 45 percent of the storage capacity for group irrigation systems is in reservoirs constructed by irrigation districts, water companies, or the states, with Federal projects accounting for the remainder. About 70 percent of the irrigated area is served by surface water, and about 30 percent is served by ground water. In years of deficient water supply, a significant portion of the area normally irrigated cannot be furnished the water required.

3-23. Since 1965, it is estimated that an additional 4 million acres have been placed under irrigation in the Missouri Basin, predominantly from ground water sources and by private enterprise. Only about one-fifth of the potentially irrigable lands in the basin are now irrigated. Consequently, a continuing growth can be expected in the future. Estimates are that over 6 million additional acres in the basin will eventually be irrigated. Of major importance, insofar as the main stem reservoirs are concerned, are the planned Garrison and Oahe diversion units. These projects contemplate drawing substantial quantities of water directly from both Garrison and Oahe Reservoirs to be used for irrigating large blocks of land in eastern North and South Dakota. A considerable portion of the irrigated land of the Garrison Unit lies outside of the Missouri basin and its irrigation will constitute a major trans-basin diversion. Benefits attributable to this diversion also include restoration of lake levels and the maintenance of a suitable water supply for municipal and industrial purposes in eastern North Dakota. Further details concerning these important projects are presented in the Garrison and Oahe Regulation Manuals.

3-24. Water Quality Control. With the exception of some tributary streams and isolated reaches of the Missouri River below cities and industries, water quality problems in the Missouri Basin have been relatively minor. Storage space has been provided in a few tributary reservoirs to serve this purpose. Recent emphasis has been on water treatment facilities rather than the dilution of poor quality water by use of storage facilities. Consequently, Missouri River flows ranging from 3,000 cfs at Sioux City to 9,000 cfs at Kansas City are considered adequate for water quality purposes. As further water treatment facilities become operational, the water quality flow requirements are expected to be less than 5,000 cfs along the entire Missouri River.

3-25. Municipal and Domestic Water Supply. In contrast to the period of basin settlement when domestic water supply was obtained from streams, cisterns, rain barrels, and hand-pumped wells, over 90 percent of the total basin population of about 9 million now has running water supplied either from central distribution systems or from individual household pressurized systems. A total of about 1,800 communities in the basin, with an aggregate population of over 6 million, now have public water service. However, about 800 incorporated communities, with an aggregate population of 97,000 and 2.3 million people living on farms, in other rural areas, and in unincorporated communities are dependent on individual water supplies. Nearly two-thirds of the rural population, about 1.5 million people, are served by individual pressure systems.

3-26. Of the approximately 1,800 communities with public water service, the great majority (over 1,500) obtain their water supplies from groundwater sources alone, about 200 communities utilize surface-water sources exclusively, and 50 communities utilize combined surface- and ground-water sources. In terms of the population served from public systems, almost 54 percent is served exclusively from surface-water sources and about 35 percent is served exclusively from ground-water sources. The major cities of Omaha, Kansas City, and St. Louis depend upon the Missouri River for water supply, as do other smaller cities along the Missouri.

3-27. Currently, the gross annual withdrawal of water for municipal, rural domestic, and industrial purposes in the Missouri River basin is 2.8 million acre-feet. About 13 percent of the gross demand, equivalent to about 350,000 acre-feet annually, is consumptive use. About 21 percent of the gross demand is obtained from ground water, 21 percent from surface water, and 58 percent from re-use of return flows from upstream systems.

3-28. Industrial Water Supply. Many industrial water users in the Missouri Basin have water supply systems separate from the municipal systems and utilize both ground water and surface water resources. Thermal-electric power generation represents the largest industrial use, with a current estimated withdrawal of over 1.7 million acre-feet annually. Activities associated with the extraction and primary processing of ores and fuels are estimated to require almost 100,000 acre-feet each year while other industries in the basin use about 400,000 acre-feet annually. Livestock production is an important part of the agricultural industry within the basin, accounting for about 70 percent of the average annual agricultural income. It is estimated that current use is about 400,000 acre-feet annually, exclusive of evaporation from ponds constructed specifically for livestock watering purposes. Total industrial use in the basin now totals about 4 million acre-feet annually, of which less than 1 million acre-feet is consumptive.

3-29. Industrial use of water in the Missouri Basin is expected to increase significantly during the future. Large thermal and nuclear power plants are being constructed along the Missouri River to take advantage of the cooling water provided by the river flows, as stabilized by upstream reservoir regulation. Additionally, a major portion of the nation's coal reserves are located in the states of Wyoming, Montana, and North Dakota. Future development of these reserves is expected to require substantial volumes of water, including supplies diverted directly from the main stem reservoir system. Over the next 50 years, water needs for industrial purposes are expected to more than double, with coal development alone expected to require one-half to one million acre-feet annually.

3-30. Streambank Stabilization. Streambank erosion is a continuing problem along most of the main streams and many tributaries in the Missouri Basin. Most bank protection projects now in existence are comparatively small and many have been of an emergency nature. Although the main stem reservoir system greatly reduces flood peaks, bank erosion is still occurring below those projects where erosion control measures have not been built. Prior to operation of the system accretions comparable to the eroded area could be expected to occur; however, since the reservoirs act as a sediment trap, this is no longer the case. Numerous areas of bank protection have been installed below the Garrison Dam and additional revetments will probably be required in future years below several of the projects. The most significant bank-erosion control achievement in the basin is that accomplished by the Missouri River Navigation and Bank Stabilization Project between Sioux City, Iowa, and the mouth, extending about 730 miles. The entire flow of the river during moderate and low flow periods is confined to one designed alignment, stabilized by permanent rock dikes and bank revetments. This also entailed closing secondary chutes and making cutoffs to obtain proper alignment.

3-31. Navigation. Commercial navigation in the Missouri Basin is presently confined to the main stem of the river between Sioux City, Iowa, and the mouth of the river. The Missouri River Navigation and Stabilization Project, discussed in the preceding paragraph, is designed to secure a permanent, continuous, open-river navigation channel with a 9-foot depth and a width of not less than 300 feet. Maintenance of these dimensions requires releases from the main stem reservoirs, as well as some dredging activities, particularly during periods of sub-normal water supply. The Missouri River navigation project forms an important link with the remainder of the Mississippi River waterway system. Low cost transportation, particularly for bulk commodities, is available at many localities in the Missouri Valley. Cities and commercial interests have provided facilities along the banks of the river for both handling and managing river traffic.

3-32. Power. The aggregate installed capacity of all power plants in the Missouri Basin exceeds 20 million kilowatts, with an annual generation of over 90 billion kwh. The investor-owned systems have about 60 percent of the basin's generating capacity. The publicly-owned systems consist of about 40 percent Federal hydroelectric capacity and 60 percent thermal capacity owned by non-Federal public bodies.

3-33. Hydropower installations in the basin total about 3.3 million kilowatts, of which about 82 percent is Federal, 14 percent is investor-owned, and 4 percent is publicly-owned. The Federal power system in the upper Missouri basin includes the six main stem power plants as well as the Canyon Ferry and Yellowtail power plants constructed by the U.S. Bureau of Reclamation. Until 1 October 1977, power from all Missouri basin Federal plants was marketed by the Bureau of Reclamation. At that time, the power marketing responsibility shifted to the Western Area Power Administration of the new Department of Energy. The Federal hydroelectric power plants are connected with the extensive Federal transmission system within the Bureau of Reclamation's Eastern Division, Pick-Sloan Missouri Basin Program, power marketing area which includes Montana east of the Continental Divide, North and South Dakota, eastern Nebraska, western Minnesota, and western Iowa. The transmission network is interconnected with numerous REA-financed cooperatives, municipal power systems, and investor-owned utilities. The Eastern Division transmission network is interconnected with the Southwestern Power Administration at Maryville, Missouri, and with the Western Division through a 100 MW D.C. tie at Stegall, Nebraska, owned by the Tri-States Cooperative. In addition, by split bus operation, a variable number of units can be operated on the Western System at Fort Peck and Yellowtail power plants.

3-34. Land Treatment. Conservation practices have been practiced by individual farmers for many years and since 1933, the Soil Conservation Service has encouraged these practices by providing incentive payments. Projects constructed enhance soil and water conservation by increasing the infiltration and water holding capacity of the soil, providing for surface water storage and stabilizing water disposal systems through such measures as terracing, contouring, strip cropping, grassed waterways, stabilization structures, crop rotation, pastures, and woodlands. Accomplishments of these programs in the Missouri basin now include land treatment measures for about 150 million acres of land, over 300,000 farm ponds, and about 6,600 structures for gully-erosion control, grade stabilization, and flood damage reduction.

3-35. The forestry program of the Department of Agriculture also affects the water resources of the Missouri basin. A large portion of the runoff appearing as stream flow in the upper Missouri basin originates in the forested mountain areas. The forestry program includes the cutting of merchantable timber in a manner which will break up extensive dense stands but maintain partial cover and provide for reproduction, thinning of even-aged stands of young timber, tree planting in denuded areas for timber production and erosion prevention, forest management for increased snow catch and water, intensification of fire and disease prevention, and construction of improvements incident to the foregoing.

III-E Streamflow Depletions.

3-36. General. Prior to 1865 streamflow in the Missouri basin was largely unused, except for transportation. At about that time, the early settlers and homesteaders started substantial irrigation and mining ventures. Additional irrigation development was induced by establishment of Indian reservations. As these uses increased, they began to have a significant effect upon streamflow within the basin. It is estimated that by 1900 the streamflow depletions in the Missouri basin averaged about 3 million acre-feet annually with this value increasing to 5.6 million acre-feet by the year 1910. Between 1910 and 1949, water use increased at a slower rate, with depletions reaching an average annual level of 6.9 million acre-feet in 1949. Of this total, about 3.8 million acre-feet occurred about Sioux City and the remainder was primarily depleted from the Platte and Kansas River flows. Plate 13 illustrates the growth of streamflow depletions between 1865 and 1970.

3-37. Historical Flow Adjustments. Records of monthly flows are available for selected locations along the main stem of the Missouri River for the period 1898 to date. Since there has been a substantial growth in the development of water related resources in the Missouri basin through this period, and this growth is expected to continue, it is necessary for comparative purposes to adjust flows to a common development level. While selection of a particular level is rather arbitrary, adjustments are facilitated by selection of a base level that is relatively recent and is prior to recent emphasis on water resource development and prior to the time that the main stem reservoir system and many major tributary projects were constructed. The selected base level of 1949 meets these criteria and all available monthly and annual Missouri River flow data have been adjusted to the 1949 base level for record purposes. Table 3 lists these flows for the station at Sioux City, Iowa. Similar data are available for other key stations on the Missouri River.

3-38. Depletion Growth, 1949-1970. Since 1949 Federal water resource development in the Missouri basin has accelerated with a corresponding increase in stream depletions, as shown on Plate 13. The increase in average annual depletions during this period is estimated to be 4.9 million acre-feet, for a total since depletions first began of 11.7 million acre-feet. About 6.5 million acre-feet of these depletions occur above Sioux City and, as such, represent a depletion to the average annual flows available for regulation by the main stem reservoir system. Irrigation developments during the 1949-1970 period are estimated to have depleted average annual flows by 2.1 million acre-feet, this representing the largest increase in water use. The

Table 3
Monthly Flows of the Missouri River

SIOUX CITY, IOWA

FLOWS IN 1,000 ACRE-FEET

ADJUSTED TO 1949 LEVEL OF DEPLETION DEVELOPMENT

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	WY TOTAL	OCT	NOV	DEC	TOTAL
1898	500	800	1400	2500	3500	7500	6400	1900	1000	27700	1000	1000	600	28100
1899	600	900	2200	6700	3800	5500	6100	2700	1200	32300	1000	1100	600	32400
1900	600	1000	2100	2800	3600	4800	3400	1200	1100	23300	1100	900	600	23200
1901	600	800	1200	2000	2800	6400	4500	2100	1700	24700	1100	800	600	24600
1902	600	800	1400	2300	2400	3900	3300	2200	1300	20700	1100	1000	600	20900
1903	600	800	1700	2200	2600	4000	4500	3100	2000	24200	1400	1000	700	24600
1904	700	1000	1700	4300	3000	5300	4200	1900	1200	26400	900	800	500	25500
1905	500	900	1600	1200	1700	3500	5100	2300	800	19800	700	800	700	19800
1906	600	700	1700	3000	2700	6800	4000	2900	2500	27100	1600	1300	900	28700
1907	900	1100	4000	3900	3700	5900	6400	2900	1600	34200	1800	1600	900	34700
1908	800	1200	1900	2500	3300	9100	6000	2600	1300	33000	1300	1400	1300	32700
1909	900	1600	2500	2900	2100	8700	7500	3700	1900	35800	1300	1100	700	34900
1910	700	1800	4900	2200	3100	3700	2300	1400	900	24100	900	800	500	23200
1911	500	700	1400	1700	1700	4500	4200	2500	2100	21500	1600	1000	800	22700
1912	800	1000	2000	5700	3200	4900	4800	3300	2400	31500	2000	1800	1700	33600
1913	1100	1100	1700	3900	2800	5300	4500	2900	1900	30700	1500	1500	1300	29500
1914	900	1100	1800	2500	3300	5800	4200	2100	1500	27500	1600	2000	1100	27900
1915	1100	1300	1900	4200	3000	5200	5100	3700	2500	32700	2200	1600	1000	32800
1916	800	1200	4100	4900	3500	4400	6600	2600	1300	34200	1400	1400	800	33000
1917	800	1400	2400	5900	4500	6000	5200	2000	1500	33300	1400	1400	800	33300
1918	800	1300	3600	2600	2600	4500	5400	2300	1300	28000	700	800	400	26300
1919	1200	1000	2000	2300	1500	2100	1300	500	400	14200	600	500	500	13900
1920	500	1000	3200	3900	4800	5500	4800	2000	1000	28300	800	800	900	29200
1921	600	1200	1700	2000	2500	6600	4100	1600	900	23700	500	600	500	22800
1922	500	1000	2300	3300	2800	5200	3600	2200	900	23400	800	1000	500	24100
1923	500	800	1800	2800	2700	5200	5200	3700	1600	26600	3200	2200	1400	31100
1924	1000	1300	2500	4300	3000	5000	3500	2000	1000	30400	1300	1400	800	27100
1925	800	1100	2600	4000	2800	5400	4300	1600	900	27000	1200	1100	700	26500
1926	700	1000	1900	1400	3100	4000	3300	1700	1700	21800	1500	1100	600	22000
1927	600	1100	2100	4000	6000	9800	5200	2600	2100	36700	1600	1100	800	37000
1928	800	3300	3400	2500	2900	4700	5500	3000	1300	30900	1100	1120	658	30278
1929	627	639	3280	3430	2450	6600	3260	1290	803	25257	1000	893	504	24776
1930	589	911	2930	2580	2530	2500	1640	1210	1170	18457	1050	857	485	18452
1931	534	905	1030	1150	898	1950	1350	664	499	11372	640	600	380	10600
1932	450	530	1600	2020	2680	4730	3440	1420	910	19400	750	600	370	19500
1933	560	500	1700	1930	2660	4260	2430	910	1230	17900	730	750	560	18220
1934	460	650	1580	1240	1600	1840	1190	580	420	11600	520	620	360	11060
1935	350	590	920	1430	1460	3360	3020	1150	620	14400	540	430	450	14320
1936	440	410	2720	1800	1820	2400	1380	750	660	13800	570	630	480	14060
1937	420	350	1140	1760	1170	3400	3100	1170	510	14700	660	572	382	14634
1938	460	561	2400	1410	1700	3790	5860	1320	1100	20215	910	789	336	20636
1939	680	524	1630	3620	1800	2990	2350	810	618	17057	630	682	704	17038
1940	355	495	826	1550	1810	2370	1380	551	587	11940	899	542	659	12024
1941	627	604	1070	1600	1300	3590	1770	898	1390	14949	1700	1330	796	16675
1942	615	724	1720	2040	5560	6330	3340	1320	861	26336	988	1130	618	25246
1943	859	783	2450	6630	3050	6090	6120	1880	991	31589	811	1140	667	31471
1944	596	910	1450	5310	2560	6360	6810	1940	1150	29704	1020	1170	476	29752
1945	514	1410	3960	2250	1500	4060	3860	1680	746	22646	1100	914	758	22752
1946	800	903	2340	1830	2020	3380	3140	948	1080	19213	1730	1440	646	20257
1947	758	1100	1930	5670	3740	5260	4490	1580	883	29227	1260	1150	525	28346
1948	816	811	2650	4110	2770	7050	5060	1790	714	28706	1010	1140	454	28375
1949	567	679	3250	5410	2490	3790	2230	837	742	22599	926	1163	576	22660
1950	441	624	2228	7524	3323	3563	4887	1986	1291	28532	1554	1067	631	29119
1951	987	779	1618	5385	2809	4896	4087	2630	2120	28563	1812	1301	693	29117
1952	584	1398	2276	12751	4797	4680	3099	1447	931	35768	846	889	420	34117
1953	689	969	2504	1983	2643	6566	4803	1762	808	24882	795	1113	744	25379
1954	710	1127	1725	2184	1635	3704	2842	1407	1115	19101	880	1055	765	19149
1955	395	492	1787	2200	1967	2895	2987	1209	472	17104	724	484	717	16329
1956	925	674	1580	2585	1645	4516	2957	1266	814	18887	767	976	749	19454
1957	541	564	1418	1787	2089	5300	4855	1271	858	21175	1063	1236	990	21972
1958	578	647	1224	2423	1431	3425	3145	1064	673	17899	781	844	738	16973
1959	682	644	1891	3453	1729	2461	3901	1048	689	18861	1095	963	1343	19899
1960	762	817	1792	7270	2036	2426	1829	844	732	21909	674	710	440	20332
1961	618	728	1497	932	927	2335	1496	688	636	11681	1023	1118	509	12507
1962	494	843	1679	4432	2986	7051	6270	2496	1080	29981	1070	1068	737	30206
1963	665	1022	2131	1614	1772	4274	4369	1210	944	20867	990	755	630	20367
1964	748	820	992	1504	2467	4675	7276	1622	1091	23570	839	885	745	23664
1965	942	1054	1457	3603	4208	5119	7412	2630	1599	30493	1671	1356	1310	32361
1966	782	1027	3639	2845	1862	2554	2286	1126	892	21350	876	947	909	19745
1967	663	945	2157	2976	2773	6965	8441	1979	930	30561	1262	1253	822	31166
1968	587	1168	2256	1816	1564	3938	5042	1662	1902	23272	1513	1330	851	23629
1969	849	949	1800	7772	3581	3804	5261	2032	971	30713	992	1109	969	30089
1970	546	972	1653	2458	4217	6003	5286	1694	931	26830	1341	1201	1032	27334
1971	621	1703	4361	4044	2990	5944	5661	1974	1431	32303	1691	1638	1087	33145
1972	734	1070	5718	3647	3509	5948	4483	2167	1648	33340	1313	1553	1130	32920
1973	1225	1317	3038	1774	2691	3585	3088	1234	1364	23312	1512	1096	1148	23072
1974	831	1474	1747	2018	2286	4141	5982	1759	1331	25325	1084	1177	1200	25030
1975	592	625	1363	2811	6551	5905	8736	3323	1438	34805	1345	1337	1375	35401
1976	1027	1708	2098	2940	2857	5695	4744	2138	1331	28595	1327	1056	869	27790
1977	717	929	1959	1775	1880	2329	1717	910	1054	16522	1272	976	718	16236
*1978	761	821	3540	9749	4049	6897	6109	2932	1797	39621	1837	1152	966	40610
AVG	684	965	2178	3302	2739	4776	4256	1820	1177	24847	1155	1064	752	24868

*Based on preliminary C.E. flow data and estimated depletions.

MRD-Reservoir Control Center
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estimated increase of 4.9 million acre-feet in average annual depletions between 1949 and 1970 is due to the following activities:

Activity	Millions of Acre-Feet
Irrigation	2.1
Evaporation from Major Impoundments	1.8
Fish and Wildlife	0.1
Land Treatment	0.3
Minor Impoundments	0.4
Rural domestic water supply	0.1
Municipal and industrial water supply	0.2
Forestry	-0.1
TOTAL	4.9

After irrigation, the largest increase is in the evaporation from major impoundments (primarily from the main stem reservoir system) amounting to 1.8 million acre-feet annually. All other resource developments during the 1949-1970 period are estimated to deplete average flows by a total of 1 million acre-feet annually. Of interest is that the forestry program is estimated to increase (accrete) flows by about 0.1 million acre-feet annually.

3-39. Areal distribution of the estimated 1949-1970 increase in average annual depletions, exclusive of evaporation from the main stem reservoirs is as follows:

Above Fort Peck Dam	465,000 acre-feet
Fort Peck to Garrison Dams	563,000 acre-feet
Garrison to Oahe Dams	284,000 acre-feet
Oahe to Gavins Point Dams	207,000 acre-feet
Gavins Point Dam to Sioux City	107,000 acre-feet
Sioux City to Nebraska City	894,000 acre-feet
Nebraska City to Kansas City	982,000 acre-feet
Kansas City to Hermann	218,000 acre-feet

3-40. Anticipated Growth in Depletions After 1970. A continued growth in the development of Missouri basin water resources is expected for many years, with this development affecting the water supply available to the main stem reservoirs. Water supplied for irrigation needs is expected to continue as the largest depleting factor to this supply. A relatively recent factor in estimating future effects on water supply is the development of the large coal resources available in Wyoming, Montana, and North Dakota. Recent estimates are that as much as 1/2 to 1 million acre-feet of water may be used annually for this purpose with some of the supply withdrawn directly from the main stem reservoirs. Substantial irrigation withdrawals from the reservoirs are also contemplated.

3-41. Recent estimates are that total depletions to the surface water supply in the Missouri basin will increase to 27.4 million acre-feet annually by the year 2020, compared to 11.7 million acre-feet in 1970. Of course, actual increases in depletions may differ materially from those based on anticipated water resource development. Experience since 1950 has been that actual depletions have lagged materially from the forecasted future depletions. However, as the depletions increase, they can be expected to have significant effects upon the functions served by the main stem reservoir system, and these potential effects must continue to be evaluated by long-term operation studies.

SECTION IV - HISTORY AND DESCRIPTION OF MAIN STEM PROJECTS

4-1. General. Limited data are presented in this section on the physical characteristics of the projects and on their history. Detailed history and descriptions of the main stem projects are presented in the individual Regulation Manuals for the projects, Volumes 2 to 7. Considerable pertinent data on the projects are shown on the "Summary of Engineering Data," page xii of this manual. Common to all the main stem projects is the provision of an earthfill dam with appurtenances, a hydroelectric plant, and chute-type spillways located in the abutments. Outlet works are provided by tunnels in the abutments except at the relatively low head projects at Big Bend and Gavins Point, where the spillway crests are sufficiently low to provide for adequate releases, supplementary to the power plant, at all normal pool elevations.

4-2. Project Authorizations. The 1944 Flood Control Act authorized construction of all the main stem projects with the exception of Fort Peck, which was originally authorized by the River and Harbor Act of 1935. The Fort Peck Power Act of 1938 authorized construction of power facilities at the project while the 1944 Act authorized multiple-purpose regulation of this project similar to the other main stem projects.

4-3. Descriptive Detail. Plates 14 through 31 present pertinent details for each of the Corps' main stem projects including maps of each reservoir area, details of embankments, spillways, and outlet facilities, area-capacity tables, tailwater curves, spillway-outlet works discharge capabilities, and power curves. A brief general history and description of each of the six main stem projects are given in the following paragraphs. The dates as given in these paragraphs and tables are dates when the service availability was essentially complete. Service to navigation and flood control was initiated, to a limited extent, at the time closure of the dam was made, and increased progressively to the in-service dates indicated when essentially complete service to these functions was rendered.

4-4. Fort Peck. The Fort Peck Dam is located on the Missouri River at mile 1772 in northeastern Montana; 17 miles southeast of Glasgow, Montana, and 9 miles south of Nashua. Construction of the project was initiated in 1933, closure was made in 1937, and the project was placed in operation for purposes of navigation and flood control in 1938. In 1943 the first unit of the power installation went on the line and the third unit became operational in 1951, completing construction of the initial power plant. Construction of a second power plant began in the late 1950's and the two units of this plant became operational in 1961. The inactive storage of the reservoir was initially filled (elevation 2150) in April 1942 and the carry-over zone (elevation 2234) first filled in 1947. Drought conditions during the late 1950's, combined with withdrawals to provide water for the initial fill of other main stem projects, resulted in a drawdown of the reservoir level to elevation 2167.4 in early 1956, followed by a generally slow increase in elevation. It was not until July 1964 that the carry over storage zone was refilled. It has remained generally filled from that time through 1976. Exclusive flood control storage space was first utilized in 1969 and again in 1970. In 1975, all space allocated for specific functions was filled and a maximum reservoir level 1.6 feet above the base of the surcharge pool occurred.

4-5. 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 purposes, with a maximum mean daily rate of 28,600 cfs in 1948. From late 1956 through early 1975 releases were never 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. In 1975, the extremely large flood inflows to the project resulted in both maximum experienced reservoir levels and a maximum-of-record mean-daily release of 35,400 cfs. Minimum mean daily releases since 1954 have usually been no less than 3,000 cfs; however, mean daily releases as low as 1,000 cfs have occasionally been made.

4-6. Garrison. Garrison Dam is located in central North Dakota on the Missouri River at mile 1390, about 75 river miles northwest of Bismarck and 11 miles south of Garrison, North Dakota. Construction of the project was initiated in 1946, closure was made in April 1953, and the navigation and flood control functions of the project were placed in operation in 1955. The first power unit of the project went on the line in January 1956, followed by the second and third units in March and August of the same year. Power units 4 and 5 were placed in operation in October 1960. The Garrison Reservoir (Lake Sakakawea) formed by Garrison Dam, first reached its minimum operating level in late 1955. Due to the drought conditions, it was not until 10 years later, 1965, that the carry-over zone was first filled. It remained generally filled from that time through 1976. Exclusive flood control storage space was used in 1969 and 1975. During 1975, all flood control space was filled and the maximum reservoir level was 0.8 of a foot above the base of the surcharge pool.

4-7. Since 1956, outflows from Garrison have generally been through the power facilities, having a maximum capacity of about 38,000 cfs. An exception was in 1975 when outflows of 65,000 cfs were required for over 1 month as a result of record-high upstream runoff. The minimum mean daily release since 1956 has been 5,800 cfs.

4-8. Oahe. The Oahe Dam is located at mile 1072 of the Missouri River, 6 miles northwest of Pierre, South Dakota. Construction was initiated on the project in September 1948. Diversion and closure were completed in 1958, and deliberate accumulation of storage was begun in late 1961, just before the first power unit came on line in April 1962. The last of the seven power units became operational in July 1966. Inactive storage space in the Oahe Reservoir was first filled in 1962 and the carry-over space in 1967. Carry-over space remained generally filled from the time through 1976, except for seasonal drawdowns in the interest of increased winter power generation. Exclusive flood control storage space in the Oahe Reservoir has been used on only one occasion, during the large 1975 flood event when a maximum lake level 0.9 of a foot above the base of exclusive flood control occurred.

4-9. Due to the control provided by the immediately downstream Big Bend project, Oahe releases have been extremely variable since the project became fully operational. Minimum mean daily outflows of 1,000 cfs or less are not uncommon, while releases near the power plant capacity of about 55,000 cfs are also frequently made. Since the power plant became operational, practically all releases have been made through the power turbines, with release fluctuations very dependent upon the power load being experienced.

4-10. Big Bend. The Big Bend Dam is located at mile 987 of the Missouri River, near Fort Thompson and about 20 miles upstream from Chamberlain, South Dakota. The Big Bend Reservoir (Lake Sharpe), formed by the dam, extends 80 miles upstream to the vicinity of the Oahe Dam. The project is basically a run-of-the-river power development with regulation of flows limited almost entirely to daily and weekly power pondage operations. Construction began in 1959 with closure in July 1963. The first power unit was placed on line in October 1964 and the last of the eight units began operation during July 1966. Since full operation began, the reservoir has been held very near the normal operating level of elevation 1420. A maximum level at elevation 1421.9, very near the base of the exclusive flood control zone, occurred in 1971. Releases experienced from this project have been very similar to that described for Oahe with a maximum mean daily outflow of 69,200 cfs occurring during 1975. Releases have been entirely through the power plant since these facilities became fully operational. A mean daily release of zero is frequently made from the project, usually on a Sunday.

4-11. Fort Randall. The Fort Randall Dam is located at mile 880 of the Missouri River about 6 miles south of Lake Andes, South Dakota. The Fort Randall Reservoir (Lake Frances Case), formed by the dam, extends to the Big Bend Dam. Construction of the project was initiated in August 1946, closure was made in July 1952, initial power generation began in March 1954, and the project reached an essentially complete status in January 1956, when the eighth and final unit of the 320,000-kilowatt installation came into service. Since that time, annual regulation of this project has been on essentially a repetitive annual cycle. A reservoir level at or above elevation 1350 is maintained through the spring and summer months. During the fall period, prior to the close of the Missouri River navigation season, the reservoir is lowered to well below the base of the annual flood control and multiple use zone. Refill of this evacuated space during the winter months results in increased hydropower generation during the winter period and compensates for reduced winter releases from Fort Randall and Gavins Point. The maximum reservoir level experienced to date was in 1967 when an elevation of 1366.5 occurred, 1.5 feet above the base of the exclusive flood control zone. The maximum mean daily release of 60,600 cfs was experienced in 1975.

4-12. Gavins Point. The Gavins Point Dam is located at mile 811 of the Missouri River, on the Nebraska-South Dakota border, 4 miles west of Yankton, South Dakota. The Gavins Point Reservoir (Lewis and Clark Lake), formed by the dam, extends 37 miles to the vicinity of Niobrara, Nebraska. Construction was initiated in 1952, closure was made in July 1955, with initial power generation beginning in September 1956. The third and final unit of the 100,000 kilowatt installation came into service in January 1957. Since full operation began, the reservoir has usually been regulated in the narrow zone extending from elevation 1204.5 to elevation 1208. A maximum level at elevation 1210.7 occurred in 1960 while in 1969 the lake was drawn down to elevation 1199.8 in anticipation of large amounts of inflow from snowmelt. Minimum mean daily releases from the project have been about 5,000 cfs while maximum releases of 61,000 cfs were made in 1975.

4-13. Historical Service to Functions. Integrated system operation is considered to have begun in 1954 when Garrison and Fort Randall were teamed up with the Fort Peck project that had been in operation for several years. Service to the various system functions have continued since that time. These are described in detail for each preceding year in the Annual Operating Plan (AOP) reports that are published every August by the MRD Reservoir Control Center. These AOP reports, published since 1953, also provide much detail on problems encountered during system regulation. A summary of the services furnished the primary system functions is also included in Section XI of this Master Manual.

SECTION V - SYSTEM STORAGE ALLOCATIONS

5-1. General. The storage capacity of the main stem system has been developed to provide beneficial service to the multipurpose functions described in preceding Sections of this manual. Regulation of a particular project for one of the functions may be compatible, to a varying degree, with regulation for another function while for still another function the regulation may be incompatible. For example, the vacating of storage capacity after a flood event to assure control of possible future events is compatible with providing releases for power, navigation and irrigation; however, it is incompatible with the objective of providing stored reserves for continuation of these functions during a subsequent drought period. These factors made it advisable to divide the storage in individual reservoirs into operational zones in order to obtain the maximum possible service to all of the functions consistent with the physical and authorizing limitations of the projects. Totaling the capacity provided in the respective zones of the individual main stem projects provides the total system capacity available in each operational zone.

5-2. Operational Zones. The operational zones, and governing criteria for operation in these zones considered necessary to achieve the multipurpose benefits for which the reservoirs were authorized, are as follows:

a. Exclusive Flood Control Reserve. A top zone in each reservoir is reserved exclusively for flood control. The storage space therein is utilized only for detention of extreme or unpredictable flood flows, and is evacuated as rapidly as feasible within limitations imposed by considerations of flood control. These considerations include project release limitations, status of storage in the other main stem projects and the level of system releases being maintained, as designated by criteria discussed in Sections IX and X.

b. Annual Flood Control and Multiple-Use Capacity. An upper "normal operating zone" is reserved annually for retention of normal flood flows and for annual multiple-purpose regulation of the impounded flood waters. The capacity in this zone, which is immediately below the top zone of exclusive flood control reserve, will normally be evacuated to a predetermined level by about 1 March to provide adequate storage capacity for the flood season. This level will remain more or less fixed from year to year. During the flood period, water will be impounded in this space as required by consideration of flood control and in the interests of general conservation functions on an annual basis. The evacuation of flood control and multiple-use storage capacity is scheduled to maximize service to the conservation functions. Schedules are limited by the flood control function in that the evacuation must be completed by the beginning of the next flood season, provided such evacuation is possible without contributing to serious downstream flooding.

c. Carry-Over Multiple-Use Capacity. An intermediate zone provides a storage reserve for irrigation, navigation, power production, and other beneficial conservation uses. At the major projects (Fort Peck, Garrison and Oahe) the storage space in this zone will provide carry-over storage for maintaining downstream flows through a succession of well below normal runoff years. It will be used to provide annual regulation in the event the storage in the annual flood control and multiple-use zone is exhausted. Storage space assigned to this zone in the Fort Randall project serves a different purpose. A portion of the Fort Randall space will be evacuated each year immediately preceding the winter season to provide recapture space for upstream winter power releases. The recapture operation results in complete refill of the space during the winter months. Deliberate long-term drawdown into the Fort Randall carry-over zone is not contemplated. While a minor amount of space in the Big Bend and Gavins Point projects was initially provided in this zone, deliberate drawdown into this zone has never been made during normal operation nor was such drawdown contemplated. Therefore, the carry-over multiple-use capacity in these projects has been reassigned into the lower inactive storage zone.

d. Inactive Capacity. A bottom inactive zone provides minimum power head and sediment storage capacity. It also serves as a minimum pool for recreation, fish and wildlife, and an assured minimum level for pump diversion of water from the reservoir. Reservoir drawdown into this zone will not be scheduled except in an unusual emergency.

5-3. Allocation of Storage as Related to Functions. The ratio of the gross storage capacity of the main stem reservoir system to the annual inflow to the system is unusually high for a major river system, the storage being in excess of the volume of three average years of runoff of the river above Gavins Point, the lowermost project. The large amount of storage provided results largely from the physical characteristics of the reservoirs and damsites. Economic studies at the time of project planning indicated the desirability of the fullest practical site development. Consequently, all of the major storage sites except Fort Peck were constructed to the maximum level permitted by major relocations in the reservoir areas. The relatively flat slope of the Missouri Valley results in a large storage volume for a given dam height. Competition between functions in the utilization of system storage is minimized by this relatively large storage capacity.

5-4. The inactive storage capacity at each project establishes the normal minimum operating pool level as well as the base of the carry-over multiple-use zone (at Big Bend and Gavins Point the base of the annual flood control and multiple-use zone). Although, due to the large amount of storage available, competition between the flood control and the other multiple-use functions was minimal in the establishment of minimum operating levels, competition between these other multiple-uses is apparent, particularly during extended periods of subnormal water supply. At the three major projects, as well as at Fort Randall, surge tank design, established runner cavitation limits, and minimum assured peaking capability were based on the selected minimum operating pool. Therefore, future lowering of these levels would appear very unlikely. Raising the minimum pool levels is also unlikely, since studies indicate that failure to draw the system and individual projects to these storage levels in the event of the occurrence of an extreme drought comparable in severity and duration to that of the 1930's would not only reduce service to navigation and other non-power functions, but would also severely curtail energy generation during the drought period. The established minimum level at Big Bend and Gavins Point could be lowered, and reservoir levels could temporarily fall somewhat below the minimum rather frequently. However, due to the relatively minor amounts of storage space involved and the lake shore development that has occurred based on the established minimums, any deliberate long-term lowering of these pools below presently established minimums is very unlikely.

5-5. Competition between flood control and other multiple-use functions existed, to a degree, in establishing the zonal boundaries between the multiple-use carry-over zones and the annual flood control and multiple-use zones. This was because the maximum limits of service (ignoring economic feasibility) in the case of flood control would be the provision of sufficient storage space to store flows from flood events of the most remote probability of occurrence. On the other hand, in the case of navigation, power and other water-use functions, the entire capacity of the system could be utilized as carry-over to provide improved service to these functions during a recurrence of the drought of the severity of that of the 1930's without reaching the full desirable level of service (again without regard to economic feasibility). In view of the magnitude of the potential flood damages, (to urban as well as rural areas and to the extensive transportation and communication facilities) it was recognized that the flood control function of the main stem reservoir system should provide for adequate control of a very severe flood which could be expected to recur at only very infrequent intervals. At the time of initial design of the main stem reservoir system in the 1940's it was considered impracticable to establish any single flood event as the "Reservoir Design Flood." However, the great flood of 1881 comprised the most critical flood series of record and served in large measure for establishing flood control storage allocations and reservoir outflow rates. Allocation of sufficient flood control storage (within the combined exclusive flood control reserve and annual flood control and multiple-use zones) to control the design flood event (with a minor amount of storage to spare) established the base of the flood control zones and thus the top levels which could be utilized for carryover purposes.

5-6. Within this total flood control space, the level separating the exclusive flood control storage zone from the annual flood control and multiple-use zone was dictated by specific flood control considerations. Sufficient storage was provided in the exclusive zone to control severe flood flows from rainfall that could occur late in the flood season after the annual flood control and multiple-use space was filled. Additionally, it was deemed important that sufficient storage remain in the annual flood control and multiple-use zones to assure continuation of full-service to non-flood control functions until the succeeding flood season without drawdown into the carry-over multiple-use capacity.

5-7. The top elevation of the exclusive flood control zone in each of the reservoirs except Fort Peck are restricted by upstream towns or projects and as such are not subject to change in the future. Sufficient surcharge storage, freeboard space and spillway capacity are provided at each project to pass the maximum probable flood while maintaining the integrity of the projects.

5-8. Thus, allocation of storage in the main stem reservoir system was essentially a matter of optimumly dividing the operational storage space made available by site development limitations at the individual projects. A total volume of over 76-million acre-feet was initially available in the system below the tops of the exclusive flood control zones of the respective projects. Of this total, approximately 18 million acre-feet was considered inactive storage. This resulted in about 58 million acre-feet of system storage space available for all beneficial uses. Above these storage zones, which were provided for normal operation of the projects, lies about 10 million acre-feet of surcharge storage, which is utilized in regulation of the various spillway design floods, and over 30 million acre-feet of freeboard storage.

5-9. Preliminary Storage Allocations. During preauthorization planning in 1943 and 1944, studies were made of flood control storage requirements in the main stem reservoirs as units in the basin program. No Standard Project Floods were developed; the relatively conservative design inflows to the system utilized in these studies were based on past flood history. Great emphasis was placed on the reconstructed

1881 flood for which records are very sparse and not subject to refined analysis. At the time, no detailed techniques for flood control regulation had been selected. Operation studies were based on not exceeding specified release rates, rather than on consideration of the potential downstream effects of these releases. As a consequence, the storage required for the control of flood flows varied over a range from about 15 to 21 million acre-feet, depending upon criteria and assumptions utilized. It was recognized in these studies that as a result of continued basin water resource development, the required flood control storage space in the main stem system would decrease. The basin water resource development includes new tributary reservoirs, many of which have flood control functions, and irrigation depletions.

5-10. In the further course of planning and design of the main stem system after authorization in the 1944 Flood Control Act, many long range operation studies were prepared, some of which were presented in the Definite Project Reports of the mid-to-late 1940's. These early long range studies (which are discussed in more detail in Section IX-b, Multipurpose Operation Plans) primarily demonstrated performance for three of the four basic functions, namely, navigation, power and irrigation. Only very general consideration was given to flood control regulation requirements in these early multiple-purpose operation studies which were generally limited, as far as flood control was concerned, to demonstration of monthly flow regulation at Sioux City during the period of record. What was considered at the time of each study to be sufficient flood control storage space, within the range developed in preauthorization planning, was allocated to flood control on an exclusive and seasonal storage basis. The storage allocations used reflected the basic assumptions made at the time of the study and in retrospect, appear inconsistent to some degree in many cases. Variations between and limitations of these early studies resulted because:

a. Preliminary area capacity curves (prior to completion of mapping) were used.

b. In many cases, no allowances were made for loss of storage to sedimentation.

c. Different levels of basin water resource development with corresponding differences in irrigation depletions were used.

d. Early estimates of future streamflow depletions were subsequently revised.

5-11. Some of the early multiple-purpose studies for the partially completed main stem system provided for temporary assignment of greater initial flood control allocations at individual projects in order to provide sufficient system storage pending completion of all main stem projects. However, all multiple-purpose operation studies of the completed six-project system, which were made prior to 1956, used a common elevation for the base of exclusive and seasonal flood control storage space in each of the major reservoirs, as follows:

Fort Peck	2246 and 2234.7	Big Bend	None
Garrison	1850 and 1838	Fort Randall	1365 and 1350
Oahe	1617 and 1610	Gavins Point	1208 and 1204.5

The selection of these levels was based on the total system storage required for the flood control function together with runoff characteristics of the incremental reaches, as defined by the individual projects. The relationship between the current storage space in the zones defined by these elevations at the major reservoirs and the maximum monthly reach inflow of record is illustrated in the table below:

Project	Max Monthly Reach Inflow	Total FC Storage	Exclusive FC Storage	Ratio of Storage to Monthly Reach Inflow	
	1,000 Acre-Feet			Total	Exclusive
Ft. Peck	4,140	3,700	1,000	0.90	0.24
Garrison	5,086	5,800	1,500	1.14	0.30
Oahe	3,979	4,300	1,600	1.08	0.25
Fort Randall	1,660	2,400	1,200	1.45	0.72

The relatively greater amount of flood control storage space provided in Fort Randall was in recognition of this project's downstream location where reregulation of upstream projects flood control releases is possible. The Gavins Point elevations are based on the design studies presented in the Gavins Point Definite Project Report.

5-12. These elevations were used in operation studies VII-D, VII-G, VII-J, and IX-A presented in Definite Project Reports. Subsequently they were also used in study PGOR-6, which was completed in 1953. The elevations were held constant for all studies, although there were considerable variations from study to study in the level of irrigation development assumed (from no depletions to as much as one-fourth the annual runoff at Sioux City). Variations in the storage curves and in the estimated growth and ultimate level of depletions were also used.

5-13. The first detailed long-range operation study of the main stem system which attempted to systematically reflect the progressive growth of irrigation depletions and the loss of storage to sedimentation were MRD studies PGOR-10A and 10B, published in April 1956. For the purpose of those studies, it was assumed that 20.7 million acre-feet of combined exclusive and seasonal flood control storage space (near the maximum developed in preliminary studies of flood control requirements) was required under the 1949 level of basin water resource development and that the flood control requirements would be reduced to 15 million acre-feet (the minimum requirement developed in preliminary studies) by the year 2010.

5-14. Long-range system regulation studies conducted in 1958 in connection with cost allocation studies recognized the streamflow depletions that had developed prior to 1949 and considered the effects of these depletions upon historical runoff into the reservoir system. These studies assumed a system flood control storage capacity of about 17 million acre-feet for the early years of system operation with this value reduced to about 15 million acre-feet by the year 2010 to reflect continued development in the basin.

5-15. All of these early long-term studies indicated the very substantial multiple benefits derived from the system, as well as basic operating principles necessary to obtain such benefits through a relatively large range of possible storage allocations to the flood control function. They also demonstrated the continued performance of the system over the years when depletion in water supplies due largely to irrigation development would occur, sedimentation in the reservoirs could be expected, and when a large number of tributary reservoirs, both upstream and downstream from the system, would be constructed.

5-16. Current Storage Allocations. As of this time, the main stem system has been in operation as an integrated system for 25 years. During this operation period, many regulation techniques have been explored in detail and, as believed warranted, regulation procedures have been modified to provide what is considered the most optimum means of sustaining all of the various functions for which the system was authorized. A basic method of exploring regulation techniques has been the long-range system regulation study as described in Section IX of this manual. Numerous long-range studies have been made since 1964 and long-range study criteria have been modified so that release restrictions imposed by the flood control function are reflected in the studies. These many long-range studies have been supplemented by detailed examination of particularly severe flood events, with the 1951-52-44 combination described in Section XI of this manual serving as an example. In addition, the data available relating to the great 1881 flood has been re-examined, together with post-1881 water resource development effects on historical 1881 flows.

5-17. While the investigation of storage allocations in individual reservoirs and the system as a whole was not the primary purpose of many of the studies described above, it served at least as a secondary purpose in all of the studies. Based on these, it has been concluded that the elevation ranges for major storage project as given in paragraph 5-11, with relatively minor modifications, provide the flood control storage capacity required in the main stem system with basin development at its present level and with regulation criteria as described in Sections IX and X of this manual. Modifications which have been made to the pre-1956 elevations given in paragraph 5-11 are as follows:

Fort Peck - Base of annual flood control lowered from elevation 2234.7 to elevation 2234.

Garrison - Base of annual flood control lowered from elevation 1838 to elevation 1837.5.

Oahe - Base of annual flood control lowered from elevation 1610 to elevation 1607.5.

Big Bend - Base of exclusive flood control set at elevation 1422 and base of annual flood control set at elevation 1420.

5-18. Long-term studies discussed in the preceding paragraph have also been made to investigate the effects of continued water resource development in the Missouri Basin. In general, these studies indicate that the flood control elevations currently applicable will continue being applicable well into the future. Loss of storage in the flood control zones of the reservoirs due to sedimentation will be balanced by the depleting effects on flood flows of continuing water resource development. However, through the years it can be expected that continuing studies will be made of the effects of changes in water resource development and in associated main stem regulation techniques. A major purpose of these studies will be the re-evaluation of storage allocations. If deemed necessary, appropriate action toward modification of storage zones contained in the reservoirs will be initiated.

5-19. The current storage allocations in each of the zones of individual main stem projects, as well as the system as a whole, is given in Table 4. Storages given in this table reflect the January 1975 elevation-storage relationships. Minor modifications from previous allocation tables are discussed below.

a. Big Bend. The table recognizes actual regulation that has been practiced since the project became operational and that is expected to continue. Previously, a carry-over zone extending between elevations 1415 and 1420 and an exclusive flood control zone extending from elevation 1420 to elevation 1423 had been provided. Since normal regulation appreciably below elevation 1420 is not contemplated, this carry-over zone has been eliminated. An annual flood control and multiple-use zone extending between elevations 1420 and 1422 is now provided for power scheduling purposes with the exclusive flood control zone extending between elevations 1422 and 1423. It should be noted that the annual flood control and multiple-use zone is not provided for seasonal regulation of flood inflows as at the other major projects, but for day-to-day and week-to-week power operations.

b. Fort Randall. Reflecting actual regulation practice, the lower limit of the carry-over multiple-use capacity (and upper limit of the inactive capacity) has been raised from elevation 1310 to elevation 1320. The carry-over capacity in this project is utilized to recapture upstream winter power releases rather than for the maintenance of a storage reserve for long-term droughts, as provided in the major upstream projects.

c. Gavins Point. Since all normal regulation of this project will be at levels above elevation 1204.5, the carry-over multiple-use capacity previously assigned between elevations 1195 and 1204.5 has been shifted into the inactive storage zone.

TABLE 4

Storage Allocations
Missouri River Main Stem Reservoirs

Project	Exclusive Flood Control Reserve	Annual Flood Control and Multiple-Use Capacity	Combined Exclusive and Annual Capacity	Carry-Over Multiple-Use Capacity	Inactive Capacity	Total Capacity
		Elevation Range, Ft. Above MSL				
Fort Peck	2246-50	2234 -46	2234 -50	2160-2234	2030-2160	2030-2250
Garrison	1850-54	1837.5-50	1837.5-54	1775-1837.5	1673-1775	1673-1854
Oahe	1617-20	1607.5-17	1607.5-20	1540-1607.5	1415-1540	1415-1620
Big Bend	1422-23	1420 -22	1420 -23		1345-1420	1345-1423
Fort Randall	1365-75	1350 -65	1350 -75	1320-1350	1240-1320	1240-1375
Gavins Point	1208-10	1204.5-08	1204.5-10		1160-1204.5	1160-1210
		Storage, in 1,000 AF				
Fort Peck	1,000	2,700	3,700	10,900	4,300	18,900
Garrison	1,500	4,300	5,800	13,400	5,000	24,200
Oahe	1,100	3,200	4,300	13,700	5,500	23,500
Big Bend	60	115	175	0	1,735	1,910
Fort Randall	1,000	1,300	2,300	1,700	1,600	5,600
Gavins Point	60	95	155	0	360	515
SYSTEM TOTAL	4,720	11,710	16,430	39,700	18,495	74,625

SECTION VI - ORGANIZATION, COORDINATION, AND COMMUNICATIONS FOR RESERVOIR REGULATION

6-1. Reservoir Control Center. Corps of Engineers reservoir regulation activities in the Missouri Basin are the responsibility of the Missouri River Division Reservoir Control Center. The primary "purpose" of the Reservoir Control Center is to achieve efficient regulation of those aspects of water resource projects in the Missouri River Division for which the Corps has responsibility. These responsibilities in general terms are: to regulate all Corps projects in accordance with their authorized purposes; to prescribe the regulation in the interest of flood control and navigation for all non-Corps projects constructed either wholly or in part with Federal funds; and to perform, prescribe, or assist the regulation of any other water resources projects where advice is officially requested, or where such responsibility has been delegated to the Corps.

6-2. The basic "objectives" of the Center are designed to provide and maintain the capability necessary to meet the responsibilities stated above. Much of the capability is maintained in the District offices, while a major role of the Center is of a managerial nature. The objectives are summarized as follows:

a. Either manage or directly perform the regulation of water control projects, including short and long range runoff predictions to complement release determination.

b. Improve the effectiveness of all supporting facilities and activities associated with water control under normal and emergency operating conditions.

c. Foster better understanding of problems encountered in water control by coordinating appropriate activities with local, state, and other Federal entities.

d. Manage or perform technical studies to develop or improve real-time regulation plans for individual water control projects and systems to meet the prevailing needs in the most satisfactory manner.

6-3. The basic operational responsibilities of the Missouri River Division Reservoir Control Center are threefold, as follows:

a. To coordinate and control regulation of the Missouri River main stem reservoirs;

b. To supervise or direct the regulation of Corps of Engineers reservoirs on tributary streams; and

c. To supervise flood control regulation of other Federal Reservoirs in the basin not built by the Corps of Engineers.

In addition to these operational responsibilities, the Reservoir Control Center is responsible for conducting technical studies relating to reservoir regulation; for review of District survey reports and design memoranda concerned with reservoir projects and with other main stem improvements such as levees, flood walls, and erosion-control measures; for review and approval of reservoir regulation manuals; and for training of selected Division and District personnel in reservoir regulation activities.

6-4. The Missouri River Division Reservoir Control Center is a branch of the Engineering Division. The Center is organizationally divided into two sections, the Reservoir Regulation Section and the Power Production Section. An organization chart is attached as Plate 32. The Reservoir Control Center is staffed by 11 persons, including 7 hydraulic engineers, a meterologist, an engineering technician, a clerk, and a secretary. Regulation of the main stem reservoir projects by the Control Center involves coordination with many diverse Federal, state, and local interests, as described in subsequent paragraphs.

6-5. Coordination within the Corps of Engineers. With regard to reservoir regulation, there are three main channels of coordination within the Corps of Engineers: from the Reservoir Control Center to the office of the Chief of Engineers, from the Reservoir Control Center to other elements of the Division office, and from the Reservoir Control Center to the District offices, the reservoir projects and the power plants.

6-6. Reservoir Control Center Coordination with the Office of the Chief of Engineers. The Reservoir Control Center operates through established channels in communicating with the office of the Chief of Engineers. The primary means of coordination is through an annual report prepared by the Reservoir Control Center and the District reservoir regulation or water control sections. This report covers main stem reservoir operations, tributary reservoir operations, technical studies, reservoir regulation manuals, funding and staffing of the Reservoir Control Center, and other pertinent aspects of the Center's operations. The Annual Operating Plan for the Missouri River Main Stem Reservoirs is included as a part of this report. The annual report is supplemented by monthly reports graphically describing regulation of each project, by periodic submission of reservoir regulation manuals and revisions thereto, by special reports describing unusual reservoir regulation activities and problems, and by copies of public information releases distributed through the basin, all of which are furnished the office of the Chief of Engineers. Starting in mid-1977, an additional means of coordination was effected through establishment of a data base system on a large computer accessible to OCE. Daily reservoir and river data is placed in the computer by RCC and District personnel. Additional coordination is by correspondence and informal telephone contacts.

6-7. Coordination Within the Missouri River Division Office. As a branch of the Engineering Division, the Reservoir Control Center coordinates with and relies upon the advice and recommendations of other elements of the Engineering Division, particularly the Hydraulics and Hydrology Section and the Mechanical and Electrical Section. These provide assistance to the Reservoir Control Center in the conduct of technical studies, in manning the Reservoir Control Center during flood emergencies, and in analyzing the seriousness of power plant equipment problems in connection with outage scheduling. There is also considerable coordination with the Operations Branch of the Construction-Operations Division, particularly in connection with equipment maintenance and its effect on power-unit availability. The Reservoir Control Center also relies on the Operations Branch for information on navigation tonnages, tow groundings, status of channel construction and maintenance, etc., and, in turn, keeps the Operations Branch informed on flows provided for navigation. The Reservoir Control Center also reviews proposed water supply contracts with particular emphasis on potential and anticipated impacts on reservoir regulation.

6-8. Coordination With Corps' District Offices and Projects. A statement of Division, District, and project relationships and responsibilities was initially formulated in a letter of 11 March 1954 from the Division Engineer to the Omaha District. Additional guidance is provided in MRD letter of 12 January 1971 to both the Omaha and Kansas City Districts, implementing the provisions of ER 1110-2-240 and ER 1110-2-1400.

In summary, the Missouri River Division Reservoir Control Center, in connection with the main stem reservoir system, is responsible for long-range, annual, and seasonal operating plans and for day-by-day operation within these plans, including scheduling of releases, of power generation, and of power-equipment outages. The Reservoir Control Center is the normal channel of communication with the agency that markets the power produced. Additional responsibility of the Reservoir Control Center include (1) preparation and revision of the reservoir regulation manuals for the main stem reservoirs, including the Main Stem Master Manual, (2) review and approval of reservoir regulations manuals for tributary reservoirs, (3) supervision of operation of Corps of Engineers' tributary reservoirs, (4) review of plans for flood control operation of Bureau of Reclamation reservoirs in the Missouri River Basin, and (5) preparation of replies to inquiries concerning main stem reservoir operations.

6-9. The Districts are charged with the responsibility for (1) preparation of reservoir regulation manuals and plans for tributary reservoirs, powerhouse manuals, and operation and maintenance manuals, (2) preparation of emergency flood reports and monthly reservoir regulation charts and tabulations, (3) establishment of hydrologic and hydroclimatic reporting networks, (4) collection of hydrologic data and forecasting of reservoir inflows and streamflows at selected locations, (5) observation and prompt reporting of any condition with a bearing on regulation of reservoirs and discharges, (6) regulation of tributary reservoirs in accordance with approved plans, and (7) preparation of the fiscal year project reports to the Federal Power Commission (FPC Form 1).

6-10. Personnel at the reservoir projects are responsible for (1) execution of release schedules, (2) intra-power plant loading, (3) furnishing of power and hydrologic data to the District and Division offices and to the Bureau of Reclamation, (4) maintenance of project facilities and equipment, including power plant equipment, and (5) performing power equipment switching as requested by the power marketing agent.

6-11. Coordinating Committee on Missouri River Main Stem Reservoir Operations. The Coordinating Committee on Missouri River Main Stem Reservoir Operations is an advisory committee established in 1953 by invitation of the Missouri River Division Engineer. It is composed of Governor-designated representatives from each of the 10 Missouri River Basin states and representatives of each of the eight Federal agencies having authorities and responsibilities directly related to main stem reservoir operations. State members are generally state engineers or engineers in charge of state water resources, and Federal members are generally regional directors of their respective agencies' interests in the Missouri River Basin. The Chief, Reservoir Control Center, is permanent Chairman of the Committee.

6-12. The Coordinating Committee was established specifically to coordinate and consolidate the viewpoints of all interests concerned with main stem reservoir operations, so that these interests might be represented adequately and equitably both in preparation of operating plans and in actual operations. The Committee functions through periodic general meetings and through interim individual contacts by and reports from the Reservoir Control Center. Committee meetings are held at least twice a year, once in the spring and again in the fall. The spring meeting is devoted to reports on water supply and reservoir operations and to group consideration of operational objectives that committee members may want the Reservoir Control Center to include in drafting plans for the subsequent year's operations. With this guidance, the Reservoir Control Center prepares a tentative operating program for the main stem reservoirs for the period beginning on 1 August of the current year and extending for 18 months thereafter. At the fall meeting, the Coordinating Committee considers this tentative operating program and recommends to the Division Engineer either that it be adopted as the operating plan for the coming year or that it be appropriately modified.

6-13. The Coordinating Committee has agreed on all main stem reservoir operating plans since the Fort Randall and Garrison reservoirs were first teamed up with the Fort Peck Reservoir in 1953. Compromises are frequently necessary in recognition of and in reconciliation of the diverse viewpoints, interests, and responsibilities of the several states and agencies involved. Local individuals and groups are encouraged to present their desires or problems to the Reservoir Control Center through their state representatives, although direct contact with the Reservoir Control Center certainly is not forbidden. The state members of the Coordinating Committee are usually familiar with most aspects of main stem reservoir regulation and are able to satisfactorily handle many local inquiries, complaints, and requests without reference to the Reservoir Control Center.

6-14. Coordination with the Missouri River Basin Commission. The Missouri River Basin Commission, composed of Governors of the basin states and representatives of the Federal departments associated with water resources development in the basin, with a Presidentially-appointed chairman, strives for overall review and coordination of preliminary planning and policies relating to water resources development. It has no direct role in daily regulation decisions made by the Reservoir Control Center; however, the Commission is informed on regulation through an observer who attends Coordinating Committee meetings and through receipt of the Annual Operating Plan. Information developed by the Commission relating to planned water resource development is used by the Reservoir Control Center in studies relating to future operation of the main stem system.

6-15. Coordination with Missouri River Basin States. Overall coordination of operation of the main stem reservoirs with the basin states is primarily through the Coordinating Committee on Missouri River Main Stem Reservoir Operations. However, coordination of special reservoir operations, or operations for individual functions, is frequently accomplished directly with the state agency or individual involved, except in those instances where specific committees have been formed at the state level for this purpose. An example of the latter situation is the Ad-Hoc Committee of the American Fisheries Society which is composed of personnel of the state fishery departments of Montana, North Dakota, South Dakota, and Nebraska. This Ad-Hoc Committee keeps abreast of the fishery resource in each reservoir and the opportunities for enhancing this resource by pool level and release manipulations during spawning periods. Recommendations for specific pool level schedules for each reservoir are furnished to the Reservoir Control Center in early spring, with one or more reservoirs selected for special emphasis. The Reservoir Control Center recognizes these recommendations in actual operations to the extent that it is practicable to do so without significant detriment to major functions. After special operations of this nature, the Ad-Hoc Committee prepares a report on the success or failure of the requested operation.

6-16. Most requests for special operations to accommodate specific activities are funneled through state members of the Coordinating Committee on Missouri River Main Stem Reservoir Operations. Some requests, however, especially those related to bridge construction or other river-affected construction projects, are frequently received directly from state highway or bridge departments, or from contractors. In either case, the Reservoir Control Center considers each request on its own merits, weighing the effects of the requested operation on other functions.

6-17. Any major departure from planned operations that appears likely to cause problems in a reservoir or downstream therefrom is called to the attention of the state member of the Coordinating Committee on Missouri River Main Stem Reservoir Operations from the affected state. Advance notification is given to the degree it is possible to do so, in order that the state member may express his views on the proposed operation and so that he may be properly briefed for handling questions from affected interests and individuals.

6-18. Coordination of tributary reservoir operations with the states is usually handled by the District offices, generally with the same state water resources engineer who is a member of the Coordinating Committee on Missouri River Main Stem Reservoir Operations. This coordination involves the same aspects of reservoir regulation as for the main stem reservoirs, generally recreational pool levels, enhancement of fish spawning, low-flow regulation, and special operations to assist construction activities. The Reservoir Control Center is kept informed of all such negotiations; and in cases of considerable importance, or where tributary reservoir regulation may have a significant effect on main stem regulation, it participates in the coordination efforts.

6-19. Coordination with the Bureau of Reclamation. Coordination with the Bureau of Reclamation on the main stem reservoir dates from preparation of the Pick-Sloan Plan in the early 1940's. Since that time, the Bureau has constructed many irrigation and reservoir projects in the Missouri Basin and regulation of these projects has a direct influence upon inflows to the main stem reservoirs and on the level or releases necessary to meet downstream water requirements. Additionally, from 1944 to 1977, the Bureau was the marketing agency for all power generated by the main stem projects. As of 1 October 1977, this power marketing responsibility, and associated power transmission activities, were assigned to the new Department of Energy (DOE) in accordance with PL 95-91, August 4, 1977. DOE established the Western Area Power Administration (WAPA) to handle the power marketing responsibilities formerly assigned to the USBR. The USBR marketing and transmission personnel were transferred en masse to DOE and it is anticipated that the close coordination which has been maintained with the USBR for over 30 years will continue, as described in the paragraphs which follow.

6-20. The Corps of Engineers - Bureau of Reclamation Work Group on Missouri River Main Stem Reservoir Operations, which was established in 1952, was composed of key personnel from the MRD Reservoir Control Center and both the upper Missouri and lower Missouri Regions of the Bureau. Membership will be expanded to include personnel from DOE. Meetings of the work group are held in advance of the spring and fall meetings of the Coordinating Committee on Missouri River Main Stem Reservoir Operations to (1) discuss accomplishments and current operations with relationship to prior plans, (2) discuss criteria for operation studies and future operations, and (3) exchange information on the plans and outlooks of the two agencies. Other meetings are held as required to discuss current operating problems, the power-market situation, criteria for long-range studies, and other problems as they arise.

6-21. Monthly power coordination meetings are held at Watertown, South Dakota, between the Power Production Section of the Reservoir Control Center and the Power Systems Operations Office of the DOE (formerly Bureau of Reclamation). The Bureau of Reclamation's Watertown Office, which was subordinate to the Regional office in Billings, Montana, handled the hour-by-hour dispatching of power generation from the main stem plants from the time the plants were first constructed until 1 October 1977. The same personnel are manning the Watertown office under DOE. At the monthly coordination meetings, the Corps of Engineers representative furnishes the latest outlook for power generation and outages of generating equipment. The DOE representatives outline plans for marketing in the month ahead. Consideration is given to effects of scheduled transmission line outages, arrangements for interchange, special power sales, and related items. The purpose of the meetings is to plan short-range operations to provide the best power service possible and the greatest practicable revenue from the sale of power, within the limitations of the other operational requirements and objectives.

6-22. Daily power conferences between members of the Reservoir Control Center and the Watertown Power Systems Operations Unit of the DOE are held to match the level of desirable power generation to allowable or required reservoir releases for other purposes. This involves consideration of flood control requirements, navigation requirements, minimum and maximum allowable releases and flow levels, intake requirements below reservoirs, storage balance, special operations, and other items.

6-23. Power unit outages are coordinated by giving the DOE opportunity to comment on scheduling of proposed maintenance outages of power-related equipment. At the time of the Annual Power Coordination Meeting described in the next paragraph, annual outage schedules are carefully formulated to maintain maximum practical integrity of the power system, considering optimum requirement for maintenance, maintenance requirements of other units, maintenance requirements at other Corps of Engineers plants, maintenance requirement of thermal generation on or near the Federal power system, and maintenance requirements of DOE generating and transmission facilities. At the monthly power coordination meetings described previously, maintenance outages schedules are re-examined. And finally, the DOE is consulted immediately prior to final issuance of an outage authorization by the Reservoir Control Center.

6-24. Annual power coordination meetings recognize the power dispatcher-operator relationship involving matters aside from water and power scheduling, and also involving other organizational elements. Some of these other considerations are safe clearance procedures and coordination thereof, operation during and after system disturbances, exchange of information at the project-to-dispatcher level, voltage levels, and governor coordination. For matters of this nature, basic coordination is accomplished during an annual power coordination meeting involving Corps of Engineers, Bureau of Reclamation, and DOE personnel at the operating level. In attendance are personnel from the Reservoir Control Center, from the Operations Branch of the Missouri River Division's Construction-Operations Division, and from the Hydro-Power Branch of the Omaha District's Operations Division, and as many dispatchers and power plant operating personnel as can be spared from their normal duties. The meeting generally lasts one and one-half days and is preceded by a half-day or 1-day meeting of Corps of Engineers personnel at which there is a discussion of some of the problems included on the agenda for the forthcoming meeting with Bureau of

Reclamation and DOE personnel. Certain problems of interest only to the Corps of Engineers are also discussed at the Corps-only meeting.

6-25. Irrigation service from the main stem reservoirs is also a matter involving coordination with the Bureau of Reclamation. No Federal irrigation projects are currently being served directly from the main stem reservoirs. A limited number of private irrigators have obtained easements from the Corps of Engineers to cross Federal lands with irrigation pipelines and to install irrigation pumps on these reservoirs. These irrigators must first obtain a valid state water right and must adhere to certain prescribed specifications in construction of their pipelines and pumping plants. Policy involved in granting these easements has been the subject to extensive discussion between the Department of the Interior and the Corps of Engineers during recent years. Initially the Department of the Interior proposed that these easements incorporate the excess land provisions of Reclamation law and that they require a water service contract with the Bureau of Reclamation. However, the Bureau subsequently agreed that if storage is not needed to meet the demand, an easement could be granted which provided that the easement "does not prohibit Interior from requiring a water service contract." None have been required as of this date.

6-26. The Snake Creek pumping plant on the Garrison Reservoir has been completed, as well as a major portion of the McClusky Canal which was designed to deliver irrigation water to some 250,000 acres of land in the Federally-sponsored Garrison Diversion Unit. Completion of this project is presently stalled, pending resolution of agreements with Canada on the quality of return flows. Since irrigation is a priority use of water in states lying wholly or in part west of the 98th Meridian, main stem reservoir operations for other functions will have to be scheduled in even closer coordination with the Bureau of Reclamation to assure that ample supplies for irrigation use are maintained in the reservoir system once Federal irrigation service begins. This coordination will require detailed estimates of expected water use and return flows. Exact procedures for obtaining and using this information have not been worked out, but established avenues of coordination are adequate for this purpose when the need arises.

6-27. Effects of upstream water resource developments on main stem reservoir inflows are estimated by the Bureau of Reclamation. In connection with preparation of the Annual Operating Plan and the 5-year extension thereof, the Bureau of Reclamation furnishes in July of each year estimates of the effects of anticipated operation of Bureau of Reclamation tributary reservoirs on streamflow, and estimates of depletions of streamflow by agricultural practices, stock-water ponds, and other upstream uses of water. Tributary reservoir effects include irrigation diversions less return flows, reservoir evaporation, and storage changes.

6.28. Flood Control regulation of USBR tributary reservoirs with storage space allocated to this function is the responsibility of the Corps of Engineers, while regulation of storage provided for irrigation in Corps of Engineers reservoirs is directed by the Bureau of Reclamation. Channels for the coordination required in connection with such regulation have been established directly between the appropriate District office of the Corps of Engineers and the appropriate Regional offices of the Bureau of Reclamation. Hydrologic data are exchanged directly between these offices, and reservoir regulation orders are usually issued with only normal staff review by the Reservoir Control Center. If the proposed regulation would have a significant direct effect upon inflows to the main stem reservoir system or upon the Missouri River below the reservoir system, the District office consults with the Reservoir Control Center prior to issuance of a regulation order. Reservoir regulation manuals for Bureau of Reclamation reservoirs containing flood control storage are developed by the Corps of Engineers.

6-29. National Weather Service. Overall coordination with the National Weather Service is achieved through the Regional Hydrologist, Central Region, Kansas City, Missouri, who is a member of the Coordinating Committee on Missouri River Main Stem Reservoir Operations. Day-by-day exchange of weather and river data, special snow survey data, reservoir operation data, and river forecasts is accomplished through contacts with the River Forecast Center of the National Weather Service in Kansas City. This interchange of information is facilitated by teletypes installed in the Reservoir Control Center. In addition, the Corps of Engineers has several cooperative programs in connection with which the National Weather Service conducts specific hydrometeorological investigations and operates river-stage, precipitation, and hydroclimatic networks. Funds for these cooperative programs are provided to the National Weather Service by the District offices of the Corps of Engineers through the office of the Chief of Engineers.

6-30. Environmental Protection Agency. Prior to 1971, the responsibilities now assigned to the EPA were held by the U.S. Public Health Service and the Federal Water Pollution Control Administration and each of these agencies was represented on the Coordinating Committee. Current representation on the Coordinating Committees is by the Missouri River Basin Coordinator, Environmental Protection Agency, Region VII, Kansas City, Missouri. Coordination with EPA, as with its two predecessor agencies, is primarily concerned with establishment of minimum-flow requiements for water quality control and the maintenance of these flow levels through reservoir regulation. In addition, the Corps has installed water quality monitors below each of the main stem reservoirs and below major tributary reservoirs. These monitors provide readings of temperature, dissolved oxygen, conductivity, and other elements. The data from these monitors and periodic samples of water from each reservoir are furnished to EPA. In past years, the U.S. Public Health Service conducted special investigations, with costs partially or wholly reimbursed by the Corps of Engineers, on taste and odor problems on the Missouri, algal growth, and spills of fertilizer or other water contaminants.

6-31. Federal Power Commission. The Federal Power Commission has participated actively in meetings of the Coordinating Committee on Missouri River Main Stem Reservoir Operations since 1953. In addition, the views of the Commission were sought during project formulation concerning area requirements for power that might be produced, size of power installations, and desirability of providing for future power installations. Upon request, the Federal Power Commission has furnished unit power and energy values for use in project formulation and evaluation. Contact with the Federal Power Commission has normally been through its Regional office in Chicago, Illinois. The past responsibilities of FPC have been incorporated in the new Federal Energy Regulatory Commission of DOE and future coordination will be with that agency.

6-32. U.S. Fish and Wildlife Service. The U.S. Fish and Wildlife Service is represented on the Coordinating Committee on Missouri River Main Stem Reservoir Operations by the Area Manager, Pierre, South Dakota. The primary area of coordination is reservoir-level management and reservoir-release scheduling for enhancement of sport-fish spawning. This coordination is achieved through Coordinating Committee meetings and through periodic meetings with both Federal and State fishery personnel.

6-33. U.S. Geological Survey. The cooperative stream-gaging program of the Corps of Engineers and the U.S. Geological Survey provides that the latter agency will maintain and operate certain gaging stations in which the Corps of Engineers has an interest. The Corps of Engineers furnishes a proportionate share of the funds required for maintenance and operation of these gages. Special reservoir operations are scheduled when requested to assist the U.S. Geological Survey in obtaining meaningful flow measurements, infra-red photographs, dye travel time measurements, and other data. The U.S. Geological Survey is represented on the Coordinating Committee on Missouri River Main Stem Reservoir Operations by the Regional Hydrologist, Central Region, Lakewood, Colorado.

6-34. U.S. Department of Agriculture. Coordination with the U.S. Department of Agriculture is accomplished primarily through that Department's representative on the Coordinating Committee on Missouri River Main Stem Reservoir Operations, who is the State Conservationist, Soil Conservation Service, Lincoln, Nebraska. The primary areas of coordination are in connection with streamflow depletions by agricultural programs and in connection with collection of mountain snow-course data. Soil Conservation Service reports on watershed projects involving reservoirs are reviewed to appraise the effects of potential improvements on Corps of Engineers flood control projects or proposals.

6.35. Coordination With Municipalities, Private Agencies, and Individuals. The District offices of the Corps of Engineers and the Area Engineers involved are responsible for liaison with local interests such as municipalities, private agencies and individuals, except for policy pronouncements and except for replies to letters regarding operation of the main stem reservoirs. This applies to those who may be affected by reservoir levels as well as those who may be affected by reservoir releases. Municipalities, private agencies, and individuals are also encouraged to work through their state representatives on the Coordinating Committee on Missouri River Main Stem Reservoir Operations to the maximum extent practicable.

6-36. Communications. Ample and timely communications are of vital importance to safe and proper regulation of the main stem reservoirs. Major facilities for routine transmission of data and regulation instructions are the Federal Telecommunications Service (FTS) telephone network, teletype networks, and the Weather Service facsimile network. Each is discussed below, together with alternate means of communication.

a. FTS Telephone Network. Daily contact between the Reservoir Control Center and District reservoir regulation units is maintained by telephone. During these contacts, any unusual situations are discussed, differences in estimated flow values at key gaging stations are reconciled, forecasts are interchanged and personnel are kept up to date on events occurring through the basin. The telephone also provides a backup means of communication to each of the reservoir projects. Continuing contact is also made with the other Federal and State agencies that provide or utilize data pertinent to the regulation process.

b. Main Stem Teletype Network. One of the principal facilities for efficient main stem reservoir regulation is the closed-circuit teletype network leased from the Bell System. This circuit includes, in addition to the send-receive teletype machine in the Reservoir Control Center, send-receive teletype machines at each of the six main stem projects, in the Omaha District Reservoir Regulation Section and in the Operations Division of the Omaha District. This teletype network is utilized for transmittal of power data and hydrologic data from the reservoir projects to the Reservoir Control Center and the Omaha District Office, for the transmittal of reservoir regulation and power production orders and power outage authorizations from the Reservoir Control Center to the reservoir projects, and for other operational purposes.

c. RAWARC. This National Weather Service Teletype network is a storm warning and hydrologic network. Data provided include precipitation reports, snow surveys, detailed river stage information, warnings and descriptions of severe storms and floods, reservoir information, river forecasts developed by the National Weather Service River Forecast Center, as well as other information pertinent to reservoir regulation. Selected hydrologic information collected on the Corps of Engineers' teletype network is also transmitted over this circuit.

d. Service C. This National Weather Service teletype circuit provides meteorologic data for the entire North American continent, stage information for key stations in the basin, meteorologic analyses, and weather forecasts of a relatively general nature.

e. National Facsimile Circuit. This National Weather Service circuit presents meteorologic data, analyses, and forecasts in map form from the continental United States and adjacent areas and Alaska. The material transmitted originates in the joint National Weather Service-Air Force-Navy Weather Central in Suitland, Maryland, or the National Severe Storm Forecast Center in Kansas City, Missouri.

f. MRD Radio Network. The MRD radio network was established primarily to supplement commercial communications to insure dependable means of contact during emergencies. It serves as a valuable back-up to alternate means of communication in regulation of the main stem projects and for transmission of general hydrologic data and reservoir operating data. Transmit and receive facilities are located at District offices, at all main stem project offices and at most of the tributary reservoir projects. These stationary facilities are supplemented by mobile units at most locations.

g. DOE Communications Facilities. The Department of Energy, in order to adequately fulfill its function of power distribution and marketing, maintains several communications systems in the Missouri River Basin. These are connected with various DOE and USBR offices and the main stem power plants. They consist of AM radio, high frequency FM radio, power line carrier, and leased line telephone system. Normally these systems will be used only for the transmission of power data and instructions relevant to the power data and instructions relevant to the power function. However, in the case of a bonafide communications emergency, they may be utilized to the extent necessary for transmission of regulation data and instructions.

6-37. Reservoir Regulation and Power Production Orders. Daily reservoir regulation and power production orders are sent by the Reservoir Control Center to the main stem reservoir projects by the leased-wire teletype circuit. These orders usually establish daily average releases to be made, but occasionally may specify releases for less than a day. Scheduled power generation and maximum allowable limits are included in the order. Maximum hourly generation is also included, in recognition of head conditions and the number of units that are available to carry load. In some cases, when no changes are likely to occur, orders may be sent to cover a period of several days. Normally, orders are sent on Friday to cover the weekend operations, but the weekend duty man may change these orders as necessary.

6-38. Orders that provide general and continuing guidance to the projects above and beyond that contained in the routine daily orders are called standing orders. These orders specify minimum permissible releases for varying durations from 1 to 8 hours, maximum permissible release fluctuations for specified durations, and similar operation limitations. When appropriate, these standing orders are referenced in the daily orders to avoid repeating this guidance in each order.

6-39. Emergency regulation procedures, in the form of orders or as instructions to the dam tender, are developed and maintained current for all reservoir projects in which the Corps of Engineers has a regulation responsibility. These orders and instructions are for use in the event of a communications breakdown. They specify actions to be taken, on the information available at the project, until such time as communications are re-established.

SECTION VII - BASIC HYDROLOGIC DATA

7-1. General. Effective regulation of the Missouri River main stem reservoir system is based on having available adequate data relating to existing and anticipated hydrologic conditions within the basin, both upstream and downstream from the system. Due to the wide seasonal and areal variations of hydrologic events within the basin, it is necessary to integrate a large volume of basic data pertinent to runoff and water supply to fulfill, in the optimum manner, the operational objectives for which the system was designed.

7-2. Responsibilities for Data Collection, Analysis, and Dissemination. It is the responsibility of each of the Districts within the Missouri River Division to make appropriate arrangements to insure adequate hydrologic coverage within their respective boundaries. In addition to the requirements for regulating the main stem reservoirs, these data are essential to permit the Districts to accomplish their mission of tributary reservoir regulation, discharge forecasting, and emergency operations on both the main stem and tributaries. Pertinent data collected by the Districts will be immediately forwarded to the Reservoir Control Center through established communication channels. In addition to data received from the Districts, the Control Center has Weather Service teletype and facsimile service drops over which considerable data are received. The Reservoir Control Center maintains direct contact by correspondence or telephone with appropriate offices of the Weather Service, Soil Conservation Service, Geological Survey, Bureau of Reclamation and other agencies and individuals collecting basic hydrologic data. Arrangements are made with these agencies for data considered necessary for efficient regulation of the main stem reservoir system and for staff supervision of the regulation of tributary reservoir projects.

7-3. All data received are continuously integrated by the Control Center so that a complete and rapid evaluation of all pertinent factors will be available prior to actual scheduling of reservoir releases. Basic information received from the various sources which is considered pertinent for immediate reservoir operations is entered into a computer or displayed on appropriate panels within the Reservoir Control Center. Daily briefings are held in the Control Center at which key personnel of the Division office are in attendance. At these times, important hydrologic and meteorologic information is brought to their attention and operational decisions made.

7-4. Precipitation. A relatively large number of precipitation stations are required for adequate coverage in the Missouri River

Basin. This precipitation station network was established and is maintained largely by the Weather Service. The stations are manned by Weather Service personnel, personnel of other Government agencies, and by individuals collecting precipitation data in the Weather Service cooperative observer program. Only a small portion of the stations report precipitation on a daily basis throughout the year over established communication channels. Most of the stations submit daily reports of precipitation only when precipitation exceeds some previously established criteria, which may vary seasonally as well as from location to location. The Reservoir Control Center is equipped with a weather map facsimile and RAWARC and Service "C" drops for obtaining precipitation data and other hydrologic and meteorologic information. A majority of the locations where precipitation is measured have no established criteria for reporting on a daily basis and, if daily reports are desired from any of these stations, it is necessary to make specific arrangements with the observer for forwarding the data. Immediately after the end of each month, all climatological stations forward records of daily precipitation to appropriate Weather Service centers for publication. Although published values are normally not available for several months after observation, monthly or daily amounts at selected stations may be obtained soon after the end of the month through special arrangements with the Weather Service.

7-5. Individual reservoir regulation manuals contain maps of key hydrologic and meteorologic stations for that portion of the Missouri Basin most pertinent to regulation of the specific reservoir under consideration. Plate 33 shows the "first order" weather stations for which meteorologic data are available more often than once daily. This basic network is augmented by many additional reports from the Weather Service and District offices at times of consequential precipitation within the basin.

7-6. Snow. A large portion of the annual stream flow which enters the reservoir system results from the melting of the winter's snow accumulation over the northern plains area during the early spring and from the high mountain area (in combination with rainfall runoff) during the late spring season. Flooding in the upper basin is nearly always associated with these events, and they also contribute to flood flows through the lower basin. Measurement of the depth and water content of the snow cover, in combination with quantitative as well as qualitative assessments of other related data, provide an index to the potential magnitude of the flood events. This, in turn, enables system regulation to be adjusted accordingly so that the flood control as well as the multiple-purpose functions may be accomplished in an efficient manner.

7-7. Plains area surveys that evaluate the water content of the plains snow blanket, are of relatively recent origin in the Missouri River Basin, having been conducted by Corps of Engineers personnel during years of high plains snowmelt runoff potential since 1948. A definite network of locations for plains snow measurements, as shown on Plate 34, has been established, as well as uniform measuring and observation criteria, so that data from year to year may be comparable. Data pertinent to estimating runoff potential are observed at specific locations and include water content of the snow cover, snow depth, amount of ice layer present on the ground surface, a qualitative estimate of surface ground saturation, amount of drifting, and the condition of the ground surface with regard to frost penetration. In addition to the Corps' network, the Weather Service has a program for obtaining and reporting snow water content at selected first-order stations in the basin. Snow depths at regular Weather Service reporting stations are received daily over the Service C teletype as well as on the Weather Service facsimile printer.

7-8. As it is the responsibility of each District office to keep informed of the flood potential within their drainage area at all times, plains snow surveys within their boundaries can be made at their discretion, with inter-district coordination by the Division Office. Basinwide surveys conducted by the Corps of Engineers over their established network are implemented by orders from the Reservoir Control Center. A partial index to the runoff potentials, upon which the implementation order is based, is obtained from available District surveys as well as precipitation and snow depth reports received through the winter from various Weather Service stations. Implementation orders to the District offices include the dates, areal coverage, and minimum observation criteria for the surveys. Accomplishment of the surveys is a District responsibility. A basin-wide survey will normally be made in early March during those years a moderate or heavy snow cover is reported; however, more than one survey may be implemented in any season if conditions so warrant.

7-9. Reports of plains snow survey observations are immediately forwarded by the District offices to the Reservoir Control Center and to the Weather Service through established communication channels. Analysis of data as it affects local flood conditions and tributary reservoirs are made by the appropriate District while the Control Center evaluates the data for regulation of the main stem reservoir system. In the event of a basin-wide survey, the Reservoir Control Center is responsible for combining the District reports with snow data that may be available from other sources and for making a basin-wide analysis of the runoff potential. The Reservoir Control Center disseminates results of these analyses to the Districts.

7-10. Snow surveys in the mountainous areas above the Fort Peck and Garrison Reservoirs have a history dating back to 1934; however, the network has been expanded considerably since that date. Of the snow courses most pertinent to main stem operation, 60 are located in the drainage area above Fort Peck and 80 in the Yellowstone basin. Surveys are conducted through the cooperative efforts of many agencies and private concerns. The Soil Conservation Service of the Department of Agriculture is the agency with the primary responsibility for coordinating mountain snow surveys in the western states. Montana surveys are collected by the SCS Snow Survey Supervisor located at Bozeman, Montana, while surveys conducted over the Wyoming portion of the drainage basin are the responsibility of the SCS Supervisor located in Casper, Wyoming.

7-11. Mountain snow surveys are normally conducted near the first of each month during the period January to June. The frequency of sampling varies from course to course; however, most courses are measured near the first of March and the first of April when the snow cover is near the maximum, with only a few courses sampled each month through the entire January-June period. Observations consist of the snow depth and water content in inches and qualitative data on ground conditions. Observations are furnished to interested agencies as rapidly as possible after the first of the month by means of printed publications. Certain key courses of particular interest to the Districts and the Reservoir Control Center are forwarded by the Weather Service RAWARC network or may be obtained directly by telephone from the appropriate Snow Survey Supervisors.

7-12. Snow pillows have been installed at various mountain locations in the Missouri River basin. These snow pillows are linked to a telemetry network implemented by the Soil Conservation Service whereby snow water content and other meteorologic information are relayed twice daily to a center. They are then verified and entered into a computer file that may be accessed by a remote computer terminal in the Reservoir Control Center. Although additional snow pillow installations are planned in a continuing program, the number of pillows already installed can be used along with established snow courses to provide continuous information about the mountain snow pack.

7-13. River Stages and Discharges. The U.S. Geological Survey, in cooperation with other Federal and State agencies, maintains a network of stream gaging stations throughout the Missouri River basin. This agency is charged with supervision and maintenance of the stations, the accomplishment of a systematic measurement program at the stations in order that the stage - discharge relationship may be kept current, and the collection and distribution of streamflow data. In addition to the stations maintained by the U.S. Geological Survey, other Federal and state agencies, including the Corps of Engineers, the Weather Service, and the Bureau of Reclamation, as well as private concerns, collect stage and occasionally discharge data at locations and during periods of their particular interest. Data pertinent to reservoir operation can usually be obtained from these parties by establishing appropriate communications channels.

7-14. The National Weather Service distributes most of the daily stage information used for regulation of the main stem reservoir system over their RAWARC and Service C networks. Arrangements for the Weather Service reporting of stage data pertinent to main stem reservoir regulation are made through the Regional Hydrologist in Kansas City, Missouri. While the teletype reports of stage are usually received only once daily, certain key stations normally report at 6-hour intervals and during flood periods, the reporting frequency may be increased substantially. Additionally, many of the key stations have telemark installations allowing inquiry at any time by personnel of the Reservoir Control Center. Plate 35 shows locations of these important streamflow stations and key reservoir reporting stations within the Missouri basin. More detailed station maps pertinent to the regulation of the individual reservoirs are presented in the individual reservoir manuals. In addition to the basic network, considerable additional stream data are received, often on a seasonal or emergency basis. Listings and locations of these stations are presented in individual regulation manuals and in appropriate disaster manuals for flood emergency operations.

7-15. Through arrangements with the U.S. Geological Survey, discharge measurements at key locations are made at a greater frequency than is normally considered adequate for historic stream-flow records. Such a procedure is necessary to maintain the most current stage-discharge relationship at these stations in order that system regulation, whether geared to multiple-purpose or to flood control purposes, may proceed as efficiently as possible. Results of discharge measurements at important stations are furnished District offices as soon as available and the District offices furnish these to the Reservoir Control Center. These measurements are used to maintain current rating curves within the Center. Upon request, the appropriate District arranges for and furnishes discharge data for stations not included in the basic network.

7-16. Reservoir Reports. Each of the main stem reservoir projects reports at least three times daily over the MRD teletype network. Data included are hourly releases, hourly power generations, hourly reservoir levels, climatological data at the project site, tailwater elevations and temperature and any other data which may be considered useful in the regulation process. When believed necessary, the frequency of reports is increased. Similar reports from tributary reservoirs that may affect system regulation are furnished daily by the District offices and by agencies responsible for operation of particular projects when these are pertinent to current main stem operations. Monthly reports, which include tabulations of inflow, releases, pool elevations, storage, evaporation losses, as well as other pertinent factors, are furnished by the Districts for each of the main stem reservoirs as well as for tributary reservoirs in which the Corps of Engineers has an interest. These reports are forwarded to the Reservoir Control Center as soon as practicable following the end of each month, utilizing MRD Form 0168. A sample report is shown on Table 5.

7-17. Evaporation Data. A standard Class A evaporation pan has been installed at each main stem reservoir site. Daily observations of evaporation depth, pan wind movement and pan temperatures are made throughout the season that freezing of the pan water does not occur. The evaporation data is furnished the National Weather Service for publication and use. Other data pertinent to evaporation estimates are also collected by the National Weather Service, including humidity, wind movement, precipitation and temperature data from location adjacent to the reservoirs.

7-18. Air Temperature. Air temperature is an important meteorological element utilized in regulation of the main stem reservoir system. Both plains-area and mountain snowmelt are responsive to the temperature regime. Ice formation on the Missouri River and its subsequent breakup are also affected by prevailing air temperatures. While temperature observations are made at each of the main stem projects, the main source of temperature data is the National Weather Service, with transmission to the Reservoir Control Center over established teletype and facsimile networks.

7-19. Tailwater Temperature. Due to the large amount of storage contained in most of the main stem reservoirs, there is a substantial lag in tailwater temperatures from mean air temperatures at the reservoir sites. While the tailwater temperature is an important water quality parameter, it is of most concern to the regulation process as an index to surface water temperature (an important element in the development of evaporation estimates) and more particularly, as an important element in predicting downstream water temperatures and estimating formation and movement of the ice cover below the projects. Tailwater temperature observations are made daily at each of the main stem reservoir projects and are an important element of the daily reports furnished the Reservoir Control Center.

7-20. River Reconnaissance. While the conditions which are expected to result from regulation of the reservoirs can be estimated

Table 5

RCS: MRDED-R-2

MONTHLY RESERVOIR OPERATION

RESERVOIR GARRISON
LAKE SAKAKAWEA, NORTH DAKOTA

RIVER MISSOURI

DISTRICT OMAHA

MISSOURI RIVER DIVISION

CORPS OF ENGINEERS, U. S. ARMY

1	2	3	4	5
MONTH – YEAR JULY 1977	RESERVOIR ELEVATION FEET ABOVE M. S. L. 12:00 MN ***	ESTIMATED EVAPORATION c. f. s.	MEAN DISCHARGE 12 MN TO 12 MN IN C. F. S.	
			OUTFLOW	ESTIMATED INFLOW
1	1837.7	900	16,000	17,000*
2	1837.8*	1,300	16,200	15,000
3	1837.7	800	16,700	13,000
4	1837.7	1,000	16,300	13,000
5	1837.7	1,000	17,300	13,000
6	1837.7	1,400	17,800	15,000
7	1837.7	1,400	16,900	17,000
8	1837.6	1,200	17,000	15,000
9	1837.5	400	15,900**	15,000
10	1837.8	200**	17,400	15,000
11	1837.6	600	18,900	15,000
12	1837.4	1,100	18,800	15,000
13	1837.6	700	18,600	15,000
14	1837.4	300	18,000	15,000
15	1837.3	1,000	17,400	15,000
16	1837.5	700	18,000	15,000
17	1837.5	1,500*	18,200	15,000
18	1837.4	1,300	18,900	15,000
19	1837.4	800	19,600*	15,000
20	1837.3	1,100	17,900	15,000
21	1837.2	1,400	17,100	15,000
22	1837.2	900	17,200	13,000
23	1837.2	1,400	16,700	13,000
24	1837.2	1,400	16,800	13,000
25	1837.1	900	16,500	10,000**
26	1837.0	700	17,200	10,000
27	1837.1	600	15,900	10,000
28	1837.1	900	15,900	10,000
29	1836.9	1,400	18,700	12,000
30	1837.4	1,200	18,300	12,000
31	1836.9**	1,100	17,000	12,000
TOTAL (dsf)		31,100	539,100	428,000
TOTAL (ac-ft)		62,000	1,069,000	849,000
MEAN (cfs)		1,000	17,400	13,800

END OF MONTH GROSS STORAGE	MONTHLY CHANGE IN STORAGE	MAX. STORAGE	MIN. STORAGE
18,164,000 A.F.	– 282,000 A.F.	18,446,000 A.F.	18,164,000 A.F.
DATE: 31 July		DATE: 1 July	DATE: 31 July

REMARKS:

** Maximum* *** Minimum* **** Reading affected by wind*

MRD FORM 0168
FEB 71

through empirical means developed from past experience, verification requires field observations. Project personnel make numerous reconnaissances of portions of the river that are affected by project releases, and of the reservoir area, to obtain data that is valuable for the regulation process. During the winter season, observations that define ice conditions in the Missouri River are routine. Effects of unusual release rates or reservoir levels are also documented by field observations. Bank erosion below projects is also a matter of concern. While most reconnaissance consists of visual observations and verbal reports to the District office and the Reservoir Control Center, these are supplemented by photographs when conditions warrant and, when particularly unusual events occur, aerial photography may be scheduled. Most reconnaissances are in response to specific needs expressed by the Reservoir Control Center or the District offices.

7-21. Missouri River Automated Data System (MRADS). MRADS is a computer operated on-line data base management system for storing and disseminating Missouri River basin real-time water control data. Each day, the current river and project water control data are entered into MRADS from medium speed remote computer terminals in the Reservoir Control Center and the Omaha and Kansas City Districts reservoir regulation sections. These data are maintained sequentially in MRADS from 60 to 120 days and monthly computer listings of the data are produced for historic files before archiving the data. Each month the most historic month of data is removed from MRADS and archived onto magnetic tape so that permanent records are maintained on magnetic tape as well as on computer printouts.

7-22. At least 60 sequential days of current water control data are always available in MRADS and may be accessed from medium speed remote terminals. MRADS also includes fixed data such as; reservoir elevation-storage tables, project storage allocations, river station stage - discharge tables, river routing coefficients, and river station miles. The fixed data are accessed by programs used for producing river reports and forecasting project and river regulation.

SECTION VIII - ANALYSES AND FORECASTS PERTINENT TO RESERVOIR REGULATION

8-1. General. Regulation of the multi-purpose Missouri River main stem reservoir system requires the scheduling of releases and storages on the basis of the observed and anticipated hydrologic events through the basin. Navigation releases are based upon the maintenance of prescribed minimum flow levels at downstream control points. The accumulation and evacuation of storage for flood control purpose is accomplished in a manner which will prevent, insofar as possible, flows exceeding those which will cause damage at downstream points. Flood potentialities must be considered at all times. Efficient system regulation requires the scheduling of releases through the power plants at times and at rates which will maximize revenue return to the Federal Government, with these release dates dependent upon current and anticipated hydrologic events. Due to the increasing value of water for multiple-use purposes, the most efficient utilization of water is desired, especially during the course of a cycle when below normal streamflow is occurring. Reliable forecasts of reservoir inflow, and of other hydrologic events which influence streamflow are of prime importance in the attainment of efficient regulation of the storage space provided in the basin reservoirs. In addition to scheduling releases from these reservoirs, the overall regulation process also includes the determination of regulation effects upon flows at specific locations below the reservoir system and subsequent evaluation of these effects.

8-2. Weather Forecasts. The preparation and public dissemination of forecasts relating to precipitation, temperatures, and other meterological elements are functions of the National Weather Service. Teletype and facsimile drops are maintained in the Reservoir Control Center, and the Omaha and Kansas City District offices, to obtain the latest meterological information, analyses, and forecasts. In addition, meteorologists or personnel with a basic meteorological background are employed in the Reservoir Control Center and at the District level to further analyze available information and prepare specialized forecasts not available from the Weather Service.

8-3. Forecasts of temperature and precipitation, the meteorological items of greatest importance to reservoir regulation, of the types and on the schedule given below are issued by the Weather Service.

a. Short-range forecasts, extending for periods up to 2 days in advance, are issued several times daily by Weather Service centers. Forecasts are on a state-by-state basis with expected variations within the state delineated.

b. Maximum and minimum temperature forecasts for selected locations within the Missouri basin are issued daily.

c. Extended forecasts for 5 days in advance are issued daily by Weather Service forecast centers on the basis of a nation-wide extended period analysis. These forecasts are qualitative in nature and apply to individual states.

d. Long-range forecasts, extending for a month in advance are issued by the Washington office of the Weather Service on approximately the 1st and 15th of the month. These forecasts cover the entire nation and are qualitative in nature.

e. Quantitative precipitation and severe storm forecasts for the entire area of the United States, extending for 48 hours into the future, are issued daily by the Weather Service and transmitted over their facsimile network.

8-4. The Reservoir Control Center staff meteorologist continuously reviews the weather conditions occurring throughout the Missouri basin and the forecasts issued by the National Weather Service. He augments these forecasts where necessary for reservoir regulation and power production purposes to provide forecasts that are more specific for the Control Center's needs than those issued by the National Weather Service.

8-5. <u>Long-Range Water-Supply Forecasts</u>. A large portion of the Missouri River flow which originates upstream from the main stem reservoir system results from the melting of snow. The long lag (extending into months) between the times that precipitation and subsequent runoff occurs, as well as the greater effectiveness of winter precipitation in producing runoff as compared to that during the summer months, makes long-range forecasts of runoff feasible. The accuracy of long-range forecasts is limited by unanticipated departures from the normal of subsequent meteorologic and hydrologic events. It is also generally realized that numerous and complex variables, whose effects are as yet not fully determinable, influence the volume of streamflow from a drainage area during any specific time period. Long-range forecasting procedures are of relatively recent origin, and due to their importance upon subsequent operations, any improvement is highly desirable; therefore, forecast procedures are still in the process of evaluation and development by interested agencies.

8-6. The National Weather Service issues forecasts for the period covering a water year (October through September) and for the residual portion of the water year remaining after each forecast date. These forecasts are issued as soon as practicable after the first of each month, January through May, and are published in the bulletin, "Water Supply Forecasts for the Western United States." Forecasts for the Upper Missouri River and numerous tributary locations are developed by the Kansas City water supply forecast unit of the NWS. Certain key forecasts are forwarded from that unit directly to the Reservoir Control Center prior to publication of the above-referenced bulletin.

8-7. The Soil Conservation Service, in addition to collecting mountain snow survey data, issues forecasts of runoff volumes. The office in Bozeman, Montana, prepares forecasts for numerous Montana locations in the Upper Missouri River basin while forecasts for tributary locations in Wyoming are prepared in their Casper, Wyoming, office. Forecasts are issued as of the first of each month, February through May, for periods extending from April through July and April through September. Soil Conservation publications entitled "Snow Survey and Water Supply Forecasts," issued by the respective offices, contain these anticipated volumes of future runoff. These publications are furnished directly to the Reservoir Control Center and District offices.

8-8. The Bureau of Reclamation makes long-range volume forecasts largely for operation of their tributary reservoirs in the upper basin. These forecasts are furnished the Reservoir Control Center and interested District offices. They also form a basis for cooperative and comparative studies of main stem operating plans.

8-9. The Reservoir Control Center develops water supply forecasts soon after the beginning of each month. These forecasts are for monthly inflows from each incremental drainage area as defined by the individual main stem projects and for the incremental drainage area between Gavins Point Dam and Sioux City, Iowa. The forecasts extend from the current month through the remainder of the calendar year and through February of the succeeding year. Procedures for the development of these long-range monthly water supply forecasts are detailed in the MRD-RCC Technical Study MH-73, "Missouri River Main Stem Reservoir System, Long Range Runoff Forecasts," and are not repeated in this manual. These long-range forecasts form the principal basis of the "Water Supply Outlooks" which are developed monthly by the RCC from January through June and furnished to various segments of the Missouri River Division and to the Chief of Engineers. They are also used for the projections of main stem operations which are made monthly and extend through the remainder of the current calendar year and extending through February of the following year.

8-10. Due to the advance planning requirements for system regulation, more reliable seasonal forecast procedures would be very valuable in optimum scheduling of system operations. At the present time, there are numerous forecasts made for runoff anticipated from the snow accumulated in the mountainous areas of the basin. However, snow accumulated over the plains area is frequently a major contributor to main stem system inflows, and reliable procedures for making quantitative forecasts of this type of runoff are lacking. Improved plains snowmelt runoff procedures are being pursued as actively as time and workloads permit. Seasonal flow forecasts for tributary areas are developed at the District level, both as an aid to tributary reservoir operation, and as a basis for the overall basin-wide evaluation of runoff potential.

8-11. Short-Range Stream Forecasts. Day-to-day scheduling necessary for operation of the main stem reservoirs on an integrated basis require daily forecasts of flows at key locations throughout the basin. Such forecasts are based on observed and anticipated precipitation and temperature, temperature-snowmelt relationships, rainfall-runoff relationships, observed streamflow in the main stem and tributaries, antecedent precipitation, and other factors which often may be subject to only qualitative analysis.

8-12. The National Weather Service is the Federal agency responsible for the preparation and issuance of river forecasts for public dissemination. Where reservoir regulation affects streamflows and vice versa, close liaison is maintained between Corps of Engineers District offices, the Reservoir Control Center, and the Weather Service offices responsible for the streamflow forecasts. The National Weather Service River Forecast Center, located at Kansas City, Missouri, prepares forecasts for stream locations throughout the Missouri basin and is also responsible for the supervision and coordination of forecasting services provided by the Weather Service River District offices located through their region. The River Forecast Center routinely prepares and distributes (over the RAWARC teletype network) 3-day stage forecasts at key gaging stations along the Missouri River from Sioux City, Iowa, to the mouth. During the Missouri River navigation season, the Center also prepares forecasts of Kansas River flows and furnishes these forecasts to the Corps' Kansas City District.

8-13. River Districts offices of the Weather Service included in the Kansas City River Forecast Center region and their areas of responsibility are given below:

a. Helena, Montana District. The Missouri River and its tributaries from its source to the Montana-North Dakota state line.

b. Billings, Montana District. The Yellowstone River basin.

c. Bismarck, North Dakota District. The Missouri River and tributary drainage area extending from the Montana-North Dakota state line to the North Dakota-South Dakota state line and that portion of the James River basin which is within North Dakota.

d. Sioux Falls, South Dakota District. The Missouri River and tributary drainage area extending from the North Dakota-South Dakota state line to and including Sioux City, with the exception of the James River basin within North Dakota.

e. Norfolk, Nebraska District. The Elkhorn River and Omaha Creek basins.

f. Omaha, Nebraska District. The Missouri River and tributary drainage area extending from below Sioux City to and including the mouth of the Platte River, with exception of the Platte River drainage not in Nebraska, the Elkhorn River, and Omaha Creek.

g. Denver, Colorado District. The Platte River drainage area in Colorado and Wyoming.

h. Kansas City, Missouri District. The Missouri River and tributary drainage area extending from below the mouth of the Platte River to and including Jefferson City, Missouri, with the exception of the Kansas River basin.

i. Topeka, Kansas District. The Kansas River basin and the Osage River basin lying within Kansas.

j. St. Louis, Missouri District. The Missouri River and tributary drainage area extending from below Jefferson City, Missouri to its mouth with the exception of the Osage drainage in Kansas.

8-14. The services provided by the River Forecast Center and River Districts are utilized to the maximum for regulation of both main stem and tributary reservoirs. These services are particularly useful at the times flood conditions are occurring or are imminent within the basin. At such times, contacts between appropriate River District offices, the River Forecast Center, the responsible Corps of Engineers District offices, and the Reservoir Control Center are maintained to allow a complete interchange of available data upon which the most reliable forecasts and subsequent reservoir regulation may be based. River stage forecasts disseminated to the public are a Weather Bureau responsibility and any stage forecasts quoted by the Corps to the public will be those issued or approved by the Weather Service.

8-15. The Corps' Omaha and Kansas City District offices also have a forecast capability and responsibility for aiding in regulation of the main stem reservoir system. This includes the forecasting of crest flows from tributary streams during periods of flood runoff as well as flow forecasts at selected locations on the main stem of the Missouri River. Most of these forecasts also serve the District in their regulation of tributary reservoirs or in their flood emergency activities. On a routine daily basis through the Missouri River navigation season, the Kansas City District furnishes the Reservoir Control Center 10-day forecasts of flows expected from the Kansas River at its mouth. During the navigation season, the Omaha District also routinely furnishes the Reservoir Control Center forecasts of reach inflow for the following locations and forecast periods:

a. The reach extending from Fort Randall Dam to Gavins Point Dam for 4 days.

b. The reach extending from Gavins Point to Sioux City, Iowa, for a period of 3 days.

c. The reach extending from Sioux City, Iowa, to Omaha, Nebraska, for a period of 3 days.

d. The reach extending from Omaha, Nebraska, to Nebraska City, Nebraska, for a period of 4 days.

e. The reach extending from Nebraska City, Nebraska, to Rulo, Missouri, for a period of 5 days.

8-16. Reach Inflow Forecasts for System Release Scheduling. As discussed later in Sections IX and X of this manual, the scheduling of releases from the system throughout the open water season is based on the maintenance of selected flows at the downstream control points of Sioux City, Omaha, Nebraska City, and Kansas City. Release scheduling, therefore, requires forecasts of the inflows originating between Gavins Point Dam, the lowermost point of system control, and the downstream release control points. Since the Reservoir Control Center is responsible for release scheduling from the system, the Center also develops forecasts of reach inflow and forecasts of flow at the control point locations as a basis for release scheduling. These forecasts are developed daily and compared to forecasts received from the Districts and the National Weather Service. If significant differences in forecasts occur, an attempt is made to reconcile the differences prior to release scheduling; however, the ultimate forecast and scheduling responsibility is with the Reservoir Control Center.

8-17. The reach inflow forecasts were originally based on hand computations utilizing the format shown on Plates 36 through 40. These forms and associated hand computations have been supplanted by a Hewlett-Packard Computer 9830A which has been programmed to accomplish the same end result. The forms are presented to illustrate the forecast process now used by the computer. These forms are constructed in such a manner that flows entered on the forms are essentially coincident with respect to water travel time to a common downstream point when compared horizontally across the forms. In general, the forecast procedures utilized with the forms are as follows:

a. Enter observed flows for the current date at all main stem and tributary locations given on the forms, including flows at the mouth of the Kansas River.

b. By subtraction, determine the current inflow to each of the reaches of the Missouri River as defined by Gavins Point Dam, Sioux City, Omaha, Nebraska City, Rulo, and Kansas City.

c. By summation of tributary flows, define the current "gaged" flows originating in each of the reaches.

d. By subtracting the current "gaged" flows as defined in c. from the current total inflow as defined in b., define the current "ungaged" flow originating in each of the river reaches.

e. Enter forecasts of flows at each tributary location and for the "ungaged" reach inflows in columns provided. The Nebraska City to Rulo (NBC-RLO) and Rulo to the mouth of the Kansas River (RLO-KAW) are entirely ungaged flows.

f. Enter the 6-day forecast of Kansas River flows (KAW) as received from the Kansas City District in the proper columns.

g. Develop forecasts of total "gaged" flows into each reach by adding forecasts of flows at tributary stations.

h. Develop forecasts of total reach inflow by adding the "gaged" and "ungaged" reach inflow forecast.

i. By adding forecasts of successive reach inflows, forecasts of the total inflow between Gavins Point Dam and downstream control points are developed.

8-18. Examination of the forms will indicate that at some tributary stations, flow forecasts will be developed in a manner similar to that described for reach inflows above. Forecasts for other tributary stations and for the "ungaged" flows are often based on developed recession tables; although at times of heavy rainfall or snowmelt, runoff forecasts will be based on the expected additional runoff. A complete and detailed explanation on the use of the forms and further details pertaining to forecast procedures for each of the locations or reaches shown on the form are presented in MRD-RCC Technical Report F-62 and not presented in this manual.

8-19. Routing Procedures. Releases from the main stem reservoir system are generally maintained at a relatively constant rate and, when changes are made, the changes are gradual, particularly when releases are increased. Sophisticated routing procedures are, therefore, not necessary for release scheduling purposes. As may be noted from discussions in the preceding paragraphs, release routing is usually accomplished by direct translation of actual or proposed system releases to appropriate downstream control points. Many years of regulation experience have also indicated that simple transition of observed or forecast flows at tributary gaging stations to downstream main stem stations is adequate. Studies utilizing other means of routing flows to downstream locations have not resulted in any recognizable improvement in the resulting release scheduling from the main stem reservoir system. Therefore, this simple method is considered to be preferable to more complex and time-consuming routing procedures, particularly when it is recognized that releases from the system are scheduled on a mean daily basis and during any particular day substantial variations from the scheduled release rate will be allowed to meet power and other multiple-purpose needs.

8-20. Analyses performed by the Reservoir Control Center include reconstitution of flows for the purpose of determining reservoir regulation effects, as described later in this section. For such purposes, a simple lag-average procedure is utilized for the routing of reservoir effects downstream to selected main stem locations at which reconstituted flows are desired. Coefficients considered to be applicable, based on examination of flood events, are given in the MRD Technical Study S-73, "Upper Missouri River, Unregulated Flow Development."

8-21. In those cases where a much more detailed examination of flood flows is desired, use will be made of the routing method described in the MRD publication "Computer Simulation of Missouri River Floods," dated January 1973. This report describes a developed flood routing method utilizing the dynamic flow equations for continuity and motion. The equations are solved on a digital computer using a finite difference method of solution. Details for application of the method are given in a user's manual.

8-22. Stage - Discharge Analyses. Since most raw stream data are received in the form of stage information, a considerable amount of interpretation of these data as discharges is required daily by the Reservoir Control Center. Current rating curves are maintained in the office, and verification or adjustments are made as often as discharge measurements are received from the U.S. Geological Survey. Additionally, it is frequently necessary to reconcile initial estimates of discharges for stream flow stations along the Missouri River on the basis of comparison with flows at adjacent stations and reports from tributary stations. Use of the forms described in paragraph 8-17 is very helpful in developing consistent daily discharge data for all main stem locations below the main stem reservoir system.

8-23. Stage data are also required in the evaluation of reservoir effects upon downstream flows. With the construction of the reservoir system, the occurrences of extreme flows (both large and small) have been reduced, particularly large flood flows immediately below the reservoir system. As a consequence, there are frequently no data available to define the current relationship between discharges that would have occurred without reservoir regulation and corresponding stages. This problem is addressed in detail in the MRD Technical Study S-73 referred to in paragraph 8-20. In essence, this report recommends the assumption that, although the stage-discharge relationship may have been warped considerably since streamflow data in the required range were last observed, the slope of the rating curve through the currently undefined portions of the curve can be expected to be similar to slopes which occurred in previous years when records were available. Simplified procedures for estimating incremental stages on the basis of incremental discharges in the extreme ranges of discharge are also presented in this report.

8-24. Another complicating stage-discharge factor experienced in the evaluation of reservoir effects is the effect of the existence of the main stem reservoir upon the ice cover at downstream locations. Ice experience immediately downstream from the projects has been altered significantly by construction of the reservoirs. The presence, or absence, of an ice cover has a material effect upon the stage-discharge relationship. Technical Study S-73 also addresses this matter and presents suggested procedures for the consideration of these effects in evaluation of reservoir effects.

8-25. Unregulated Flow. With the construction of reservoirs in the Missouri basin, streamflows have been materially altered. Flood peaks have been reduced and low flows augmented by reservoir regulation. A quantitative estimate of the effects of regulation is frequently required. In order to accomplish this rather laborious task, a computer program (MRD 724C0200) has been developed. The output from this program includes daily unregulated flows at Fort Peck Dam, Garrison Dam, Oahe Dam, Fort Randall Dam, Gavins Point Dam, and Sioux City, Iowa. Reservoir Control Center Technical Study S-73 described the logic utilized in the computer program. Items considered in the development of unregulated flows include reservoir evaporation, precipitation on the reservoir surface, variations in travel time (from the natural or unregulated travel time) resulting from reservoir development and resulting from variations in reservoir levels, channel area inundated by the reservoirs, runoff that could have been expected from overbank areas now inundated by reservoirs, inflows, outflows, and changes in storage. In addition to a printout of mean daily flows, computer output is also stored on tape and plotted. Examples of the plots available are shown on Plates 41 through 43.

8-26. Streamflows at the 1949 Development Level. As discussed in Section III of this manual, water resource development in the Missouri basin has been relatively continuous ever since settlement of the basin began. In recent years, this development has accelerated and continuing development can be expected into the future. A major effect of this development is the depletion and redistribution of flows that would have otherwise occurred under natural conditions. Hydrologic studies require consistent flow data; therefore, it is necessary to adjust observed flows of the Missouri River to a common base level. While any development level could have been used for this base, the water resource development prevailing in 1949, prior to recent rapid expansion of development, has been selected as the base. Therefore, one of the analyses performed by the Reservoir Control Center is the continuing computation of reach inflows adjusted to the 1949 basin development level for the entire Missouri basin above Sioux City. With these available, the current water supply can be compared with historical supplies dating back to 1898.

8-27. Adjustments to the 1949 level require the evaluation of regulation effects as discussed in paragraph 8-25; however, this is necessary for only post-1949 projects. (The entire main stem reservoir system is considered to be a post-1949 project even though Fort Peck was in operation prior to that date.) These adjustments also require consideration of depleting effects unrelated to reservoir regulation. These include irrigation depletions, land treatment, evaporation from stock ponds and small lakes, forestry practices, municipal and industrial use and other depleting effects. Much of this information relating to depletion is developed by the Department of Interior and is furnished the Reservoir Control Center by the Bureau of Reclamation. The Reservoir Control Center makes preliminary analysis of this information immediately following the end of each month on the basis of data then available and develops preliminary reach inflow data (1949 development level) for the month. A more complete detailed analysis is later made when all information is available by utilizing computer program 724C0200 previously referenced. Daily 1949 flows are developed at key gaging stations in the upper Missouri basin, for comparison with both the regulated and unregulated flows. Monthly reach inflows at the 1949 level are also developed for comparison and study purposes. In this manner, the available hydrologic record, at a constant base level, is extended.

8-28. Evaluation of the Effects of Reservoir Regulation. One of the purposes for development of unregulated flows along the Missouri River is the development of monetary benefits realized from operation of the reservoirs. The Reservoir Control Center is responsible for the development of all crest stage and discharge data pertinent to this evaluation for main stem locations above St. Joseph, Missouri. The Center is also responsible for apportioning the total Missouri River benefits realized from reservoirs above St. Joseph, Missouri to individual tributary reservoirs and to the main stem system as a whole. The Center also furnishes the Kansas City District the daily regulation effects (holdouts) from projects above St. Joseph in order that the Kansas City District can combine these effects with the effects of tributary reservoirs in their District for evaluation purposes along the main stem of the Missouri River from St. Joseph downstream. For tributary streams, development of reservoir regulation effects, and subsequent benefit evaluations, are the responsibility of the respective District offices. The overall evaluation of effects of both tributary and main stem projects requires considerable coordination between the Reservoir Control Centers and counterpart units in the District offices. Step-by-step procedures for this task, including criteria relating to assignment of monetary effects to individual projects, are outlined in the MRD-RCC Technical Study S-73 referenced previously.

8-29. Long-Term Regulation Studies. A continuing major effort of the Reservoir Control Center is the improvement of regulation techniques and procedures through analyses of past operations and period-of-record inflows under various assumed operating criteria. These analyses are also required to determine the effects of other phases of water resource development in the basin upon service provided by the main stem system. A particularly useful tool in these analyses is the long term regulation study that examines the effects of alternative operation criteria through the entire period of available hydrologic record since 1898. Computer program 724C0100, which has been developed to conduct these studies, is described in the MRD Reservoir Control Center Technical Report J-75. In brief, this program allows thorough examination of modifications in regulation criteria (or resource developments) by providing output which gives details as to the service provided to system functions by each of the main stem projects and the system as a whole through the available period of hydrologic record. Details provided include reservoir levels, service to navigation, energy generation, peaking capability, reservoir releases, and flows at downstream locations in the Missouri River. Further discussion relating to these studies is given in Section IX of this manual.

8-30. Ice Formation Below Power Plants. Ice formation on the Missouri River reduces channel capacities and restricts releases from individual main stem projects. Since the winter season is also a season of large power demand, it is necessary to carefully schedule releases, particularly from Fort Peck and Garrison, during the period of ice formation and subsequent stabilization. Procedures developed for anticipating adverse ice effects are scheduling releases during this critical period are outline in MRD-RCC Technical Study JY-73 for Fort Peck and Technical Study F-73 for Garrison. The analyses outlined in these studies relate air temperature, release temperature, release rate, and distance to current ice cover to the rate of ice formation. This rate of ice formation (or ice melt) is then utilized to forecast the probable location of the head of the solid ice cover downstream from the projects.

8-31. Reservoir Evaporation. Evaporation from the surface of the main stem reservoirs is a major water loss. Annual evaporation from the reservoirs is estimated to average about three million acre-feet (gross) and maximum daily evaporation rates are believed to exceed 10,000 cfs. Consideration of precipitation upon the reservoir surface and probable runoff from land areas now inundated by the reservoirs results in reducing the water loss to about 1.5 million acre-feet (net evaporation). A reasonable definition of rates throughout the year is required in the development of reservoir inflows and in the analyses of regulation effects.

8-32. At one time, main stem reservoir evaporation estimates were based entirely on data from evaporation pans in the vicinity of each project and on general estimates during periods pan data were not available. A pan-to-lake coefficient of 0.7 was assumed applicable at all times. Considerable research concerning lake evaporation has occurred during the past years with the most comprehensive research studies conducted by the National Weather Service and the U.S. Geological Survey. This research indicated that, in general, the 0.7 pan-to-lake coefficient was applicable for relating annual pan evaporation to annual lake evaporation, however, during any year the coefficient could be expected to vary considerably. A major cause of this variation appears to be the differences that occur between pan water temperature and lake surface temperature. The research also indicated that the most practical method for determining evaporation from lakes on a current short term (less than annual) basis was to calibrate appropriate mass-transfer coefficients for each reservoir through comparison with evaporation computed by energy budget procedures.

8-33. In cooperation with the U.S. Geological Survey, an attempt was made to calibrate Garrison Reservoir during the late 1960s. However, after 2 years of gathering data relating to energy budget evaporation and the coincident factors required for mass-transfer computations, it was concluded that reliable calibration of this reservoir for application of this method was not possible. Therefore, further studies were conducted in the Reservoir Control Center to develop a means of estimating evaporation on a basis consistent with available research. Results of these studies, and the resulting procedures selected for estimating evaporation from the main stem projects, are presented in the MRD-Reservoir Control Center Technical Report JE-73. In essence, the report recommends the use of a variable pan coefficient when pan data are available and a mass-transfer method during periods evaporation pans are not in operation. The coefficients considered applicable for each of the reservoirs for each month of the year are given in the study report, as well as procedures for developing estimates when particular data are unavailable.

SECTION IX - MULTIPLE PURPOSE REGULATION

IX-A. Operational Objectives and Requirements.

9-1. General. Presented in this section of the manual are the operational objectives and requirements, together with descriptions of multi-purpose operation plans for functions other than flood control. These functions include irrigation, navigation, water supply, power, fish and wildlife, water quality, and recreation. Objectives, requirements, and procedures for the specific flood control functions of the reservoir system are presented in Section X.

9-2. Basis for Service. As an introduction to a discussion on functional requirements, the need to conform to certain basic storage provisions and basic principles of reservoir operation should be recognized. The bottom inactive storage zones of the reservoirs are to remain permanently filled with water. This will insure the maintenance of minimum power heads, minimum irrigation diversion levels, and minimum pools for recreation, fish and wildlife purposes. Similarly, the top storage zones are provided for handling of the largest floods and will be reserved exclusively for this purpose. The storage zones intermediate to the lower inactive zones and upper flood control zones provide active storage for the multiple purposes enumerated above, as well as providing space for the control of moderate floods and, together with the upper exclusive flood control zone, providing control of major floods.

9-3. The following general approach which was developed and generally agreed upon during planning and design of the reservoirs, is observed in operation planning and in subsequent reservoir regulation procedures:

First, flood control will be provided for by observation of the requirement that an upper block of this intermediate storage space in each reservoir will be vacant at the beginning of each year's flood season, with evacuation scheduled in such a manner that flood conditions will not be significantly aggravated if at all possible. (This space is available for annual regulation for flood control and all multiple purpose uses, but should be vacant at the beginning of each year's flood season.)

Second, all irrigation, and other upstream water uses for beneficial consumptive purposes during each year will be allowed for. This allowance also covers the effects of upstream tributary reservoir operations, as anticipated from operating plans for these reservoirs or from direct contact with the operating agencies.

Third, downstream M&I water supply and water quality requirements will be provided for.

Fourth, the remaining water supply available will be regulated in such a manner that the outflow from the reservoir system at Gavins Point provides for equitable service to navigation and power.

Fifth, by adjustment of releases from the reservoirs above Gavins Point, the efficient generation of power to meet the area's needs consistent with other uses and power market conditions will be provided for.

Sixth, insofar as possible without serious interference with the foregoing functions, the reservoirs will be operated for maximum benefit to recreation, fish and wildlife.

9-4. Changes in Service Requirements. The main stem system of reservoirs was authorized as a major element of the overall Missouri River basin development program. The total program, as described in Section III, calls for many other improvements, including tributary reservoirs, channel improvements, and levee projects as well as irrigation projects which will affect Missouri River flows. The program is a long-range coordinated program and its development is scheduled to continue over a long period of years. It will probably be after the year 2020 before the complete development, as now visualized, is realized. The development of the main stem reservoir system in itself represented about a 30-year program. Throughout the entire basin development period, the main stem system will be operated to achieve the maximum possible overall benefits consistent with the priorities established by law, the availability of water supply and the provision of equitable service to authorized functions. As water resource development progresses, or as a result of changing national and regional goals and policies, service requirements for the main stem system and its components will change.

9-5. Service requirements for the flood control function of the main stem reservoirs may be used as an illustration of these changes. Initial regulation of Fort Peck Reservoir for flood control consisted largely of storing water during the high-water season to be released during the late summer and fall and controlling releases so as to provide protection in the river reach immediately below the project, with benefits further downstream only incidental to such operations. As downstream reservoirs of the main stem system were completed and placed in operation, more positive flood protection for a greater portion of the basin was assured. As tributary reservoir development continues, together with increased depletions from flood flows resulting from irrigation development, it may be found practicable to allocate more storage space for multiple-purpose uses and still provide the required degree of flood protection. Downstream channel improvements and levee projects constructed during the coming years could also have a marked effect on requirements for successful flood control operations.

9-6. In addition, power transmission facilities, power markets and rates, integration of hydrogeneration with thermal generation, irrigation above, below and directly from the projects, and many other factors will have a direct bearing on the methods of reservoir regulation. For these reasons, continuing studies to provide the greatest possible overall service to all functions for which the reservoirs were authorized are made, with regulation practices adjusted accordingly.

9-7. Flood Control. Planning and subsequent operation for the flood control function of the main stem system of reservoirs constitutes a major phase of this manual and is presented in detail in Sections X and XI. For this reason, it is not discussed in this section on multiple-purpose regulation. However, it is evident that the storage of water in the system for multiple-purposes during periods of high runoff, for later release during low-flow periods, will be compatible with the flood control function. Similarly, storage of water for the control of floods is also compatible to a great extent with multiple-purpose operation of the system.

9-8. Irrigation. Federally developed irrigation projects served directly from the main stem reservoir system are being constructed; however, at this time none are in operation. Releases from the reservoirs are utilized by numerous private irrigators as well as by Federally financed projects. Private irrigation directly from the reservoirs is also developing. While minimum releases established for water quality control or for satisfactory water intake operation are usually ample to meet the needs of irrigators, at times low river stages and associated exposure of sandbars and drying up of secondary channels makes it difficult or inconvenient to obtain access to the available supply. Instances of such occurrences are discussed in individual main stem project regulation manuals. As the large Federally developed irrigation projects diverting directly from the reservoirs begin operation, their effects upon streamflow must be recognized; however, active manipulation of releases through the downstream outlet facilities will not be necessary since these projects will pump their requirements directly from the reservoirs or appurtenant facilities.

9-9. Water Supply. It is essential that the main stem reservoirs be operated in a manner to provide sufficient streamflow in intervening reaches between reservoirs and in the lower Missouri River reach from

Yankton, South Dakota, to the mouth at St. Louis, Missouri, in order to sustain public water supplies of the numerous communities along the banks of the river. Numerous water intakes are located along the Missouri River both within and below the system of reservoirs. These intakes are primarily for the purposes of municipal water supplies, fossil and nuclear-fueled electric plant cooling purposes, and for irrigation supplies withdrawn directly from the Missouri River. Over the past years, problems have been associated with several of these intakes; however, the problems have been a matter of intake access to the water rather than insufficient water to supply requirements.

9-10. Operating experience has demonstrated that a minimum daily average release of 3,000 cfs from Fort Peck Reservoir is satisfactory for municipal water supply. This is also an ample rate to meet all irrigation demands below the project. However, the formation of sandbars has at times restricted flows to the intake of the Bureau of Indian Affairs irrigation pumping plant near Frazer, Montana, temporarily requiring Fort Peck releases above this minimum level. At Garrison, it is desirable to maintain minimum average daily releases of at least 6,000 cfs during the open-water season and about 4,000 cfs during the ice-cover season to provide sufficient river depths for satisfactory operation of water intakes in North Dakota. In this reach of the river, as well as below Fort Peck Reservoir, changes in release levels at times require the resetting of irrigation pumping facilities to achieve access to available water or to prevent inundation of pumps.

9-11. No restriction on minimum releases from Oahe and Big Bend is necessary for adequate service to water intakes, since the headwaters of downstream reservoirs usually extend to near the upstream dam sites. However, maintenance of minimum flows from Oahe of at least 3,000 cfs during the daylight hours of the recreation season is desirable to enhance downstream boating and fishing. Mean daily releases of 1,000 cfs are adequate to meet the supply requirements immediately below Fort Randall while below Gavins Point flows considered necessary for water quality control are also sufficient for water supply requirements. However, the minimum daily flow requirements established for water quality control could create operational problems at the municipal water supply intake at Yankton, South Dakota and municipal and electric power plant intakes at numerous other locations along the Missouri River below the reservoir system. Similar to problems which have been experienced within the system, this is a matter of intake elevations or access to the available water supply. Evaluations are continuing by the Environmental Protection Agency in coordination with water plant operators and appropriate state agencies, to determine the minimum stage and flow required at each intake for satisfactory hydraulic operation. With system storage reserves at normal or high levels, releases for navigation and for power production purposes during the non-navigation season will be at levels which operating experience has indicated are adequate for these downstream needs. However, if it should become necessary to reduce system releases below the 10,000 cfs level, continuing surveillance of these downstream intakes will be required in order to assure adequate supplies.

9-12. Water Quality Control. The Missouri River main stem dams have provided a very stabilizing effect upon the quality of reservoir inflows, resulting in high quality impounded water. A program for monitoring the quality of releases from all projects except Big Bend (where outflows are very similar to those from the upstream Oahe project) was started in 1967. In addition, there is a program for sampling inflows from each of the major tributaries and sampling the water stored in the reservoirs. Sample analysis includes temperatures, dissolved oxygen, conductivity, turbidity, pH, alkalinity, BOD, COD, fecal coliform, dissolved solids, and specified elements and radicals. These analyses indicate that both the stored and released water are of better quality than the water quality standards criteria imposed by any Missouri River basin state. Dissolved oxygen levels are always near saturation and only minimum variations are observed in pH values. High nutrient levels (ammonia, nitrates and phosphorous) are present, but no nuisance algae blooms have occurred. Water temperatures range between natural seasonal variations with maximum summer release water temperatures ranging from approximately 50 degrees F. at Fort Peck, Montana, to 75 degrees F. at Yankton, South Dakota.

9-13. Water quality requirements for all projects upstream from Gavins Point will be met by the releases discussed previously. Tentative flow requirements for satisfactory water quality were established by the U.S. Public Health Service and presented in the 1951 MBIAC Report on Adequacy of Flows in the Missouri River. These tentative requirements were used until 1969 when the earlier values were revised by the Federal Water Pollution Control Administration, after consideration of current sewage treatment practices along the river and maintenance of satisfactory dissolved oxygen levels (5 ppm). These requirements do not include allowance for the effects of wastes from feedlots or other agricultural operations. Pending further investigations of these factors, minimum daily flow requirements listed in the following table will be used for operational purposes.

TABLE 6

MINIMUM DAILY FLOW REQUIREMENTS FOR ADEQUATE DISSOLVED OXYGEN IN CUBIC FEET PER SECOND

Metropolitan Area	December January February	March April	May	June July August September	October November
Sioux City	1,800	1,350	1,800	3,000	1,350
Omaha	4,500	3,375	4,500	7,500	3,375
Kansas City	5,400	4,050	5,400	9,000	4,050

9-14. Navigation. Successful commercial navigation on the Missouri River from Sioux City, Iowa, to the mouth is dependent upon low flow supplementation from the main stem reservoir system, with occasional assistance from certain tributary reservoirs. Navigation is limited to the ice-free season and, based on historical records of ice formation on the Missouri River together with experience gained in system operations to date, opening and closing dates of a normal 8-month navigation season are scheduled as follows:

	Opening Date	Closing Date
Sioux City	March 23	November 22
Omaha	March 25	November 24
Kansas City	March 28	November 27
Mouth	April 1	December 1

It should be recognized that in some years ice conditions will undoubtedly delay the opening of the season and in others may force an early shutdown.

9-15. To encourage commercial traffic, it is desirable to utilize all of the available season by maintaining navigable flows throughout this 8-month period. During past navigation seasons, 10-day extensions, either beyond or prior to this normal season, have been scheduled on a trial basis, ice conditions permitting. Experience with extensions and attempted extensions prior to the normal opening dates of the navigation season has not been very satisfactory. In many years, the ice cover below the system is still in place at the time it is necessary to schedule increased releases from the system to provide the extension, prohibiting the early opening. Additionally, in those years when earlier-than-normal navigation releases are possible, experience has indicated that towboat groundings during this early period are much more frequent than during the remainder of the season. The increased incidence of groundings appears to be related to the cold water temperatures and their effect upon channel topography. Although early opening of the navigation season is faced with problems, market conditions favor early transport of grain, fertilizer, and other commodities on the river and reservoir releases necessary to provide satisfactory depths are generally much smaller than for a fall extension. Therefore, provision of an early opening will continue to be explored as conditions warrant. Any additional releases made from the main stem reservoirs for this purpose will be recouped later during the same navigation season, unless flood storage evacuation releases in excess of navigation requirements are necessary. With an adequate water supply, consideration will also be given to extensions beyond the normal closing date. While the provision of a scheduled season of a full 8 months is highly desirable, it will be practicable to curtail the length of navigation season considerably in occasional and infrequent critical low flow periods, if actually necessary because of a scarcity of water, without jeopardizing the success and long-term value of navigation on the present project, providing that full 8 months seasons can be maintained during most years. This occasional shortening of the season is considered preferable to reducing releases below what are considered minimum satisfactory service levels.

9-16. Construction of the navigation project has as yet not been completed and, after completion, several additional years will be required before the river itself completes its part of the job of carving out the finished channel. Based on actual experience with the incompleted channel, minimum downstream flows which will permit satisfactory navigation are 25,000 cfs at Sioux City and Omaha, 31,000 cfs at Nebraska City, and 35,000 cfs at Kansas City. When these minimum flow levels occur, dredging is required to maintain satisfactory navigation and a relatively high incidence of grounds can be expected. With the present level of streamflow depletions, inflows to the reservoir system are sufficient to support these minimum flow levels or higher in about 3 years out of 4 without any loss of water in storage. When system storage reserves are adequate, it is, therefore, desirable to maintain navigation flows above the minimum levels. This will result in decreased dredging requirements and can also result in barge loadings to greater depths than would be possible with minimum flows. In addition, the increased releases which provide the improved service to navigation will reduce the probability of having to release at rates which provide little or no benefit to navigation or to hydropower generation during flood storage evacuation. Based on numerous operation studies, a release rate equal to or slightly in excess of the long-term normal that can be sustained from the system provides the most efficient regulation of an essentially filled system. Therefore, after consideration of the effects the flow levels will have upon navigation, target flow levels 6,000 cfs greater than the minimum flows specified above have been selected as the "full-service" level for navigation under present-day depletion conditions. Utilization of the target-flow concept, with target flow levels 6,000 cfs greater than the minimums specified above, will result in average navigation season flows at Sioux City of about 35,000 cfs.

9-17. To facilitate application of regulation criteria, a numeric "service level" has been adopted. Quantitatively this service level approximates the normal 8-month navigation season flow past Sioux City. For the "full-service" level described above, the numeric service level is 35,000 cfs. This service level is utilized for selection of appropriate navigation flow targets at downstream control points on the Missouri River. The relationships between service level and control point target discharge are as follows:

TABLE 7

RELATION OF TARGET DISCHARGES TO SERVICE LEVEL

Control Point	Target Discharge Deviation from Service Level
Sioux City	-4,000 cfs
Omaha	-4,000 cfs
Nebraska City	+2,000 cfs
Kansas City	+6,000 cfs

From the above, it is evident that the "full-service" level of 35,000 cfs at Sioux City results from target discharges of 31,000 cfs at Sioux City and Omaha, 37,000 cfs at Nebraska City and 41,000 cfs at Kansas City. Selection of the appropriate service level to be maintained is based on accumulated system storage as of 15 March and 1 July of each year as follows:

TABLE 8

RELATION OF SERVICE LEVEL TO SYSTEM STORAGE

Date	Service Date	System Storage, Million AF
15 March	35,000 cfs (full-service)	54.5 or more
	29,000 cfs (minimum-service)	46.0 or less
1 July	35,000 cfs (full-service)	59.0 or more
	29,000 cfs (minimum-service)	50.5 or less

Interpolation defines intermediate service levels. In the event of high flood inflows during the early spring flood period which signficantly increases system storage after 15 March, an analysis will be made to determine if the navigation service level should be raised prior to 1 July.

9-18. In the event of a severe extended drought, it may be necessary to shorten the navigation season to less than the normal 8-month length in order to conserve the remaining available water supply. Current criteria relate the navigation season ending date to storage remaining in the main stem system as shown in the table below.

TABLE 9

SYSTEM STORAGE VS NAVIGATION SEASON LENGTH

1 July System Storage 1,000 AF	End of Navigation Season Sioux City Date
41,000 or more	22 November
40,000	15 November
39,000	7 November
37,500	31 October
36,500	22 October
35,000	15 October
33,500	7 October
32,000	30 September
30,000	22 September
27,500	15 September
25,000 or less	7 September

9-19. Fall extensions of the navigation season beyond the normal 8-month length will be scheduled (ice conditions permitting) in years with above-normal water supply when such extensions will not result in significant drawdown into the system carryover storage space. Based on experience to date, these extensions will be limited to 10 days beyond the normal closing dates given in paragraph 9-14. In addition to enhancing navigation, the 10-day extension of the navigation season also enhances the power function of the system by transferring an additional block of power from the normal navigation season to the more critical (for power purposes) winter season.

9-20. Frequent groundings are often experienced during the early portion of the navigation season. These are believed to be due to a combination of cold water temperatures and the requirement for channel dimensions to adjust from the winter release level to navigation flows. To alleviate this situation, navigation releases at the beginning of the season may be scheduled for a few weeks at a level of up to 5,000 cfs higher than storage conditions at the time would indicate to be applicable for the season. The quantity of water necessary to sustain the higher than normal early season flows will then be recouped by appropriate release reductions during the mid-summer and early autumn period, when groundings are normally at a minimum, unless storage evacuation requirements make the reductions unnecessary.

9-21. Day-by-day regulation of the system to support navigation requires forecasts of inflow to various reaches of the river below the system as described in Section VIII. From these forecasts and current target flows, the control point (either Sioux City, Omaha, Nebraska City, or Kansas City) is determined daily. Anticipated traffic or absence of traffic at the control points will also have a bearing on the control point selection. For this reason, it is necessary that the Reservoir Control Center be continuously aware of traffic movement on the navigation channel. After selection of the control point, releases from the system are adjusted so that, in combination with the anticipated inflows between the system and the control point, they will provide the target discharge at the control point.

9-22. Power Production. Hydroelectric power generation at the main stem power plants represents one of the basic functions of the system. The power output of the system will continue to be of great importance and of direct interest because of (a) the day-by-day direct benefits realized by a large segment of the basin's population in the form of relatively low-cost power, and (b) the annual return of very substantial cash revenues to the Treasury of the United States (on the order of $100,000,000 annually).

9-23. Hydroelectric power generation is not a consumptive use of water. However, the realization of the maximum power potential provided by the water passing through the dams of the reservoir system requires that power operations be carefully integrated into operation of the overall system. This requires consideration of many factors, including generating capacity at each plant, marketability and current market price of generated power, necessary peaking capability, anticipated long-range storage balance requirements, regional power emergencies, and others. Regulation of the reservoirs is scheduled to develop the maximum power benefits consistent with equitable service to other system functions.

9-24. Hourly patterning of the average daily releases is also of major importance in realizing the full power potential of the main stem power plants and the need for a greater range in power releases will develop as upstream irrigation depletions grow. Based on past experience with both open water and a downstream ice cover, it appears that (with the exception of Gavins Point) no limit need be placed upon daily peaking, up to the capacities of the individual power plants, provided the limiting mean daily discharge is not exceeded. At the downstream Gavins Point project, it appears prudent during the navigation season to limit variations in discharge to the extent that cumulative releases will not depart more than 10 percent of the total daily release from a flat schedule. The peaking capability of this project during the winter months is limited to the capability of two units. The minimum allowable hourly generation, and corresponding release, is dependent upon the hydraulic characteristics of the river below each of the projects and the effect upon water use in the downstream reaches. Downstream water supply intakes, the status of irrigation pumping below projects, fish spawning activities in the downstream channel, recreational usage and other factors which may be seasonal in nature influence the selection of minimum limits. These restraints at particular projects are summarized above and discussed in more detail in the appropriate project regulation manuals.

9-25. In addition to hourly patterning, it is possible, due to the flexibility inherent in such a system of reservoirs, to pattern project releases (with the exception of Gavins Point) to cycles extending for periods longer than a day in duration for maximum power development, while still providing full service to functions other than power. During the navigation season, when downstream flow requirements are high, large amounts of water are normally released from Gavins Point. This requires that large volumes of inflow to Gavins Point be supplied from Fort Randall. Fort Randall, in turn, requires similar support from Big Bend, and Big Bend from Oahe. Here the chain can be interrupted; Oahe Reservoir is large enough to support high releases for extended periods without correspondingly high inflows. High summer releases from Gavins Point, Fort Randall, Big Bend, and Oahe mean high generation rates at these plants. To avoid generating more power than can be marketed advantageously under these circumstances, the usual practice during this time of year is to hold releases and generation at Fort Peck and Garrison to quite low levels unless the evacuation of flood control storage space, or the desire to balance storages between projects, becomes an overriding consideration. With onset of the non-navigation season, conditions are reversed. Releases from Gavins Point drop to about one-fourth to one-half of summer levels and the chain reaction proceeds upstream curtailing discharges from Fort Randall, Big Bend, and Oahe. At this time, Fort Peck and Garrison releases are usually maintained at the maximum levels permitted by the downstream ice cover to partially compensate for the reduction in generation downstream.

9-26. The disparity between summer power generation, when releases from four of the six main stem projects are relatively large to support Missouri River navigation, and winter generation, when system releases must be restricted due to the limited ice-covered channel capacity, may be eased by another aspect of system operation: the draft and refill of a portion of the Fort Randall carryover storage space. In this operation, Oahe and Big Bend releases are reduced several weeks before the end of the navigation season. This leaves Fort Randall storage with the task of supplying a portion of downstream flow requirements for the remainder of the season, a process which results in evacuation of a portion of its carryover storage space. This vacated carryover storage space is then refilled from Oahe and Big Bend releases during the non-navigation season. Whereas the volume of winter releases from Oahe and Big Bend, in the absence of this recapture operation, would be about equal to those from Fort Randall, the refill of the evacuated Fort Randall space allows winter releases from these upstream projects to substantially exceed those from Fort Randall.

9-27. During the period of initial fill and operation of the system in years prior to 1971, as much as two million acre-feet of storage below the base of seasonal flood control were drawn out of Fort Randall during this operation. The refill of the evacuated storage space allowed Oahe and Big Bend releases to exceed Fort Randall releases by an average of 8,000 cfs for the winter. This operation resulted in substantially more winter energy generation, exceeding 300,000,000 kwh when the Oahe pool was at its normal level. However, generating capability in early December was reduced by 60,000 to 70,000 kilowatts due to the lowered Fort Randall pool level. There were also penalties to other functions of the reservoir system. A lowered Fort Randall pool has an adverse effect upon recreation in and around the reservoir area while the exposed reservoir floor becomes undesirable in an esthetic sense. The effects of this drawdown operation upon the surrounding environment became an increasing concern in recent years, particularly when this drawdown proceeded below elevation 1340. Studies conducted in 1971 and 1972 resulted in a compromise being accepted limiting the drawdown to elevation 1337.5 in most years. Drawdown to this level will be delayed as late in the navigation season as practical in order that any adverse environmental effects will continue for the shortest possible period of time. This will also coincide with the period during which there is a marked decline in the recreational usage of the reservoir. The drawdown level of elevation 1337.5 makes available about 900,000 acre-feet of storage space below the base of the annual flood control zone for recapture of winter power releases from Oahe and Big Bend. During drought periods, when system storage reserves and system releases are reduced, additional drawdown of Fort Randall to as low as 1320 is scheduled to permit Oahe and Big Bend releases to be maintained at 15,000 cfs during the winter period.

9-28. While not as significant (in terms of pool level fluctuation) as Fort Randall recapture operations, a similar operation of Oahe Reservoir coordinated with upstream Garrison and Fort Peck releases also significantly increases the amount of winter energy generation. During the 4-month winter period, Garrison releases normally are scheduled to be at least 1 million acre-feet more than Oahe releases. Recapture of these upstream releases results in a rise of up to 5 feet or more in Oahe elevation during the winter months.

9-29. Similar to release selection for navigation, the level of system releases during the non-navigation season to support the power function is dependent upon system storage. Selection is based on the accumulated system storage as of 1 September of each year as follows:

TABLE 10

RELATION OF WINTER RELEASE LEVEL TO SYSTEM STORAGE

1 September System Storage, Million AF	Average Fort Randall Winter Releas
58.0 or more	15,000 cfs
43.0 or less	5,000 cfs

Interpolation defines intermediate release levels. Gavins Point (system) release is equivalent to the Fort Randall release plus incremental inflow originating between the two dams. A modification to the maximum release of 15,000 cfs from Fort Randall occurs during those winter seasons when the preceding season's water supply has been so large that evacuation of system flood control storage cannot be accomplished at full-service navigation season releases (discussed in paragraph 9-17) and with a 10-day extension of the navigation season (discussed in paragraph 9-19). With an excess water supply, winter season Gavins Point release will be scheduled at a rate of up to 20,000. Release rates in excess of 20,000 cfs may occur as discussed in Section X, paragraph 10-17.

9-30. Day-by-day regulation of the system for power purposes is closely coordinated with the Western Area Power Administration (the marketing agency for Federally generated power in the basin), and with regulation of the system for non-power purposes. Detailed advance planning, as described later in this section, is essential in order that releases from each of the projects for any of the other multipurpose functions may be utilized to the fullest extent practicable for optimum power production. Daily schedules of power production from each plan are prepared and furnished the Bureau of Reclamation who in turn make such daily changes in the power marketing arrangements as are necessary. Power production orders, which include the scheduled daily generation as well as limits of power plant loading, are issued to individual plants. Within the limits of the daily schedules, the actual hourly loadings of the plants are controlled by the Bureau of Reclamation, subject to the limitations imposed by load limits in the power production orders, and discharge limits imposed by concurrent reservoir regulation orders. Typical weekly patterns of power plant loadings during the navigation and non-navigation seasons are shown on Table 11.

9-31. Fishery Management. Fish production and development in and below the main stem projects are directly affected by reservoir levels and releases, particularly during the spawning period. The Federal and state fish and wildlife agencies recognize that it is not possible to operate each reservoir each year for optimum fish management and have indicated that a good spawn of a fish species 1 year out of 4 or 5 is adequate to maintain the fishery resource in a specific reservoir. Therefore, one or more reservoirs may be selected each year for emphasis in the enhancement of fish management and, to the extent that inflows and regulation requirements for other purposes permit, the selected projects are regulated to improve the fishery resource.

9-32. Fish and wildlife interests have expressed their desire to provide conditions suitable for the spawning of northern pike in all of the main stem reservoirs at appropriate intervals. This involves raising the levels to where shoreline vegetation is present, and regulating at or above these levels during the spring spawning season. In the downstream Big Bend, Fort Randall, and Gavins Point Reservoirs this can normally be accomplished with little disruption of the other functions the system was designed to serve. Provision of desirable pool levels in Oahe Reservoir for spawning activities will usually require the accumulation of a plains snow cover during the winter months, and moderate early spring runoff from the melting of this snow cover, if other system functions are not to be adversely affected. The normal seasonal distribution of inflows into Fort Peck and Garrison Reservoirs, together with regulation for other purposes, in particular power generation, results in pool level variations which are not at all favorable for northern pike spawning. The major adverse effect upon power generation necessary for development of northern pike spawning habitat in these reservoirs and for providing satisfactory spawning conditions has precluded operation of these two upstream projects specifically for pike spawning. However, particular hydrologic and reservoir storage conditions which would be conducive to achieving satisfactory spawning conditions without major operational changes have been identified with a view to taking advantage of these situations when they occur.

TABLE 11

TYPICAL WEEKLY VARIATION IN MAIN STEM POWER

Navigation Season

Project	Wed	Thur	Fri	Sat	Sun	Mon	Tue
Fort Peck							
Generation (GWH)	3422	3432	3448	3405	3002	3408	3441
Peak (GW)	176	180	181	180	133	178	187
Garrison							
Generation (GWH)	6649	6014	6052	6002	5398	6635	6603
Peak (GW)	324	342	326	322	295	377	397
Oahe							
Generation (GWH)	8401	9027	8605	7271	6085	9570	10755
Peak (GW)	362	522	568	493	391	584	569
Big Bend							
Generation (GWH)	2995	2869	2572	2948	2070	3075	3895
Peak (GW)	229	240	231	233	172	283	290
Fort Randall							
Generation (GWH)	7104	7144	7094	6358	5122	6870	6694
Peak (GW)	306	306	305	286	252	302	305
Gavins Point							
Generation (GWH)	2286	2302	2322	2335	2336	2312	2296
Peak (GW)	96	97	97	98	98	98	97
Total System							
Generation (GWH)	30857	30788	30093	28319	24103	31870	33684
Peak (GW)	1650	1613	1588	1517	1299	1779	1766

Non-Navigation Season

Project	Wed	Thur	Fri	Sat	Sun	Mon	Tue
Fort Peck							
Generation (GWH)	4583	4594	4602	4583	4599	4601	4595
Peak (GW)	196	197	196	197	198	201	196
Garrison							
Generation (GWH)	9703	9711	9802	9859	9485	9796	9625
Peak (GW)	449	453	459	459	455	454	450
Oahe							
Generation (GWH)	6913	5467	5743	4056	1578	4639	4972
Peak (GW)	579	490	480	502	311	399	450
Big Bend							
Generation (GWH)	2734	2257	2005	1626	596	2100	1993
Peak (GW)	244	182	186	126	110	244	278
Fort Randall							
Generation (GWH)	2533	2505	2520	2512	2201	2695	2658
Peak (GW)	193	192	198	193	205	212	210
Gavins Point							
Generation (GWH)	1341	1341	1341	1340	1330	1326	1325
Peak (GW)	56	56	56	56	56	56	56
Total System							
Generation (GWH)	27807	25875	26113	23976	19789	25157	25168
Peak (GW)	1703	1566	1536	1504	1253	1511	1492

9-33. Another area of increasing concern to fisheries interests is the propagation of forage fish to feed the game fish species. Since the forage fish spawn later in the season than northern pike, a stationary or rising pool level extending through June is considered desirable. Fortunately, such an operation is usually compatible with normal operation for other purposes at Fort Peck and Garrison, and can often be accommodated with relative ease during years of high water supply to Oahe and Fort Randall. During years of deficient supply or abnormal distribution of the supply, such an operation would not be possible at one or more of the main stem projects.

9-34. Fish spawning below the projects is also recognized. During the spawning season, outflow from a particular project may be continuously maintained at or above some specified level to assure adequate water depths for spawning or continuous inundation of spawning beds. This is particularly true below Fort Randall Dam where an outstanding sauger fishery has been established.

9-35. Recreation. The Missouri River main stem reservoirs, reaches of the Missouri River below the reservoirs, and areas adjacent to these bodies of water, provide outstanding opportunities for the enjoyment of outdoor recreational pursuits. While manipulation of the levels of larger reservoirs (Fort Peck, Garrison, and Oahe) to enhance this function is not practical, recreation will be recognized during periods of system storage drawdown by maintenance of balanced storage within these two projects to the extent practical. Pool level manipulations at the smaller projects are scheduled if desired by recreation interests and, if compatible, with other system functions. For example, the Gavins Point pool is often raised toward the base of exclusive flood control prior to the normal 1 August date if hydrologic conditions permit in order to enhance recreational use of the reservoir. For recreational use, releases from any particular project may be adjusted from those otherwise maintained, provided that this would not have a serious effect upon other system functions.

9-36. Environment. Development of the main stem reservoir system has transformed a major portion of the Missouri River valley extending from eastern Montana through the Dakotas from an area typical of alluvial streams through this region into a chain of long, relatively deep lakes. This development, in an area where such lakes did not exist naturally and which is characterized as being relatively dry, has had a great effect upon the environment of the area. Purchase and subsequent management of lands associated with the individual projects has changed use patterns of lands adjacent to the lakes from use experienced prior to projects. Regulation of the reservoirs also has significantly affected the regime of the Missouri River through those reaches below the main stem system and in those reaches between main stem reservoirs where the river is still more or less in its natural state. The full impact of each of the main stem reservoirs and its operation upon the environment is under continued study at this time and complete findings are not expected to be available for a few years. However, through observations and discussion with interested individuals and agencies, suggestions for environmental enhancement have been received and are being implemented to the degree feasible with overall project purposes.

9-37. A major point of emphasis in environmental considerations has been the effect of various operational practices upon fish and wildlife. Improvement of fish spawning activities by appropriate management for habitat development and subsequent spawning is an important consideration in reservoir operations as discussed elsewhere in this report. Suggestions have been made and adopted to the degree practical for improving migratory waterfowl habitat and hunter access along the river below the projects. However, other suggestions such as that flows be significantly reduced during the migration period in order that more sandbars be available cannot be implemented at all times without serious effect upon other project functions. As further suggestions are received they will be evaluated with Federal and state fish and wildlife agencies and, if found desirable, will be instituted to the degree practical.

9-38. Fluctuating water levels of the reservoirs are also a concern to many. However, in this connection, it must be recognized that some fluctuation in the reservoir levels is unavoidable if the reservoirs are to perform functions for which designed. A continuing objective in regulation of the system is to minimize departures in pool elevation from normal full multi-purpose levels to the maximum practical extent consistent with other project functions. The partial elimination of the annual drawdown of Fort Randall Reservoir is a good example.

9-39. The maintenance of relatively uniform release levels is also an environmental objective of many interested parties. While reservoir operation has had a great effect on reducing high flows and supplementing low flows which naturally occur on the river, some fluctuations in release rates continue to be unavoidable if authorized project functions are to be served. As a consequence, stream bank erosion may be greater than would occur with constant releases. Additionally, access to the river may be more difficult at times, fishing success may be affected, the sediment load in the river may be increased and use of fixed boat docks may be inconvenienced. To the extent practical, considering release requirements for other authorized purposes, release fluctuations are being minimized. Suggestions have been made and are being considered for the construction of re-regulating structures for the purpose of further minimizing downstream flow fluctuations.

9-40. Improvement of the downstream water quality is another environmental consideration receiving much emphasis at this time. As discussed elsewhere, relatively good quality water is stored and released from the reservoirs. As problem areas are brought to the attention of the Reservoir Control Center, regulation to alleviate these problems will be an additional goal.

9-41. Integration of Downstream Requirements. System releases are designed to provide equitable service to all multiple-use functions, while at the same time recognizing the important flood control function of the system. In years of excess water supply, system releases in excess of full-service navigation requirements are required to evacuate flood control storage space. In recognition that these higher-than-normal releases can have an adverse effect upon downstream floods, should unexpected rainfall occur, the higher releases are concentrated in periods when floods from downstream tributaries are less probable. Also, the magnitude of these releases during the open water season is reduced somewhat by scheduling winter releases at a higher rate than would be the case with a normal water supply. While this has the effect of somewhat increasing the possibility of adverse effects of flood control storage evacuation during the winter months, it reduces this possibility during the open water season which is the season of maximum flood potential. In addition, it also increases the service provided to the power and navigation functions by extending the navigation season length and increasing the amount of winter energy generation. Flood storage evacuation releases above full-service navigation requirements during the open water season also usually have a beneficial effect upon the navigation and power functions.

9-42. With a normal or less-than-normal water supply, navigation and power releases during the open water season will be based on existing and anticipated system storage and may provide less than full-service navigation requirements when storage reserves are depleted. Under such conditions, winter power releases are also reduced and are scheduled on the basis of maintaining an average Fort Randall winter release about 20,000 cfs less than the average navigation service level at Sioux City. Full-service winter power releases of 15,000 cfs from Fort Randall correspond with full-service navigation service which, in normal runoff years, provides an average navigation season flow of about 35,000 cfs at Sioux City. If, due to a severe depletion in system storage reserves, it becomes necessary to reduce navigation season lengths to less than 8 months, winter power releases from Gavins Point will be reduced to the minimum necessary for water intake or water quality requirements. The minimum release considered applicable at this time is 6,000 cfs. Releases this low would occur only during drought periods of several years duration, which would provide adequate time for modification of downstream intakes, if required.

IX-B. Multi-Purpose Operation Plans.

9-43. General. In the course of the planning, design, construction and regulation of the main stem reservoir system, many long-range regulation studies have been made to establish and demonstrate the capabilities of the system and to establish criteria for planning, design and operational purposes. Other shorter term studies, on a continuing basis, lead to Annual Operating Plans, 5-year projections, and many other special purpose plans.

9-44. In these studies, flood control is recognized by providing sufficient predetermined vacant storage capacity at each of the reservoirs at the beginning of the flood season. Early studies gave very little additional recognition to flood control below the reservoir system; however, more recent studies based on historical runoff do recognize release limitations imposed by the flood control function. Since the long-range studies are based on time increments of up to a month in length, they do not serve as a vehicle for examination of detailed flood control regulation criteria. Additionally, floods that might conceivably tax the total amount of storage space allocated to the flood control function have not been experienced in the available historical runoff period since 1898.

9-45. Long-Range Operation Studies. Long-range operation studies of the main stem system encompassing the hydrologic period from 1898 to the time of the study have been referred to previously, particularly in Section V, System Storage Allocations, where some of the limitations of these studies were discussed. Major studies have been published and distributed to interested Corps' offices, the Bureau of Reclamation, the Federal Power Commission, and others. Table 12 lists the major studies performed in the past and pertinent data as to the basic conditions assumed in their performance.

9-46. Service to Functions. The studies described in the preceding paragraph demonstrate the service which the main stem reservoirs will furnish to the basic functions (except flood control) under various levels of basin development and conditions of water supply.

They also serve to examine variations in regulation criteria and in this manner keep criteria consistent with changing emphasis upon specific functions through the years. The latest studies reflect current conditions (or presently anticipated future conditions) and the service to functions provided by the system when regulated by current criteria. As such, they are utilized by the Bureau of Reclamation in making their long-term power marketing arrangements.

9-47. Annual Operation Plans. An Annual Operating Plan (AOP) for operation of the Missouri River main stem reservoirs has been prepared by the Reservoir Control Center each year since system operations began in 1953. The report on the plan includes a discussion of basic operational considerations, a summary of actual operations and accomplishments during the preceding year, a record of the past year's water supply and estimates of future inflows under several water supply conditions, plans for future reservoir operations, and expected results. The AOP is considered by the Coordinating Committee on Missouri River Main Stem Reservoir Operations at its fall meeting, published in final form shortly thereafter, and widely distributed.

9-48. The Annual Operating Plan serves several major purposes. Briefly, it provides:

a. A basis for advance coordination with the Federal, state, and local agencies which are concerned with operation of the main stem reservoirs;

b. A guideline to actual operations;

c. A record of past operations and accomplishments; and

d. A means of informing interested agencies and individuals concerning past and expected future operations.

9-49. Operation of the reservoir system is reviewed in the Annual Operating Plan for the 12-month period beginning 1 August of the preceding year. Subjects covered in this review are:

a. Water supply available;

b. System operations;

c. Special operations;

d. Reservoir releases and storage; and

e. Summary of results by functions.

TABLE 12

MISSOURI RIVER MAIN STEM RESERVOIRS
LONG RANGE RESERVOIR OPERATIONS STUDIES

Study No.	Date of Study	Primary Purpose	System Storage Million AF	Development Level	Annual* Depletions Million AF	Installed Capacity in 1000 KW	Dec. 1933 Peaking Capability in 1000 KW	Average Annual Energy Generation in Billion KWH
VII-D-G	1945	Garrison DPR	69.7	2010	7.1			
VII-J	1946	Ft Randall & Oahe DPRs	71.9	2010	7.4	1145	774	5.9
IX-A	1950	Gavins Point DPR	72.5	2010	7.4	1382	1044	8.3
WA-1	1950	Water Adequacy	73.6	1960	2.1	1492	–	8.2
WA-2	1950	Water Adequacy	72.5	1970	4.0	1492	–	7.8
WA-3	1950	Water Adequacy	71.3	1980	5.9	1492	–	7.0
WA-4	1950	Water Adequacy	69.0	2000	7.7	1492	–	6.3
PGOR-6	1953	General	74.8	1970	4.0	1530	1010	8.0
PGOR-10A	1956	General	74.1	1970	1.2	1702	1435	9.3
PGOR-10B	1956	General	71.9	1990	4.8	1702	1388	8.1
16MB65	1958	Cost Allocation	74.5	1965	0.6	1797	1732	9.7
16MB75	1958	Cost Allocation	73.4	1975	1.7	1797	1699	9.2
16MB85	1958	Cost Allocation	72.3	1985	2.6	1797	1612	8.8
16MB25	1958	Cost Allocation	67.9	2025	6.4	1797	1512	7.2
PGOR-19A	1964	General	76.0	1970	1.2	2048	1970	9.19
PGOR-19B	1966	General	71.0	2020	6.8	2048	1958	6.90
4-67-70B	1967	Navigation Extension**	76.0	1970	1.3	2048	1957	9.24
4-67-70C	1967	Navigation Extension	76.0	1970	1.3	2048	1957	9.25
2-68-1970	1968	General	75.5	1970	1.3	2048	1949	6.27
5-68-1980	1968	General	73.2	1980	2.7	2048	1957	8.85
6-69-1970	1969	Basin Planning	75.3	1970	1.6	2048	1991	9.23
6-69-1980	1969	Basin Planning	73.2	1980	3.5	2048	1953	8.49
6-69-2000	1969	Basin Planning	70.8	2000	6.6	2048	2030	7.46
6-69-2020	1969	Basin Planning	68.3	2020	10.4	2048	1925	5.86
7-71-1970A	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1961	9.18
7-71-1970B	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1962	9.22
7-71-1970C	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1975	9.24
7-71-1970D	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1975	9.24
7-71-1970E	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1962	9.21
7-71-1970F	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1960	9.22
8-71-1970	1971	General	75.0	1970	1.6	2048	1975	9.24
12-71-1970A	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1971	9.21
12-71-1970B	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1958	9.16
12-71-1970C	1971	Ft Randall Drawdown	75.0	1970	1.6	2048	1944	9.11
1-72-1970	1972	Modified Allocations***	75.0	1970	1.6	2048	2124	9.20
1-72-1970C	1972	Ft Randall Drawdown	75.0	1970	1.6	2048	1971	9.26
5-72-1970	1972	Ft Randall Drawdown	75.0	1970	1.6	2048	1973	9.26
6-72-1970	1972	Ft Randall Drawdown	75.0	1970	1.6	2048	1967	9.26
2-73-1970	1973	General	75.0	1970	1.6	2048	1937	9.35
3-73-1970	1973	General	75.0	1970	1.6	2048	1918	9.04
1-74-1970	1974	General & Coal Development	68.7	1970	1.6	2048	1940	9.37
1-74-1980	1974	General & Coal Development	73.4	1980	2.6	2048	1894	9.12
1-74-1980, D700	1974	General & Coal Development	73.4	1980	2.7	2048	1887	9.07
1-74-1980, D1400	1974	General & Coal Development	73.4	1980	2.8	2048	1897	9.03
1-74-1980, D3000	1974	General & Coal Development	73.4	1980	3.0	2048	1905	8.94
1-74-2000	1974	General & Coal Development	70.0	2000	4.2	2048	1993	8.69
1-74-2000, D700	1974	General & Coal Development	70.0	2000	4.8	2048	1931	8.41
1-74-2000, D1400	1974	General & Coal Development	70.0	2000	5.3	2048	1994	8.51
1-74-2000, D3000	1974	General & Coal Development	70.0	2000	6.6	2048	1872	7.49
1-74-2020	1974	General & Coal Development	68.7	2020	5.0	2048	1884	8.14
1-74-2020, D700	1974	General & Coal Development	68.7	2020	5.7	2048	1847	7.80
1-74-2020, D1400	1974	General & Coal Development	68.7	2020	6.4	2048	1808	7.45
1-74-2020, D3000	1974	General & Coal Development	68.7	2020	8.7	2048	1775	6.26
1-74-MAX-ULT	1974	General & Coal Development	68.7	Ultimate	11.4	2048	2184	5.15
12-75-2000	1975	General & Coal Development	70.0	2000	4.2	2048	1935	8.56
12-75-2000, C500	1975	General & Coal Development	70.0	2000	4.7	2048	1902	8.30
12-75-2000, C1000	1975	General & Coal Development	70.0	2000	5.2	2048	1953	8.09
12-75-Ultimate	1975	General & Coal Development	70.0	Ultimate	8.5	2048	1802	6.55
2-76-1975	1976	Elimination of Navigation	74.6	1975	2.1	2048	1895	9.19
2-76-1975A	1976	Elimination of Navigation	74.6	1975	2.1	2048	2022	9.23
2-76-1975B	1976	Elimination of Navigation	74.6	1975	2.1	2048	2095	9.28

*Above Sioux City and above 1949 level of basin development. Excludes main stem reservoir evaporation averaging about 1.6 million acre-feet.

**Extension of Navigation to Yankton, South Dakota.

***Effects of Storage Allocation Modifications.

9-50. The Annual Operating Plan includes forecasts of water supply that will be available for the period from 1 August to 1 March of the following year. During this period of time, flows are relatively low and stable, and they can be forecast with reasonable reliability. A basic forecast of monthly inflows is made for each of the reservoir reaches above Sioux City, Iowa. Following 1 March, inflows depend on many factors that cannot be forecast at the time of preparation of the Annual Operating Plan. Therefore, for the studies of future operation beyond 1 March, a wide range of potential water supply conditions is considered, based on a statistical analysis of reach inflows during the period of record since 1898. The years selected for use in the AOP are the Upper Decile, Upper Quartile, Median, Lower Quartile, and Lower Decile. Selection of the monthly and annual runoff values considered appropriate for each of these water supply conditions is discussed in MRD-RCC Technical Report A-75.

9-51. Annual Operating Plan studies for the period from 1 August to 1 March of the current year are based on the basic forecast water supply described in the preceding subparagraph, on 80 percent of the basic forecast water supply, and on 120 percent of the basic forecast water supply. Expected reservoir releases, storages, elevations, evaporation, and power generation and capability are determined for each month for each water supply condition. Similarly, studies are made for the Upper Decile, Upper Quartile, Median, Lower Quartile, and Lower Decile, conditions for the March-December period of the next year. These studies are made with the aid of an electronic computer, and the results are plotted using an automatic data plotter. The studies for the year ahead are illustrative of possible operations rather than predictive of operations actually anticipated. Results of the studies are discussed in the plan, and detailed plottings are reproduced therein.

9-52. A 5-year extension of the Annual Operating Plan is presented as a part of the plan to serve as a guide for longer-range planning of operations and for the guidance of the Western Area Power Administration's power transmission and marketing program. The studies for the 5-year extension are based on the following conditions:

a. A succession of 5 Median years following the AOP Median year;

b. A Lower Quartile succession of 5 years following the AOP Lower Quartile year; and

c. A Lower Decile succession of 5 years following the AOP Lower Decile year.

The 5-year extension of the Annual Operating Plan based on Lower Decile years serves as a basis for establishment of the Western Area Power Administration's estimate of the amount of short-term capability it will contract to sell on an assured basis.

9-53. 3-Week Forecast. On each Thursday, a 3-week forecast of operation of the main stem reservoirs is prepared by the Reservoir Control Center. This study is prepared on 1-day time increments and serves as a guide for expected short-term trends. In graphical form, it serves as a briefing aid in the Division Office. Summarized data from this forecast are furnished the projects each Friday.

9-54. Special Unscheduled Operation Studies. Special purpose studies are often made in response to inquiries from higher authority, from Congress and from other Federal and State agencies. Additionally, throughout the year as forecasts of future runoff become available or are revised, studies are made to serve as a supplement to, and updating, of the Annual Operating Plan. Generally these additional AOP-type studies are made on a monthly basis if inflow conditions depart significantly from previous studies.

SECTION X - SYSTEM FLOOD CONTROL REGULATION

10-1. Objectives of Flood Control Regulation. The Missouri River main stem reservoirs are regulated, insofar as is practical, to prevent flows originating above or within the system from contributing to damaging flows through the downstream reaches of the Missouri River. Regulation of individual reservoirs which comprise the system is integrated to successfully meet this objective. In addition, each individual reservoir is regulated to prevent, insofar as practicable, reservoir releases from contributing to damaging flows through the downstream reaches in which the particular reservoir affords a significant degree of control.

10-2. Method of Flood Control Regulation. In general, the developed method of regulation of the Missouri River reservoir system as described in subsequent paragraphs may be classified as Method C, as defined in EM 1110-2-3600. This represents a combination of the maximum beneficial use of the available storage space during each flood event with regulation procedures based on the control of floods of approximate reservoir design magnitude. Specific procedures for the accomplishment of flood regulation are given in succeeding paragraphs, while examples of this regulation are presented in Section XI.

10-3. Storage Space Available for Flood Control. During any specific flood event, all available storage space within the main stem system of reservoirs will be utilized to the maximum extent practicable for flood control. This control will be provided in combination with other beneficial water uses for which the system was designed. Approximately 16.4 million acre-feet of system storage space are allocated for flood control purposes of which 4.7 million acre-feet is for this purpose exclusively; the remainder combining flood control with other uses. Most of this storage space is located in the Fort Peck, Garrison, Oahe, and Fort Randall Reservoirs with that contained within the Big Bend and Gavins Point projects being of relatively minor magnitude. In addition to allocated flood control storage space, surcharge space is available in each of the reservoirs, primarily to insure the safety of the project, but which will provide downstream flood reductions during extreme flood events. Carry-over storage space, when evacuated, will also serve the flood control function; however, deliberate evacuation of this space to serve flood control will not be scheduled.

10-4. As discussed in Section V of this manual, the current flood control storage allocation of the main stem system is based to a large degree on control of the 1881 flood as it actually occurred. This allocation has been examined and confirmed by many long range operation studies which continue through the current time. The availability of upstream tributary reservoir flood control storage space was not recognized in the 1881 flood studies while the early long range main stem regulation studies also did not consider tributary reservoirs regulated specifically for flood control along the main stem of the Missouri River. It is evident that tributary reservoir storage space upstream from the main stem system can be effective in reducing flood crests in the lower Missouri River if regulated for that purpose. Therefore, in recent years and in certain tributary reservoirs, a portion of the available storage space has been allocated to flood control use on a "replacement" basis. This is storage space which will be regulated in close coordination with the main stem system and, as a consequence, can replace a portion of the annual flood control and multiple-use space in the system. This effectively allows an increase in the amount of carryover storage which can be retained in the main stem reservoirs, with resulting multiple-use benefits, while continuing the same degree of downstream flood protection for which the main stem system was designed. Long range regulation studies conducted in recent years have incorporated this replacement storage concept and have demonstrated the resulting increased multiple-purpose benefits and continued flood control effectiveness of the expanded system of reservoirs.

10-5. Replacement flood control storage space has been provided in the upstream Clark Canyon, Canyon Ferry, and Tiber Reservoirs. These are all Bureau of Reclamation projects controlling drainage areas having relatively high yields that produce significant portions of the flood season runoff above the main stem system. There is a reasonably firm assurance that, in years of large runoff which could conceivably tax the flood control abilities of the main stem system, the replacement storage space in these reservoirs would be utilized for the control of main stem floods. Actual regulation of the main stem system proceeds as if this upstream tributary replacement space was a part of the main stem system's annual flood control and multiple-use zone. Consequently, at times main stem reservoir storage, or storage in a particular main stem reservoir, enters the flood season above the base of flood control and may appear to exceed that allowed by flood control criteria, when in fact it is consistent with those criteria due to the availability of upstream replacement storage space.

10-6. In addition to the tributary reservoirs which have assigned replacement flood control storage space, as discussed above, there are many other tributary reservoirs upstream from the main stem system which have no flood control space or flood control space assigned only for the purpose of local flood control. At times these reservoirs are drawn well below their deliberate fill level prior to the flood season.

Efficient basin water resources management requires that the status of storage in these reservoirs be considered to the extent practical, and to the extent that tributary reservoir fill is assured, in regulation of the main stem system while maintaining the overall flood control capability designed into the system.

10-7. Flow Regulation Devices. Releases from individual reservoirs comprising the main stem system may be made through respective power plants, outlet works, and spillways at each of the projects. In order to achieve the maximum economic return from the project, the power plants will be utilized to the fullest extent possible with the greatest portion of releases made in this manner under normal operating conditions. When releases greater than the power plant capacity or demand are necessary, the outlet works and spillways will be used. The spillway, in combination with surcharge storage provided, insures the safety of the dam in the case of extreme floods. Capacities of flow regulating devices at the projects are indicated on rating curves represented on Plates 16, 19, 22, 25, 28, and 31.

10-8. General Plan of Flood Control Regulation. Regulation of the main stem reservoirs in the interest of flood control to meet the objectives stated in paragraph 10-1 is based on careful consideration of factors given below:

a. Channel capacities through reaches of the river downstream from individual reservoirs and below the system.

b. Observed and anticipated inflows to those portions of the river through which the individual reservoirs and the system affords a positive degree of control.

c. Observed and anticipated inflows to the individual reservoirs and the system as a whole.

d. Space currently available within individual reservoirs and in the total system for the storage of future flood flows.

e. The flood producing potential of the drainage area both above and below the system and its relationship to individual reservoirs within the system.

f. Release requirements from individual reservoirs and the total system for purposes other than flood control.

10-9. Normally, the flood control storage space of the entire system is evacuated prior to the start of the flood season in March or early April. The space allocated to annual flood control and other multiple uses will be allowed to fill or partially fill through the flood season, with the rate and amount of fill largely determined by observed and anticipated hydrologic conditions. Optimum multiple-use regulation requires the fill of a portion of this storage space during the flood season, provided sufficient inflows above multiple-use releases occur. The exclusive flood control storage space provided in the system is reserved entirely for the control of floods, and will not be encroached on unless necessary for that purpose. Surcharge storage space is provided to assure project integrity and will be utilized only in the case of extreme floods.

10-10. Seasonal regulation of the storage within the individual projects of the system will, to a degree, parallel that for the system as described above. However, efficient regulation of the reservoirs for all functions requires some deviations, based on anticipated inflows and other factors, as described below:

a. The early spring flood potential is defined by the accumulation of plains snow and by ground conditions in the incremental areas above and between the reservoirs. Since it is possible to manipulate the Gavins Point pool elevation in a relatively short period of time, the reservoir elevation at the start of the flood season will be somewhat dependent on this potential. When the potential from the Fort Randall to Gavins Point reach is high, the Gavins Point pool will be drawn down well below its base of flood control immediately prior to the snowmelt period and allowed to refill during the snowmelt runoff. The limit of this drawdown will be dependent on its effect upon facilities within the reservoir area as well as anticipated runoff from the Fort Randall-Gavins Point incremental area. Experience in 1960 and 1962 indicated a drawdown to elevation 1200.0, 4.5. feet below the base of flood control, is feasible and desirable. When the runoff potential between Fort Randall and Gavins Point is very low, as evidenced by the lack of a plains snow cover or by a lack of antecedent rainfall over the incremental drainage area, complete evacuation of the annual flood control zone may not be necessary. Continued surveillance of the potential in this incremental area is required, and if it increases during the March-July flood season, appropriate measures will be taken to lower the Gavins Point pool to near the base of the annual flood control zone. In this connection, there is continued pressure from recreation interests to maintain Gavins Point pool elevations at the highest practical level consistent with the flood potential. Additionally, keeping the Gavins Point reservoir level high (with a corresponding storage decrease in upstream reservoirs) increases system power production since the small size of Gavins Point provides a greater amount of power head for unit of storage than any of the other main stem projects. Since releases from this downstream project are normally greater than from other projects, the additional head is more effective for increased energy production than a corresponding head increase at other projects. Following the March-July flood season, the Gavins Point elevation will normally be maintained near its base of exclusive flood control to enhance both recreation and power.

b. The early spring flood potential of the drainage area between Oahe Reservoir and Fort Randall is defined in a manner similar to that discussed above for the area between Fort Randall and Gavins Point. Manipulation of Fort Randall pool levels is also practical (but requires a greater amount of storage than Gavins Point for a specified increment of elevation). This manipulation is usually achieved by varying release rates from upstream reservoirs. In years when the early spring flood potential between Oahe and Fort Randall, as well as the flood potential immediately below Fort Randall downstream to Sioux City or below, is high, as evidenced by plains snow accumulation over the incremental drainage areas, the Fort Randall pool may be held below its base of annual flood control prior to the onset of floods inflows by reduction of later winter power releases from Oahe and Big Bend. The additional storage space in Fort Randall allows capture of flood flows with less severe disruption of power releases from upstream reservoirs through the flood period. During those years that the flood potential below Oahe Reservoir is low, it may be desirable to raise the Fort Randall pool above its base of flood control by 1 March. This allows an increased amount of energy to be generated during the high demand winter period. Additionally, it provides a necessary reserve of available storage which may be used to satisfy short-term demands for increased system releases during the following navigation season. Experience has indicated that a pool level of about 1355, 5 feet above the base of the Fort Randall annual flood control zone, is satisfactory for meeting these short-term demands while still maintaining a minimum pool elevation of 1350 for recreational purposes during the April to September recreation season. Consequently, any deliberate fill of the Fort Randall pool, based on low flood potential prior to 1 March, will normally be limited to elevation 1355. Manipulation of the Gavins Point and Fort Randall pool elevations as described in this and preceding subparagraphs has no effect upon the overall availability of evacuated flood control storage space in the system prior to early spring floods in that desired pool levels are realized by release scheduling from upstream projects. System releases are not affected.

c. The winter season is the period when the firm power demand from the system is the greatest. In order to enhance winter energy generation, winter releases from the upstream Fort Peck and Garrison

Reservoirs are often maintained at the highest level consistent with the downstream ice-covered channel capacity. Due to the somewhat unpredictable behavior of a downstream ice-cover, the exact volume of winter releases which will be possible from these upstream projects cannot be anticipated. However, pre-winter storage levels are scheduled on the basis that reasonable maximum winter releases will be made through these upstream power plants. If channel conditions during the winter are such that the reasonable maximum releases assumed in pre-winter scheduling are not possible, some storage imbalance will result by the following spring. However, this imbalance will favor downstream flood control, with additional evacuated space in downstream reservoirs. Additionally, open water channel capacities below these upstream projects are sufficient to allow a relatively fast restoration of storage balance following the ice break-up, should this appear necessary.

10-11. Flood Control Regulation Criteria. In order to conduct system flood control operations in an optimum manner while at the same time providing the maximum possible service to the other multiple-use functions of the system, storage space allocated for flood control in the downstream Big Bend, Fort Randall, and Gavins Point projects should be maintained in as near an evacuated condition as possible consistent with the discussion in paragraph 10-10. The basis for this type of regulation are as follows:

a. Vacant space in the downstream reservoirs provides a firmer degree of flood control for the main damage centers below the system than a corresponding amount of space in upstream projects.

b. When the Big Bend and Fort Randall pools are near the base of their annual flood control space, tailwater levels at the respective immediately upstream Oahe and Big Bend projects will be such as to provide maximum power heads.

c. In case of heavy runoff originating below the system, it would be possible, with vacant annual space in the downstream reservoirs, to store upstream reservoir releases necessary to maintain the optimum system power generation while, through reduced release rates from the downstream projects, providing the maximum practical flood reductions.

10-12. Flood control releases from the system, and from individual reservoirs comprising the system, will be made in such a manner as to satisfy the general requirements given below:

a. At all times when allocated storage space within Fort Randall Reservoir is available for the control of the existing or anticipated flood events, maximum system releases will be those which will not contribute to flows of over 100,000 cfs at Sioux City, Iowa. If insufficient storage is available in the Fort Randall Reservoir for control of the existing or anticipated flows, releases will be increased as necessary to insure the safety of the project while at the same time providing all possible downstream flood reductions.

b. Due to restricted channel capacities under ice conditions, releases from specific projects during the winter ice-cover period will be limited as follows:

(1) Fort Peck. At the time active ice formation is anticipated or occurring in the reach between Fort Peck Dam and the mouth of the Yellowstone River, mean daily releases are limited to a maximum of 10,000 cfs. After an ice cover has formed, releases will be limited to prevent stages from exceeding 11 feet at Wolf Point or 13 feet at Culbertson. Experience indicates that after the downstream ice cover has formed and stabilized, mean daily releases of up to 15,000 cfs, the power plant capability, become possible. However, increases in release from the 10,000 cfs freeze-in level toward the maximum ice-covered level should be made in increments of 500 to 1,000 cfs. Additionally, tributary inflows between Fort Peck and the downstream Wolf Point and Culbertson gages due to plains snowmelt prior to the time river becomes ice-free are a consideration in release scheduling.

(2) Garrison. During the period of active ice formation in the reach extending from the headwaters of Oahe Reservoir upstream beyond Bismarck, North Dakota, mean daily releases are limited to a maximum of 20,000 cfs. After the ice has stabilized in the Bismarck reach, a gradual increase in releases, as limited to prevent Bismarck stages from exceeding 13 feet, may be initiated. Experience has been that approximately 1 month after the initial freeze-up at Bismarck, releases approaching 35,000 cfs, the approximate Garrison power plant capacity are possible. Tributary inflows between Garrison Dam and Bismarck prior to the time the river becomes ice free are a consideration in release scheduling.

(3) Oahe. Experience has indicated that normal power plant peaking operations maintains the 7-mile reach between Oahe Dam and the head of Big Bend Reservoir largely in an ice-free condition even under severe weather conditions. Therefore, the channel capacity available requires no restrictions on winter discharges through the Oahe power plant.

(4) Big Bend. This project discharges directly into the Fort Randall Reservoir, consequently no restrictions on winter releases are necessary.

(5) Fort Randall. Although the ice-covered Missouri River channel between Fort Randall Dam and the head of Gavins Point pool could sustain higher discharges without resulting in damage, the average winter season release from this project is normally limited to about 15,000 cfs. This is in recognition of the restricted ice-covered channel capacity below Gavins Point combined with the small amount of storage space available to re-regulate flows in this downstream project. Additionally, system operations associated with an average winter release of 15,000 cfs from Fort Randall represents full winter service to the power function of the system. Winter release rates may be increased to an average of about 18,000 cfs or slightly more when necessary to evacuate flood storage. Daily average releases in excess of 20,000 cfs may be made in response to fluctuating power demands.

(6) Gavins Point. In the reach of river from Gavins Point to about Kansas City, ice jams quite often reach damaging proportions. This reach is particularly vulnerable due to intermittent freeze-ups and break-ups throughout the winter. This reach of the river valley is also relatively highly developed and, therefore, subject to high damages in the event of serious ice jams. Consequently, prudent regulation requires that releases from Gavins Point be limited to the 15,000 to 20,000 cfs range during the winter period, except in extremely high flood inflow years. At times, reductions below the 15,000 cfs level may be necessary due to the formation of severe ice blocks.

c. Maximum releases during the open-water season will be based on downstream channel capacities described in Section II-D at all times flood control storage space is available to control existing or anticipated inflows.

d. Insofar as practical, the available flood control storage space contained in the upstream Fort Peck, Garrison, and Oahe Reservoirs will be utilized for the control of floods in preference to that space contained in downstream reservoirs. The allocated flood control space in the downstream Big Bend, Fort Randall, and Gavins Point project will be utilized to the degree necessary to re-regulate upstream reservoir releases and to control flows originating below the Oahe Project.

e. Insofar as practical, a reasonable balance of the vacant storage space (in terms of percent of allocated space) within both the annual and exclusive flood control zones will be maintained among the upstream Fort Peck, Garrison, and Oahe Reservoirs when the flood control storage in the system is taxed or expected to be taxed by anticipated inflows. When flood control storage reserves are more than ample to contain anticipated inflows, departures from storage balance criteria will be permitted in the interest of enhancing power generation, fish propagation, or other purposes.

f. Evacuation of storage space within the system immediately following flood inflows will be accomplished, insofar as practical, on the basis of established priorities as follows:

(1) Surcharge storage from all reservoirs.

(2) Exclusive flood control storage space in the downstream Gavins Point, Fort Randall, and Big Bend projects.

(3) Exclusive flood control storage space in the upstream Fort Peck, Garrison, and Oahe projects.

(4) Annual flood control and multiple-use storage space in Gavins Point and the Fort Randall annual flood control and multiple-use storage space above elevation 1360. Evacuation of Fort Randall storage below elevation 1360 is influenced greatly by power loads and the required power generation at Oahe and Big Bend.

(5) Annual flood control and multiple-use storage space in the upstream Fort Peck, Garrison, and Oahe projects.

In general, evacuation of at least the upper portions of the flood control storage zones in the upstream reservoirs should be conducted in such a manner as to maintain a balance of available allocated space within all three reservoirs. However, due to the restricted channel capacities below Fort Peck, it may be necessary, dependent on conditions, to distort this balance in order to assure the evacuation of that project.

g. Evacuation of the annual flood control and multiple-use space will be made in a manner which, insofar as possible, will assure complete evaluation of this space prior to the beginning of the next flood season while achieving the maximum beneficial conservation use of the stored water. The serious hazard of downstream damages in the case of late fall or winter ice conditions may make complete evacuation of flood control space inadvisable in certain extreme high water years, there being a lesser risk involved in maintaining the flood control storage space in a partially unevacuated condition prior to the succeeding flood season than by continuing the evacuation and possibly contributing to downstream damages during the late fall and winter months. However, even in these high water years, a major portion of the flood control space will be evacuated.

10-13. Scheduling of System Releases. The flood control function of the system continues to be a consideration in scheduling system releases, irrespective of the amount of storage contained in the system or the character of inflows to the system. Multiple-purpose regulation techniques described in Section IX of this manual are consistent with flood control objectives. During the winter months, multi-purpose releases are restricted due to the possibility of ice formation and consequent severe loss in channel capacity. Navigation releases during the open-water season are based on maintaining specified target flows of downstream control points; this type of multi-purpose regulation serves flood control as well as navigation most of the time.

10-14. However, there are times when the service provided to other purposes must be modified in the **interest of flood control**. During winter months, severe ice jams can form on the Missouri River below Gavins Point Dam, even with the restrictions to system releases that are imposed during the winter season. Fortunately, since this is the non-crop season, damages associated with the resultant high river stages are usually much less than would occur if similar stages were experienced during the summer season. Particularly severe ice jamming could result in flooding of adjacent developments. Therefore, when severe ice jamming is occurring at downstream locations, a reduction in system releases may be warranted. While past experience indicates that those release reductions will have very little effect upon stages associated with the jams, action by the Corps will indicate awareness of the problem and the desire to alleviate the adverse conditions. Such release reductions will usually be only temporary, extending at the most for a week or two; therefore, the overall level of service to other system functions can usually be maintained by compensating release adjustments after the jamming ceases.

10-15. Since the ability to evacuate system storage is severely restricted during the winter months, the necessary increases in system release rates for storage evacuation purposes above the rates necessary for navigation and other multiple-purposes will largely be made during the navigation season. Based on regulation experience to date, it has been concluded that the most practicable method of scheduling these above normal system releases as well as reduced releases during periods of downstream flood events is extension of the "service-level" and "target flow" concepts described in Section IX of this manual.

10-16. Service Level. Basic to utilization of the "service-level" concept is a definition of the minimum and maximum service levels that can be maintained while sustaining the design functions of the system. As discussed in Section IX, the minimum open water level which will sustain the navigation function throughout the Missouri

River navigation project is the 29,000 cfs service level. Target flows for this service level are 25,000 cfs at Sioux City and Omaha, 31,000 cfs at Nebraska City, and 35,000 cfs at Kansas City. Release reductions to below this service level for flood control purposes could have a serious adverse effect upon navigation. Adverse effects upon power production and other system functions are also quite probable with sharply reduced system releases. Consequently, release reductions to below the minimum navigation service level should be made only when it appears positive that the reductions will be of benefit from the flood control standpoint. Reductions below the minimum service level on the basis of potential flood control enhancement which may (or may not) occur will not be made unless it appears evident that such reductions would have only a minor adverse effect upon other system functions. The full-service level of downstream open-water flows is at 35,000 cfs. Target flows for this service level are 31,000 cfs at Sioux City and Omaha, 37,000 cfs at Nebraska City, and 41,000 cfs at Kansas City. However, the navigation function is enhanced to some extent by flows in excess of those provided by this full-service level. Power plant capacities of the downstream power plants are also generally sufficient to utilize system release rates somewhat in excess of those necessary for full-service flows. Any enhancement to navigation and power production would be negligible for service levels increased beyond the 45,000 cfs level; however, increases above this level may be necessary for flood storage evacuation.

10-17. During the winter season, a 5,000 cfs or higher release level from Fort Randall can be sustained during all past hydrologic conditions since 1898, with the present level of water resource development. Reductions below this level will not be made. The full-service winter level corresponds to a 15,000 cfs average winter release from Fort Randall. Experience has indicated that the winter release level can be increased to a 20,000 cfs release rate from Gavins Point with only a modest increase in the potential for downstream ice-jamming. This increased potential is held to a minimum by selective release scheduling through the winter season based on temperature forecasts and observations of current ice conditions. In inflow years when full evacuation of the accumulated flood control storage zone during an extended navigation season would result in release rates that are substantially above normal, consideration will be given to increases above the 20,000 cfs level.

10-18. Selection of appropriate service levels for flood storage evacuation purposes in excess of the full-service levels will be dependent upon anticipated runoff from the Missouri River drainage area above the main stem system; depeletions to this runoff that can be expected to occur prior to the time this runoff appears as inflows to the main stem reservoirs; current storage conditions in the main stem system and in major tributary reservoirs above the main stem system; and evaporation from the main stem reservoirs. Plate 44 has been developed for definition of the service level at any time throughout the year and may be utilized for service levels less than full-service (as discussed in Section IX) as well as for storage evacuation purposes. It relates the water supply and time of year to the appropriate service level. With a significant growth in depletions, appropriate revisions should be made to the plate since the supply necessary to maintain indicated service levels is based on depletions expected at the 1975 level of basin development. The "water supply" to be used for service level definition is a combination of (a) forecast runoff* above Gavins Point Dam from the current date through December; (b) current system storage; and (c) tributary reservoir storage deficiency.

10-19. The forecast of runoff for the remainder of the calendar year is developed by procedures as described in Section VIII of this manual, with specific forecast techniques described in the MRD-RCC Technical Study MH-73. Current main stem system storage is the accumulation of the current storage in each of the six main stem reservoirs. The current tributary storage deficiency is developed by first accumulating the current reservoir storage in each of the following 10 tributary reservoirs above the main stem system.

Lima
Clark Canyon
Hebgen
Canyon Ferry
Gibson
Tiber
Bull Lake
Boysen
Buffalo Bill
Yellowtail

These reservoirs, when filled to levels that can be expected during years of excess runoff, would contain a total of over 6 million acre-feet of water. However, to be conservative, a 5.5 million acre-feet level of tributary reservoir storage has been selected as the base level for computation of storage deficiencies or excesses in the tributary reservoirs listed. Therefore, this deficiency could be negative (an excess of storage) whenever more than 5.5 million acre-feet are stored in the tributary reservoirs. The tributary reservoir storage deficiency at any given time is subtracted from concurrent storage total in the six-reservoir main stem system and the resulting storage

*Runoff is as adjusted to the 1949 level of basin development, the base level utilized by the MRD-RCC for study purposes.

is then added to the forecasted remaining calendar year runoff to obtain the current water supply value which, in turn, is used to enter Plate 44 to determine the appropriate service level on which system releases should be based.

10-20. Essentially, Plate 44 consists of storage (water supply) curves that can be expected to occur if the indicated service level is maintained through the remainder of the open water season and comparable releases are also maintained through the winter to the succeeding 1 March. The 1 March points on the curves are consistent with the service level definitions given in Section IX. Since forecasts of future runoff (which may not materialize) are basic to use of this plate and also since the potential for downstream flood inflows is greater during the spring and early summer months, the service level actually provided should not be increased above the 35,000 cfs full-service level prior to 1 July unless an indicated service level of 40,000 cfs or greater is given by Plate 44. Additionally, as a conservative measure prior to 1 July, a selected service level greater than the full-service level should be 5,000 cfs less than indicated by use of Plate 44.

10-21. The 35,000 cfs service level is considered to be the full-service level for multiple-purpose functions of the system. The initial increase above this full-service level has been designated as the "expanded full-service level" and consists of extending the navigation season 10 days beyond its normal closing data of 1 December at the mouth of the Missouri River. Additionally, as a storage evacuation measure, winter releases averaging 20,000 cfs will be scheduled from Gavins Point. While a primary purpose of this expanded full-service is for the evacuation of storage space in the main stem reservoir system, it is also of benefit to other functions. An additional 10 days of navigation service are provided and the operation also results in the transfer of a substantial block of power from the normal navigation season (when power is relatively abundant) to the normal winter season. In some years, ice conditions may preclude the extension and, if such occurs, it may be necessary to carry a minor amount of storage over to the succeeding flood season. In recognition of ice problems which may occur, releases during the 10-day exclusion of the navigation season will be made at the full-service level unless storage evacuation requirements are such that higher releases are deemed necessary.

10-22. Target flows. Normally the relationship between the selected service level and target flows at control points below the main stem system will be the same for evacuation of flood storage as utilized for scheduling navigation releases. This results in Sioux City and Omaha targets 4,000 cfs less than the current service level, a

Nebraska City target 2,000 cfs greater than the service level and a Kansas City target 6,000 cfs greater than the service level. Similar to navigation targets, storage evacuation targets are for minimum flows at the controlling location. For example, with a 40,000 cfs service level a target flow of 42,000 cfs at Nebraska City might be controlling with Sioux City, Omaha, and Kansas City anticipated flows in excess of their respective targets of 36,000, 36,000, and 46,000 cfs. If, however, flows at the noncontrolling locations approach danger levels from a flood damage standpoint, the service level-target flow concept is modified to emphasize operations for flood control instead of navigation or storage evacuation as described below.

10-23. As a flood control measure, the normal relationship between service levels and target flow levels will be modified when large amounts of inflow are anticipated between Gavins Point Dam and downstream control points. Selected criteria for these modifications are as follows:

a. Target flows will be reduced to those consistent with the full-service (35,000 cfs) level in order that the anticipated resultant downstream flows do not exceed the current service level flow value by more than:

6,000 cfs at Omaha	(target flow plus 10,000 cfs)
12,000 cfs at Nebraska City	(target flow plus 10,000 cfs)
36,000 cfs at Kansas City	(target flow plus 30,000 cfs)

For example, if the current service level was 40,000 cfs, system releases would be reduced consistent with the full-service level if this was necessary to maintain flows at or below 46,000 cfs at Omaha, 52,000 cfs at Nebraska City, or 76,000 cfs at Kansas City. These target flows may be modified up to 5,000 cfs after consideration is given to antecedent, current, and projected hydrometeorologic conditions.

b. Target flows will be further reduced to those consistent with the minimum-service (29,000 cfs) level in order that the anticipated resultant downstream flows do not exceed the current service level flow value by more than:

11,000 cfs at Omaha	(target flow plus 15,000 cfs)
22,000 cfs at Nebraska City	(target flow plus 20,000 cfs)
66,000 cfs at Kansas City	(target flow plus 60,000 cfs)

Modification of target flows to full-service and minimum-service levels as described above provide a safety margin for the inability to accurately forecast inflows due to errors resulting from unexpected rainfall occurring within the forecast period.

10-24. Coordination of Main Stem and Tributary Reservoir Flood Control Releases. At Kansas City, the downstream control point used for scheduling main stem system releases, control of streamflow is also provided by tributary reservoirs in the Kansas River basin. At times, there will be competition between the two reservoir systems for the available Missouri River channel capacity at Kansas City. Flood control regulation criteria and techniques applicable to the Kansas basin reservoirs when this competition does not exist are described in the Kansas River Basin Master Manual and in project manuals for individual Kansas basin reservoirs. When storage evacuation is required from the Kansas basin reservoirs, coordinated regulation of the two systems of reservoirs will proceed as follows:

a. If the main stem system water supply is such that a service level of 35,000 cfs or less is applicable, Kansas basin reservoirs will have priority for the Kansas City channel capacity. Target flows on the Missouri River upstream from Kansas City will be reduced to the minimum service level (if required) in order that main stem releases do not contribute to forecasted Kansas City flows in excess of the current service level flow value plus 66,000 cfs.

b. Releases from Kansas basin reservoirs with accumulated flood control storage in Phase II or higher will have priority over main stem releases for the available channel capacity, irrespective of the current main stem service level. Main stem releases will be scheduled as described in paragraph 10-22 after consideration is made of the effects of Phase II and Phase III releases from Kansas basin reservoirs upon Kansas City flows.

c. If main stem storage evacuation requires a service level greater than the 35,000 cfs level, the main stem release requirements will have priority over releases from Kansas basin reservoirs with accumulated flood control storage in the Phase I zone. Releases from the Phase I zone of Kansas basin reservoirs will be scheduled on the basis of main stem releases made in accordance with criteria given in paragraph 10-22.

10-25. During period of flood storage evacuation from Kansas basin reservoirs, close coordination between the Kansas City District office responsible for regulation of the Kansas basin reservoirs and the Reservoir Control Center is required for the development of release schedules. Essentially, this coordination consists of the following actions:

a. The Kansas City District will develop release schedules for their reservoirs with storage levels in Phase II or higher and furnish the resultant anticipated flows of the Kansas River at its mouth to the Reservoir Control Center.

b. Based on the above, the Reservoir Control Center will schedule releases from the main stem reservoir system and furnish this schedule to the Kansas City District.

c. The Kansas City District will then take advantage of any remaining channel capacity available at Kansas City and downstream locations to schedule releases from their reservoirs in the Phase I zone.

10-26. Lower Missouri River Flood Flows. Since the water travel time to Missouri River locations below Kansas City is over 6 days, the Kansas City control point is the most downstream location for which main stem reservoir releases will normally be scheduled on a forecast basis. However, if release reductions are not necessary for Kansas City or upstream control points and forecasts indicate that main stem release reductions will result in flood damage reductions below Kansas City, a reduction in main stem releases will be scheduled. Due to the long-range forecasts required, and the current state-of-the-art, such main stem release reductions for this purpose will seldom be necessary except during severe downstream flood occurrences.

10-27. Individual Reservoir Regulation Techniques. Volumes 2 through 7 of the Main Stem Reservoir Regulation Manual series present the details necessary for integrating regulation of the individual main stem reservoirs with system regulation described in this volume. While regulation of many of the tributary reservoirs in the Missouri basin is independent of main stem system regulation, integrated regulation will at times be required. Paragraphs 10-24 and 10-25 describe the coordination necessary in regulating Kansas basin reservoirs. Main stem project manuals describe coordinated regulation with those tributary reservoirs which are most closely related with each individual main stem project, particularly those tributary reservoirs which have a replacement storage function.

10-28. During extreme floods, approaching the magnitude of the greatest floods of historical record, it is quite probably that surcharge regulation will be required of one or more of the main stem projects. If such an event were to occur, system operations would be conducted largely on a reservoir-by-reservoir basis and would be based on techniques described in the individual project manuals. System releases would be as defined by the Gavins Point procedures. In the event of a prolonged communications failure between the Reservoir Control Center and individual projects, system releases would be defined by the emergency procedures outlined in the project manuals.

10-29. <u>Responsibility for Application of Techniques</u>. Due to the necessity for integrated operation to secure the maximum degree of beneficial use from all system storage, the Reservoir Control Center will normally be responsible for and will direct the operation of all the main stem reservoirs in accordance with the relationship between the Reservoir Control Center and District offices outlined in Section VI of this manual. Such direction will normally be in form of regulation orders to the projects which specify releases to be maintained, the permissible fluctuations in this release rate, and the period through which the order will be applicable. The respective District offices provide personnel for operation and maintenance of the projects, and are responsible for the physical manipulations necessary to carry out the directives.

10-30. Although regulation procedures for the main stem reservoirs are normally developed in the Reservoir Control Center, it is the responsibility of the District to maintain adequate provisions for maintaining the integrity of the dams at all times. The Reservoir Control Center will be informed, and specific methods of reservoir operation may be recommended, by the District at any time it is believed that any part of the project structure may be endangered by existing or anticipated conditions. In addition, the Reservoir Control Center will be advised when local flood conditions are such that improved conditions may result by specific methods of main stem reservoir operations. The Reservoir Control Center will consider this information and field recommendations in conjunction with other known existing conditions in the basin prior to issuing regulation instructions. If it is believed that the integrity of a dam is endangered and communications with the Reservoir Control Center are not possible, the project office and/or the District office may modify instructions (regulation orders), if believed necessary to ensure the safety of the structure. Under emergency conditions, when communication to the Reservoir Control Center is impossible, the District or project is entirely responsible for application of emergency regulation techniques.

10-31. Normally, tributary reservoir regulation is a function of the Districts with pertinent operational information furnished to the Reservoir Control Center. However, when tributary reservoir operation affects main stem flood flows, their regulation will become a direct concern of the Reservoir Control Center. During such periods, the Center will issue pertinent operating instructions in order that flood damages may be held to a minimum through integrated operation of all flood control reservoirs. The appropriate District, with only nominal

Division supervision, will direct tributary reservoir operation during periods of tributary floods not extending to the main stem. The provisions of the preceding paragraph regarding safety of the project and conflicts between local and general flood protection will also apply to tributary reservoirs during periods when operated as directed by the Reservoir Control Center.

10-32. Reports of Flood Control Operation. Reports of operation will be furnished at least once daily from each main stem reservoir project to the Reservoir Control Center. They will include reservoir elevation, storage, estimated inflows, and release for the past 24 hours, and any other hydrologic data believed pertinent to the flood control operation of the reservoir or system of reservoirs. At times of large flood flows, operation reports will be increased in frequency at the discretion of the District or the Reservoir Control Center. During severe flood periods, daily summaries of hydrologic conditions and reservoir operations will be furnished to Office, Chief of Engineers, by the District Engineer in accordance with EM 500-1-1. Various types of information relative to floods are required in such reports; pertinent data specifically required for reservoirs are as follows: Name of reservoir, reservoir stage, predicted maximum stage and anticipated date, rates of inflow and outflow in cfs, percent of flood control storage utilized to date, and any specific information pertinent to the flood situation. Prior to furnishing information relating to the main stem reservoirs, coordination with the Reservoir Control Center is required.

10-33. Each month, the Reservoir Control Center will be furnished tabulations prepared by the District offices which indicate pool elevation, storage, inflows, releases, and estimated evaporation for all reservoirs in the Missouri basin having a flood control function.

SECTION XI - EXAMPLES OF REGULATION

XI-A. Historical Regulation.

11-1. General. Although Fort Peck Reservoir was placed in operation in 1937, additional projects on the main stem were not operable prior to the 1950's and early 1960's. Limited system operation was initiated in 1954 following the closure of the Fort Randall embankment in 1952 and Garrison in 1953. Gavins Point was closed in 1955, Oahe in 1958, and Big Bend in 1963. Although this completed the embankment closures on the main stem, system operations were somewhat limited in the early years of operation by project construction and real estate activities. It was July 1966 when installation of all present power units was completed; since that time, the main stem reservoirs have been regulated as a completely integrated system.

11-2. System Storage Accumulation. Initial fill of the reservoir system was accompanied by a period of below normal runoff from the Missouri River drainage area above the system. Runoff was well below normal during each year of the 8-year, 1954-1961 period and the cumulative effect resulted in the second most severe extended drought period since 1898. However, runoff above the system has averaged somewhat above normal since 1961, with well above normal amounts occurring in some years. Plate 45 illustrates month-by-month accumulation of storage in the system and its distribution to the individual main stem reservoirs. From this plate, it is evident that the carry-over multiple-use zone (total system storage of 58.2 million acre-feet at the top of the zone) was first filled in 1967 and since that time, storage levels have generally remained within the annual flood control and multiple-use zone (system storage between 58 and 70 million acre-feet, approximately). The typical annual variation in system storage is also shown on these plates. This reflects the normal accumulation of storage during the March-July flood season and normal evacuation of storage space during the remainder of the year.

11-3. Regulation Effects on Stream Flow. The accumulation and evacuation of main stem system storage has had a major effect upon streamflow below the system. Plate 46 presents hydrographs of mean monthly flows at Yankton, South Dakota, immediately below Gavins Point Dam. The regulated flows are essentially Gavins Point releases. Unregulated flows represent the regulated flows adjusted for upstream reservoir effects, including storage effects, evaporation from the reservoir surface and precipitation upon the reservoirs. The reservoir effects utilized in the development of unregulated flows include those from major tributary reservoirs as well as the main stem projects; however, the major portion of the reservoir effects results from regulation provided by the main stem reservoir system. Unregulated flow development was on a mean daily basis although mean monthly flows are shown on Plate 46.

11-4. Plates 41, 42, and 43 illustrate in more detail effects of historical reservoir regulation. Regulated and unregulated flows on these plates are defined as described in the preceding paragraph; however, mean daily flows have been plotted on these plates rather than the mean monthly flows as given on Plate 46. The 1961 hydrographs illustrate the supplementation of flows provided by upstream reservoir storage during low flow years while the 1967 and 1972 hydrographs illustrate the effects of reservoir regulation upon substantial flood inflows. They also illustrate characteristic patterns of release from the main stem system. Similar hydrographs are available for other years of operation since 1950, and for other locations within and below the six-reservoir system.

11-5. Regulation of 1961 Runoff. Of interest are the low unregulated flows during the August-September period of 1961. Detailed analyses indicate that these unregulated flows averaged about 1,500 cfs for a 12-day period. Furthermore, these analyses also indicate that consumptive use by additional water resource development in the upper Missouri basin since 1961 had the effect of further reducing unregulated flows to such an extent that, with a repetition of the 1961 runoff, they would be computed to be negative. Of course, negative flows on the river are impossible; Gavins Point Dam (primarily resulting from irrigation) exceed the runoff above this location. Water to overcome the excess of depletions over runoff, plus water to maintain a live river, must be provided from storage accumulated in the reservoirs.

11-6. Regulation of 1967 Runoff. The 1967 hydrographs on Plate 42 illustrate the regulation provided at the time initial fill of the reservoir system was being completed and also at the time service floods were occurring in the lower Missouri basin. Actual flows at Hermann,Missouri, exceeded 200,000 cfs from 13 June through 5 July, with a crest flow of 372,000 cfs on 28 June. The crest stage at this time was over 30 feet, 9 feet above flood stage. In early June, system releases were based on maintaining a navigation service level of 32,000 cfs with corresponding target flows of 28,000 cfs at Sioux City and Omaha, 34,000 cfs at Nebraska City, and 39,000 cfs at Kansas City. On 12 June, it became evident that substantial runoff would occur from the lower Missouri basin. Inquiry revealed that no river traffic was scheduled for the Sioux City to Omaha reach of the river; therefore, the Sioux City target was ignored for the period 12-18 June and flow scheduling was based on maintaining target flows at the remaining downstream locations with resultant Sioux City flows expected to be below the minimum service level for navigation. With the expected recession of downstream flood runoff, full-service navigation releases were re-established after 20 June. The minimum mean daily release of 14,000 cfs on 17 June approximately coincided (with allowance for travel time) with the 372,000 cfs crest flow at Hermann.

11-7. Regulation of 1972 Runoff. The 1972 regulation is illustrated on Plate 43. This was a year when large amounts of runoff were anticipated from the drainage area above the main stem system. In early March, calendar year inflows to the system were forecast to be 15 percent greater than normal and by early April, these forecasts had been increased to an anticipated runoff amounting to 125 percent of normal. Actual runoff experienced during 1972 above Sioux City, Iowa, amounted to 133 percent of the long-term average.

11-8. Regulation during calendar year 1972, based on procedures described in previous sections of this manual, was as follows. The service level was defined periodically throughout the year as described in paragraphs 10-12 through 10-21 and as illustrated in the table below:

	Values in 1,000 AF				
	1 March	1 April	1 May	1 June	1 July
1. Tributary storage[1/]	4,450	4,550	4,050	4,350	5,700
2. Trib. storage excess[2/]	-1,050	-950	-1,450	-1,150	200
3. Main stem storage	59,500	64,600	64,400	66,200	68,500
4. Forecast runoff[3/]	24,600	20,100	18,350	14,100	8,650
5. Water Supply [4/]	83,050	83,750	81,310	79,150	77,350
6. Service level, 1,000 cfs[5/]	39.0	45.0	45.0	46.0	49.0

1/ Accumulated storage in tributary reservoirs designated in paragraph 10-19.

2/ Base storage (5,500) less tributary storage.

3/ Runoff from the current date through 31 December as adjusted to the 1949 level of basin development. Forecast runoff is that from the total drainage area above Gavins Point Dam.

4/ Total of tributary storage excess, main stem storage and forecast runoff.

5/ From Plate 44.

11-9. Gavins Point releases during January, February, and the first half of March 1972 were at the expanded full-service level of

20,000 cfs due to the large water supply available and anticipated. As indicated in the preceding paragraph, service level determinations on 1 March indicated that flows above the full-service level would be required for storage evacuation purposes. As discussed in Section IX, during early portions of the navigation season, releases 5,000 cfs above the navigation service level are made to facilitate proper configuration of the navigation channel. Therefore, releases during the last part of March were based on a 40,000 cfs service level with downstream target flows of 36,000 cfs at Sioux City and Omaha, 42,000 cfs at Nebraska City and 46,000 cfs at Kansas City.

11-10. Strict adherence to the rules outlined in paragraph 10-20 of this manual would have required releases based on service levels of 40,000 cfs in April and May and a service level of 41,000 cfs in June. However, during 1972 an unresolved problem relating to the channel capacity below Fort Randall Dam continued. After considerable study, it was concluded that adverse effects would be at a minimum if the 5,000 cfs reduction from the service levels indicated by Plate 44 was not made. Additionally, it was concluded that a relatively uniform release rate should be maintained provided that the flood control criteria described in paragraph 10-23 could be met. The selected rate of 40,000 cfs was then maintained through most of the April-June period. Reductions were made at times during this period in order to meet flood control targets of 57,000 cfs at Nebraska City (45,000 cfs service level plus 12,000 cfs).

11-11. Regulation through the remainder of the 1972 navigation season proceeded in a manner similar to that described above. Increasing forecasts of the water supply available required increases in the service level as indicated by paragraph 11-8 and Plate 43, however, on occasion releases were reduced below the general level being maintained due to downstream runoff. With the large water supply, extended full-service flows were provided at the close of the navigation season, consisting of 10-days of additional release at full-service levels beyond the normal closing date. Winter releases at the extended full-service level of 20,000 cfs were maintained during the latter part of November and through December.

11-12. Historical Service to System Functions. Although full-service to the various authorized functions of the system was not provided until initial fill was accomplished in 1967, partial service has been provided since the time that closure of Fort Peck Dam was made in 1937. Detailed descriptions of the service provided each year are included in Annual Operating Plans that have been published each year since 1953. A summary of this service follows:

a. Flood Control. In all years that substantial runoff has originated above the main stem system, crest flow reductions through downstream reaches have resulted from system regulation. Accumulated damages prevented by system regulation through the 1977 flood season total over 900 million dollars. In 1967 alone, the damages prevented approached 250 million dollars.

b. Irrigation. Federally developed irrigation projects are not yet being served directly from the main stem reservoirs. However, approximately 100 irrigation pipeline easements have been granted to private irrigators to permit them to obtain water from the main stem reservoirs to serve about 40,000 acres. Numerous irrigation intakes are also located downstream from individual reservoirs and at times their requirements have been an operational consideration. The amount of such irrigation made possible by main stem system operation is not known; however, it is believed that a large amount would not have been practicable without the stabilizing influences upon flows exerted by the system. The value of upstream storages to serve this function during low water years was discussed in paragraph 11-5.

c. Water Supply and water quality control. Regulation provided by the system has assured a relatively uniform supply of water for downstream municipalities and industrial uses. At times, releases from particular projects have been adjusted to assure continued satisfactory functioning of water intakes. By trapping sediment inflows, the main stem reservoirs have significantly reduced the amounts of suspended sediment throughout the Missouri River from Fort Peck to the mouth of the river. Releases have been of a uniformly good quality.

d. Navigation. Service was provided to navigation on the lower Missouri River during the years that Fort Peck was operating alone. With the construction and fill of additional reservoirs, this service has been expanded. Full length (8-month) seasons were initiated in 1962 and have continued since that time. Full-service navigation flows have been provided since June 1967. Commercial traffic has ranged to as high as 3.3 million tons although construction has not been completed on the navigation channel from Sioux City to the mouth.

e. Power. Since completion of power installations at projects, most project releases have been through the respective power plants. When release requirements were exceptionally high, due to flood control storage evacuation, it became necessary to make substantial spillway releases at Gavins Point. Some spills have also been required at Fort Randall for this purpose. However, in most years releases from all projects are through the power plants at all times. Since initial fill of the system in 1967, energy production by the system has averaged over 11 billion kilowatt-hours annually. Annual revenues from the sale of power have ranged upward to about 100 million dollars.

f. Fish Management. In each of the last several years, one or more of the main stem reservoirs has been regulated to enhance the fish population associated with the reservoirs. For example, during the early spring period of 1974, Fort Peck releases were reduced to the minimum required for downstream water supply, in order that established terrestial vegetation would be inundated by rising lake levels and provide spawning habitat for northern pike. During this special operation, the power load that normally would have been carried by Fort Peck was distributed to other main stem projects. During May 1974, the instantaneous releases from Fort Randall were not allowed to fall below 15,000 cfs in order that increased habitat for sauger spawning would be available below the project. This required compensating release adjustments at other main stem projects. In addition, Fort Randall reservoir levels were held below a specified level (1356) throughout 1974 to permit vegetation to grow down to elevations that could be inundated to enhance fish spawning in future years. While no quantitative evaluation of the effects of operation for fish management is available, reports from fish and wildlife representatives indicate that positive results have been obtained and continued operations for this purpose are desired.

g. Recreation. Numerous adjustments of both temporary and relatively permanent nature have been made to system regulation to enhance recreational activities associated with the reservoirs. An example is the limitation placed on power peaking operations during particular periods in order that downstream boating may be facilitated. Recreational use of the projects has increased through the years with current visitor-day attendance at the projects approaching 10 million annually.

XI-B. Regulation Studies (Long Range).

11-13. General. The development and uses of long-range reservoir regulation studies were discussed in Sections V and IX of this manual. Outputs from these studies serve as examples of potential reservoir regulation procedures and results during recurrence of the entire period of hydrologic record available at the time of each study. These studies also illustrate the regulation changes that can be expected to occur with increased water resource development in the basin. Plates 47 and 48 illustrate reservoir regulation through the period of hydrologic record as developed by one of the recent long-range studies, 1-74-1970. This study illustrates regulation at the 1970 level of water resource development in the basin. Many additional examples of this type are available in long-range study reports and files of the Reservoir Control Center.

XI-C. Reservoir Regulation During a Hypothetical Flood Sequence of 1951-1952-1944.

11-14. General. In planning studies of the main stem reservoir system, the entire flood history available to date was utilized. Great floods, referenced in Section II of this manual, were examined in as great a detail as available records would permit. Only since 1929 have sufficient measurements of streamflow been obtained to permit a detailed examination of the effects of individual main stem reservoir operation. Prior to that year, synthetic flows had to be derived at numerous locations to illustrate system regulation. The synthesis (with corresponding associated uncertainties) necessary to reconstitute the great floods prior to 1929 precluded their inclusion in this manual as comprehensive illustrations of reservoir regulation. However, from the records which are available, a general examination was made of the past floods, in particular the large floods occurring in 1881 and 1927, to confirm the applicability and reliability of flood control regulation techniques utilized in this manual. These studies indicated that with reasonable allowances made for the basin development since the date of flood occurrence, the techniques developed in this manual for the system as a whole would provide adequate control should such floods recur.

11-15. Reasonable detailed flow records available since 1929 include one of the greatest-known flood events downstream from the system occurring in 1951, as well as one of the greatest-known events originating from the drainage area controlled by the main stem system, occurring in 1952. Detailed records are also available for the large 1944 flood. Flood flows during 1952 occurred during the March-April period while in 1944 large amounts of runoff originated above the main stem reservoirs during the June-July period. Examination of the sources of runoff during the 1951, 1952, and 1944 events indicates that a runoff sequence combining the events extending from March 1951 through May 1952 with those events extending from June 1944 through March 1945 is not unreasonable. This was done and regulation studies developed to illustrate regulation techniques and their results during this combination of events.

11-16. The computer printouts on Plates 49 and 50 present results of these regulation studies. Further explanation of the data utilized, the study procedures, and the study results are presented in paragraphs that follow.

11-17. Reach Inflows. The reach inflows used in the studies were developed from the published hydrologic record. Plates 49 and 50 present the monthly inflow volumes for incremental drainage areas between dams and between gaging stations downstream to Hermann, Missouri. Reach inflows shown for the main stem system portion of the table are the accumulated reach inflows above Sioux City, Iowa. While only monthly reach inflows are shown on these plates, it should be recognized that simulated regulation of the system to meet specified flood control and navigation targets required the use of daily inflows for reaches between Gavins Point Dam and Kansas City.

11-18. Reservoir Evaporation. The monthly evaporation volumes from each of the main stem reservoirs during this examined period are also shown on Plates 49 and 50. Evaporation depths were assumed to be normal depths, and consist of normal reservoir evaporation amounts adjusted for normal precipitation on the reservoir surface. The evaporation volume is a function of the evaporation depth and reservoir area at the time.

11-19. Inflow Adjustments. The reach inflows described in paragraph 11-17 are those that actually occurred at the time of the runoff events. Since that time, water resource development of the Missouri Basin has progressed. The inflow adjustments shown on Plates 49 and 50 represent estimates of the effects of this basin development upon the reach inflows, from the time the flows actually occurred to the present time. These estimates are based on data furnished by the Bureau of Reclamation and consist largely of irrigation effects, including storage effects of tributary reservoirs whose primary function is irrigation. The adjustments for the Nebraska City to Kansas City reach also contain regulation effects of the Kansas River basin reservoirs.

11-20. Modified Inflows. The modified inflows to each of the main stem reservoirs as shown on Plates 49 and 50 consist of observed reach inflows plus the reach inflow adjustment plus the release from the reservoir immediately upstream less the evaporation from the main stem reservoir receiving the inflow. In this connection, it should be noted that all reach inflows between Oahe and Fort Randall are assumed to originate below Big Bend, since inflows between Oahe and Big Bend are quite low. Additionally, it is assumed that Gavins Point and Big Bend operate at a constant reservoir level with modified inflows equal to releases. These are not tabulated for Big Bend. At locations below the main stem reservoir system, the modified inflows given are the observed reach inflows plus the reach inflow adjustments.

11-21. Storage and Pool Elevation. Values given for the individual main stem projects and for the system as a whole are end-of-period values corresponding to the dates given on the plate. System storage values listed include Big Bend and Gavins Point storage volumes.

11-22. Releases and Flows. The average monthly releases and monthly flow volumes are shown for the main stem reservoirs and downstream control points. However, it should be recognized that at times the daily flows or releases would be significantly different that the monthly averages shown.

11-23. Power Production. Average power, peak power, and energy production for each of the main stem projects and for the system as a whole are shown for each of the time intervals examined throughout the entire period of the example. Peak power values given are those at the end of each time interval.

11-24. Service Level. As discussed in Section X, the service level to be maintained by the reservoir system at any given time is a function of system storage, forecast runoff above the main stem reservoir system, and tributary reservoir storage. Plate 44 is used to define this level. Table 13 illustrates the service level definition through the 1951-52-44 flood sequence period. Forecast runoff amounts and the departure of total tributary storage from the base level as given in this table are reasonable values assumed for illustrative purposes.

11-25. Definition of System Releases. System releases were determined on a daily basis through the April-November period of each year, using the procedures described in Section VIII of this manual. Plates 36 through 40 illustrate the use of these procedures and indicate data required on a given day. Further particulars on the use of the forms presented on these plates is given in MRD-RCC Technical Report F-62 discussed in Section VIII of this manual. The date of 15 May 1952 was arbitrarily selected for illustrative purposes on these forms and antecedent flows were entered to the extent that they were required on this date. A service level of 65,000 cfs was appropriate at this time, resulting in target flows of 61,000 cfs at Sioux City and Omaha, 67,000 cfs at Nebraska City, and 71,000 cfs at Kansas City. The computations illustrated on the form indicate that a release rate of 54,000 cfs would be required to meet the Sioux City target, 50,500 cfs to meet the Omaha target and 51,000 cfs to meet the Nebraska City target. Additionally, sheet 5 of the forms indicates that Nebraska City flows of 59,500 cfs are necessary to meet Kansas City targets (average of the 3-day and 4-day forecasts of required Nebraska City flows). Since this is 7,500 cfs less than the Nebraska City target flow, it is evident that a 43,000 cfs release from Gavins Point would suffice for the Kansas City target flow.

TABLE 13

Service Level Determination for 1951-52-44 Flood Sequence

	Volume, 1,000 Acre-Feet				Service Level 1,000 cfs	
Date	System Storage	Forecast Runoff	Trib. Storage Departure	Water Supply	Defined[1]	Selected[2]
1 Apr 51	59.0	21.5	-1.3	79.2	35.0	35.0
1 May	61.8	17.2	-1.5	77.5	35.0	35.0
1 Jun	62.7	13.6	-0.9	75.4	35.0	35.0
1 Jul	64.5	9.3	0.0	73.8	38.0	38.0
1 Aug	65.3	6.7	-0.3	71.7	41.0	41.0
1 Sep	65.0	5.0	-0.7	69.3	45.0	45.0
1 Oct	64.7	3.5	-0.8	67.4	55.0	55.0
1 Nov	63.3	1.7	-1.0	64.0	60.0	60.0
1 Dec through 28 Feb					Expanded Full Service	
1 Mar 52	60.4	34.4	-1.3	93.5	60.0	55.0
1 Apr	61.4	34.0	-1.4	94.0	65.0	60.0
1 May	70.0	23.5	-1.0	92.5	70.0	65.0
1 Jun	70.4	20.1	-0.5	90.0	75.0	70.0
1 Jul	73.6	11.4	-.2	85.2	75.0	75.0
1 Aug	72.0	5.8	-0.1	77.7	65.0	65.0
1 Sep	69.1	3.1	-0.3	71.9	60.0	60.0
1 Oct	66.3	2.3	-0.7	67.9	60.0	60.0
1 Nov	63.8	1.2	-1.0	64.0	60.0	60.0
1 Dec through 28 Feb					Expanded Full Service	

1/ Based on Plate 44
2/ Selected after considering flood control criteria discussed in Section X

11-26. Since the above indicates that the maximum release necessary for the downstream target flows is the 54,000 cfs required for the Sioux City control point, this is selected as the tentative release rate. Resultant downstream flows from this release are forecast to be 61,000 cfs at Sioux City, 64,500 cfs at Omaha, 70,000 cfs at Nebraska City, and 81,000 cfs at Kansas City. The variations of these forecast flows from the then current service level of 65,000 cfs were as follows:

Sioux City	-4,000 cfs
Omaha	-500 cfs
Nebraska City	5,000 cfs
Kansas City	16,000 cfs

These variations were less than those allowed by flood control considerations specified in paragraph 10-23 of this manual; therefore, the 54,000 cfs release rate was considered appropriate for 15 May.

11-27. If forecast variations from the current service level had exceeded those specified in paragraph 10-23, reductions in the system release rate would have been required as a flood control measure. For example, if the resultant flow forecast for Kansas City had been 105,000 cfs (instead of 81,000 cfs), the variation at this location from the 65,000 cfs service level would have been 40,000 cfs, or 4,000 cfs greater than allowed by the flood control function when the current service level was greater than the full-service level. A system release of 50,000 cfs (instead of 54,000) would then be appropriate, which would still continue downstream flows at all other target locations at well above the full-service level.

11-28. As another example, if the resultant Kansas City forecast from a 54,000 cfs release had been 135,000 cfs (instead of 81,000 cfs), the Kansas City variation from the 65,000 cfs service level would be 70,000 cfs. This is 34,000 cfs greater than allowed by the criteria given in Section X with greater than full-service releases from the system. However, reducing system releases by 34,000 cfs to 20,000 cfs would provide Sioux City resultant flows of 27,000 cfs, below the full service level. Therefore, in accordance with Section X criteria, a full-service level system release of 24,000 cfs would be scheduled to result in Sioux City full-service flows of 31,000 cfs. The resultant Kansas City flow would be 95,000 cfs or 30,000 cfs greater than the current service level. Since this variation from the service level is less than that required by Section X criteria for release reductions to the minimum-service level (a variation of 66,000 cfs), the 24,000 cfs system release is satisfactory.

11-29. Effect of Regulation on Crest Flows. A comparison of observed crest flows and estimated crests resulting from regulation of the current system of main stem and tributary reservoirs during the 1951-52-44 flood sequence is given in Table 14.

TABLE 14

1951-1952-1944 FLOOD CRESTS

Location	Observed Crest 1,000 cfs	Observed Date	Regulated Crest 1,000 cfs	Regulated Date
		1951 Flood		
Sioux City	152	8 Apr	67	19 Jun
Omaha	152	11 Apr	107	28 Mar
Nebraska City	163	29 Mar	155	28 Mar
Kansas City	573	24 Jul	370	14 Jul
		1952 Flood		
Sioux City	441	14 Apr	65	11 Apr
Omaha	396	18 Apr	85	1 Apr
Nebraska City	414	19 Apr	108	2 Apr
Kansas City	400	24 Apr	120	24 Apr
		1944 Flood		
Sioux City	136	7 Jul	109	12 Jul
Omaha	138	17 Jun	113	13 Jun
Nebraska City	214*	14 Jun	180	14 Jun
Kansas City	186*	20 Jun	145	16 Jun

*Crests at Nebraska City and Kansas City appear inconsistent; however, are as reported in USGS water supply papers.

11-30. Examination of the crest flow data given above indicates that the system of reservoirs in the Missouri basin has substantial effects upon crest flows, particularly those crests resulting from upper basin runoff. However, Missouri River floods can continue to be expected, particularly in downstream portions of the basin. With the storage evacuation requirements, the long travel times involved to lower basin damage centers and the lack of reliable quantitative rainfall forecasts for several days in advance, there may even be occasions when system operations augment downstream flood events. A continuing objective of system regulation will be to reduce any such augmentations to the practicable minimum.

XI-D. Regulation During Extreme Floods and During Emergencies.

11-31. Extreme Floods. During extremely large floods that may utilize all of the flood control storage capacity provided in any of the individual projects, regulation will primarily be based on conditions affecting the particular project rather than the system as a whole. Consequently, examples of regulation during this type of flood are not included in this manual. Individual project manuals address this subject with the Gavins Point procedures pertinent to system releases during such events.

11-32. Emergency Procedures. Regulation criteria in the event of communications failure with the Reservoir Control Center are detailed in individual project manuals and their associated instructions to project personnel for such events. Examples of their application are contained in project manuals.

SECTION XII - CONTINUING STUDIES

12-1. General. It is recognized that the manner of operation of the main stem reservoirs cannot be prescribed and expected to remain fixed in the future. It is impossible to foresee the effects of actual future sequences of floods and droughts, the time and conditions under which water conservation measures may be implemented on tributaries and their effects on streamflow, the future rates of growth of irrigation depletions, changes in power market characteristics, changes in future water requirements for navigation and possible changes in emphasis on one primary function or another with changing national policies and economic conditions. However, there are studies which should be undertaken at the present time for improvement of the methods of operation proposed in this interim manual and also fairly firm forecasts of future developments whose effects on future operation of the main stem reservoirs should be items of continuing studies at the present time. Major items in this category will be discussed in the following paragraphs.

12-2. Forecasting Techniques and Procedures. As the demand for water supply continues to increase, the value of water stored in the main stem system will also increase proportionately. If future flows could be accurately known sufficiently in advance, it would be unnecessary to allocate storage space specifically for flood control purposes as this objective of system operation could be provided for by utilizing all or any part of the storage space necessary to optimumly control future events while still obtaining the maximum conservation benefits that the entire system storage space would allow. Due to the inability to completely anticipate future events, such procedures are not possible. However, it is evident that any indication of future flood events within the basin could lead to improved system operation. The more accurately and the further in advance that events can be anticipated, the greater will be this improvement, insofar as both flood control and other beneficial uses of the available water supply are concerned, with a corresponding increase in the sizeable economic benefits which may be attributed to system operations. For this reason, major emphasis will be placed on continuing studies designed to improve forecasts of streamflow, both into the main system and into the Missouri River below the system.

12-3. Optimum Evacuation Schedules. Evacuation of storage from the system at greater rates than required for conservation purposes will often be necessary following major flood inflows in order to provide space for the control of future flood events. The evacuation should be made in an orderly manner which will insure the maximum beneficial use of the stored water and should minimize the risk of contributing to damaging flows in the lower reaches. Sufficient storage in the annual flood control zone should be retained to provide for optimum conservation operation through subsequent low-flow periods insofar as consistent with future flood control operations. Evacuation schedules, upon which system operation as well as operation of each of the reservoirs within the system will be predicated, will be made the subject of continuing studies.

12-4. Tributary Developments. There are several different categories of future tributary developments which will effect the main stem system which need appraisal. Reservoirs may have seasonal or exclusive flood control capacity, or both, or no capacity specifically assigned for flood control but in each case there will be effects on the main stem system (firmer evaluation of these effects is also essential for estimating flood control benefits to be assigned to tributary reservoirs). Effects of soil conservation and forestry practices on flood flows and water yields also need further appraisal. The rapid growth of privately developed irrigation pumping in recent years indicates that this development may become a factor of some importance on water yield during future low water years.

12-5. Channel Characteristics. The characteristics of the Missouri River (such as channel capacities, water travel times, and ice formation) will need to be the subject of continuing studies insofar as it affects system reservoir operation. The results of changes in flow regimen caused by system and tributary reservoir development can be fully determined only through continuous observation and study. Improvements, such as channel realignments, bank stabilization, and levee construction are being made which could affect system operation to a considerable degree. Studies relating to the maximum permissible flow rates under ice cover conditions should be continued, as any change in the presently estimated capacities would be of importance not only from the standpoint of flood control, but also from the standpoint of winter power generation.

12-6. Sedimentation. The Missouri River ordinarily carries a great sediment load through its entire length and, as a result of reduced velocities, most of the sediment originating upstream from the system will be deposited in the reservoirs. Theoretical studies of the sediment deposition in the individual reservoirs have been made, as an indication of the manner and amount of deposition obtained. These studies will be corroborated by continuing observations of actual depositions in the reservoirs. Sediment ranges have been established in each of the reservoirs, as described in the individual project manuals, for this purpose. Continuing studies relative to allocations of storage will take into consideration storage space which may be occupied by this sediment deposition.

12-7. Degradation. A problem somewhat similar to sedimentation within the reservoirs will be that of degradation below the reservoirs. The anticipated degradation below each project was taken into account when establishing the elevation of stilling basins and draft tubes as referenced in Section II of this manual. Continuing observations of degradation will be made in order that its extent may be defined and in order that, if necessary, remedial measures may be taken to insure the maximum economic return from power production of the project.

12-8. Flood Control Storage Allocations. As referenced in Section V, the storage allocations utilized in this manual are tentative, pending completion of detailed comprehensive studies now in progress. These studies are necessary not only for the definition of total system flood control allocations, but for the optimum distribution of the total flood control allocation through the reservoirs comprising the system. In these studies, greater consideration will be given to the effects of present tributary reservoir development, including the effects of those projects with specifically allocated flood control space as well as those projects operated entirely for conservation purposes. Depletions to streamflow resulting from evaporation on main stem and tributary reservoirs, irrigation, conservation practices in the basin, and the development of the multitude of stock and farm ponds will also be considered. With these considerations, and others as may be deemed appropriate, design inflows to the system and each reservoir comprising the system will be developed on the basis of past flood history and the flood potential of the basin.

12-9. Restrictions on releases from individual reservoirs imposed by flood control considerations will be analyzed in greater detail. In this connection, studies concerning evacuation schedules and channel characteristics as referenced earlier in this section will be necessary. Restrictions imposed by the downstream flood potential will be further evaluated. Consideration will also be given to necessary service to functions of other than a flood control nature which must be maintained at the time of flood control operations.

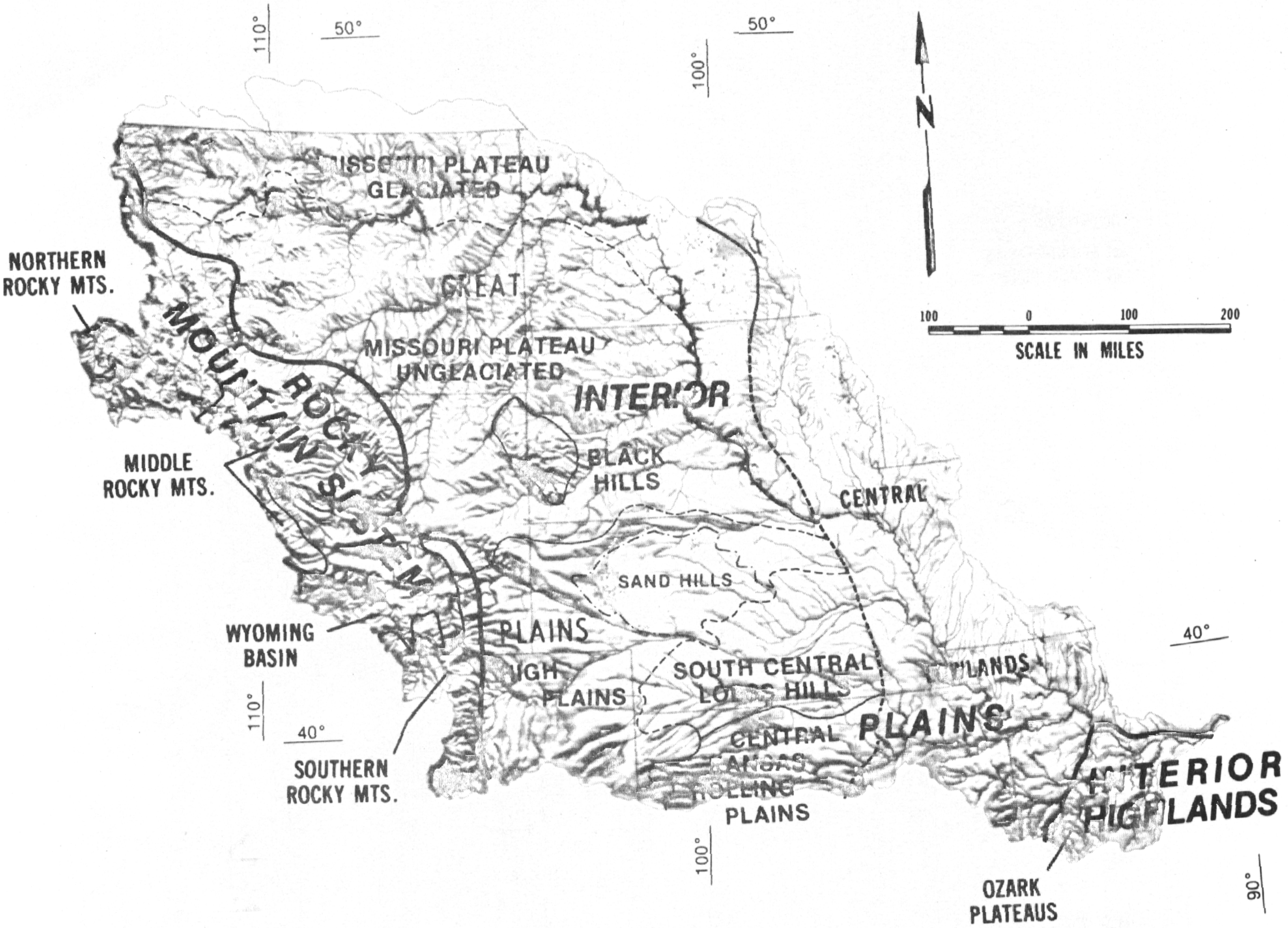
12-10. With the detailed analysis of design flood inflows to the system and permissible releases from the system during the inflows, the storage required for control of the design flood will be re-examined. Such determination will take into account allocations for both seasonal and exclusive flood control functions and their corresponding differing operating criteria. Upon determination of the necessary amounts of flood control storage in the system as a whole, and within each reservoir comprising the system, it will be possible, for the present level of basin resource development, to firmly allocate the storage space between the inactive pool and the base of required surcharge storage in each reservoir.

12-11. As basin development continues, with more tributary reservoirs coming into operation, greater blocks of land placed under irrigation, downstream channel improvements accomplished, and levee projects completed, further analysis will need be made of developed storage allocations. Other continuing studies as referenced in this section will also have a bearing on the analysis. Only by keeping current with developments as they occur, and making such adjustments in operating procedures and allocations as are necessary, can the full potential benefits of the system be realized through their period of operation. An anticipation of future development, with associated studies is also essential, not only for orderly long range planning of operation of the main stem system, but also for planning tributary reservoir operation and future benefit evaluation. Consequently, it is visualized that periodic complete reanalysis of developed storage allocations will be necessary.

12-12. Regulation Techniques. Any changes in storage allocations will require a re-examination and, if necessary, a revision in the system flood control regulation techniques presented in this mannual. It is also anticipated that as experience is gained in operation of the system for flood control purpose that other revisions to developed techniques will become apparent. Further studies for development of improved methods for defining the downstream flood potential to be used during periods of flood regulation will also be made. Additionally, system operating techniques based on the downstream flood potential will be the subject for further study, particularly those techniques which provide Sioux City flows of 100,000 cfs at times the Fort Randall storage is in the exclusive flood control range.

12-13. Emergency regulation techniques for each of the individual reservoirs will be further studied and tested with various types of floods so their applicability may be assured. It may develop that several different sets of techniques will be necessary for each project dependent upon the anticipated flood events in the basin. In such a case, operating personnel would need to be continuously informed as to those to be utilized in case an emergency should develop.

PHYSIOGRAPHIC FEATURES OF THE MISSOURI BASIN



BOUNDARY LEGEND

━━━ PHYSIOGRAPHIC DIVISIONS

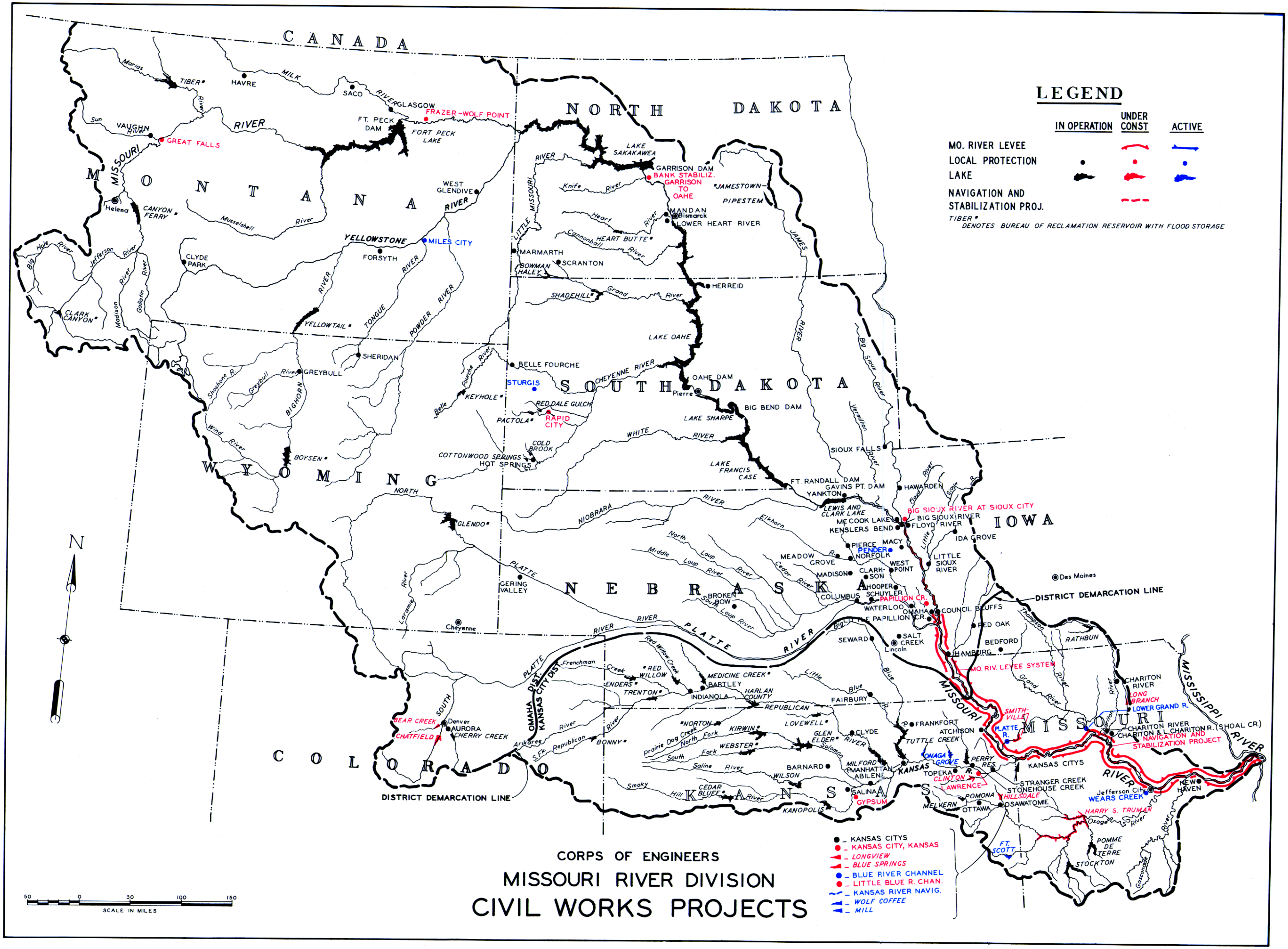
━━━ PHYSIOGRAPHIC PROVINCES

─── PHYSIOGRAPHIC SECTION

—·—·—·— PHYSIOGRAPHIC SUBSECTION

DASHED LINES REPRESENT BOUNDARIES POORLY KNOWN, HIGHLY GENERALIZED OR NOT CLEARLY DEFINED.

PLATE 1



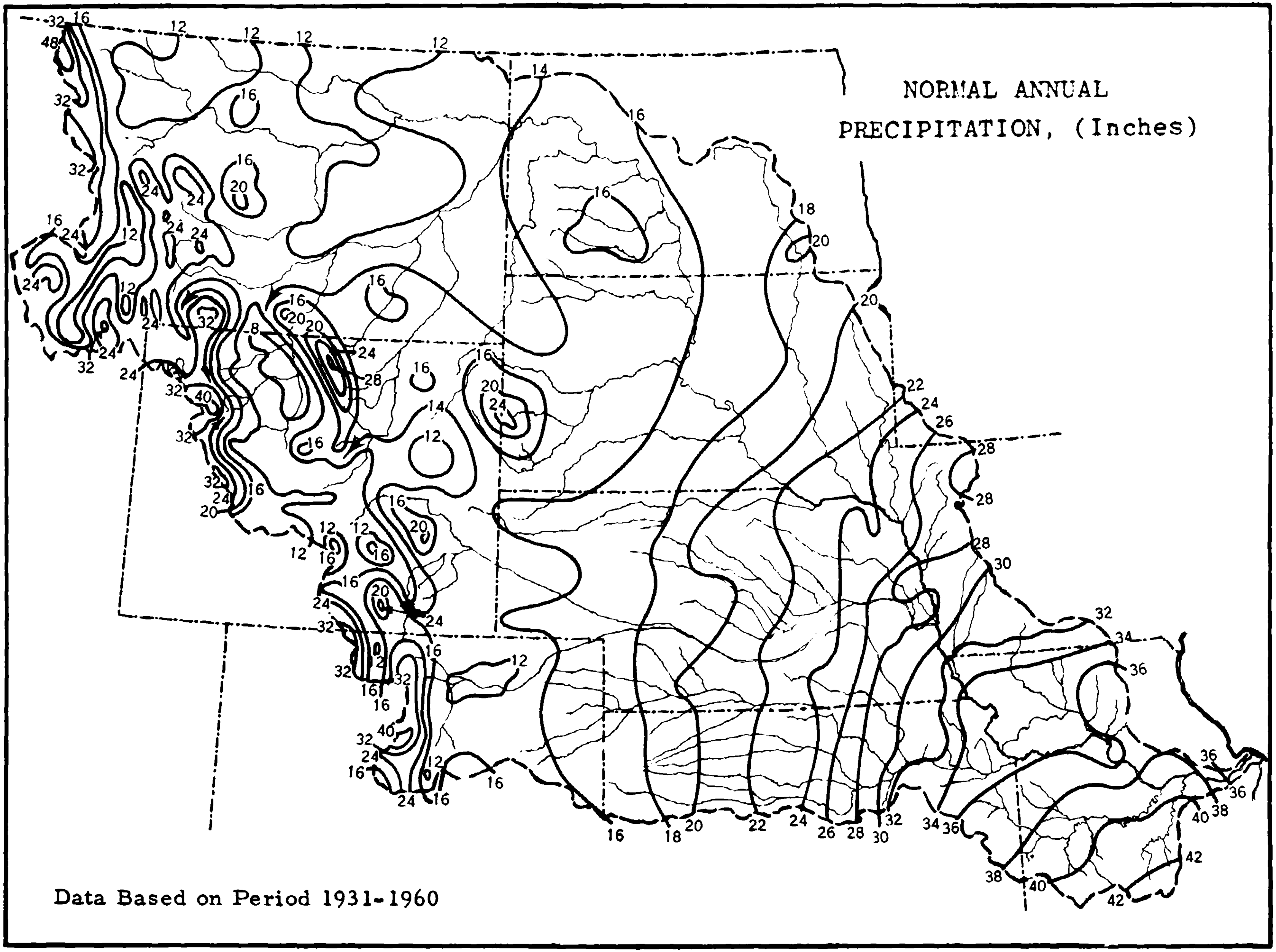
CORPS OF ENGINEERS

MISSOURI RIVER DIVISION

CIVIL WORKS PROJECTS

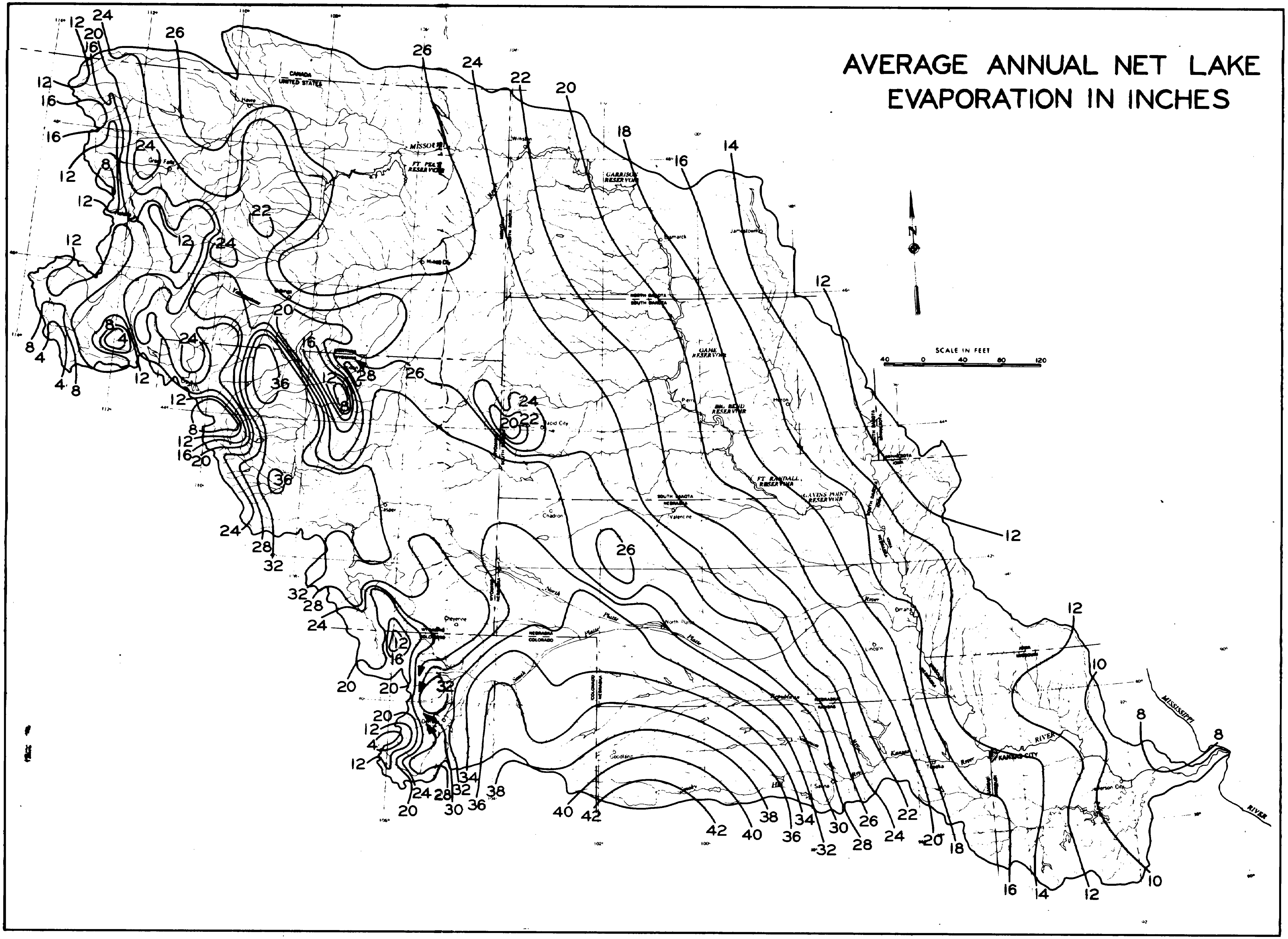
PLATE 2

PLATE 3



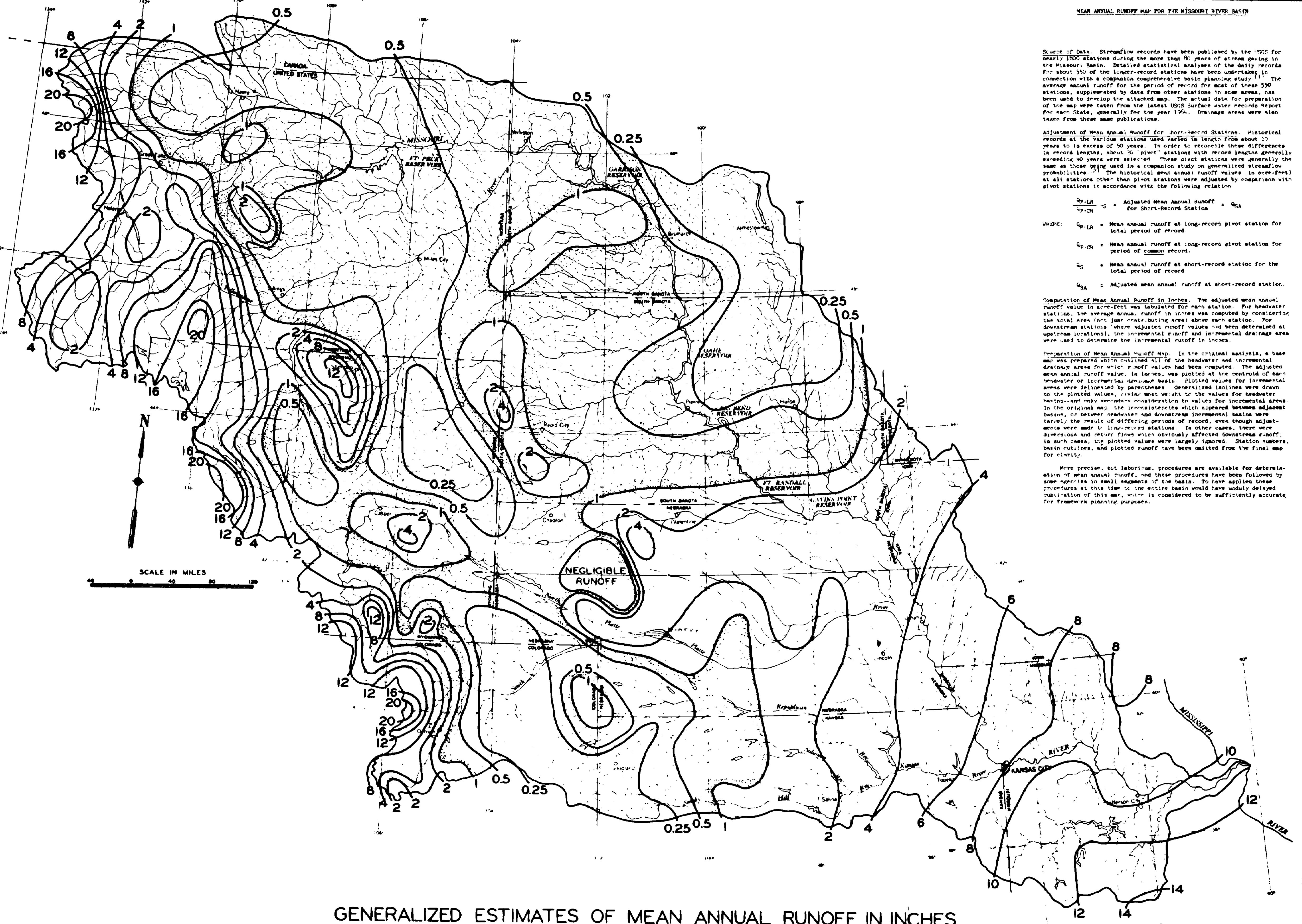
NORMAL ANNUAL PRECIPITATION, (Inches)

Data Based on Period 1931-1960



AVERAGE ANNUAL NET LAKE EVAPORATION IN INCHES

PLATE 4



MEAN ANNUAL RUNOFF MAP FOR THE MISSOURI RIVER BASIN

Source of Data. Streamflow records have been published by the USGS for nearly 1800 stations during the more than 80 years of stream gaging in the Missouri Basin. Detailed statistical analyses of the daily records for about 550 of the longer-record stations have been undertaken in connection with a companion comprehensive basin planning study.(1) The average annual runoff for the period of record for most of these 550 stations, supplemented by data from other stations in some areas, has been used to develop the attached map. The actual data for preparation of the map were taken from the latest USGS Surface Water Records Report for each State, generally for the year 1964. Drainage areas were also taken from these same publications.

Adjustment of Mean Annual Runoff for Short-Record Stations. Historical records at the various stations used varied in length from about 10 years to in excess of 50 years. In order to reconcile these differences in record lengths, about 30 "pivot" stations with record lengths generally exceeding 40 years were selected. These pivot stations were generally the same as those being used in a companion study on generalized streamflow probabilities.(2) The historical mean annual runoff values (in acre-feet) at all stations other than pivot stations were adjusted by comparison with pivot stations in accordance with the following relation

$$\frac{Q_{P \cdot LR}}{Q_{P \cdot CR}} \cdot Q_S = \text{Adjusted Mean Annual Runoff for Short-Record Station} = Q_{SA}$$

WHERE:

$Q_{P \cdot LR}$ = Mean annual runoff at long-record pivot station for total period of record.

$Q_{P \cdot CR}$ = Mean annual runoff at long-record pivot station for period of common record.

Q_S = Mean annual runoff at short-record station for the total period of record

Q_{SA} = Adjusted mean annual runoff at short-record station.

Computation of Mean Annual Runoff in Inches. The adjusted mean annual runoff value in acre-feet was tabulated for each station. For headwater stations, the average annual runoff in inches was computed by considering the total area (not just contributing area) above each station. For downstream stations (where adjusted runoff values had been determined at upstream locations), the incremental runoff and incremental drainage area were used to determine the incremental runoff in inches.

Preparation of Mean Annual Runoff Map. In the original analysis, a base map was prepared which outlined all of the headwater and incremental drainage areas for which runoff values had been computed. The adjusted mean annual runoff value, in inches, was plotted at the centroid of each headwater or incremental drainage basin. Plotted values for incremental areas were delineated by parentheses. Generalized isolines were drawn to the plotted values, giving most weight to the values for headwater basins--and only secondary consideration to values for incremental areas. In the original map, the inconsistencies which appeared between adjacent basins, or between headwater and downstream incremental basins were largely the result of differing periods of record, even though adjustments were made to long-record stations. In other cases, there were diversions and return flows which obviously affected downstream runoff; in such cases, the plotted values were largely ignored. Station numbers, basin outlines, and plotted runoff have been omitted from the final map for clarity.

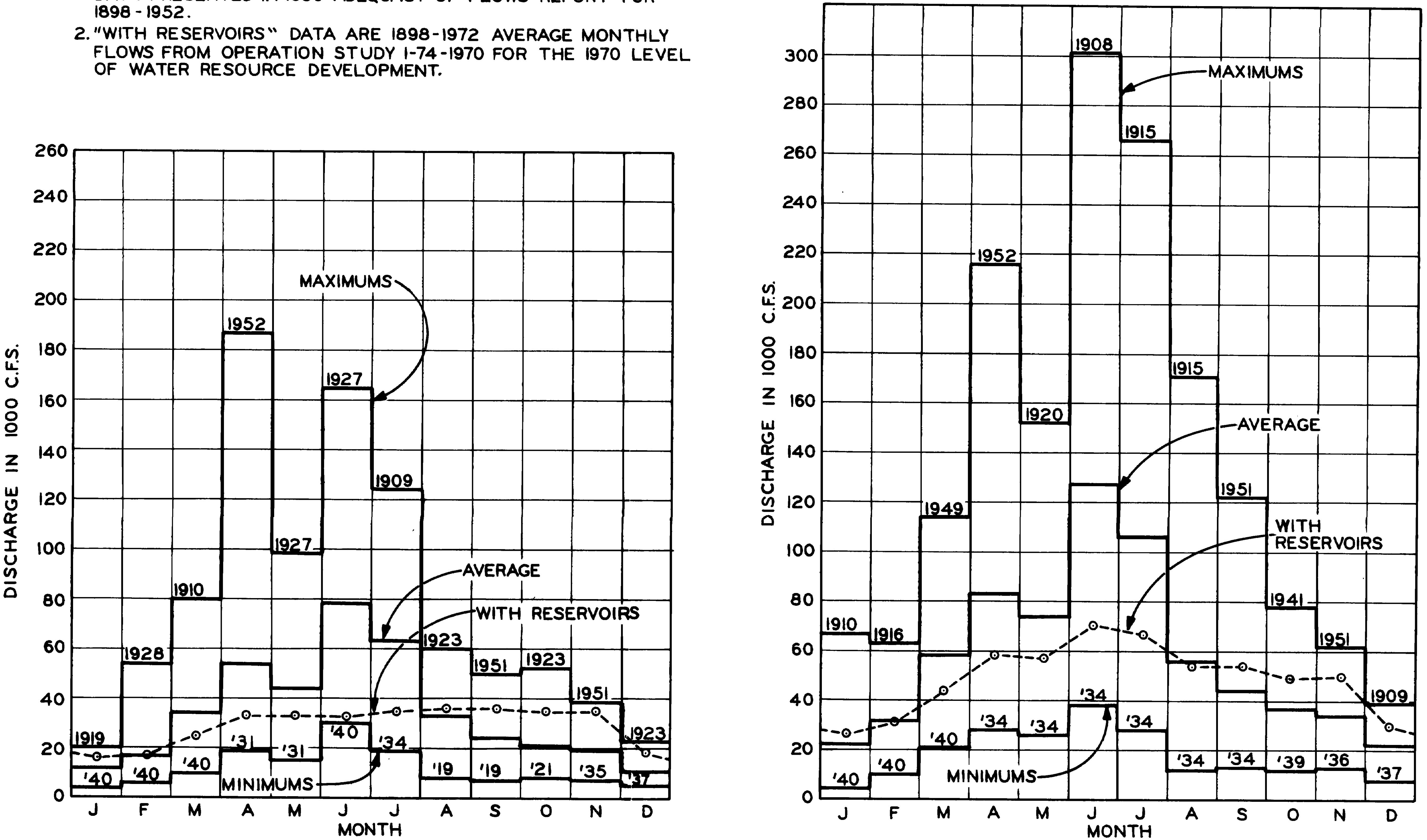
More precise, but laborious, procedures are available for determination of mean annual runoff, and these procedures have been followed by some agencies in small segments of the basin. To have applied these procedures at this time to the entire basin would have unduly delayed publication of this map, which is considered to be sufficiently accurate for framework planning purposes.

GENERALIZED ESTIMATES OF MEAN ANNUAL RUNOFF IN INCHES
(BASED ON PERIOD OF RECORD FOR EACH STATION AS ADJUSTED TO LONG RECORD STATION DATA)

PLATE 5

NOTES: 1. MAXIMUM, AVERAGE AND MINIMUM VALUES ARE FROM HISTORICAL DATA PRESENTED IN 1959 ADEQUACY OF FLOWS REPORT FOR 1898 - 1952.

2. "WITH RESERVOIRS" DATA ARE 1898-1972 AVERAGE MONTHLY FLOWS FROM OPERATION STUDY 1-74-1970 FOR THE 1970 LEVEL OF WATER RESOURCE DEVELOPMENT.



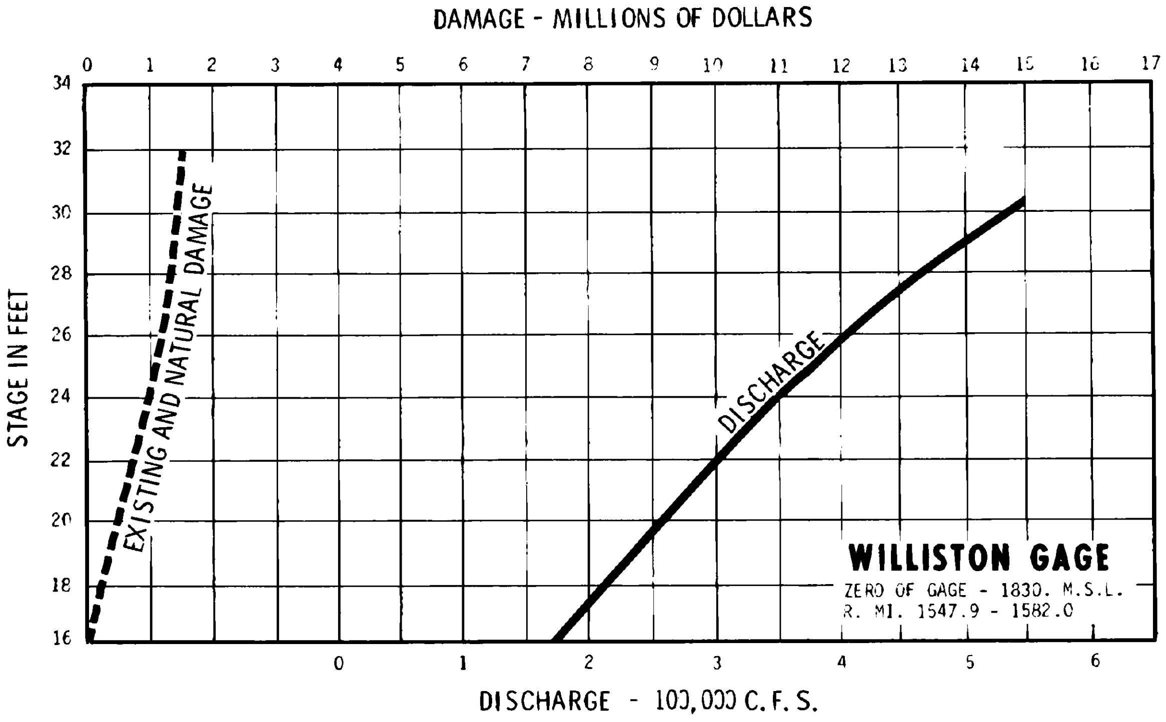
SIOUX CITY

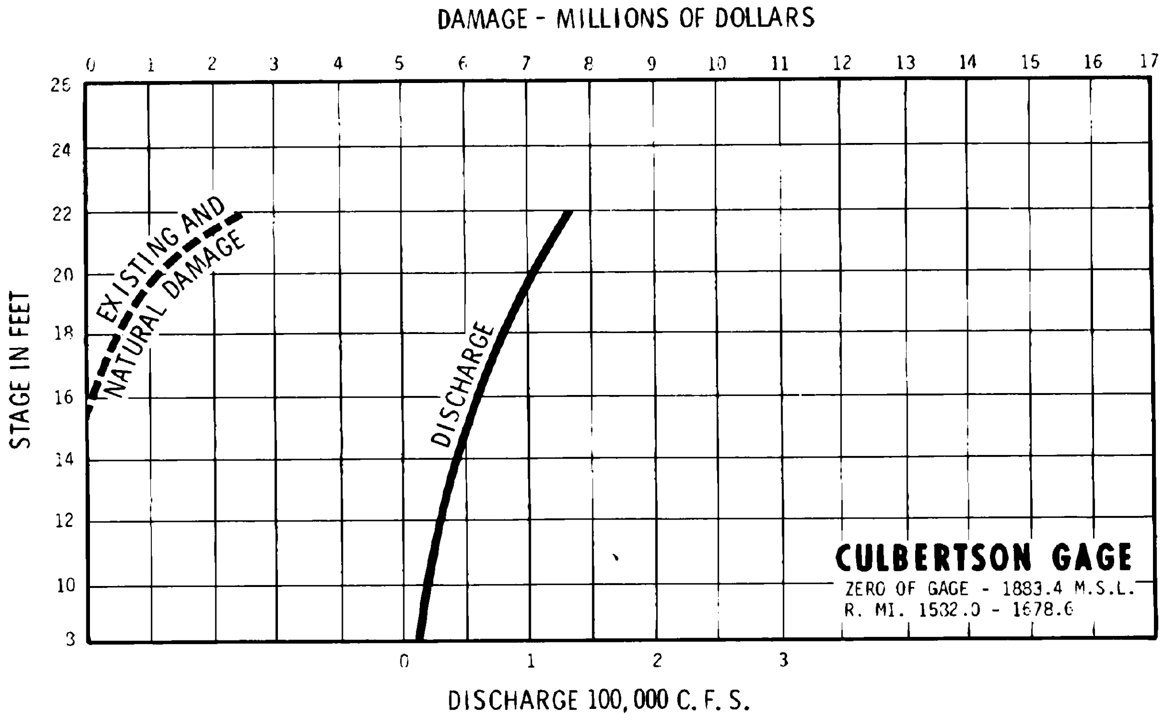
KANSAS CITY

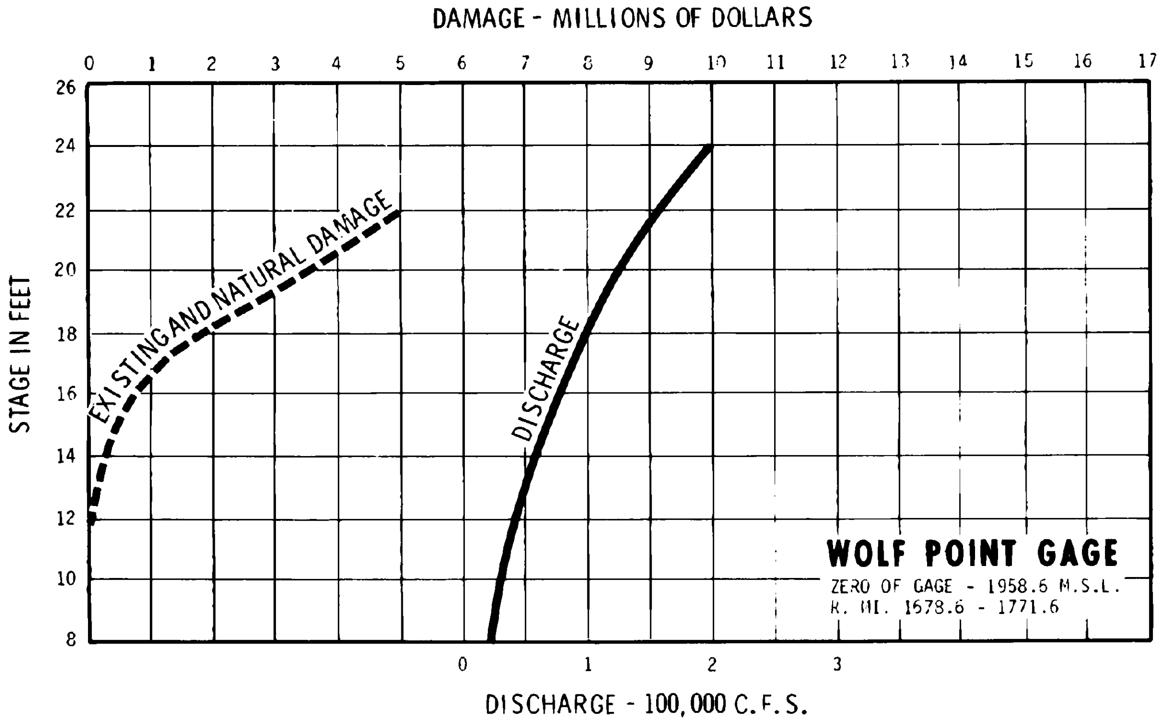
MISSOURI RIVER
MONTHLY STREAMFLOW
DISTRIBUTION

PLATE 6

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972-788-846



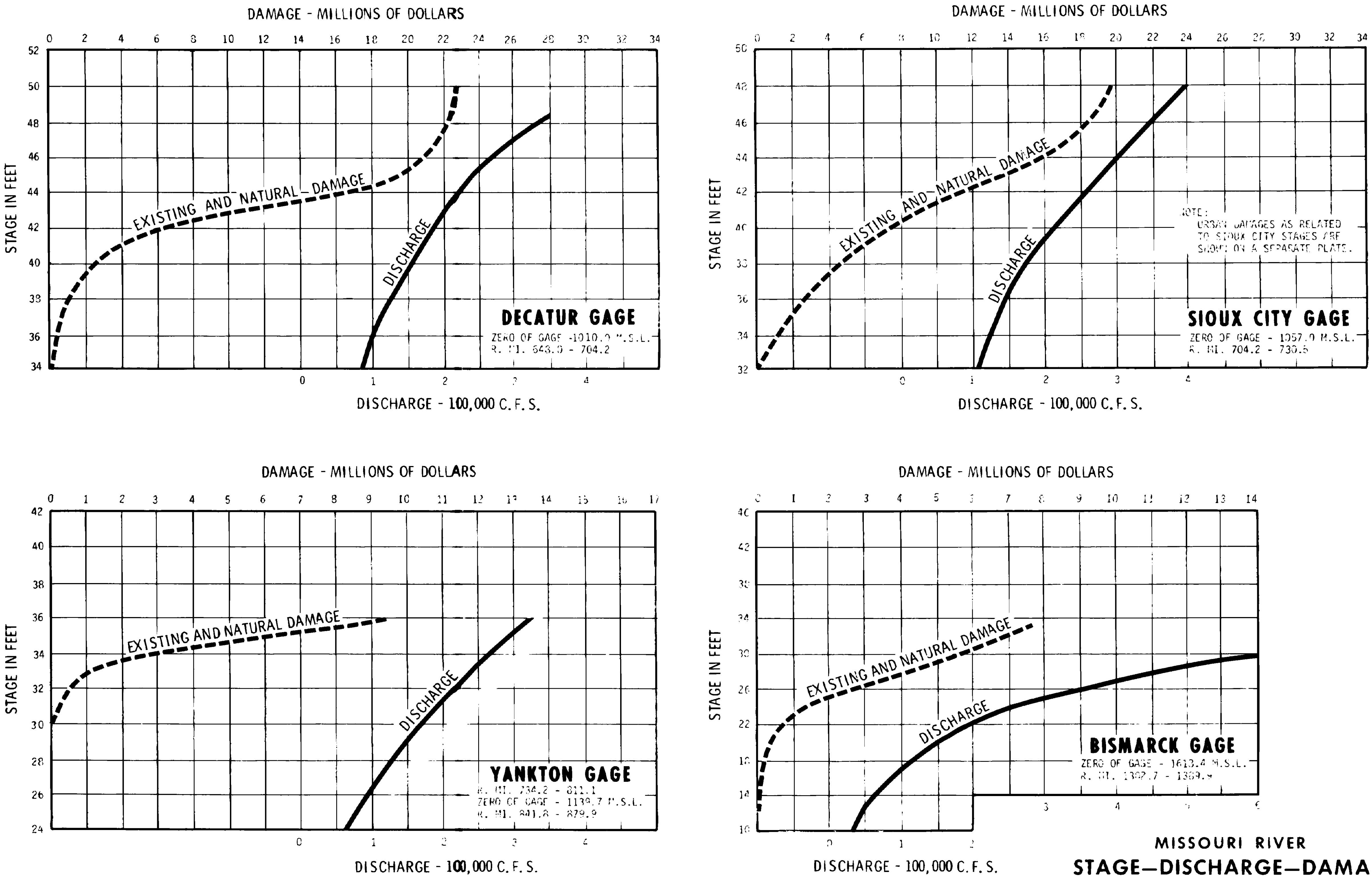




NOTE: DAMAGE CURVES ARE BASED ON ESTIMATED 1978 AVERAGE ANNUAL DAMAGES PER CROP YEAR.

MISSOURI RIVER
STAGE - DISCHARGE - DAMAGE CURVES
RURAL AREAS
WILLISTON, CULBERTSON AND WOLF POINT GAGES

PLATE 7



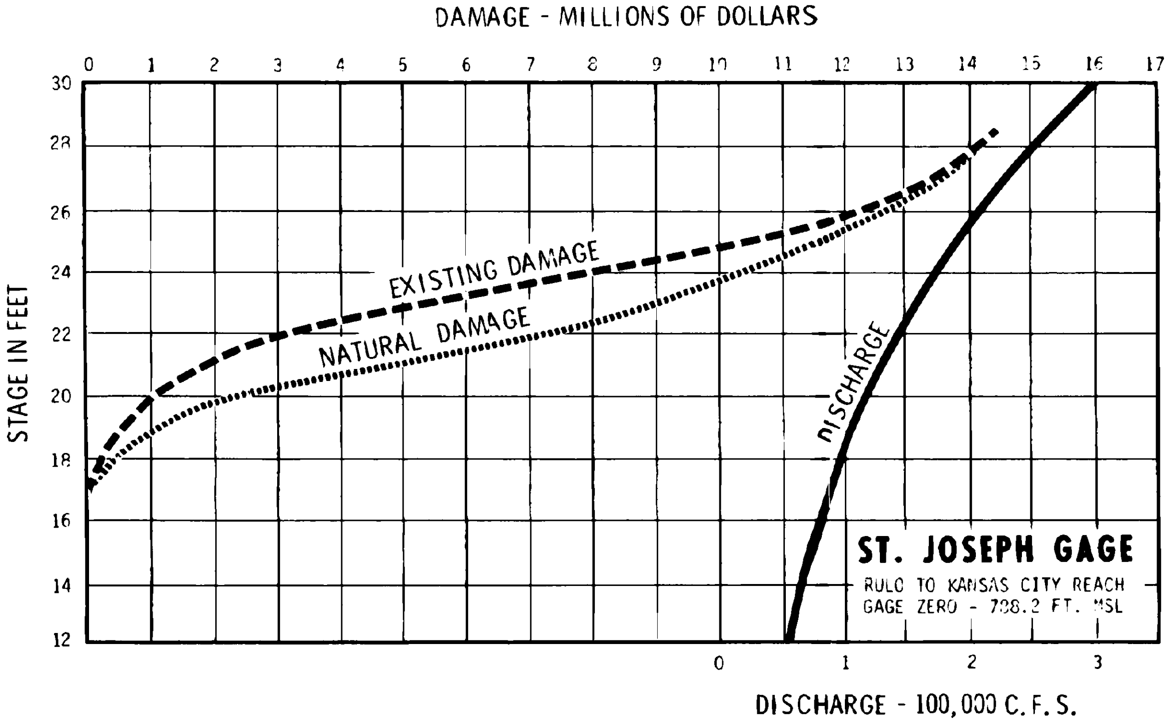
NOTE: DAMAGE CURVES ARE BASED ON ESTIMATED 1978 AVERAGE ANNUAL DAMAGES PER CROP YEAR.

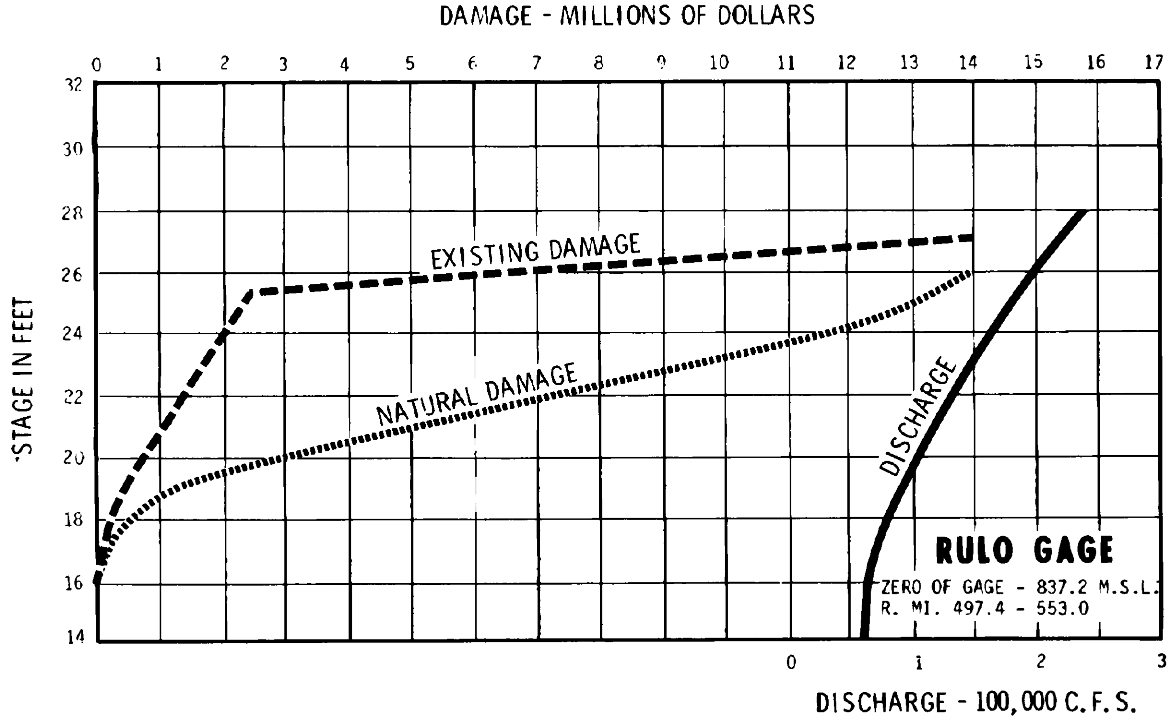
MISSOURI RIVER

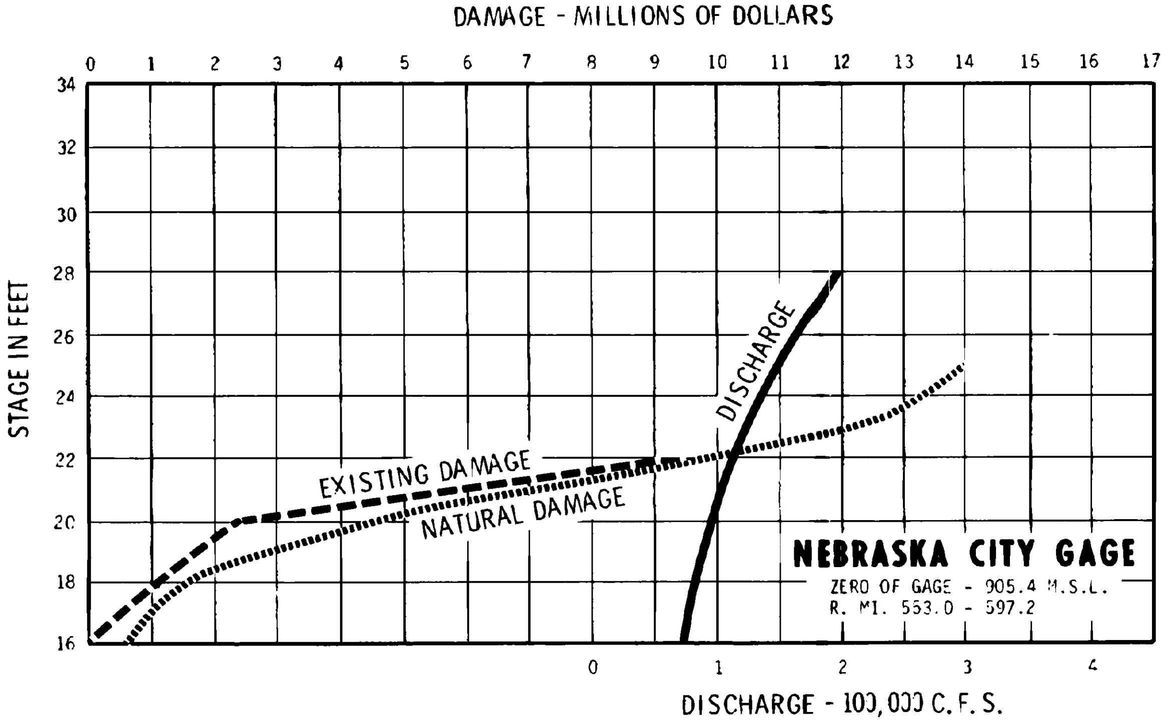
STAGE—DISCHARGE—DAMAGE CURVES

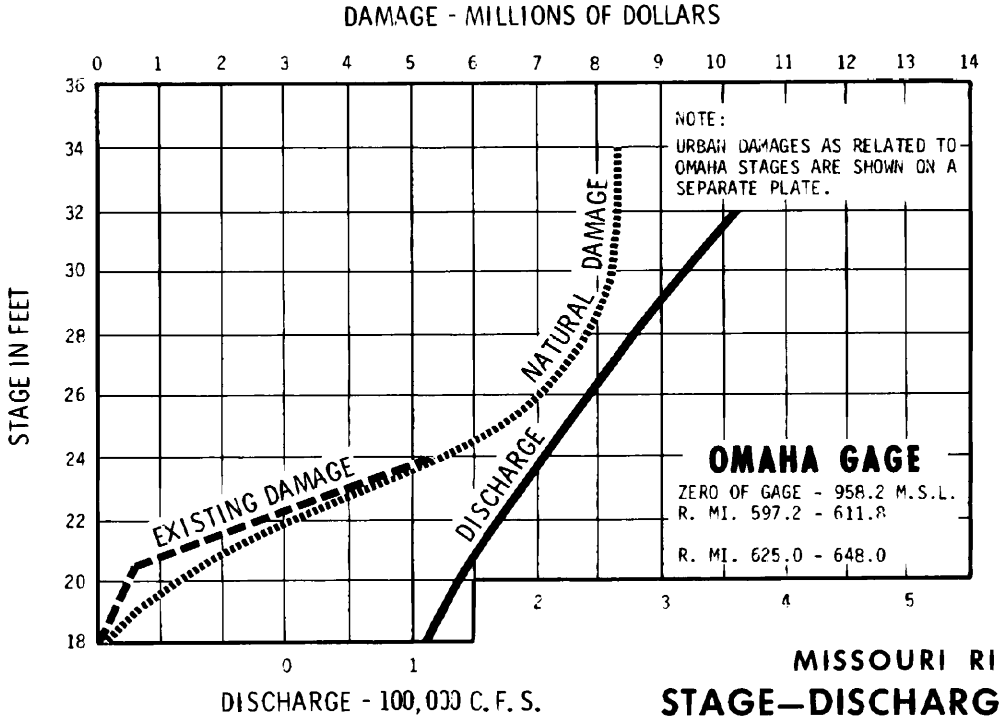
RURAL AREAS

DECATUR, SIOUX CITY, YANKTON
AND BISMARCK GAGES









NOTE: DAMAGE CURVES ARE BASED ON ESTIMATED 1978 AVERAGE ANNUAL DAMAGES PER CROP YEAR.

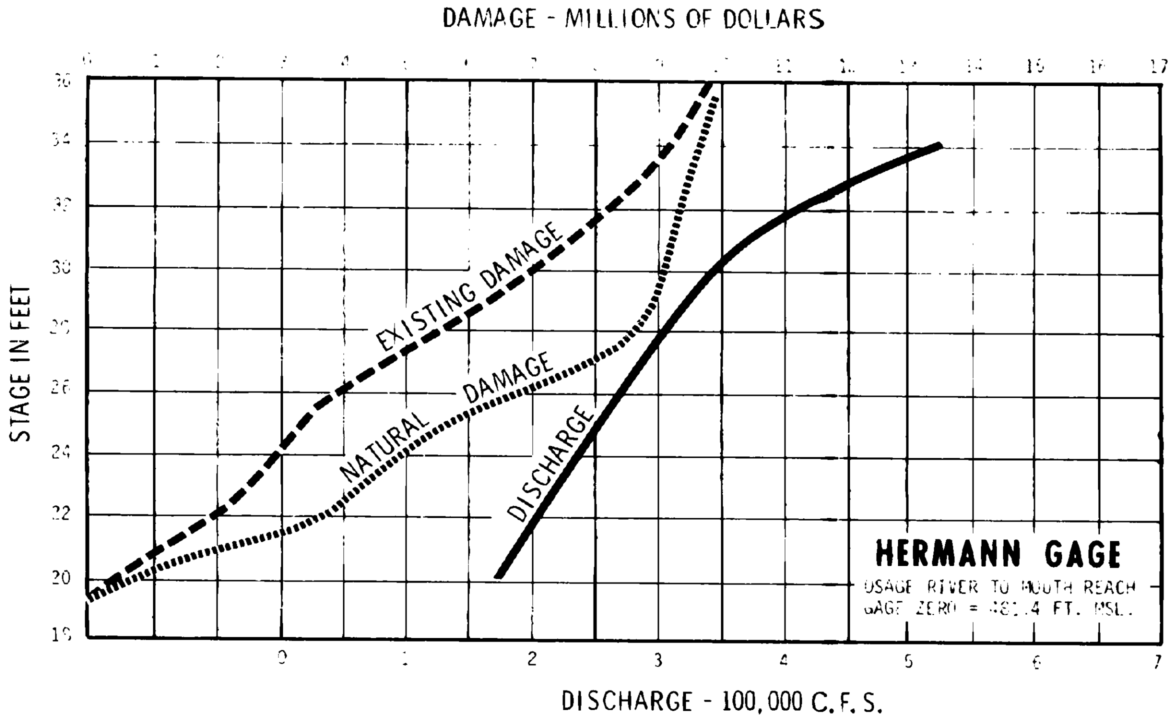
MISSOURI RIVER

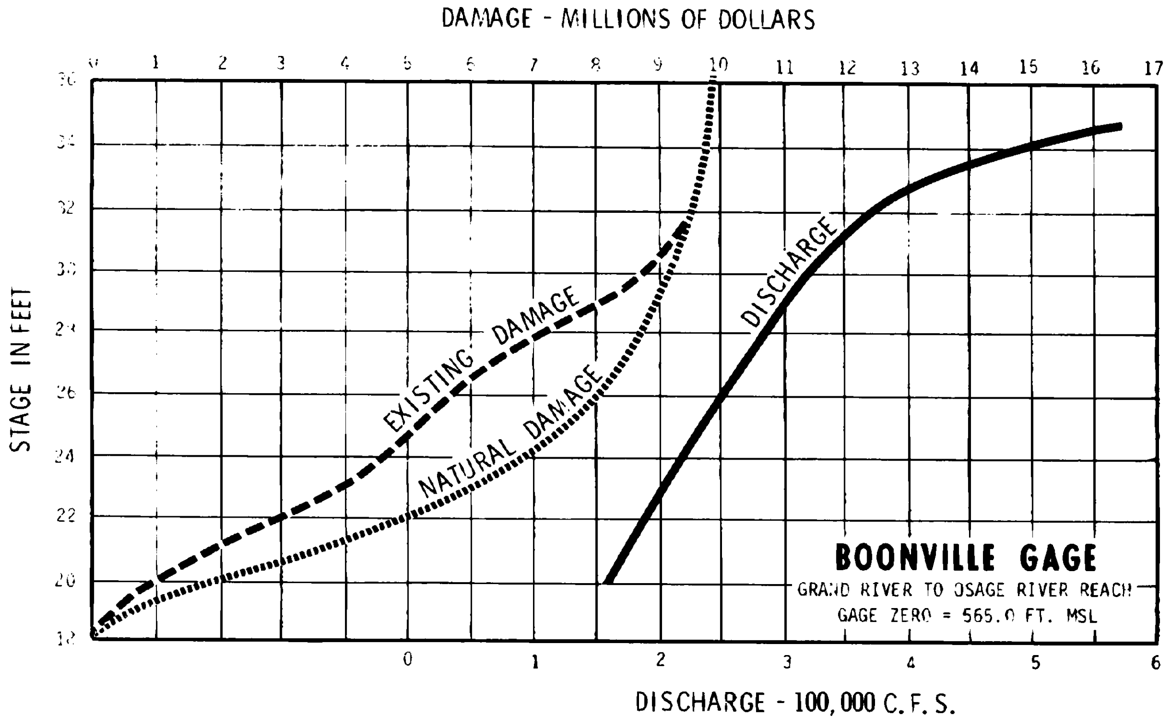
STAGE—DISCHARGE—DAMAGE CURVES

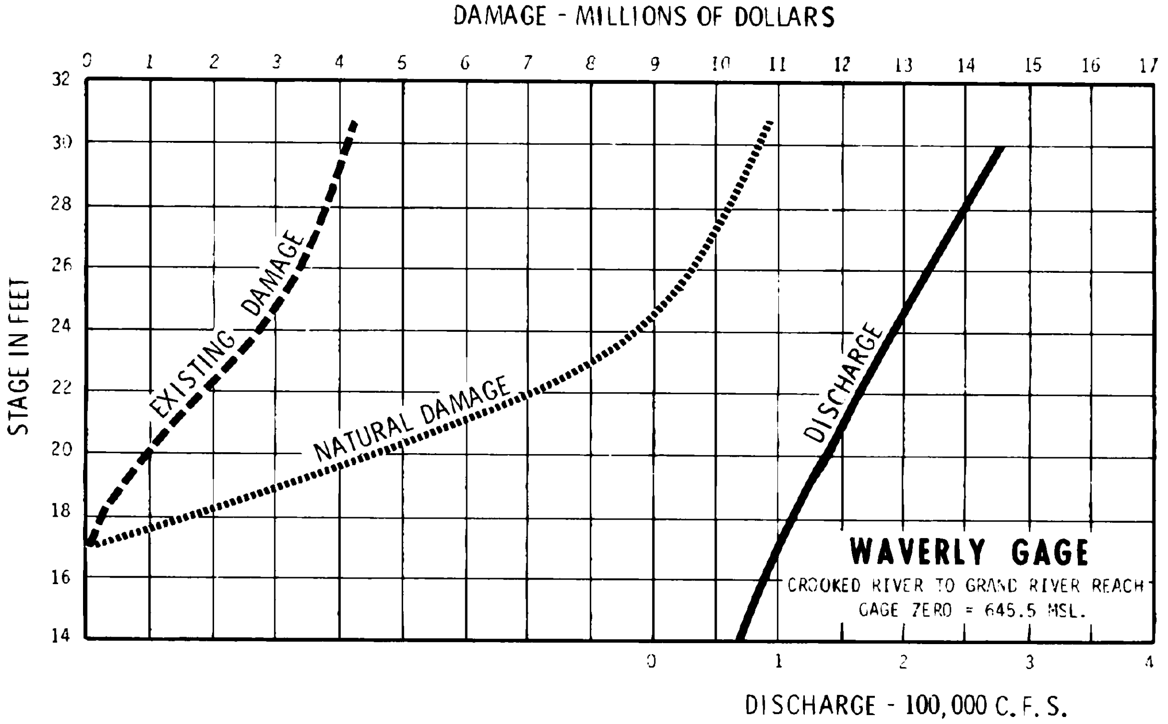
RURAL AREAS

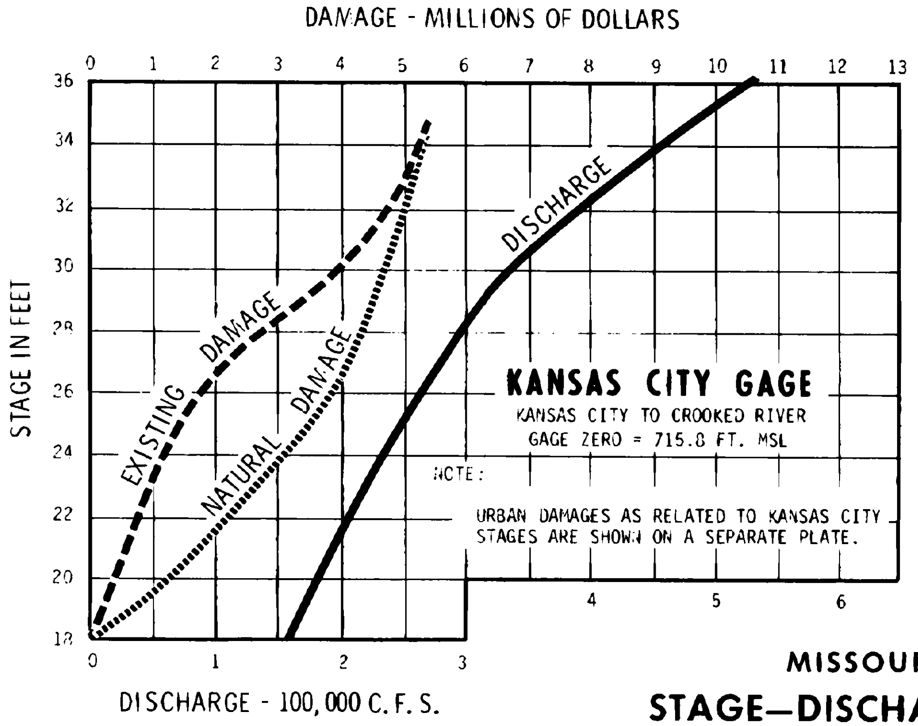
ST. JOSEPH, RULO, NEBRASKA CITY AND OMAHA GAGES

PLATE 9









NOTE:

URBAN DAMAGES AS RELATED TO KANSAS CITY STAGES ARE SHOWN ON A SEPARATE PLATE.

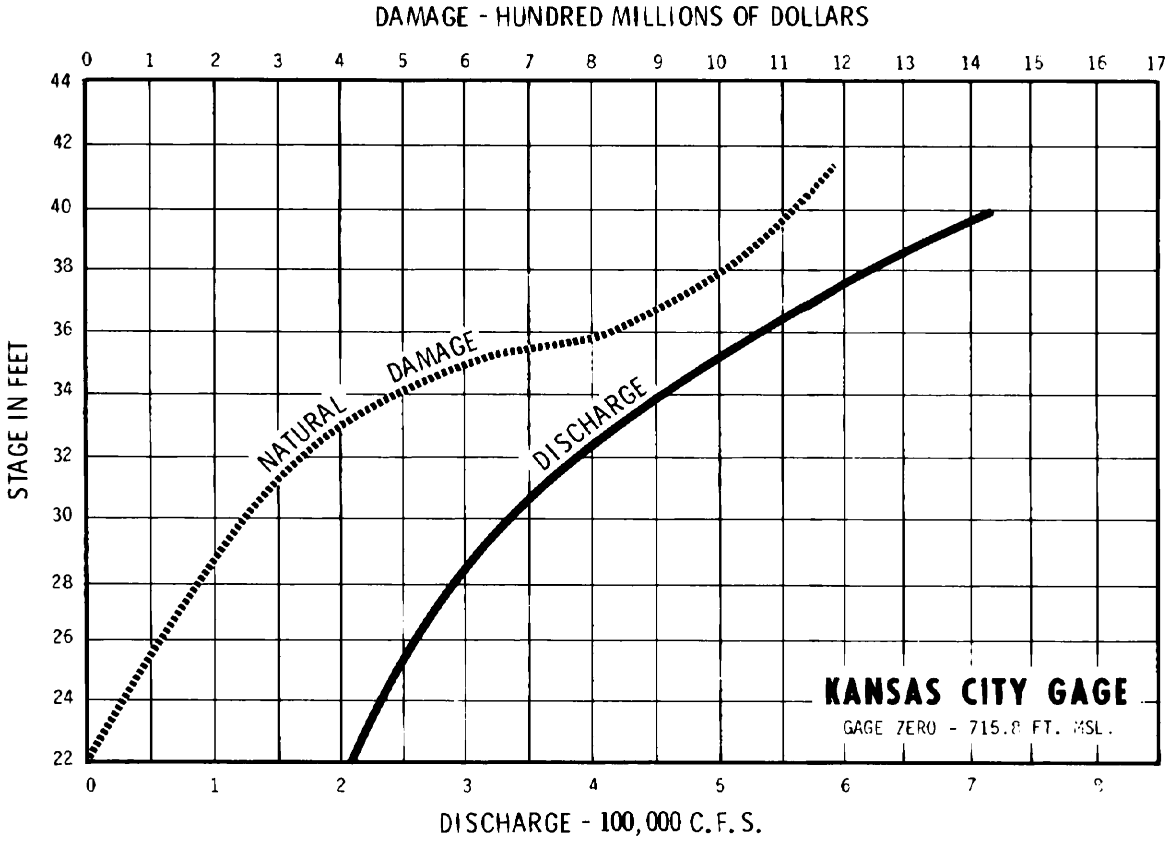
NOTE. DAMAGE CURVES ARE BASED ON ESTIMATED 1978 AVERAGE ANNUAL DAMAGES PER CROP YEAR.

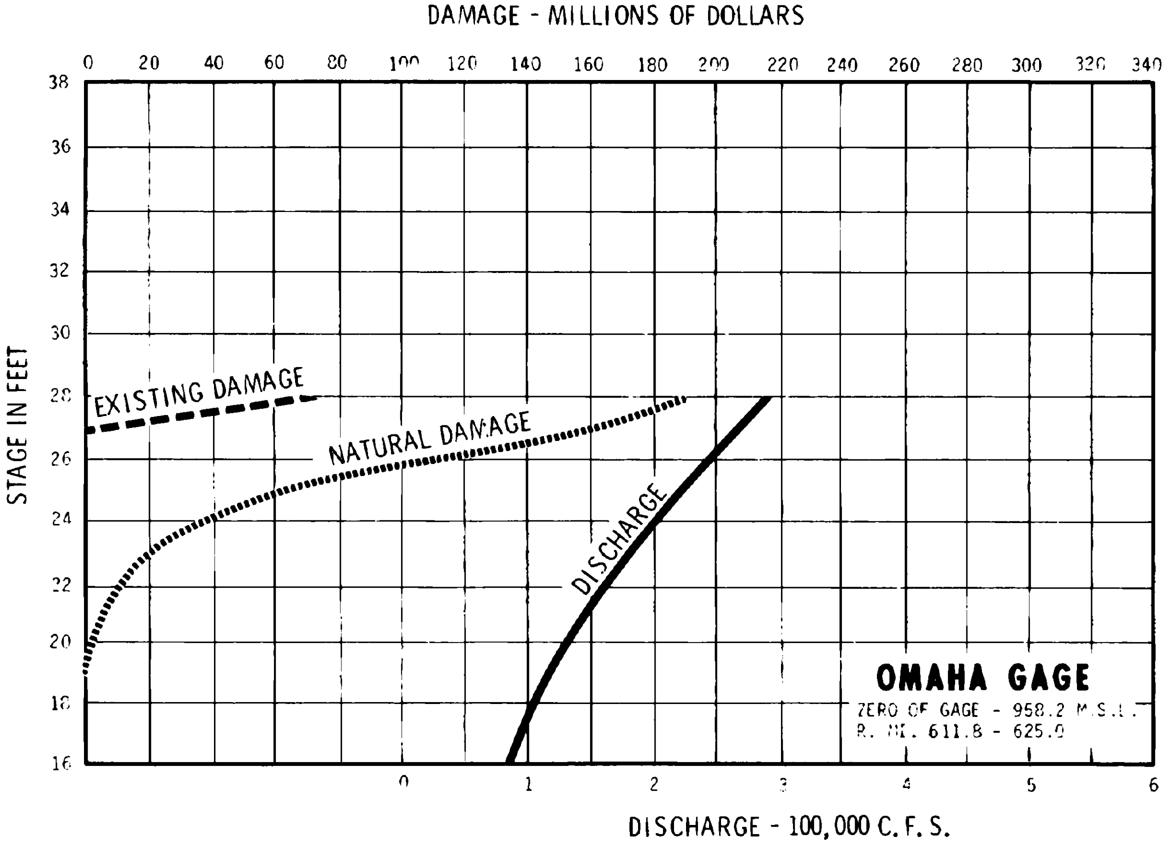
MISSOURI RIVER

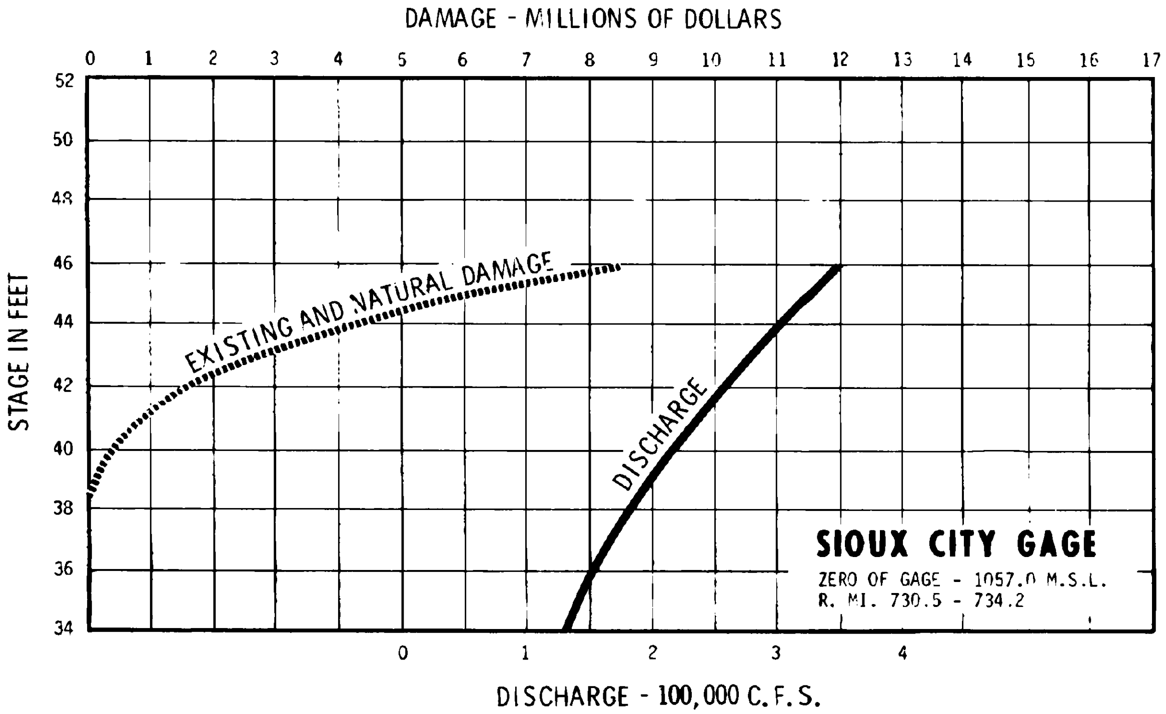
STAGE—DISCHARGE—DAMAGE CURVES

RURAL AREAS

KANSAS CITY, WAVERLY, BOONVILLE
AND HERMANN GAGES





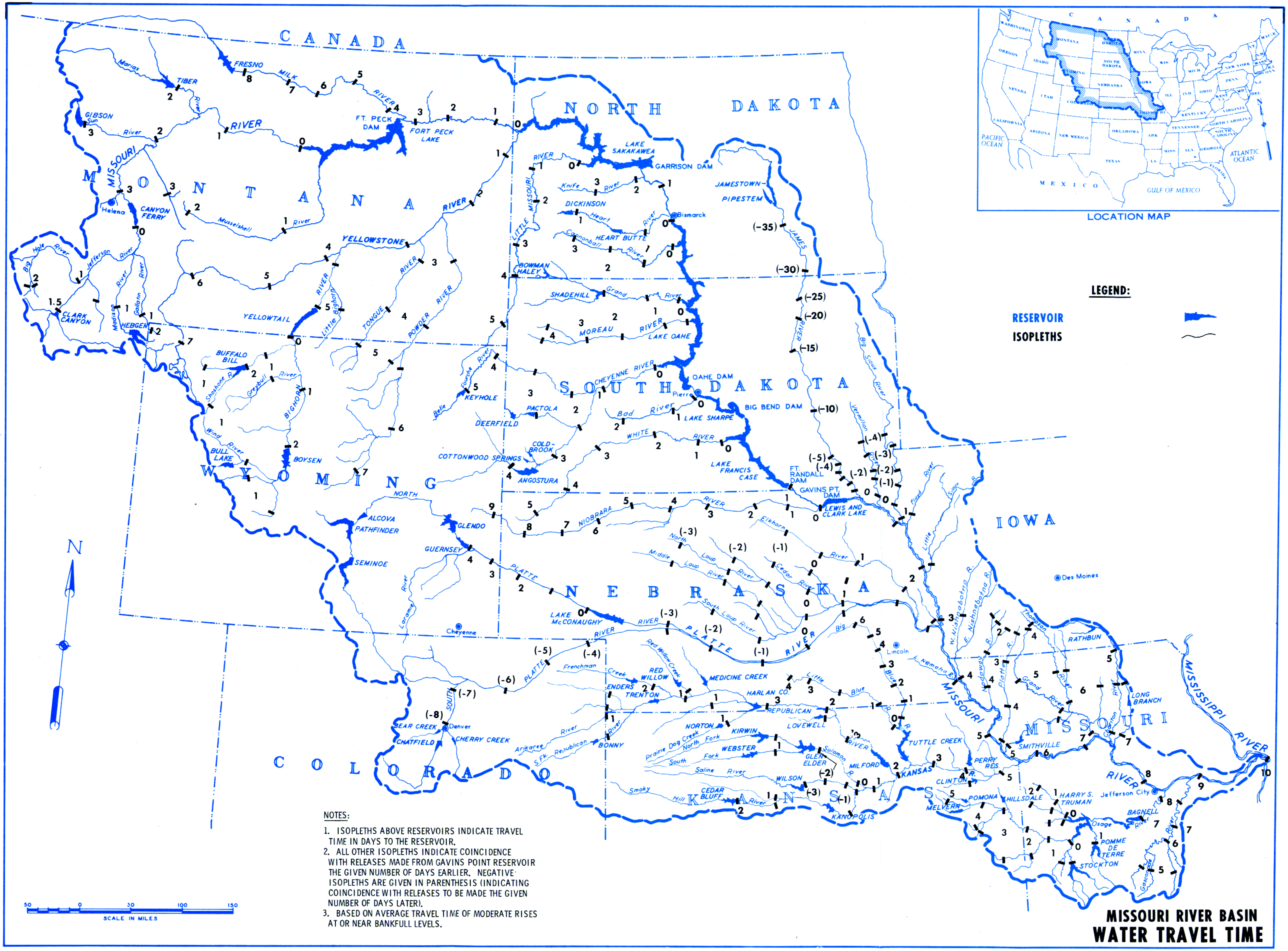


NOTE: DAMAGE CURVES ARE BASED ON ESTIMATED 1978 AVERAGE ANNUAL DAMAGES PER CROP YEAR.

MISSOURI RIVER
STAGE - DISCHARGE - DAMAGE CURVES
URBAN AREAS

KANSAS CITY, OMAHA AND SIOUX CITY GAGES

PLATE II

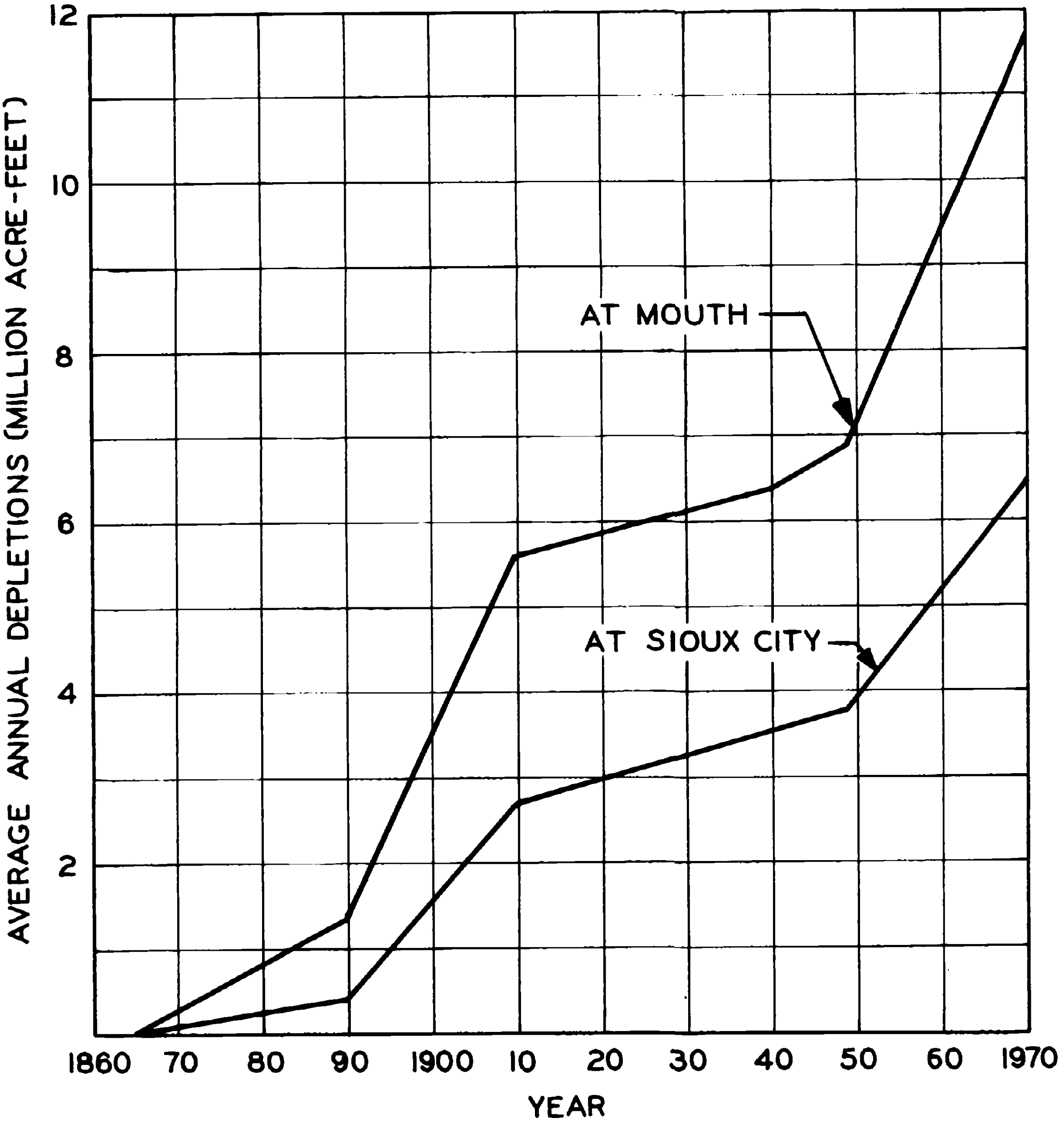


NOTES:

1. ISOPLETHS ABOVE RESERVOIRS INDICATE TRAVEL TIME IN DAYS TO THE RESERVOIR.
2. ALL OTHER ISOPLETHS INDICATE COINCIDENCE WITH RELEASES MADE FROM GAVINS POINT RESERVOIR THE GIVEN NUMBER OF DAYS EARLIER. NEGATIVE ISOPLETHS ARE GIVEN IN PARENTHESIS (INDICATING COINCIDENCE WITH RELEASES TO BE MADE THE GIVEN NUMBER OF DAYS LATER).
3. BASED ON AVERAGE TRAVEL TIME OF MODERATE RISES AT OR NEAR BANKFULL LEVELS.

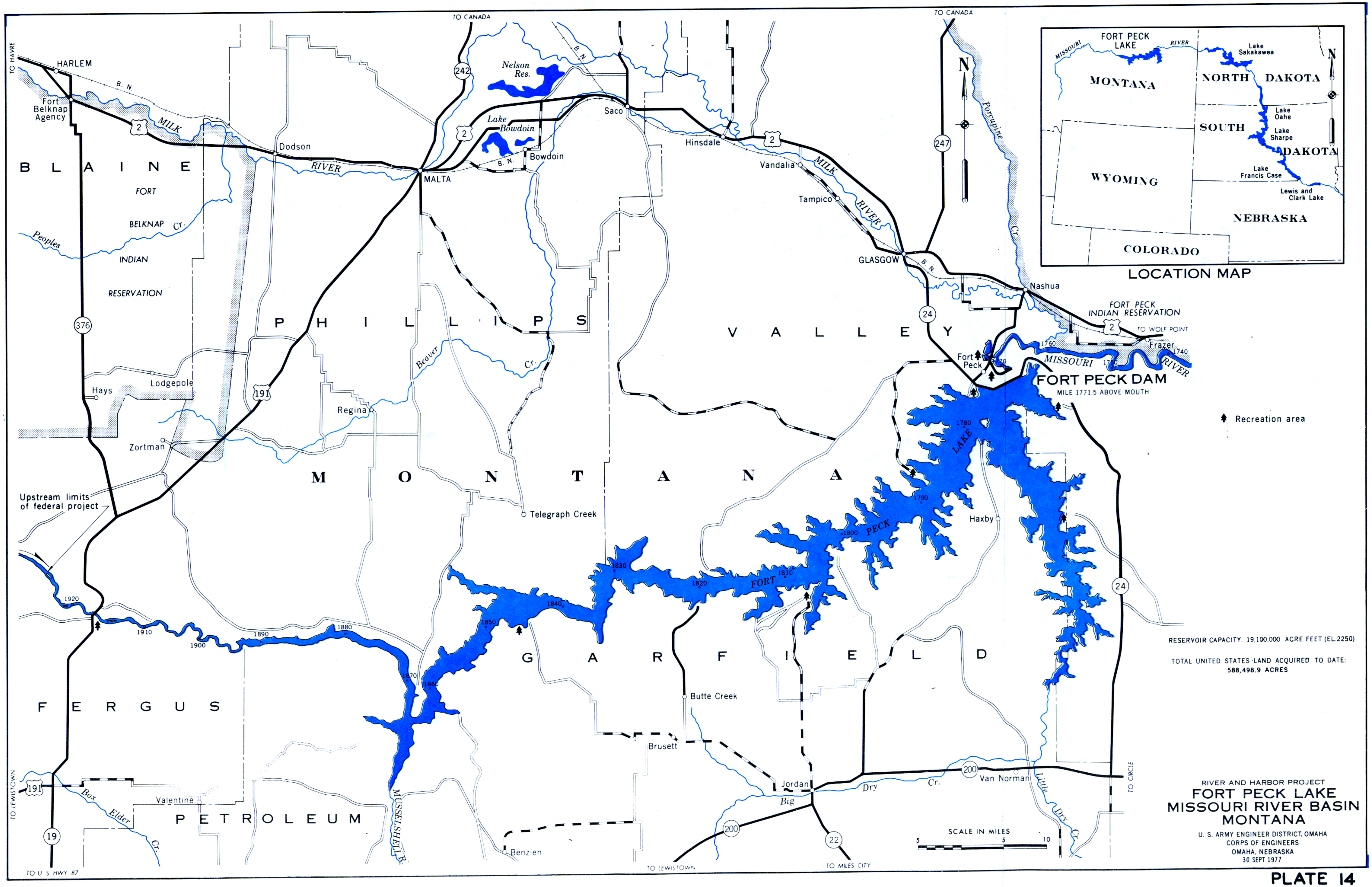
MISSOURI RIVER BASIN
WATER TRAVEL TIME

PLATE 12



GROWTH OF STREAMFLOW DEPLETIONS

PLATE 13

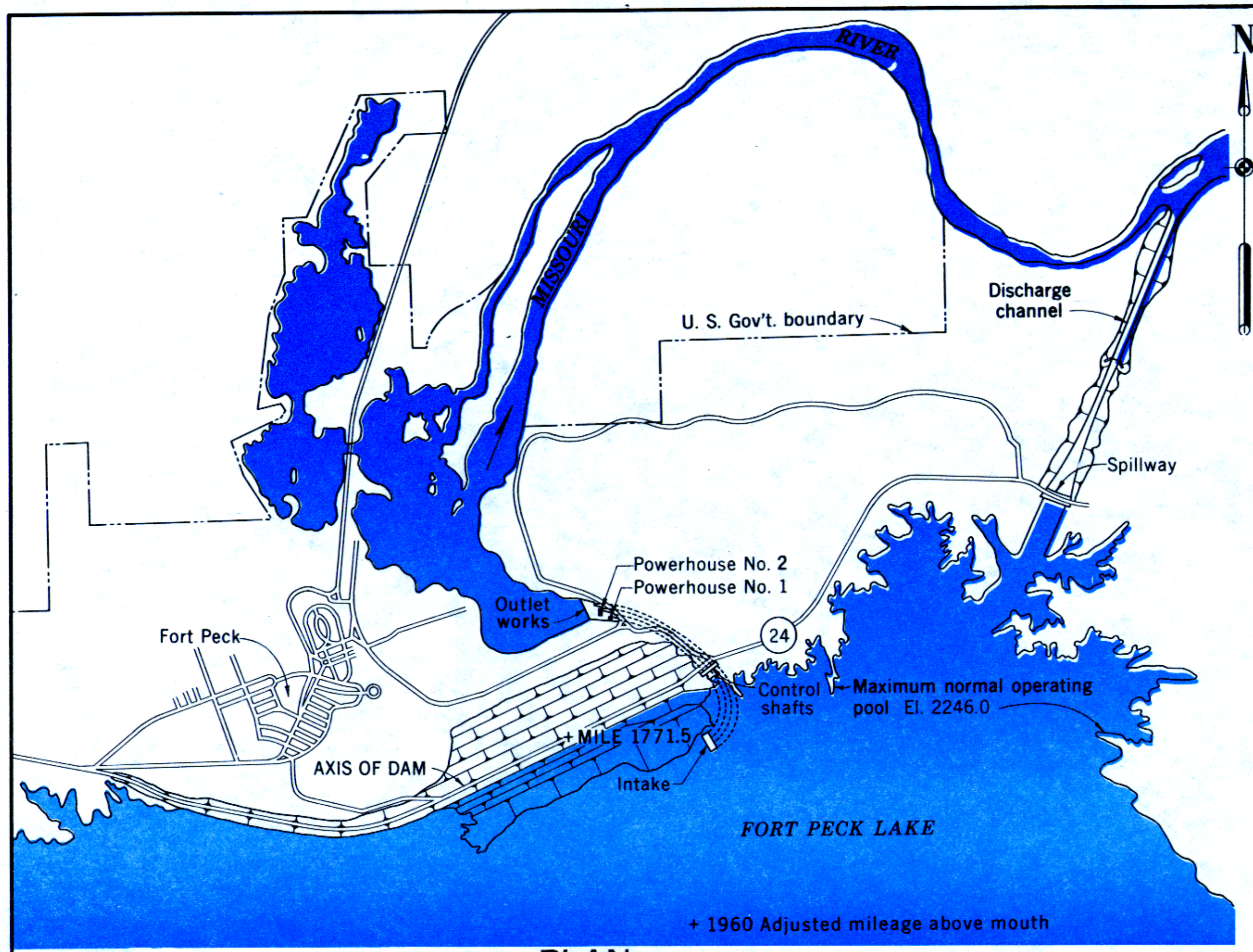


RESERVOIR CAPACITY: 19,100,000 ACRE FEET (EL.2250)

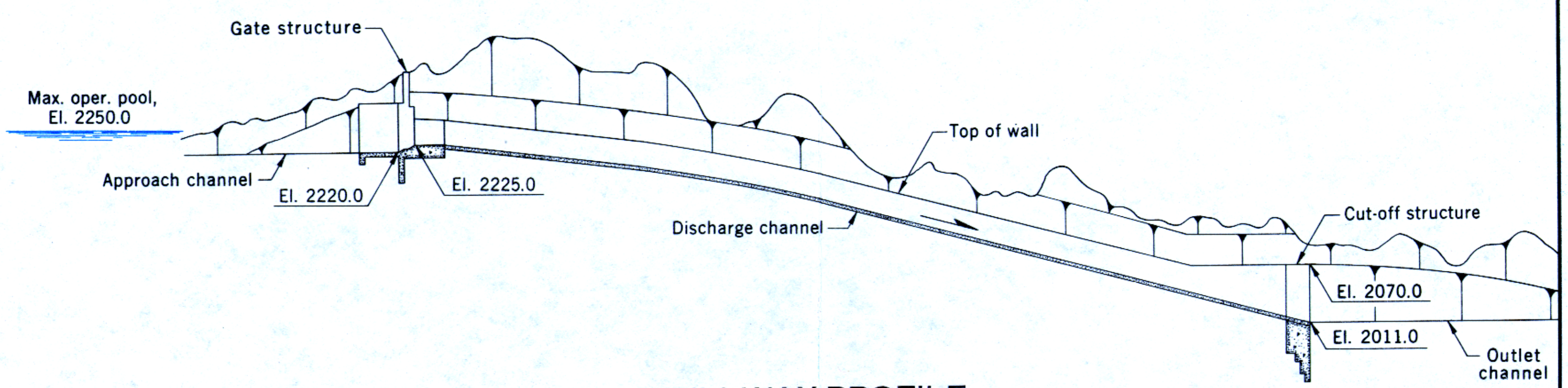
TOTAL UNITED STATES LAND ACQUIRED TO DATE:
588,498.9 ACRES

RIVER AND HARBOR PROJECT
FORT PECK LAKE
MISSOURI RIVER BASIN
MONTANA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

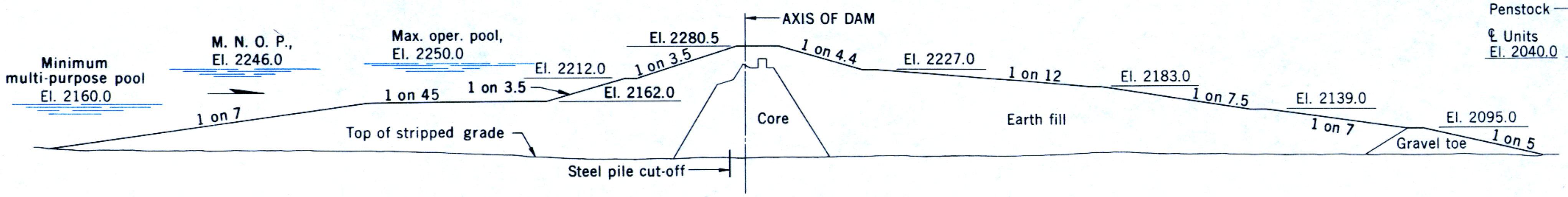
PLATE 14



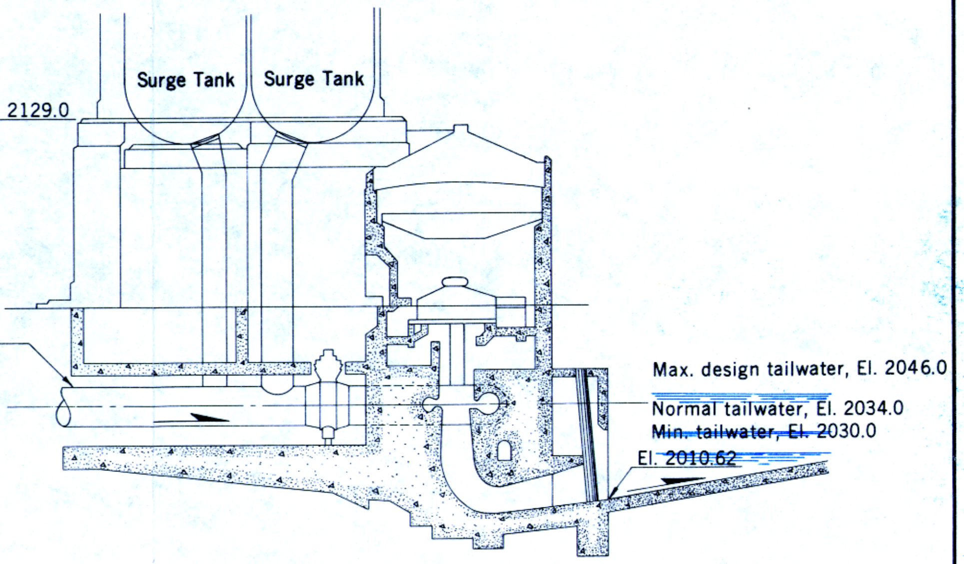
PLAN



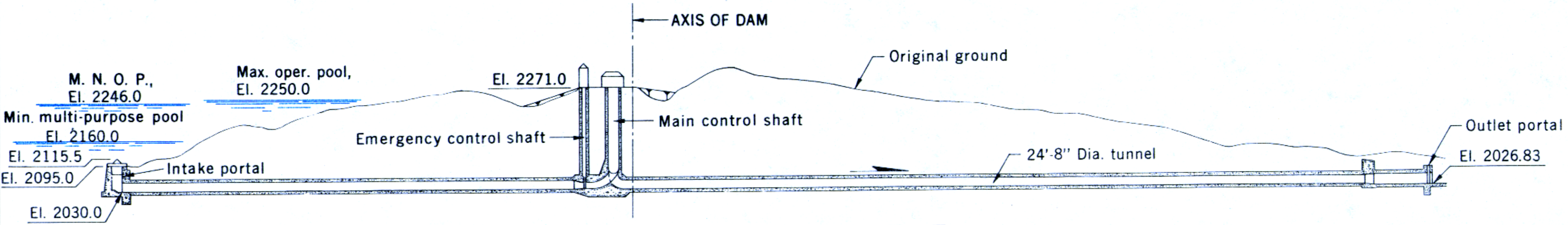
SPILLWAY PROFILE



MAXIMUM EMBANKMENT SECTION



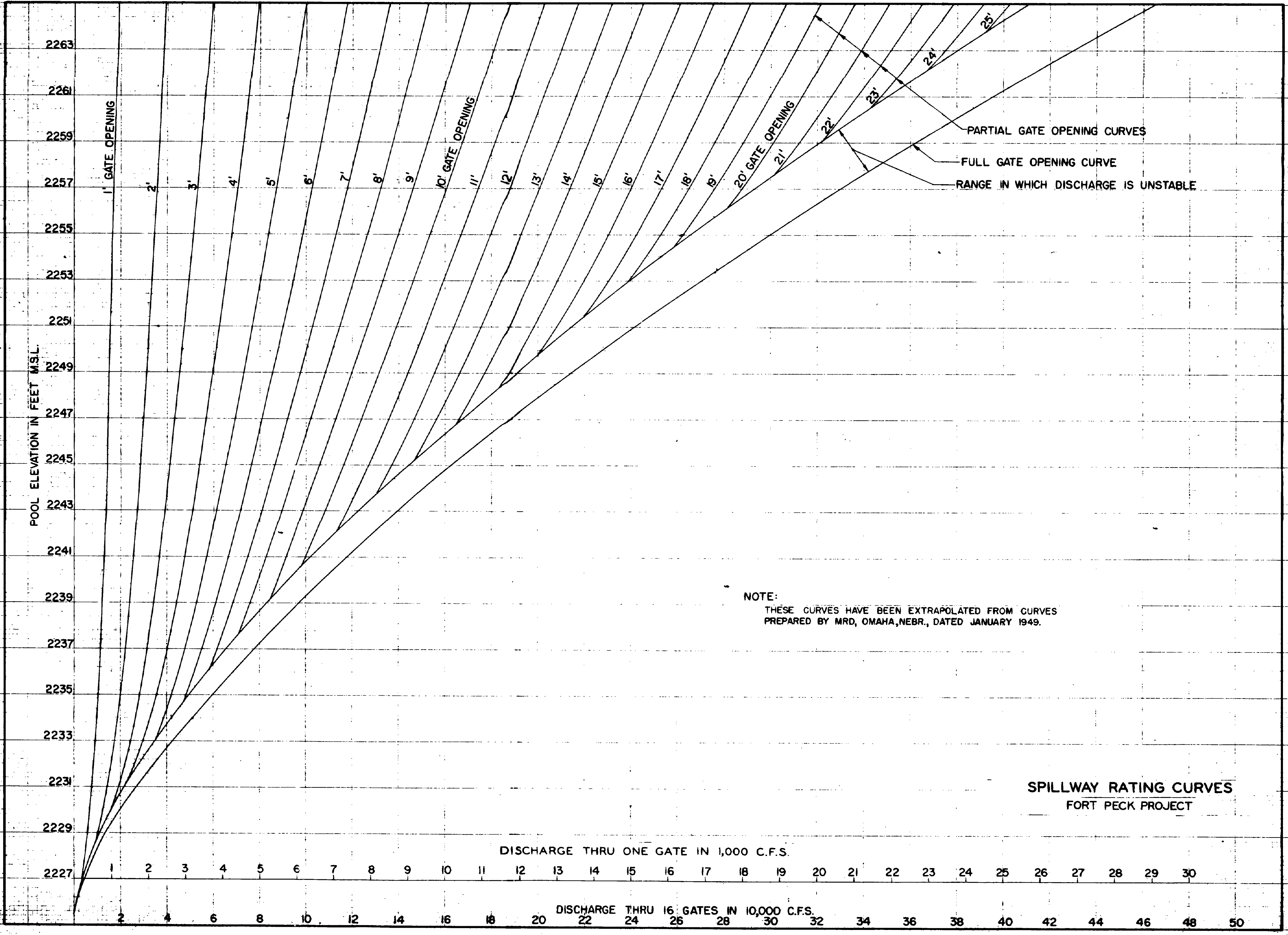
POWERHOUSE SECTION
FIRST POWER PLANT



OUTLET WORKS PROFILE

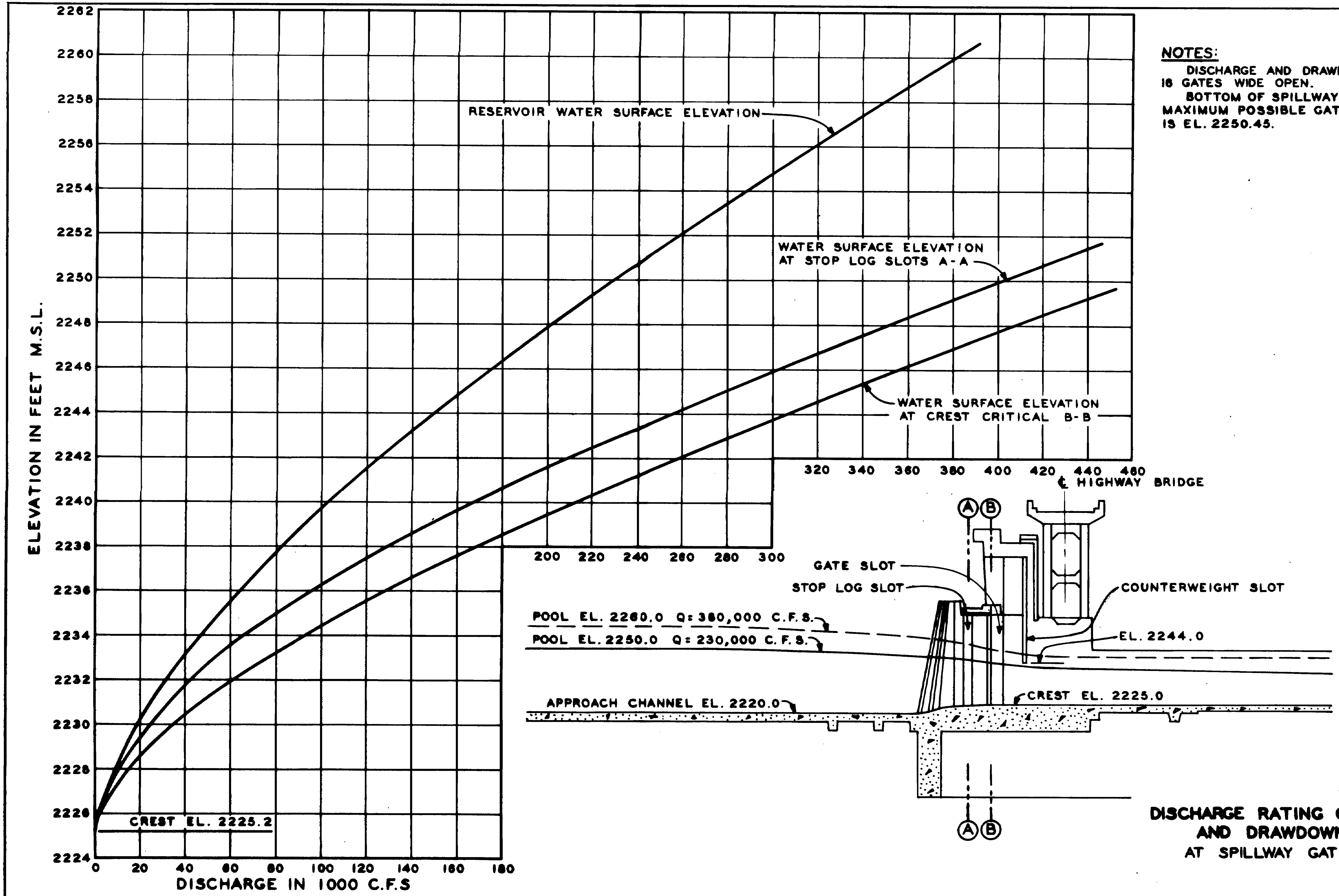
RIVER AND HARBOR PROJECT
FORT PECK LAKE
MISSOURI RIVER BASIN
MONTANA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

PLATE 15



NOTE:
THESE CURVES HAVE BEEN EXTRAPOLATED FROM CURVES PREPARED BY MRD, OMAHA, NEBR., DATED JANUARY 1949.

SPILLWAY RATING CURVES
FORT PECK PROJECT

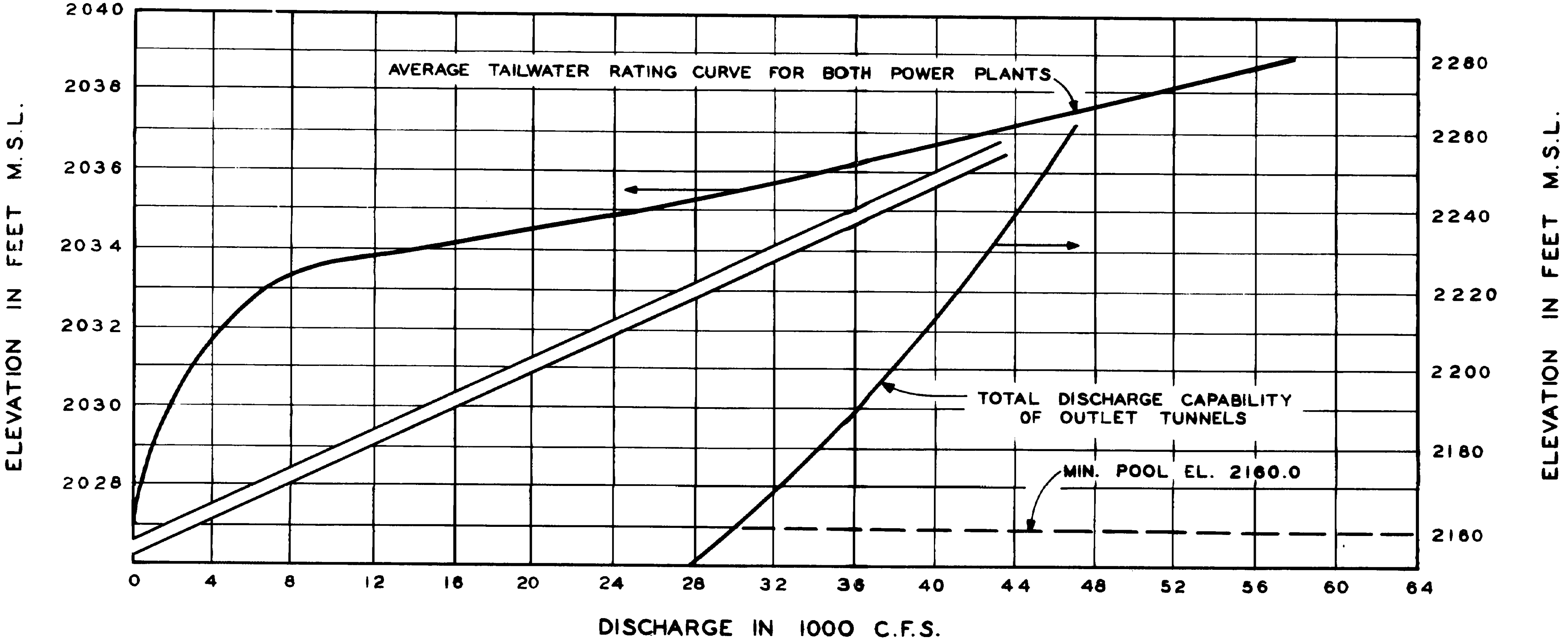


NOTES:

DISCHARGE AND DRAWDOWN WITH 16 GATES WIDE OPEN.

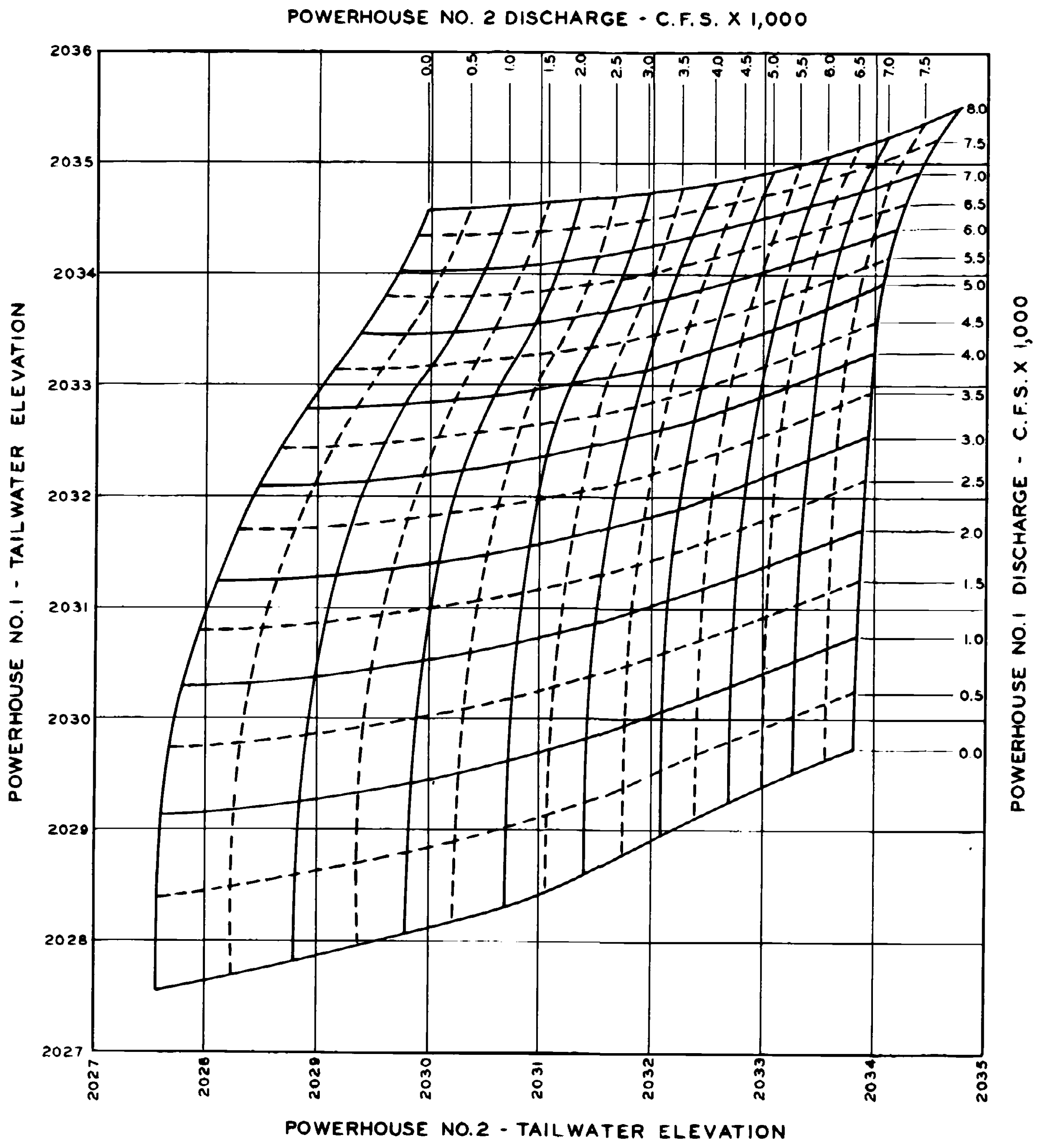
BOTTOM OF SPILLWAY GATE AT MAXIMUM POSSIBLE GATE OPENING IS EL. 2250.45.

DISCHARGE RATING CURVE AND DRAWDOWN
AT SPILLWAY GATES



POWER PLANT, TAILWATER RATING CURVE AND DISCHARGE CAPABILITY OF OUTLET TUNNELS

FORT PECK PROJECT



DIRECTIONS:

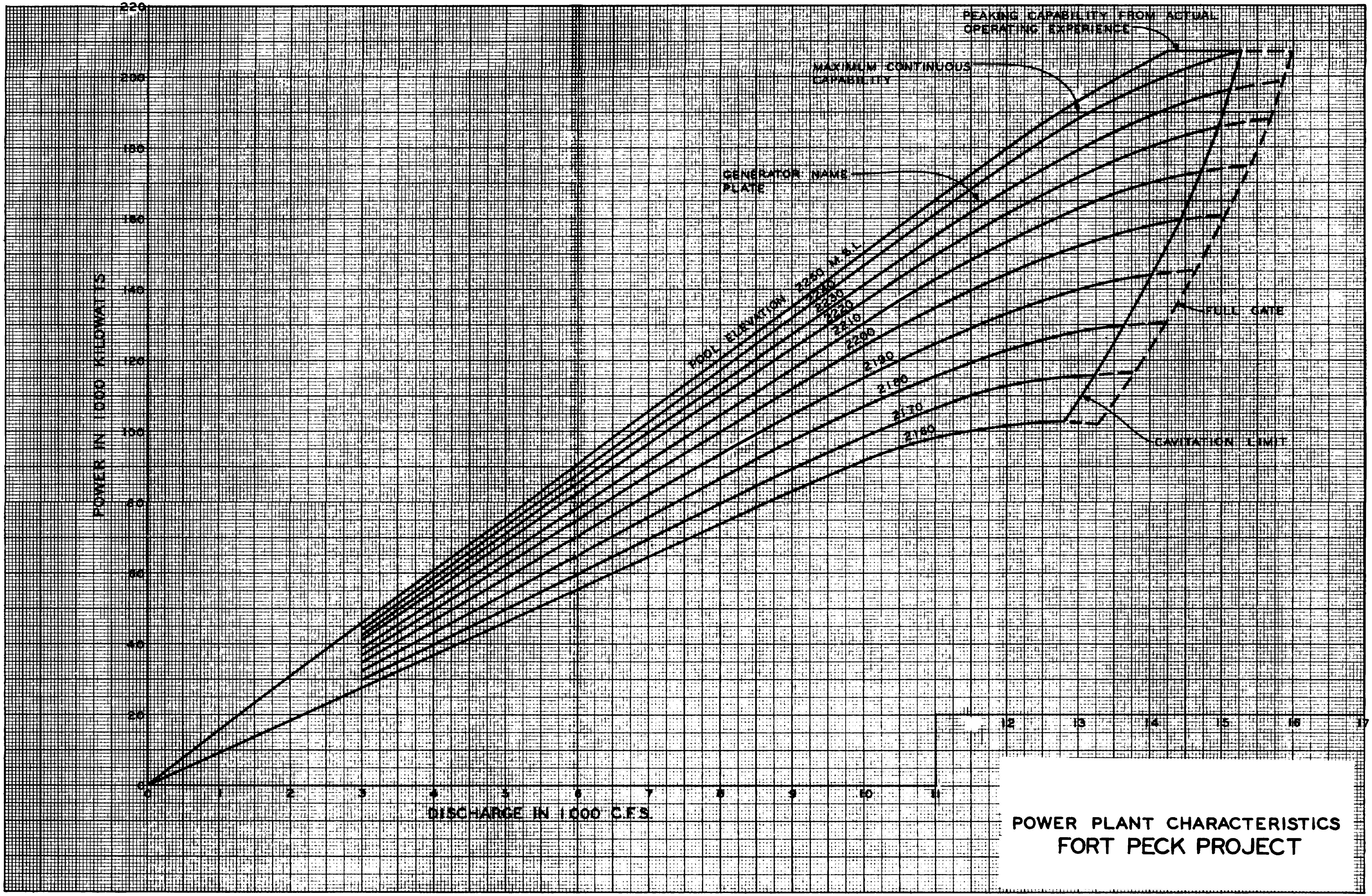
Tailwater elevation can be determined by following the Powerhouse No. 1 discharge curve to the left until the correct Powerhouse No. 2 discharge is reached. From this point read directly to the left for Powerhouse No. 1 tailwater elevation and straight down for Powerhouse No. 2 tailwater elevation.

NOTES: These curves are only good when steady state flow conditions exist at both powerhouses.

The curves are based on steady state flow periods determined from the 1963 through 1965 stage recorder charts of both powerhouses. Discharges for these periods were obtained from the hourly powerhouse releases.

TAILWATER RATING CURVES
POWER PLANT NO. 1 AND
POWER PLANT NO. 2
FORT PECK PROJECT

PLATE 16D



POWER PLANT CHARACTERISTICS
FORT PECK PROJECT

PLATE 16E

FORT PECK
AREA AND CAPACITY DATA

Effective 1 Jul 1973

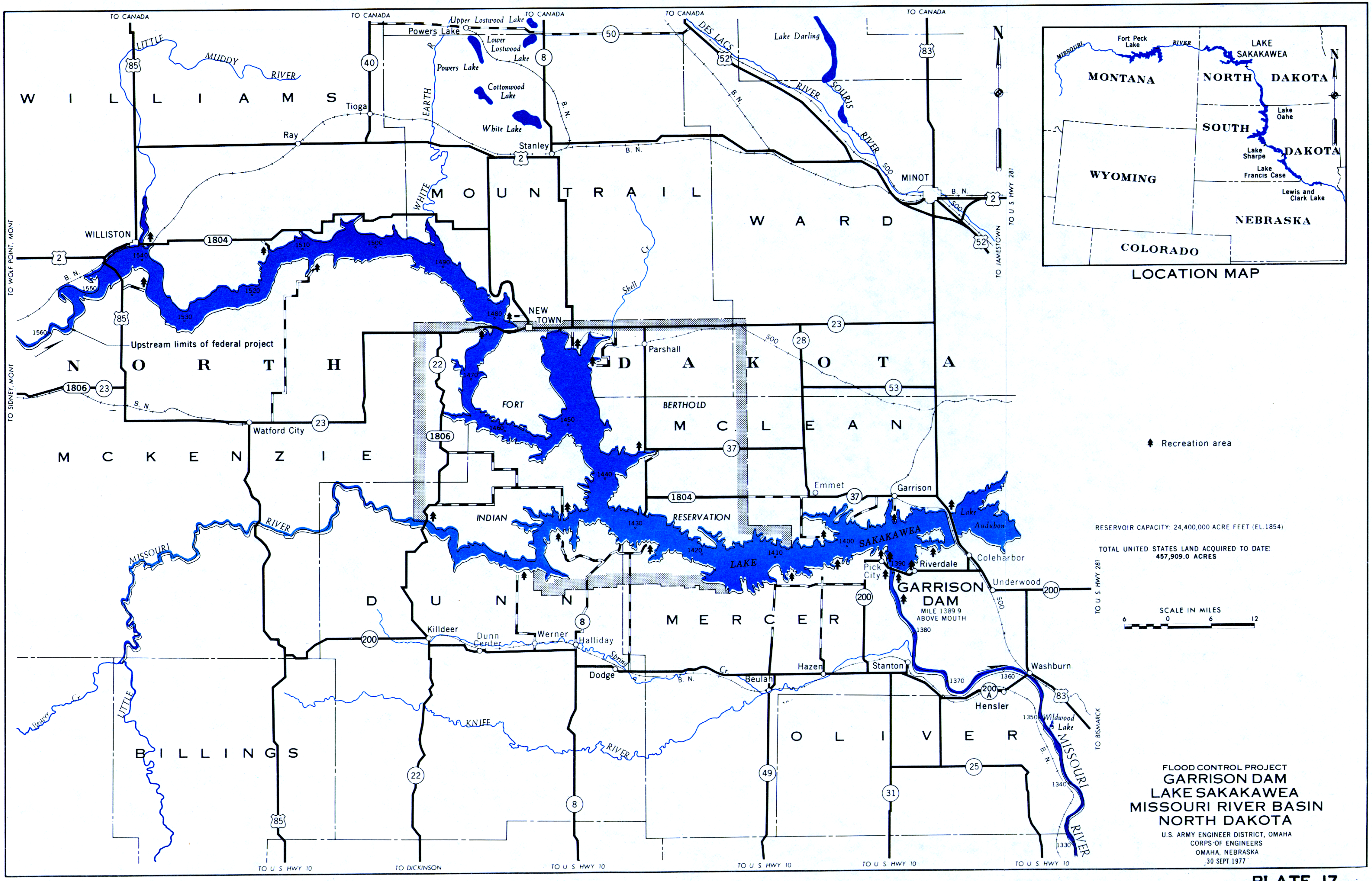
FORT PECK PROJECT
AREA IN ACRES
(1972 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
2030	0	0	0	0	32	77	115	167	249	359
2040	481	589	693	808	934	1075	1228	1362	1462	1512
2050	1523	1531	1559	1728	2061	2406	2674	2949	3325	3801
2060	4309	4764	5214	5720	6283	6829	7312	7844	8508	9304
2070	10211	11116	11912	12579	13117	13639	14254	14838	15274	15561
2080	15710	15846	16126	16596	17256	17956	18537	19137	19905	20839
2090	21882	22896	23816	24656	25418	26159	26944	27729	28459	29135
2100	29752	30357	31026	31789	32646	33535	34379	35212	36089	37008
2110	37914	38773	39668	40663	41757	42855	43872	44926	46122	47458
2120	48893	50308	51634	52879	54043	55168	56324	57502	58671	59832
2130	61013	62221	63395	64494	65516	66534	67611	68663	69612	70459
2140	71231	72014	72867	73789	74780	75800	76791	77768	78763	79775
2150	80779	81759	82760	83814	84920	86052	87166	88263	89363	90465
2160	91512	92503	93577	94819	96230	97649	98936	100281	101854	103656
2170	105630	107587	109380	110997	112437	113840	115353	116848	118190	119377
2180	120435	121490	122676	124023	125531	127079	128533	129993	131575	133277
2190	135050	136795	138483	140136	141757	143358	144967	146591	148224	149864
2200	151509	153153	154792	156428	158059	159697	161344	162980	164592	166181
2210	167734	169272	170853	172503	174221	175961	177666	179366	181101	182871
2220	184632	186356	188107	189934	191839	193766	195651	197534	199468	201452
2230	203422	205337	207293	209365	211552	213748	215855	217998	220291	222733
2240	225265	227764	230189	232565	234890	237190	239508	241842	244175	246509
2250	248844	251177	253511	255844	258178	260512	262846	265180	267513	269847
2260	272182									

Effective 1 Jul 1973

FORT PECK PROJECT
CAPACITY IN ACRE-FEET
(1972 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
2030	0	0	0	0	7	65	161	295	496	793
2040	1215	1755	2394	3141	4010	5010	6161	7467	8886	10391
2050	11910	13437	14972	16556	18428	20678	23240	26027	29139	32677
2060	36742	41295	46271	51724	57712	64290	71370	78915	87058	95931
2070	105667	116353	127900	140178	153058	166412	180337	194921	210014	225469
2080	241136	256890	272829	289143	306022	323656	341934	360730	380209	400540
2090	421887	444304	467680	491936	516993	542773	569312	596662	624770	653581
2100	683040	713086	743754	775138	807333	840430	874403	909188	944828	981366
2110	1018844	1057195	1096391	1136532	1177717	1220047	1263427	1307791	1353280	1400035
2120	1448197	1497821	1548813	1601090	1654572	1709176	1764909	1821825	1879914	1939168
2130	1999578	2061194	2124021	2187985	2253009	2319017	2386077	2454240	2523403	2593464
2140	2664321	2735927	2808350	2881661	2955928	3031221	3107529	3184804	3263065	3342330
2150	3422616	3503888	3586135	3669409	3753763	3839250	3925868	4013582	4102394	4192308
2160	4283325	4375333	4468331	4562487	4657970	4754948	4853269	4952821	5053832	5156530
2170	5261144	5367791	5476319	5586552	5698313	5811426	5925994	6042133	6159691	6278513
2180	6398446	6519383	6641426	6764735	6889472	7015797	7143630	7272863	7403617	7536013
2190	7670171	7806114	7943762	8083080	8224035	8366594	8510751	8656528	8803934	8952976
2200	9103662	9255995	9409968	9565580	9722825	9881699	10042219	10204388	10368180	10533573
2210	10700542	10869041	11039087	11210748	11384093	11559190	11736015	11914522	12094748	12276725
2220	12460490	12645990	12833203	13022205	13213072	13405884	13600605	13797186	13995674	14196122
2230	14398579	14602967	14809253	15017553	15227983	15440658	15655479	15872369	16091476	16312951
2240	16536942	16763482	16992471	17223861	17457602	17693642	17931983	18172659	18415667	18661009
2250	18908686	19158697	19411041	19665719	19922730	20182076	20443755	20707769	20974116	21242796
2260	21513811									

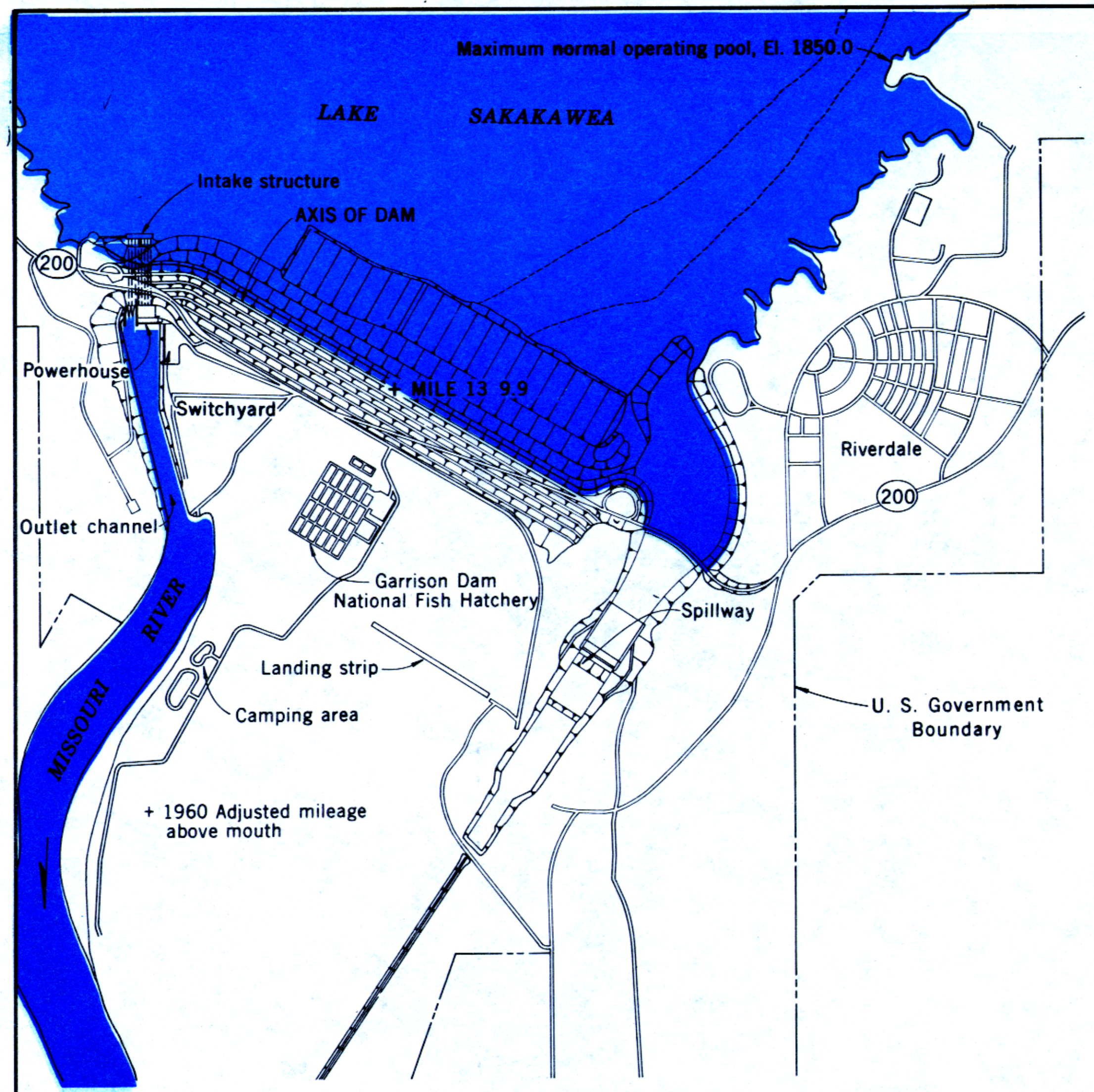


RESERVOIR CAPACITY: 24,400,000 ACRE FEET (EL.1854)

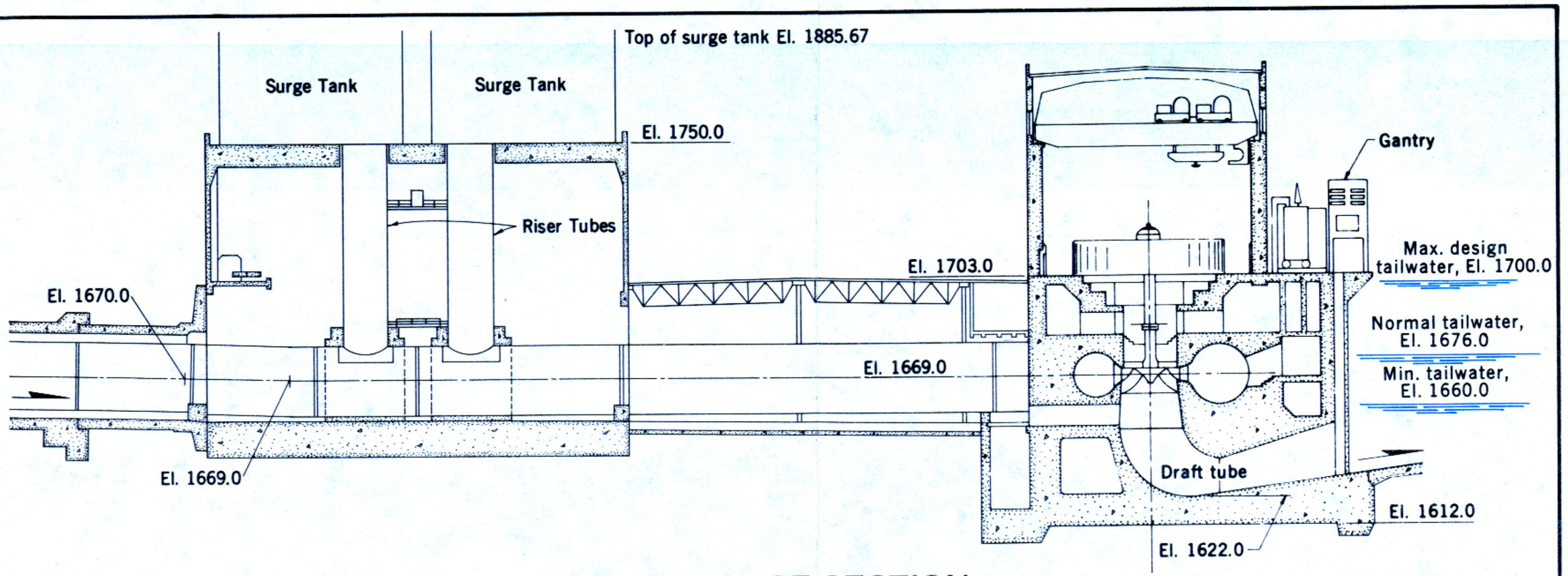
TOTAL UNITED STATES LAND ACQUIRED TO DATE:
457,909.0 ACRES

FLOOD CONTROL PROJECT
GARRISON DAM
LAKE SAKAKAWEA
MISSOURI RIVER BASIN
NORTH DAKOTA
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

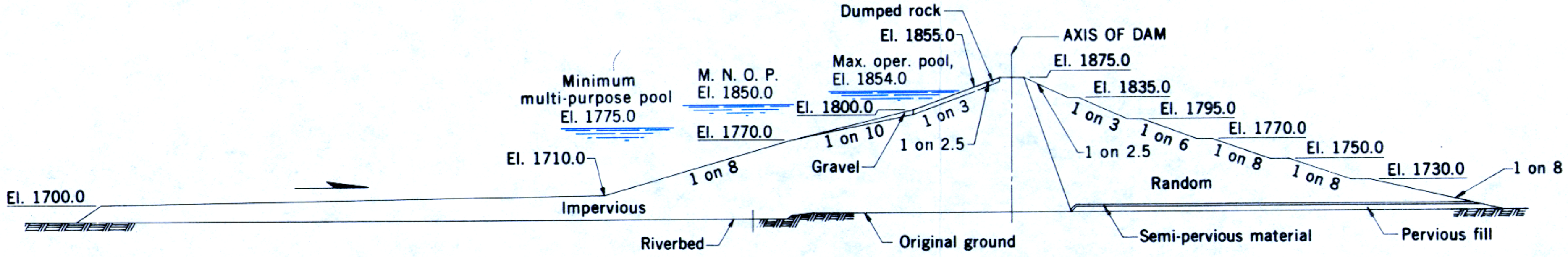
PLATE 17



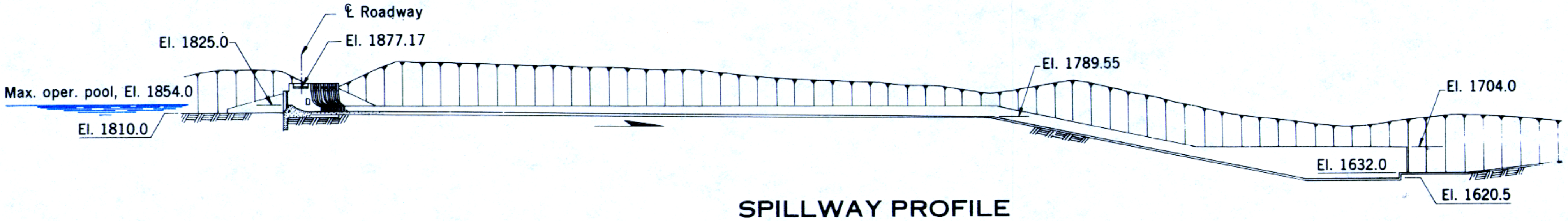
PLAN



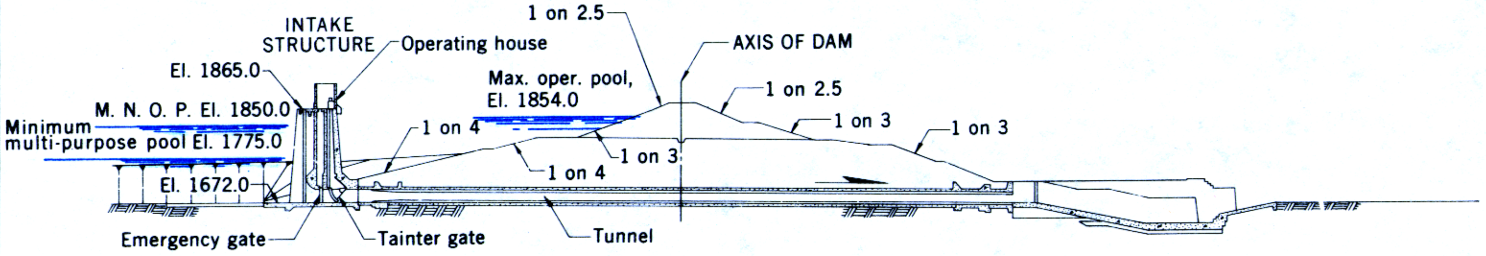
POWERHOUSE SECTION



EMBANKMENT SECTION

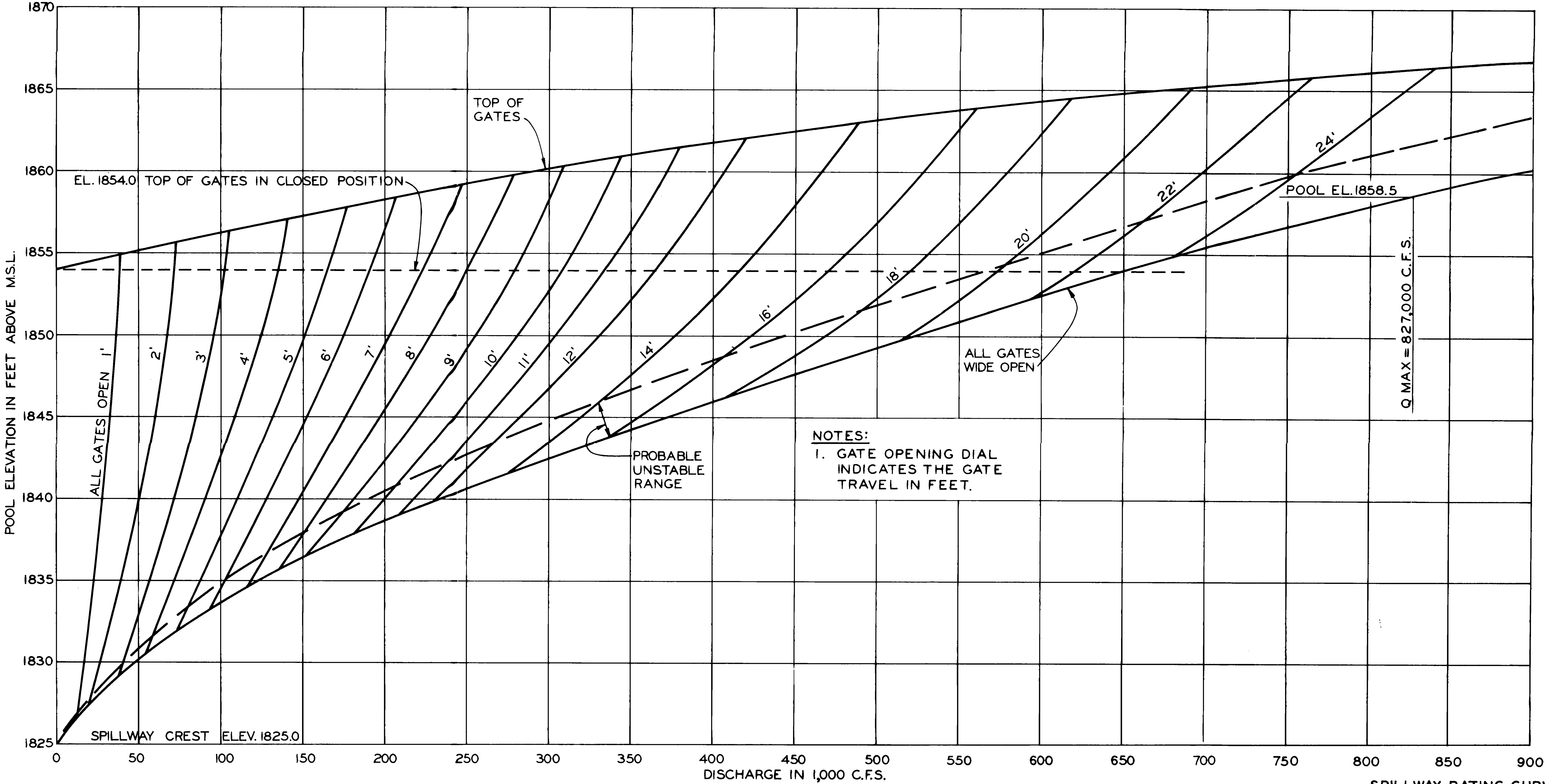


SPILLWAY PROFILE



OUTLET WORKS PROFILE

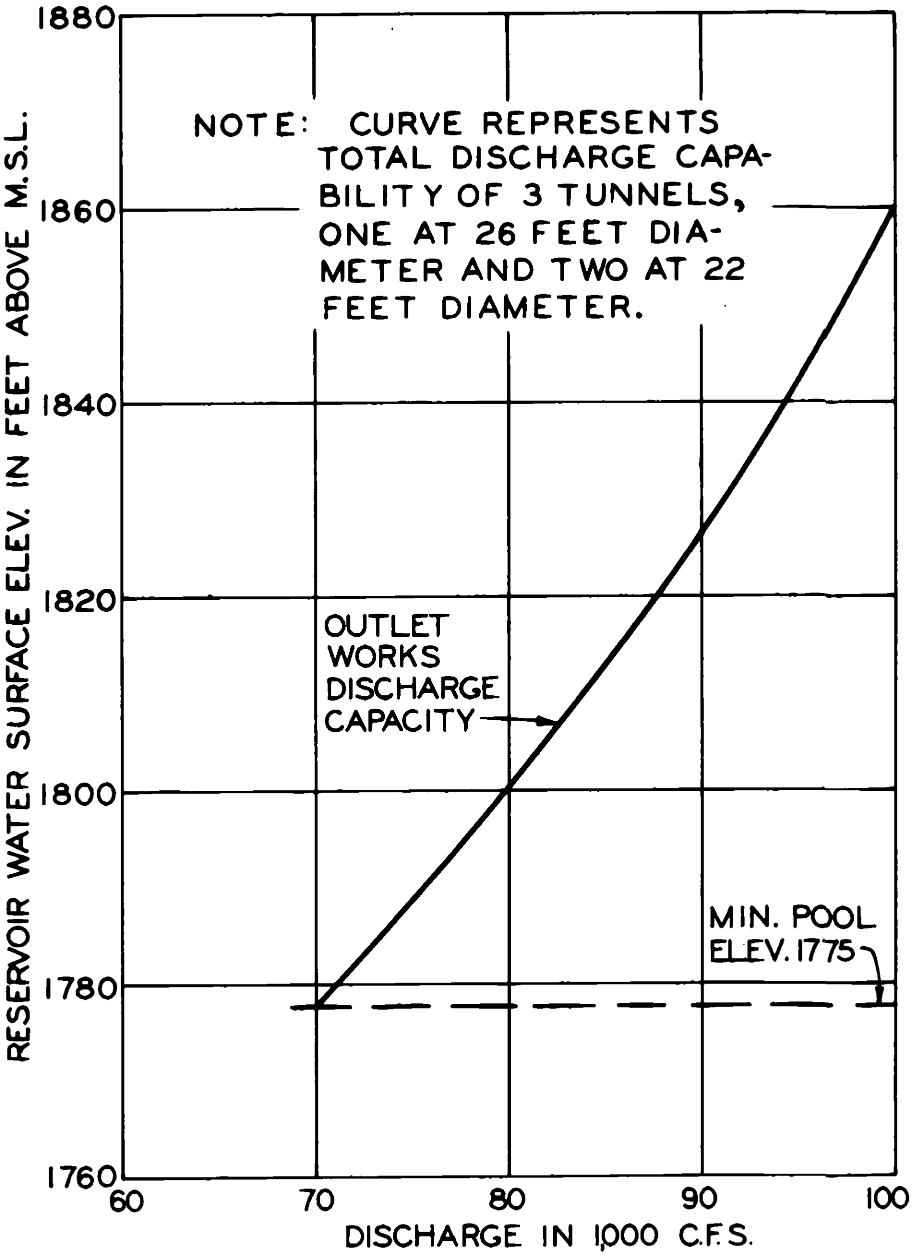
FLOOD CONTROL PROJECT
GARRISON DAM
LAKE SAKAKAWEA
MISSOURI RIVER BASIN
NORTH DAKOTA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977



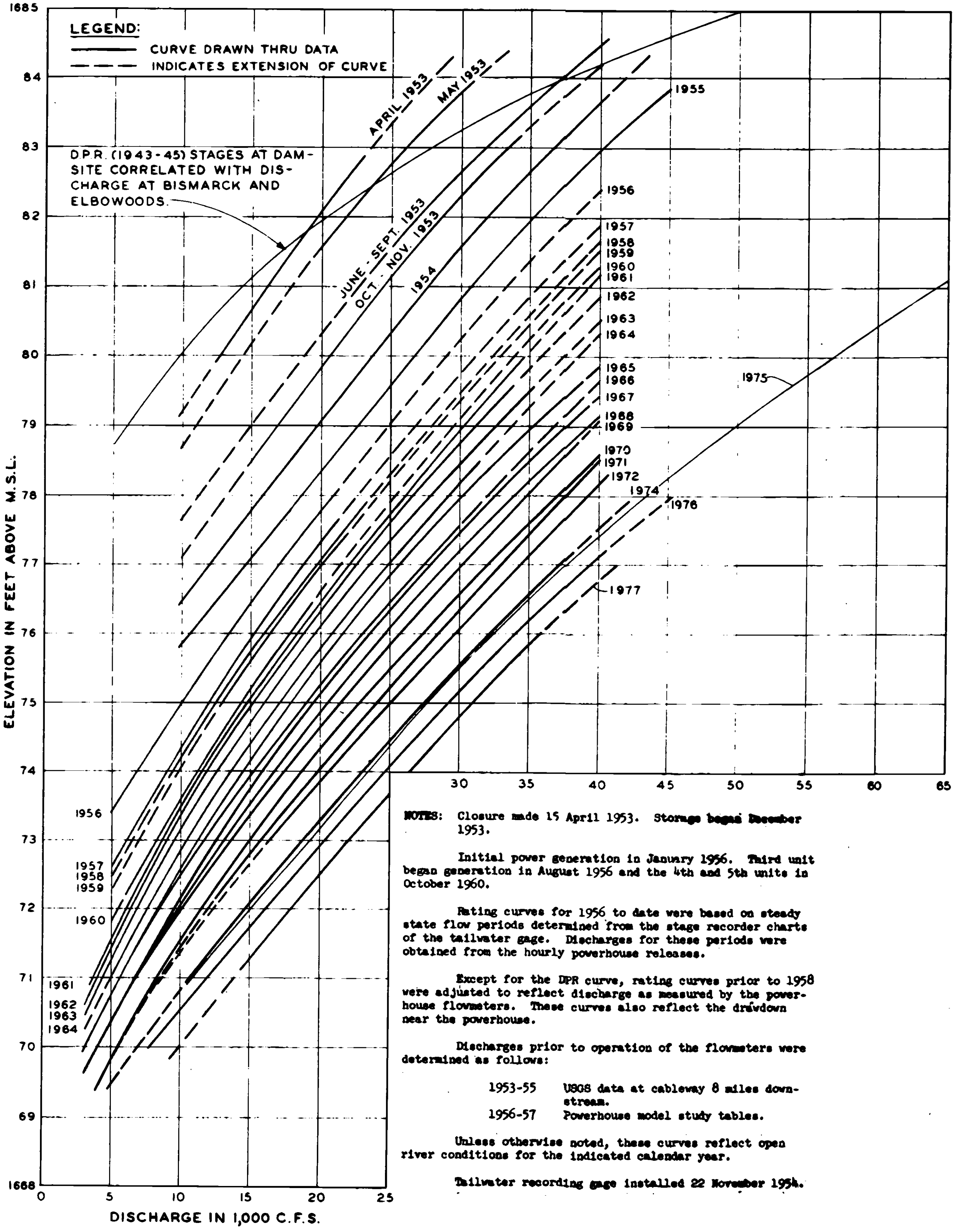
NOTES:
1. GATE OPENING DIAL INDICATES THE GATE TRAVEL IN FEET.

SPILLWAY RATING CURVES
GARRISON PROJECT

PLATE 19A



DISCHARGE RATING CURVE
FOR
FLOOD CONTROL TUNNELS



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 date were based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Discharges for these periods were obtained from the hourly powerhouse releases.

Except for the DPR curve, rating curves prior to 1958 were adjusted to reflect discharge as measured by the powerhouse flowmeters. These curves also reflect the drawdown near the powerhouse.

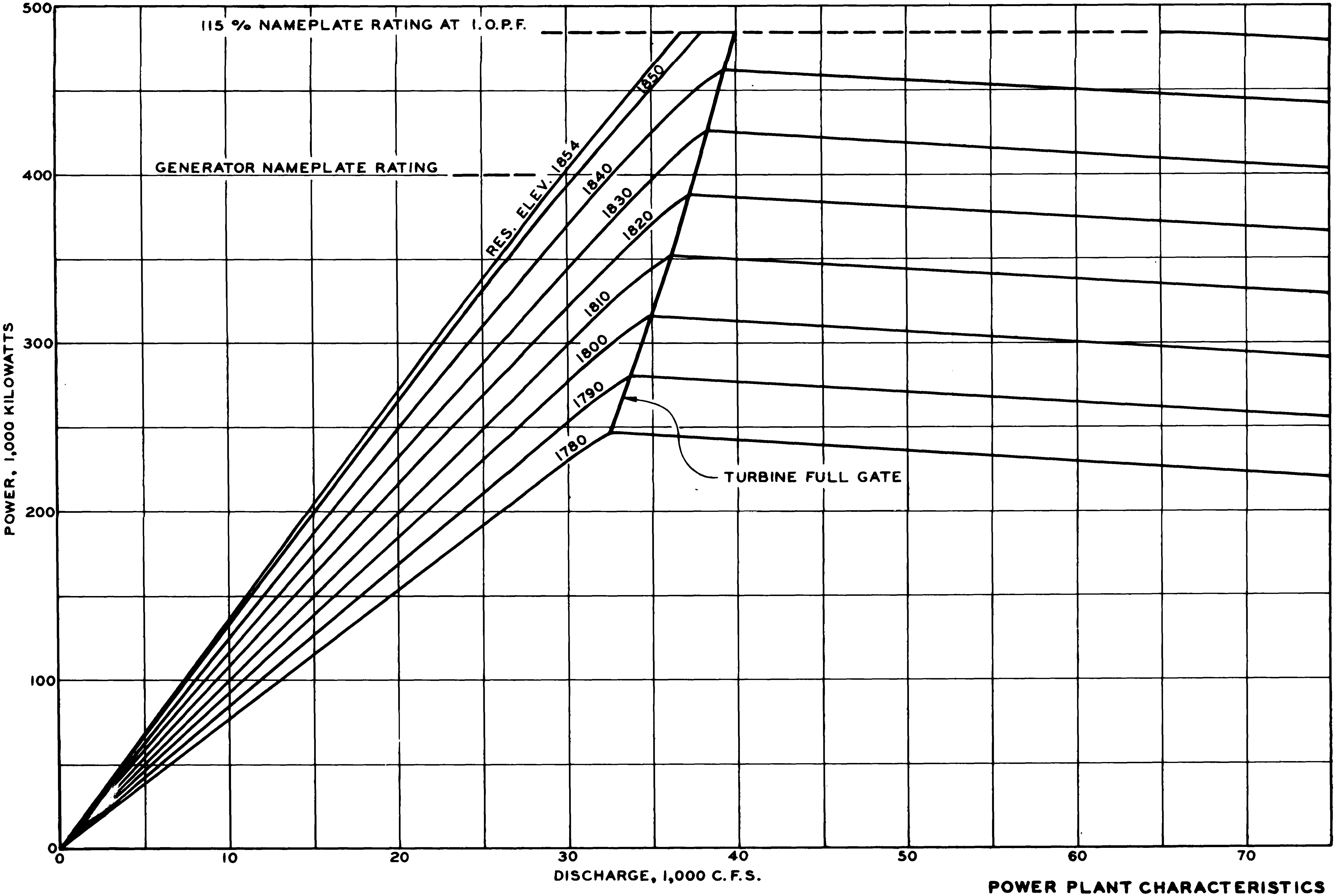
Discharges prior to operation of the flowmeters were determined as follows:

1953-55	USGS data at cableway 8 miles downstream.
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



**POWER PLANT CHARACTERISTICS
GARRISON PROJECT**

PLATE 19D

AREA AND CAPACITY DATA
GARRISON RESERVOIR

GARRISON PROJECT

AREA IN ACRES EFFECTIVE 1 JUL 1971

(1969 SURVEY)

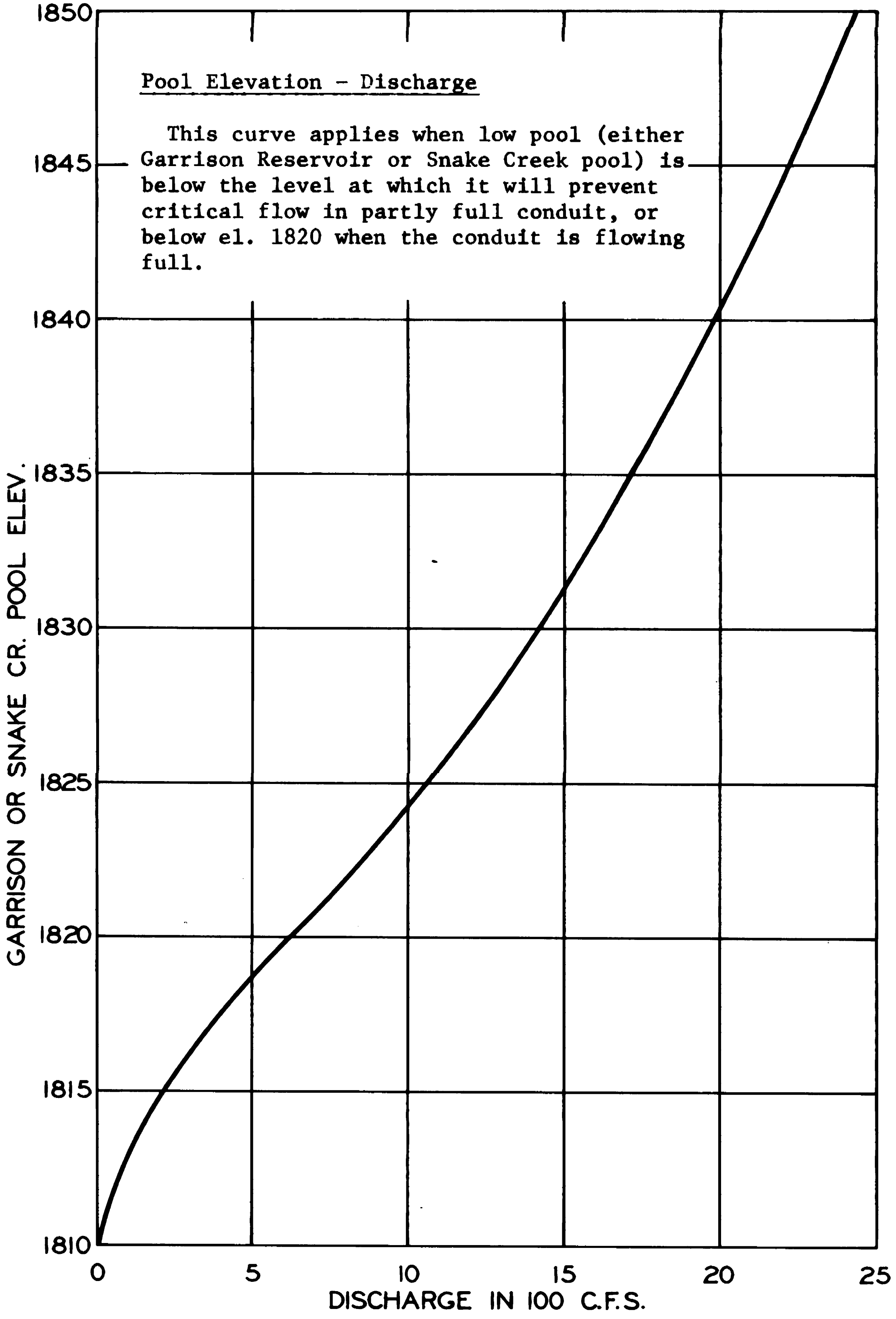
ELEV	0	1	2	3	4	5	6	7	8	9
1660	0	0	0	0	0	0	0	0	0	23
1670	50	85	114	136	164	209	252	301	338	345
1680	390	445	483	563	701	913	1216	1530	1832	2360
1690	2943	3344	3781	4358	5078	5813	6447	7115	7947	8942
1700	10006	11002	11963	12964	14003	15042	16049	17072	18153	19292
1710	20424	21501	22612	23830	25154	26507	27799	29093	30463	31909
1720	33343	34701	36109	37668	39377	41086	42671	44318	46187	48278
1730	50527	52749	54827	56764	58560	60309	62129	63961	65721	67409
1740	69057	70724	72422	74134	75861	77602	79346	81073	82779	84463
1750	86123	87778	89459	91178	92934	94692	96419	98160	99955	101804
1760	103703	105607	107459	109240	110951	112670	114453	116197	117815	119307
1770	120663	121986	123462	125160	127078	129061	130925	132784	134781	136916
1780	139081	141158	143250	145465	147801	150169	152467	154769	157159	159639
1790	162084	164420	166845	169508	172410	175332	178075	180887	183997	187403
1800	190988	194502	197874	201158	204354	207501	210671	213881	217105	220344
1810	223593	226840	230077	233304	236521	239742	242977	246201	249393	252557
1820	255681	258790	261946	265175	268478	271842	275204	278506	281738	284901
1830	287896	290779	293887	297396	301304	305247	308890	312649	316907	321664
1840	326791	331874	336608	340978	344983	348881	352974	357078	360959	364616
1850	368139	371710	375393	379150	382981	386849	390693	394512	398332	402150
1860	405966									

GARRISON PROJECT

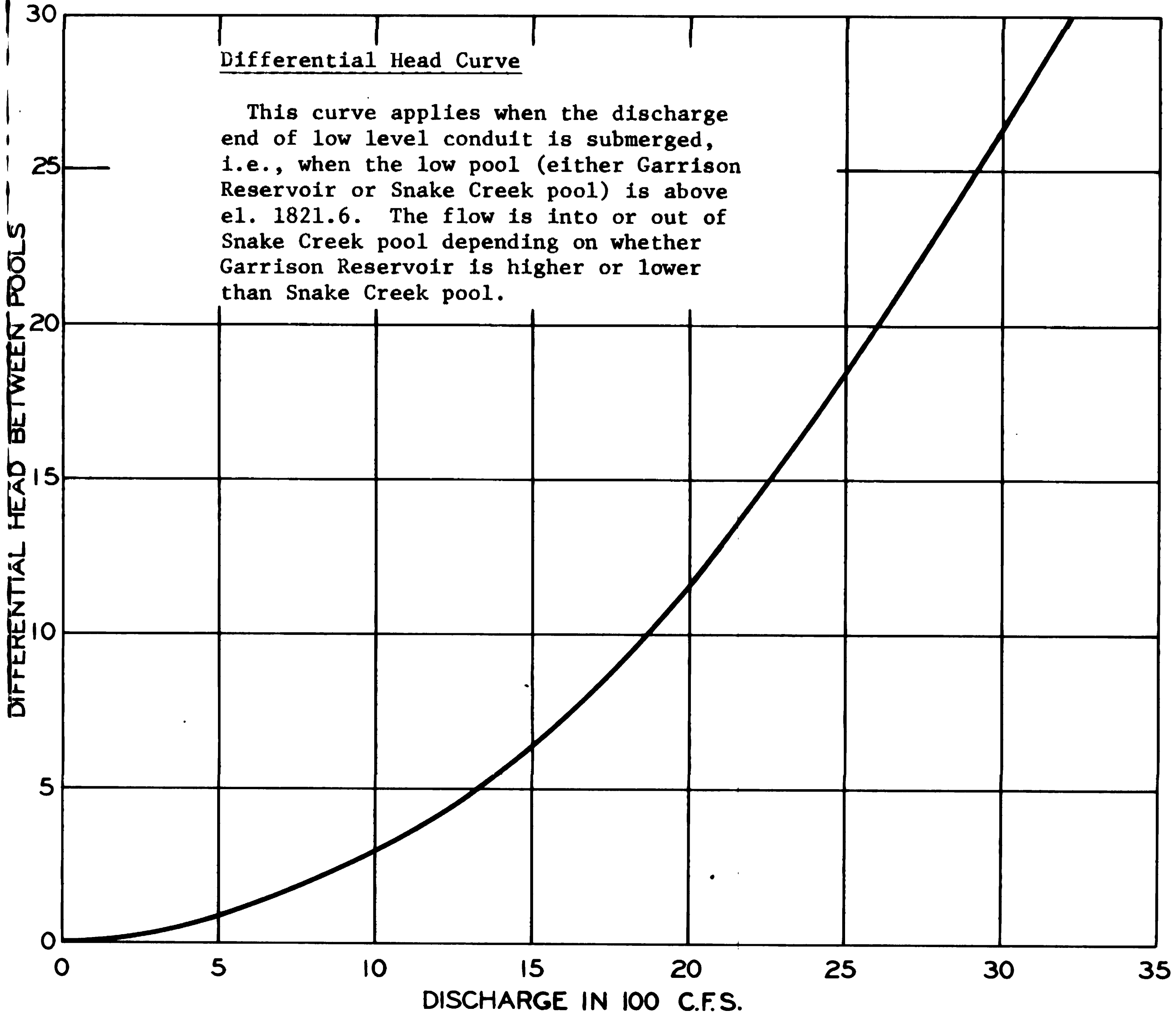
CAPACITY IN ACRE-FEET EFFECTIVE 1 JUL 1971

(1969 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1660	0	0	0	0	0	0	0	0	0	11
1670	45	111	215	340	487	669	905	1174	1507	1850
1680	2198	2630	3089	3597	4216	5000	6043	7433	9103	11098
1690	13823	16984	20512	24546	29229	34702	40856	47596	55087	63490
1700	72971	83502	94975	107429	120903	135435	150987	167534	185132	203840
1710	223716	244698	266718	289913	314378	340222	367393	395820	425580	456747
1720	489398	523433	558801	595652	634137	674406	716310	759749	804947	852124
1730	901503	953179	1007002	1062833	1120530	1179953	1241149	1304212	1369071	1435654
1740	1503890	1573769	1645339	1718614	1793608	1870336	1948813	2029028	2110960	2194587
1750	2279887	2366834	2455443	2545752	2637799	2731621	2827183	2924459	3023503	3124369
1760	3227111	3331775	3438326	3546693	3656806	3768596	3882146	3997503	4114540	4233133
1770	4353155	4474459	4597128	4721384	4847448	4975541	5105571	5237391	5371139	5506953
1780	5644972	5785115	5927288	6071615	6218218	6367218	6518557	6672153	6828095	6986472
1790	7147374	7310641	7476215	7644332	7815232	7989153	8165896	8345303	8527671	8713297
1800	8902478	9095273	9291483	9491021	9693799	9899729	10108802	10321076	10536565	10755286
1810	10977253	11202472	11430933	11662626	11897542	12135669	12377027	12621624	12869429	13120411
1820	13374543	13631773	13892123	14155665	14422473	14692622	14966157	15243030	15523170	15806507
1830	16092973	16382299	16674532	16970074	17269324	17572683	17879819	18190464	18505118	18824279
1840	19148446	19477862	19812194	20151078	20494150	20841045	21191912	21546994	21906069	22268912
1850	22635302	23005190	23378723	23755976	24137023	24521938	24910722	25303324	25699747	26099988
1860	26504047									

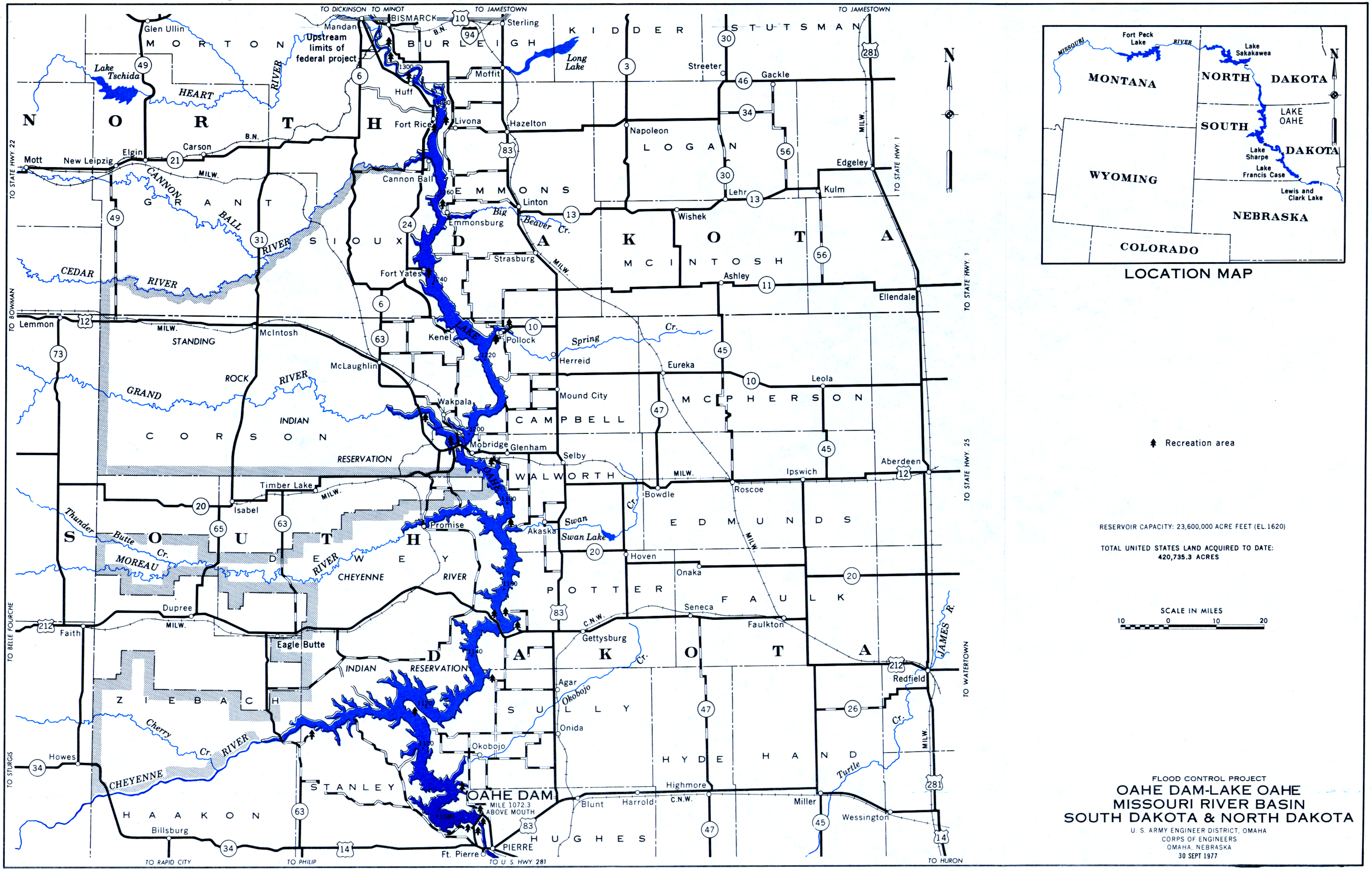


This curve applies when low pool (either Garrison Reservoir or Snake Creek pool) is below the level at which it will prevent critical flow in partly full conduit, or below el. 1820 when the conduit is flowing full.



This curve applies when the discharge end of low level conduit is submerged, i.e., when the low pool (either Garrison Reservoir or Snake Creek pool) is above el. 1821.6. The flow is into or out of Snake Creek pool depending on whether Garrison Reservoir is higher or lower than Snake Creek pool.

CONDUIT RATING CURVES
FOR
SNAKE CREEK EMBANKMENT



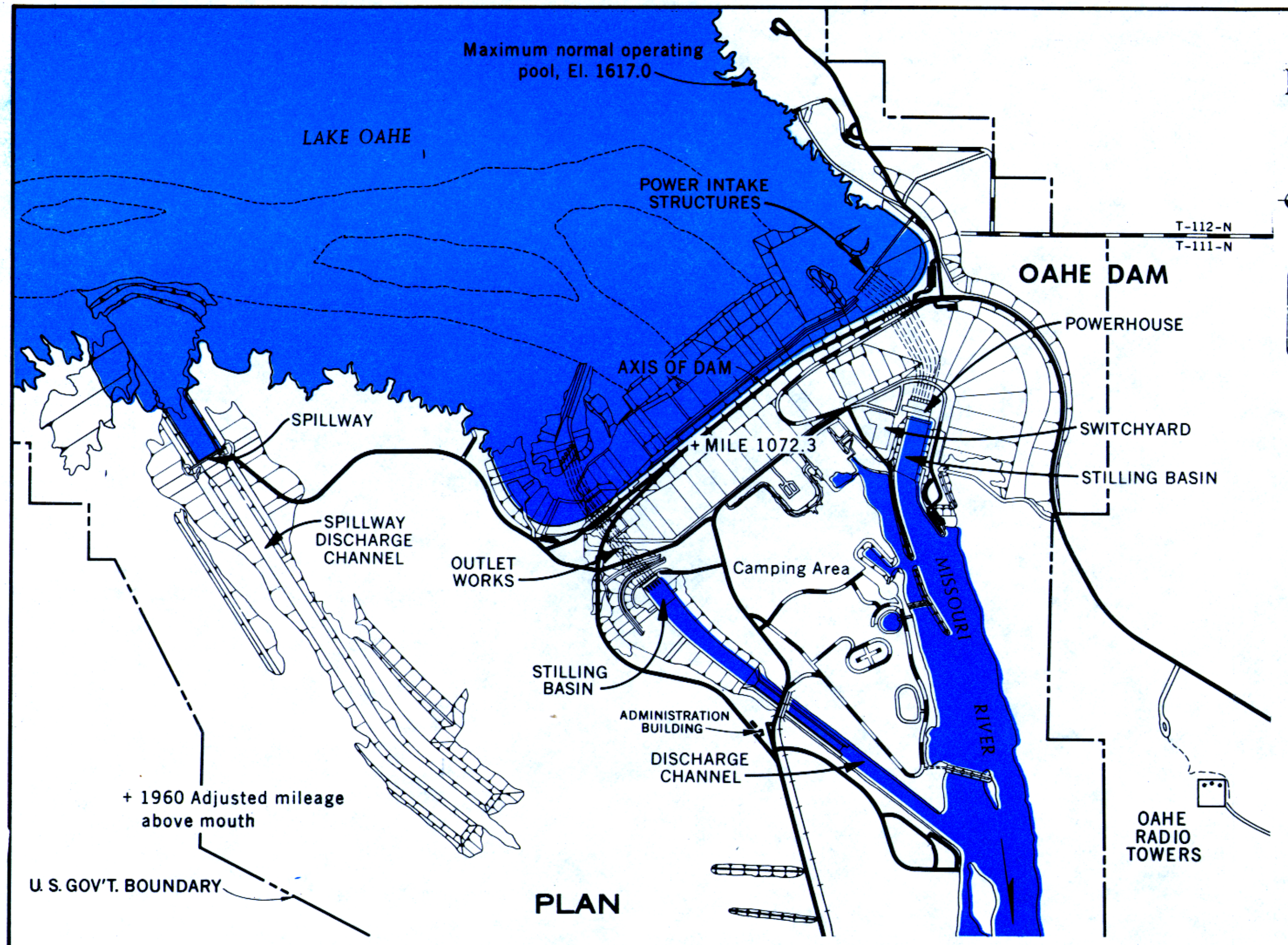
↑ Recreation area

RESERVOIR CAPACITY: 23,600,000 ACRE FEET (EL.1620)

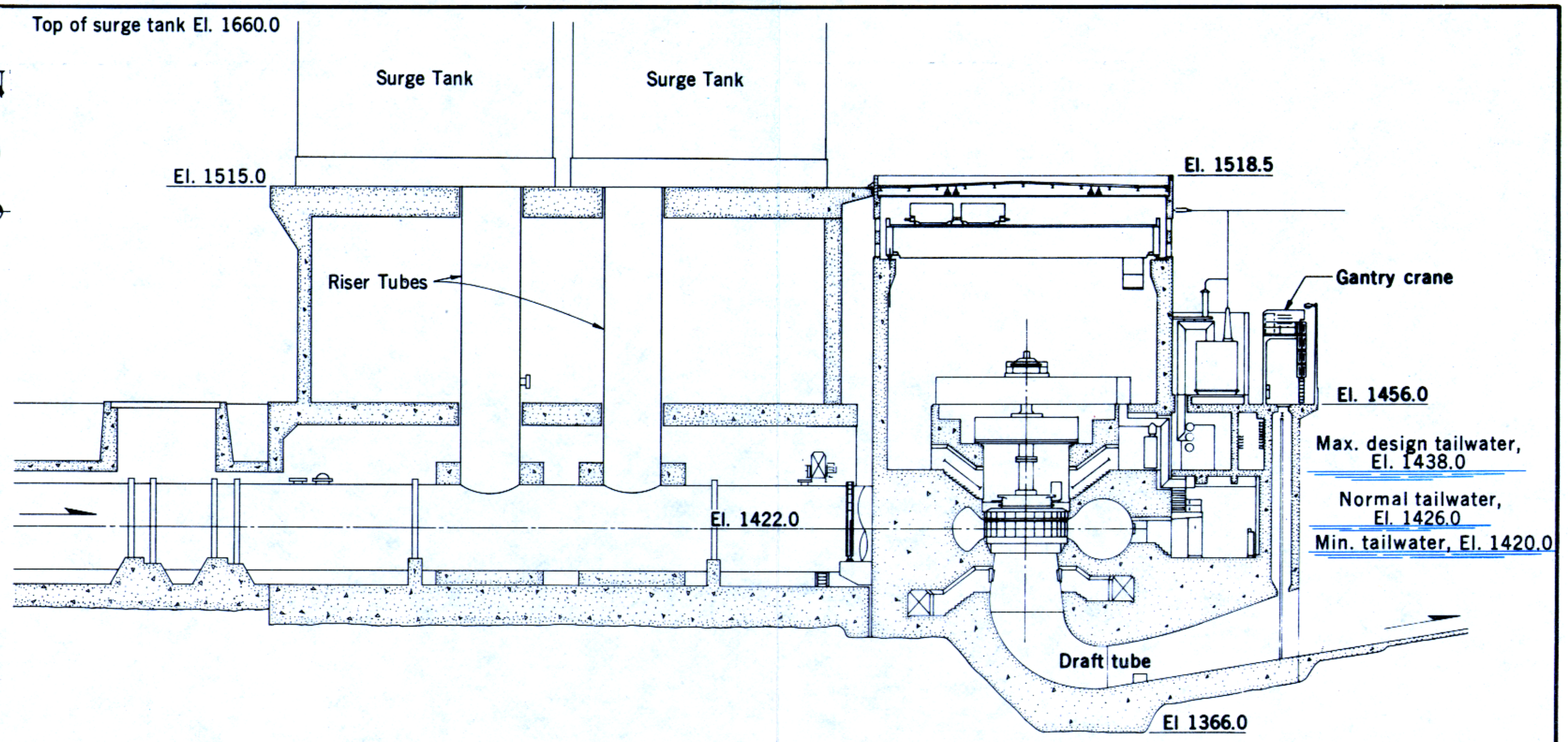
TOTAL UNITED STATES LAND ACQUIRED TO DATE:
420,735.3 ACRES

FLOOD CONTROL PROJECT
OAHE DAM-LAKE OAHE
MISSOURI RIVER BASIN
SOUTH DAKOTA & NORTH DAKOTA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

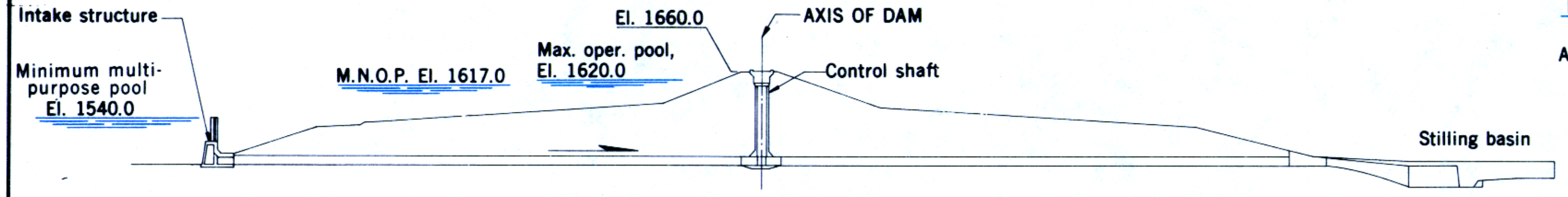
PLATE 20



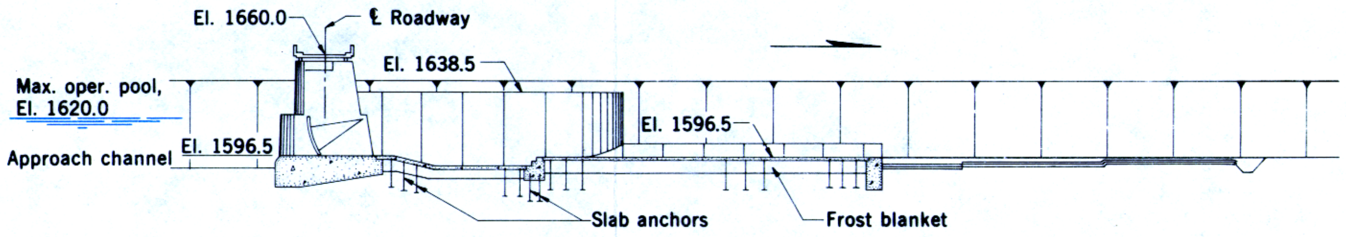
PLAN



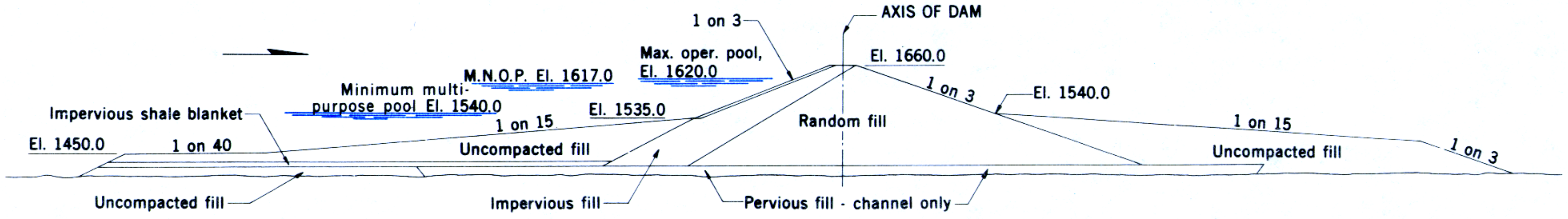
POWERHOUSE SECTION



OUTLET WORKS PROFILE
FLOOD CONTROL TUNNELS

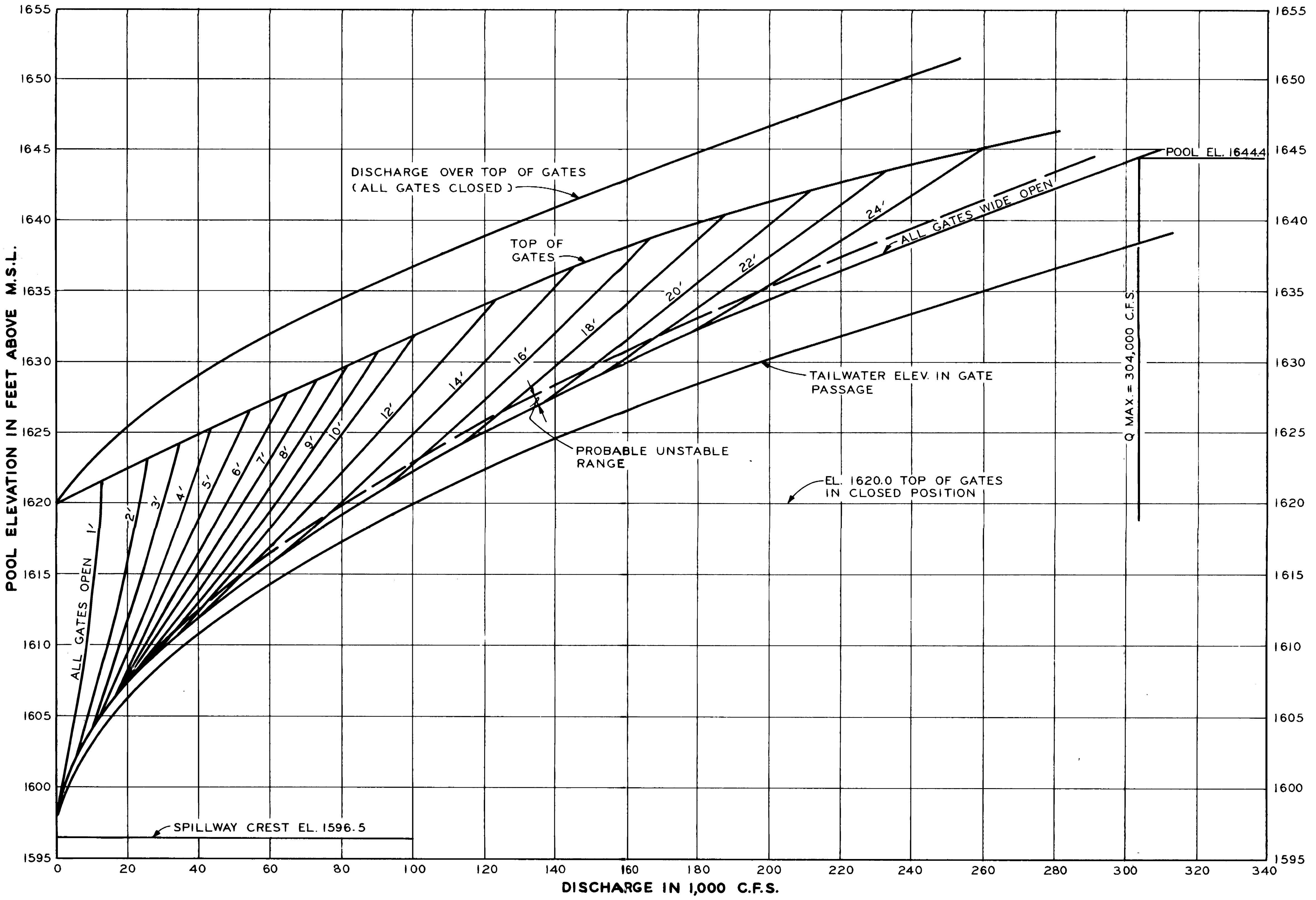


SPILLWAY PROFILE

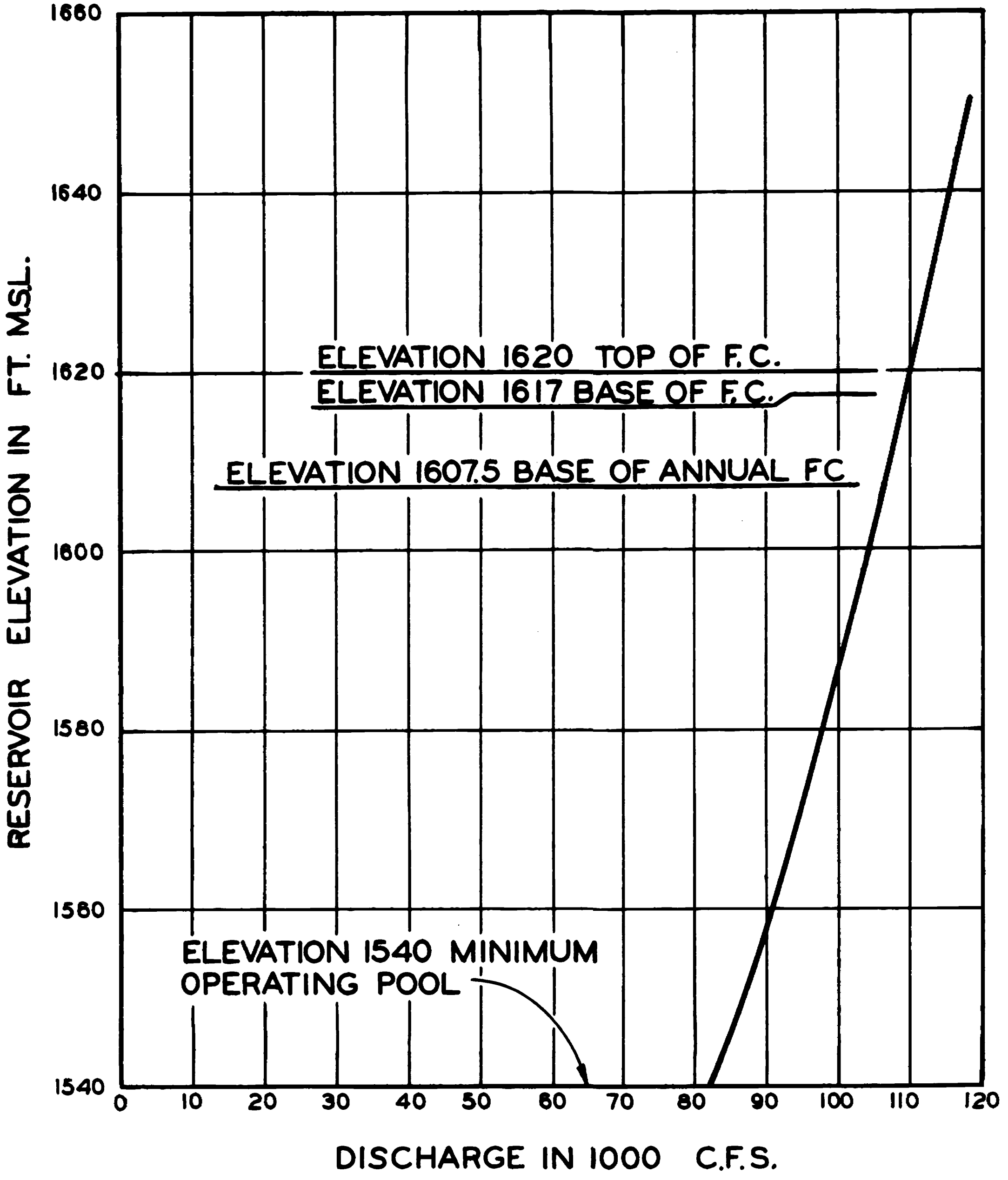


EMBANKMENT SECTION

FLOOD CONTROL PROJECT
OAHE DAM-LAKE OAHE
MISSOURI RIVER BASIN
SOUTH DAKOTA & NORTH DAKOTA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

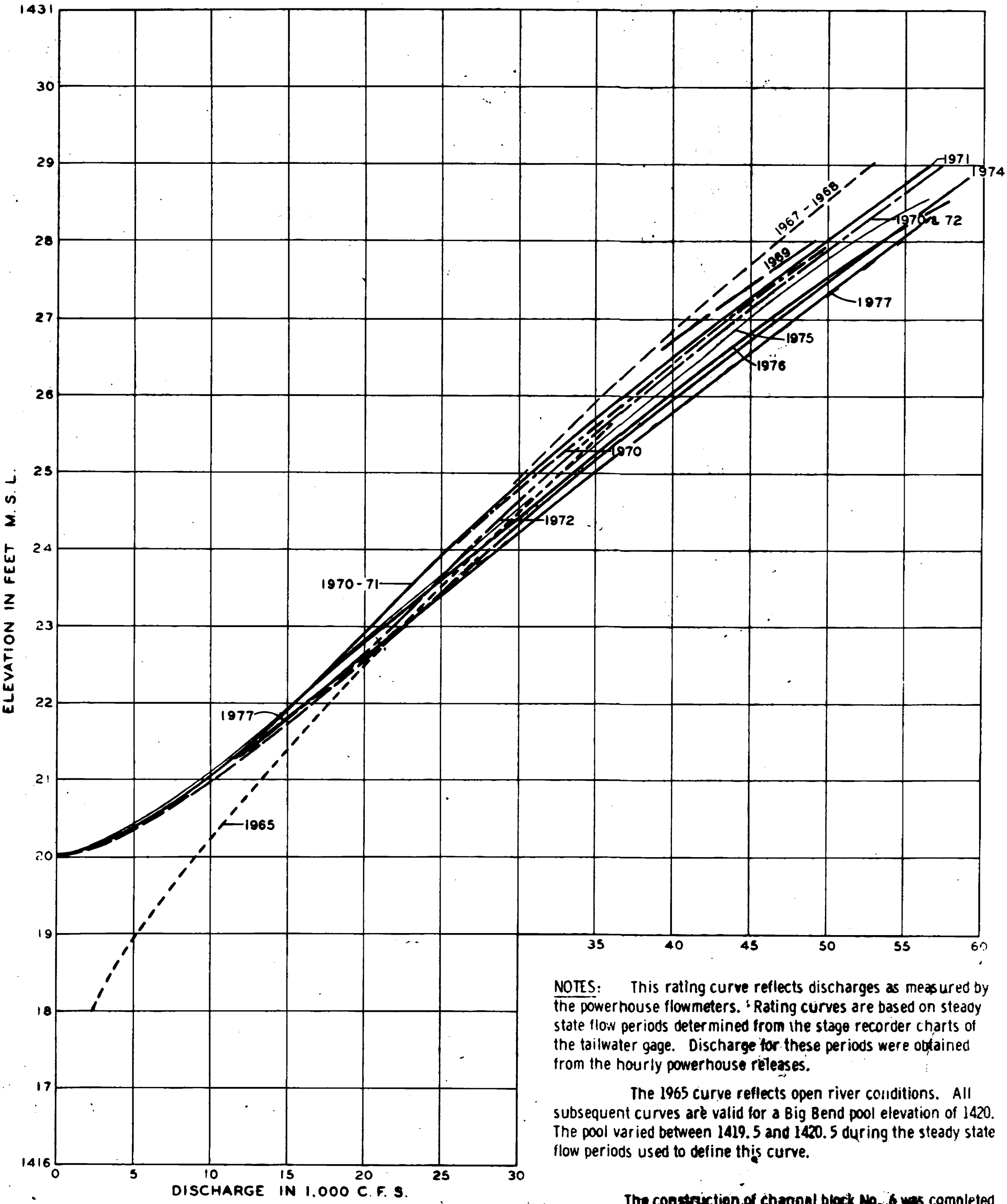


SPILLWAY RATING CURVES
OAHE PROJECT



NOTE:
CURVE REPRESENTS TOTAL DISCHARGE CAPABILITY OF 6 TUNNELS.

OUTLET WORKS RATING CURVE
OAHE DAM & RESERVOIR

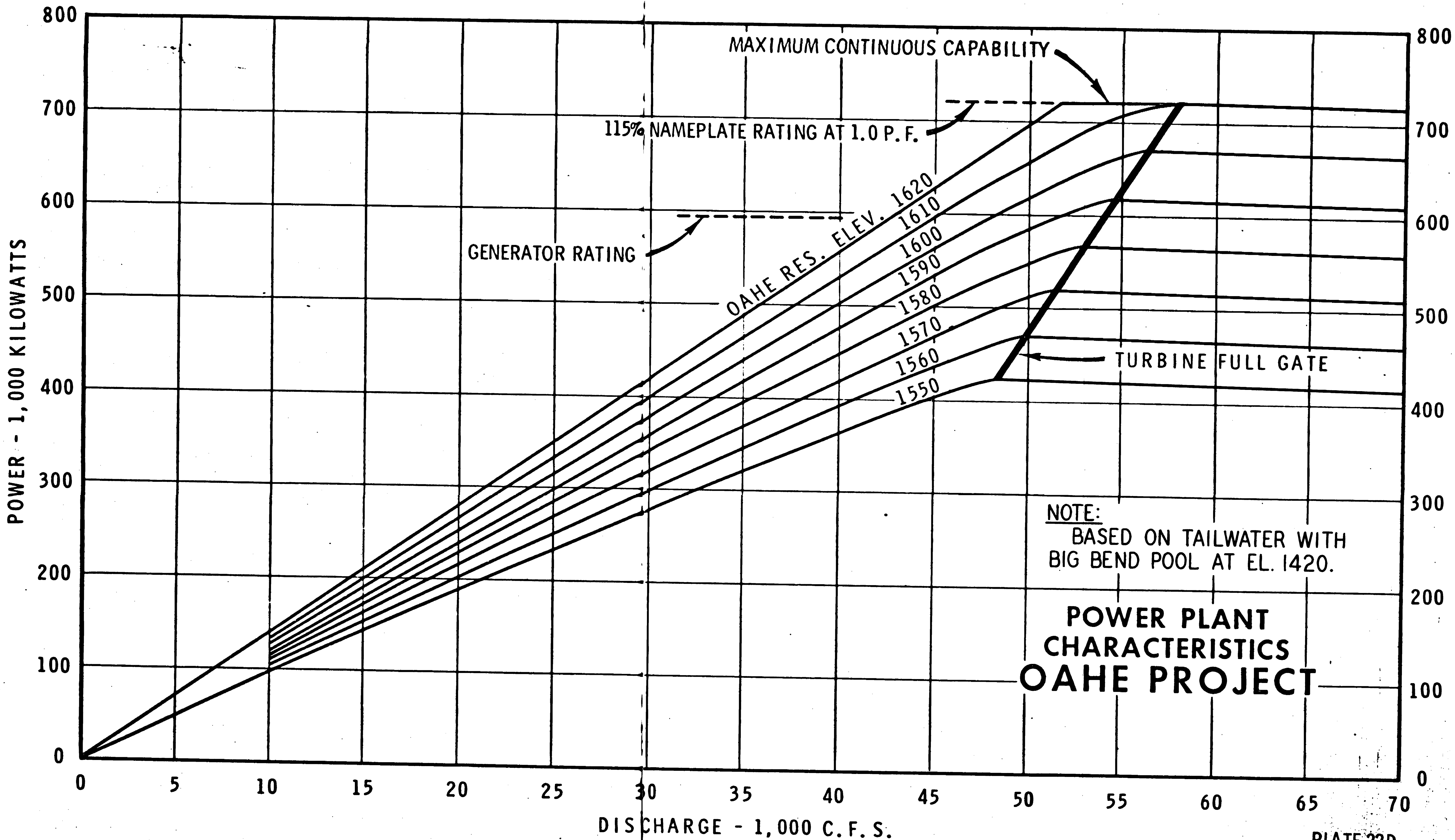


NOTES: This rating curve reflects discharges as measured by the powerhouse flowmeters. Rating curves are based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Discharge for these periods were obtained from the hourly powerhouse releases.

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



NOTE:
BASED ON TAILWATER WITH BIG BEND POOL AT EL. 1420.

POWER PLANT CHARACTERISTICS
OAHE PROJECT

PLATE 22D

AREA AND CAPACITY DATA
OAHE RESERVOIR
OAHE PROJECT
AREA IN ACRES
(1968 SURVEY)

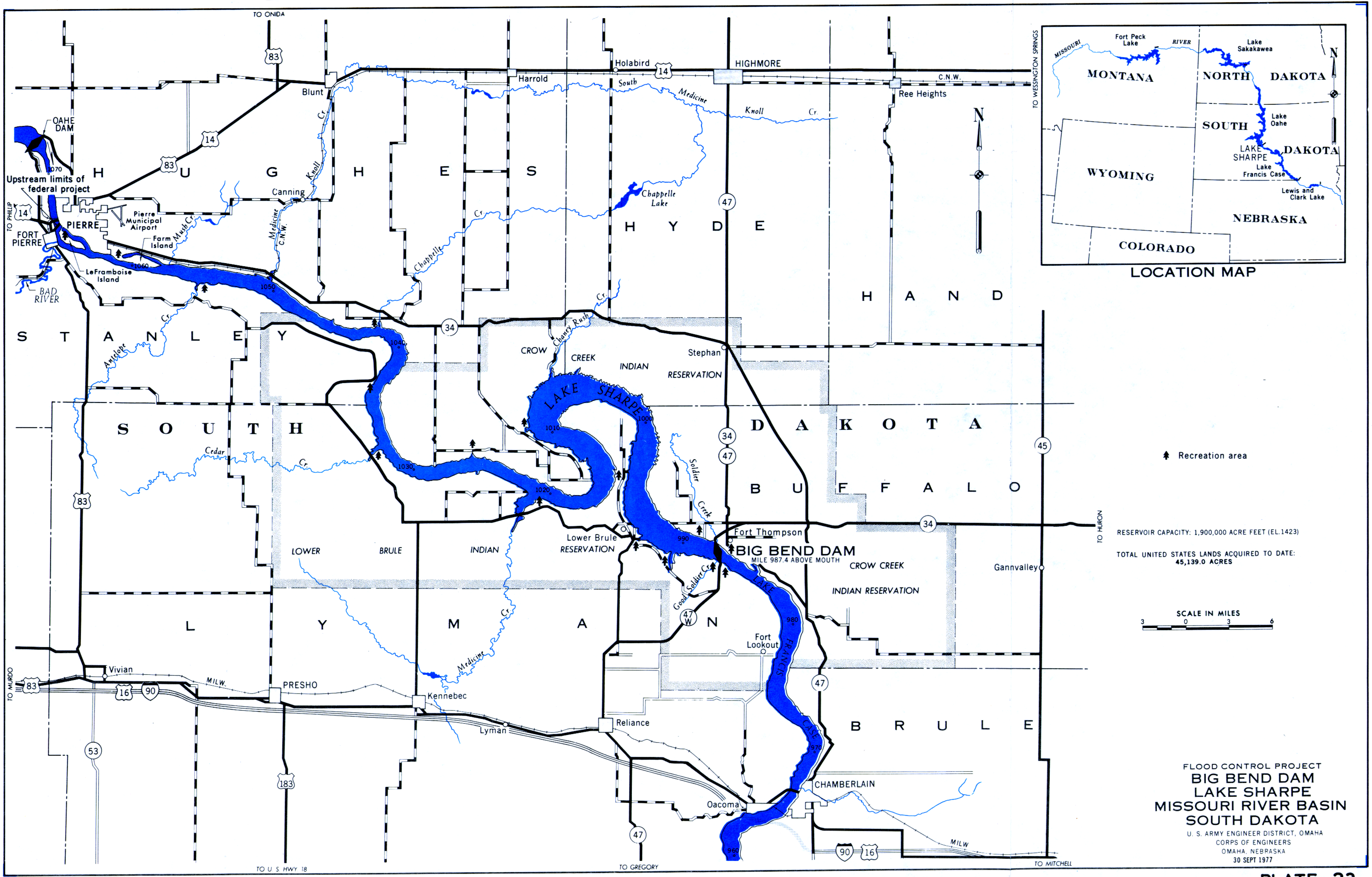
EFFECTIVE 1 JAN 1972

ELEV	0	1	2	3	4	5	6	7	8	9
1410	0	0	0	0	0	0	0	12	24	36
1420	213	405	477	607	796	1044	1350	1715	2140	2622
1430	3073	3399	3685	4019	4403	4834	5314	5444	6422	7048
1440	7626	8065	8473	8951	9500	10120	10810	11570	12402	13303
1450	14197	14989	15730	16487	17262	18055	18865	19692	20536	21398
1460	22222	22964	23697	24483	25322	26213	27158	28155	29205	30309
1470	31424	32491	33517	34533	35537	36530	37513	38484	39445	40395
1480	41312	42194	43087	44023	44999	46017	47077	48179	49323	50508
1490	51702	52856	53978	55094	56201	57301	58394	59480	60558	61629
1500	62671	63678	64694	65747	66838	67966	69132	70335	71577	72855
1510	74123	75326	76502	77696	78910	80141	81390	82658	83945	85250
1520	86466	87520	88570	89741	91032	92444	93977	95630	97404	99298
1530	101200	102959	104626	106297	107971	109648	111327	113010	114695	116383
1540	118002	119511	121026	122632	124330	126120	128002	129975	132041	134199
1550	136236	137967	139643	141490	143508	145695	148054	150584	153283	156153
1560	158922	161312	163587	166016	168600	171337	174229	177275	180475	183830
1570	187156	190240	193213	196239	199320	202455	205644	208888	212185	215538
1580	218940	222349	225713	229017	232259	235441	238562	241622	244623	247563
1590	250343	252957	255634	258515	261599	264888	268380	272077	275978	280083
1600	284052	287545	290901	294463	298227	302195	306368	310745	315325	320110
1610	324827	329176	333380	337698	342128	346668	351321	356086	360963	365952
1620	370950	375818	380602	385385	390169	394953	399736	404520	409304	414087
1630	418870	421198	423873	429350	435347	441802	447591	453341	460229	468255
1640	477063	485705	493648	500952	507616	513960	520518	527289	534059	540830
1650	547600									

OAHE PROJECT
CAPACITY IN ACRE-FEET
(1968 SURVEY)

EFFECTIVE 1 JAN 1972

ELEV	0	1	2	3	4	5	6	7	8	9
1410	0	0	0	0	0	0	0	6	24	55
1420	97	481	908	1435	2122	3027	4210	5728	7641	10008
1430	12886	16154	19684	23524	27723	32330	37392	42959	49080	55803
1440	63177	71055	79307	88001	97210	107002	117450	128622	140591	153426
1450	167197	181820	197176	213280	230151	247805	266261	285535	305645	326608
1460	348442	371053	394370	418447	443336	469091	495763	523407	552074	581818
1470	612692	644667	677674	711702	746740	782776	819801	857802	896770	936693
1480	977560	1019318	1061948	1105493	114994	1195492	1242029	1289647	1338388	1388294
1490	1439405	1491699	1545118	1599656	1655306	1712059	1769909	1828848	1888869	1949965
1500	2012128	2075308	2139485	2204696	2270980	2338372	2406912	2476636	2547583	2619790
1510	2693294	2768037	2843947	2921041	2999340	3078861	3159622	3241642	3324939	3409533
1520	3495440	3582465	3670481	3759606	3849963	3941671	4034851	4129625	4226112	4324433
1530	4424708	4526834	4630626	4736087	4843221	4952030	5062517	5174685	5288537	5404075
1540	5521303	5640080	5760326	5882132	6005590	6130792	6257831	6386797	6517782	6650879
1550	6786180	6923352	7062114	7202638	7345095	7489654	7636486	7785763	7937654	8092330
1560	8249961	8410175	8572586	8737349	8904619	9074549	9247293	9423007	9601844	9783958
1570	9969504	10158271	10349985	10544697	10742463	10943337	11147373	11354626	11565150	11778997
1580	11996226	12216878	12440925	12668305	12898959	13132824	13369841	13609948	13853086	14099195
1590	14348212	14599882	14854127	15111151	15371157	15634350	15900933	16171111	16445088	16723067
1600	17005254	17291172	17580344	17872975	18169270	18469430	18773661	19082167	19395151	19712818
1610	20035371	20362473	20693723	21029234	21369120	21713490	22062456	22416132	22774629	23138059
1620	23506534	23879960	24258171	24641164	25028941	25421503	25818848	26220976	26627888	27039584
1630	27456063	27877324	28298460	28725070	29157160	29595764	30040765	30490946	30947447	31411405
1640	31883958	32365532	32855369	33352829	33857274	34368062	34885195	35409098	35939773	36477217
1650	37021433									

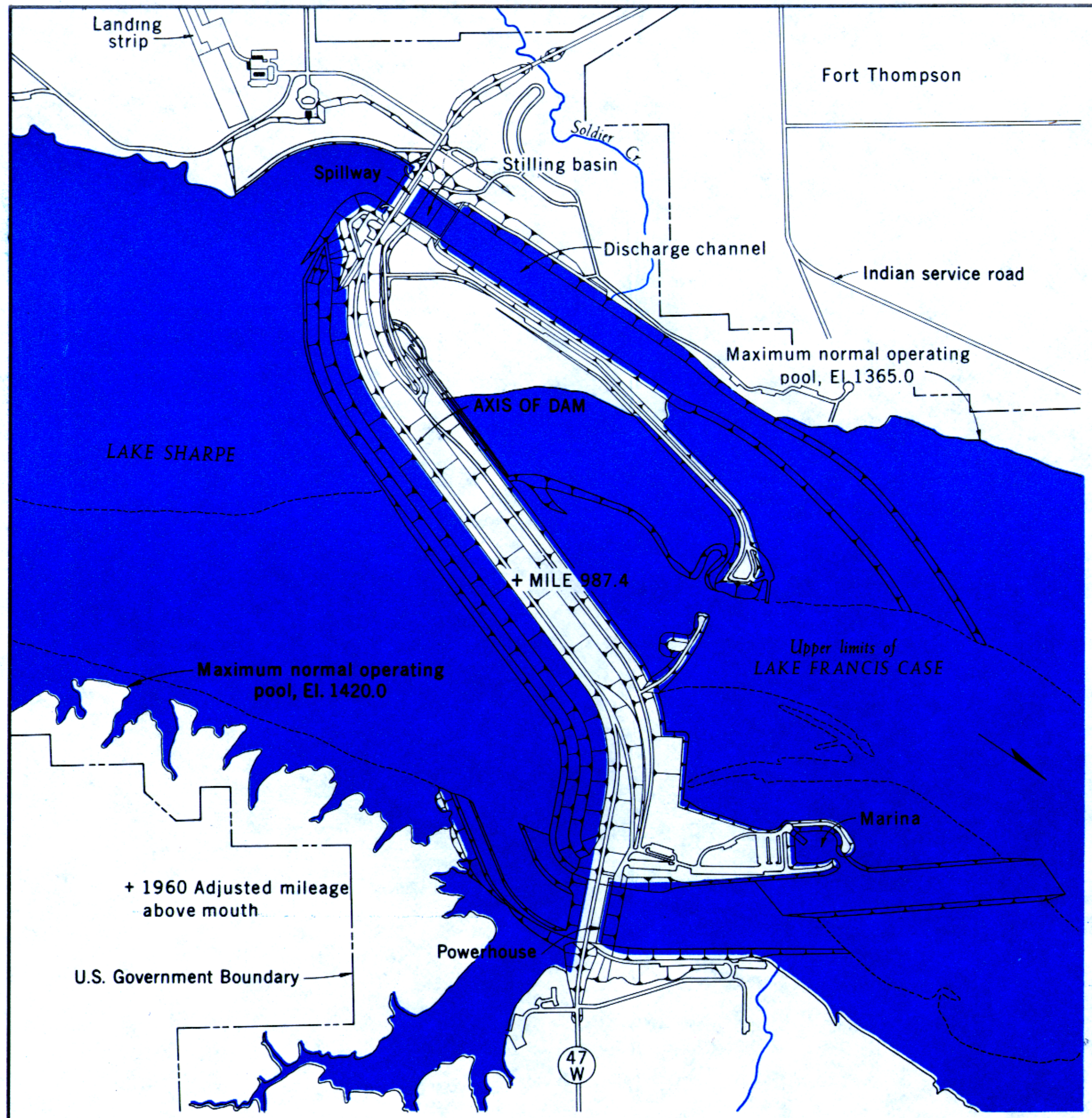


RESERVOIR CAPACITY: 1,900,000 ACRE FEET (EL.1423)

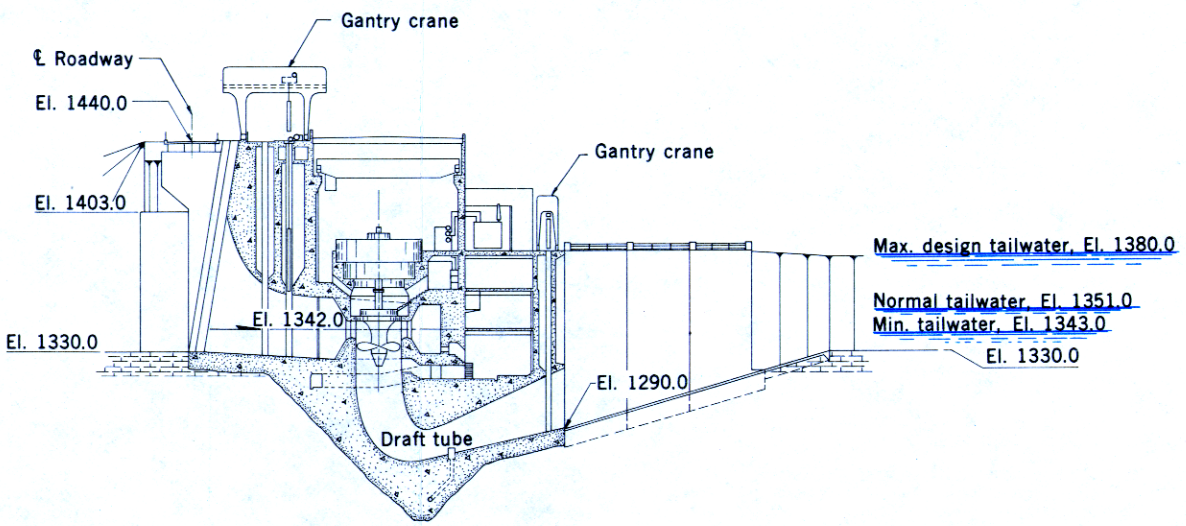
TOTAL UNITED STATES LANDS ACQUIRED TO DATE:
45,139.0 ACRES

FLOOD CONTROL PROJECT
BIG BEND DAM
LAKE SHARPE
MISSOURI RIVER BASIN
SOUTH DAKOTA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

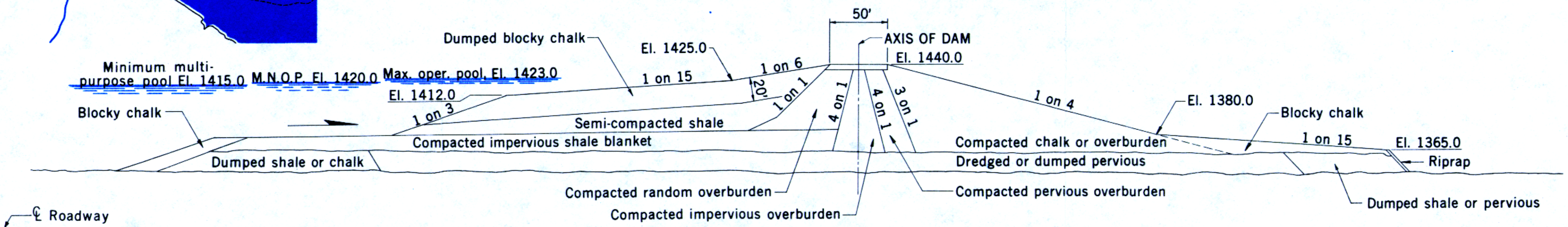
PLATE 23



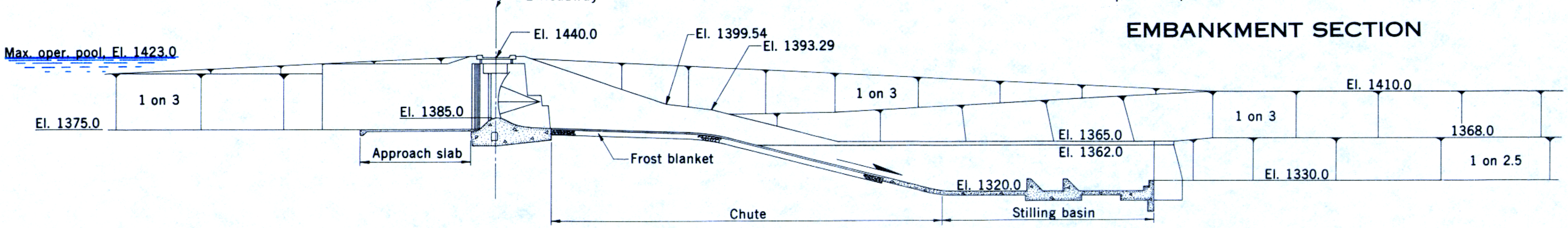
PLAN



POWERHOUSE SECTION



EMBANKMENT SECTION

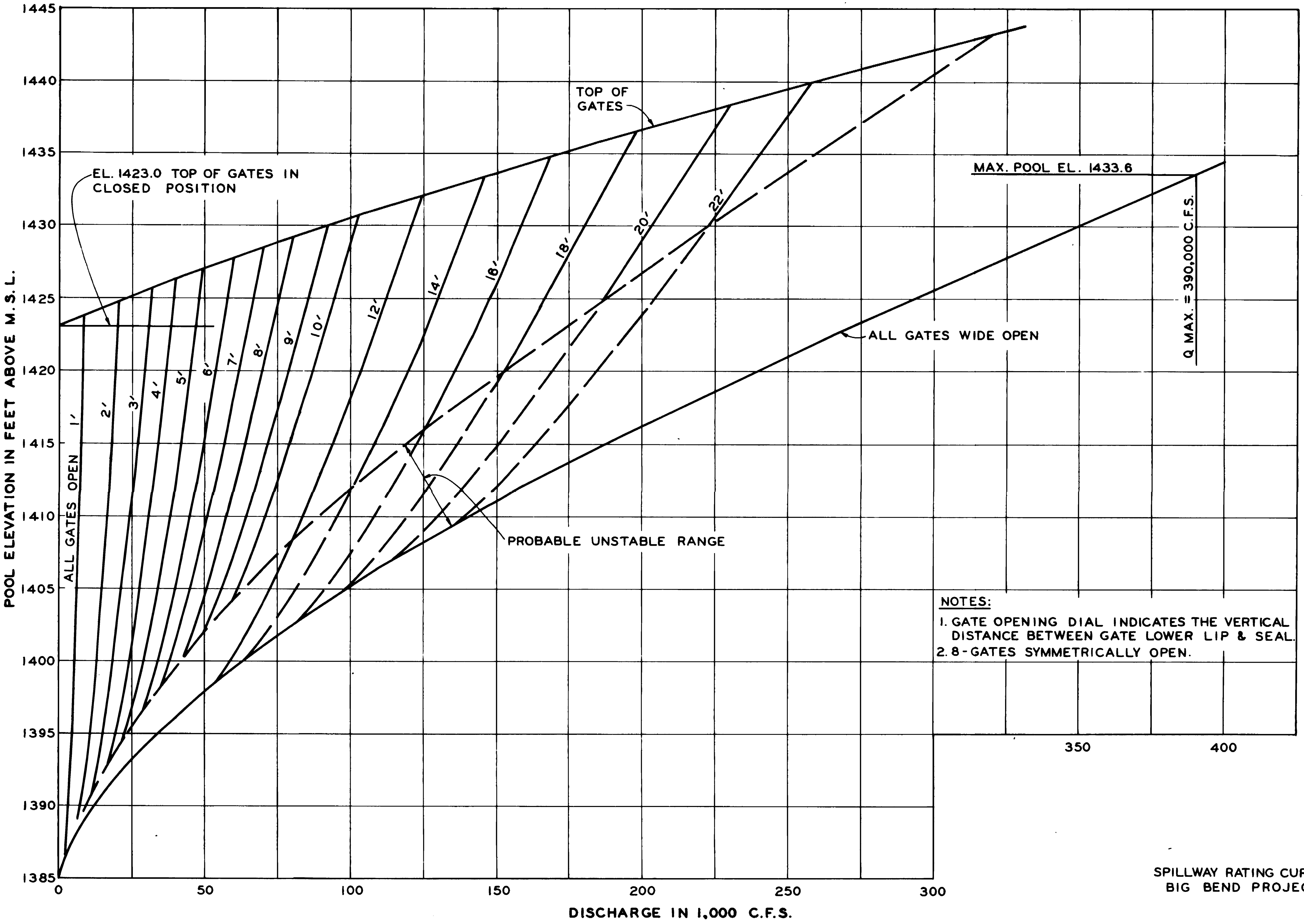


SPILLWAY PROFILE

FLOOD CONTROL PROJECT

BIG BEND DAM
LAKE SHARPE
MISSOURI RIVER BASIN
SOUTH DAKOTA

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

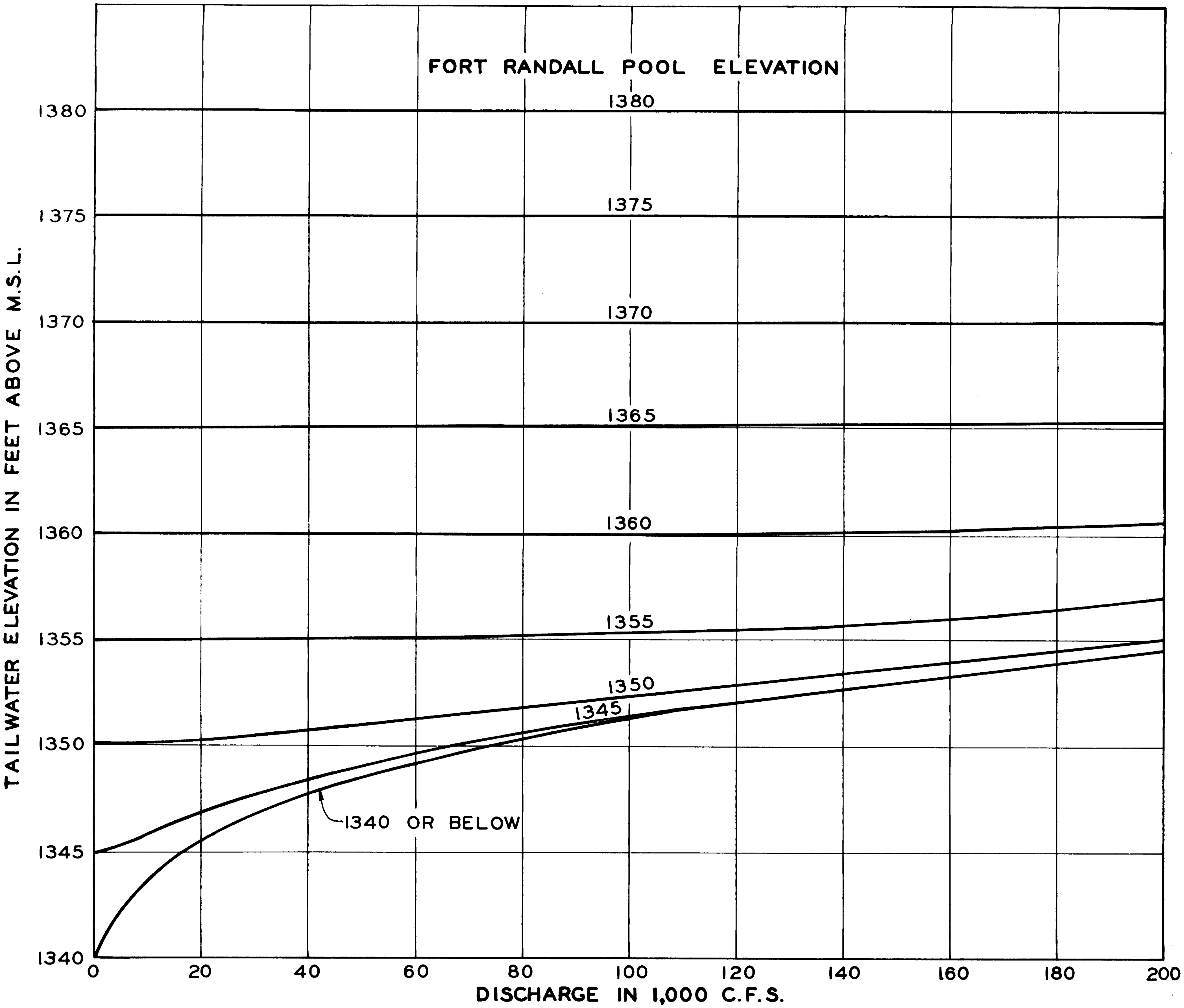


NOTES:

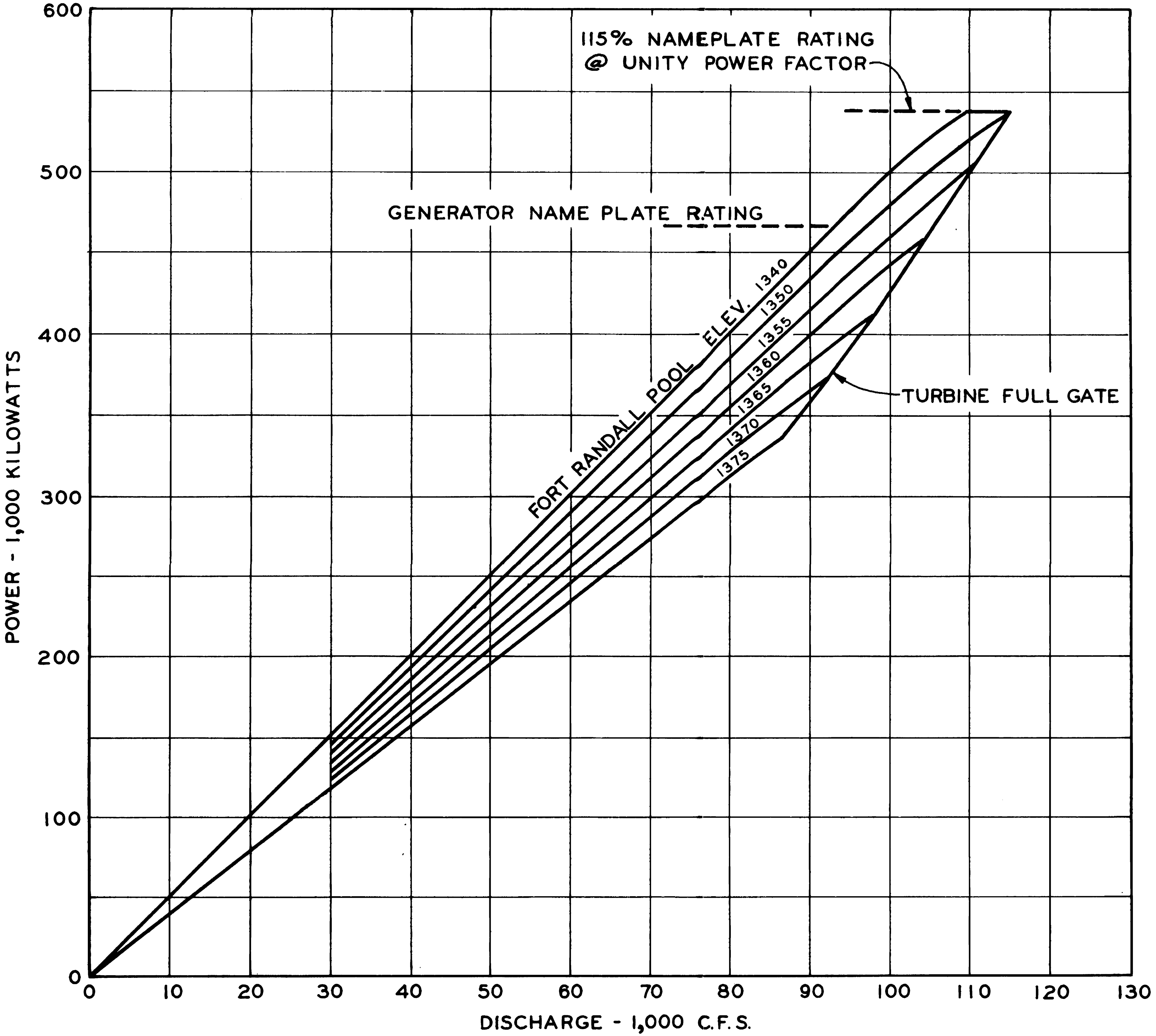
1. GATE OPENING DIAL INDICATES THE VERTICAL DISTANCE BETWEEN GATE LOWER LIP & SEAL.
2. 8-GATES SYMMETRICALLY OPEN.

SPILLWAY RATING CURVES
BIG BEND PROJECT

PLATE 25A



TAILWATER RATING CURVES
BIG BEND PROJECT



NOTES:

1. Curves shown assume constant Big Bend pool elevation of 1420 feet, M.S.L.

2. Fort Randall Reservoir elevations above 1340 feet, M.S.L., affect Big Bend tailwater elevations. Resulting effect on Big Bend power generation is shown on the curves.

POWER PLANT CHARACTERISTICS
BIG BEND PROJECT

BIG BEND PROJECT

CAPACITY IN ACRE-FEET

EFFECTIVE 1 JAN 1978

(1975 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1340	0	0	76	209	384	600	914	1256	1722	2410
1350	3416	4658	6072	7781	9909	12588	15687	19149	23123	27770
1360	33249	39583	46665	54461	62936	72053	81798	92193	103263	115031
1370	127520	140743	154684	169325	184648	280635	217301	234657	252681	271354
1380	290653	310556	331076	352249	374107	396685	419981	443973	468663	494053
1390	520145	546891	574289	602412	631335	661130	691770	723205	755478	788631
1400	822708	857644	893412	930106	967822	1006656	1046526	1087368	1129304	1172458
1410	1218952	1262811	1309954	1358342	1407937	1458700	1510629	1563750	1618066	1673579
1420	1730292	1788205	1847317	1907627	1969133	2031836	2095735	2160830	2227122	2294611
1430	2363296									

BIG BEND PROJECT

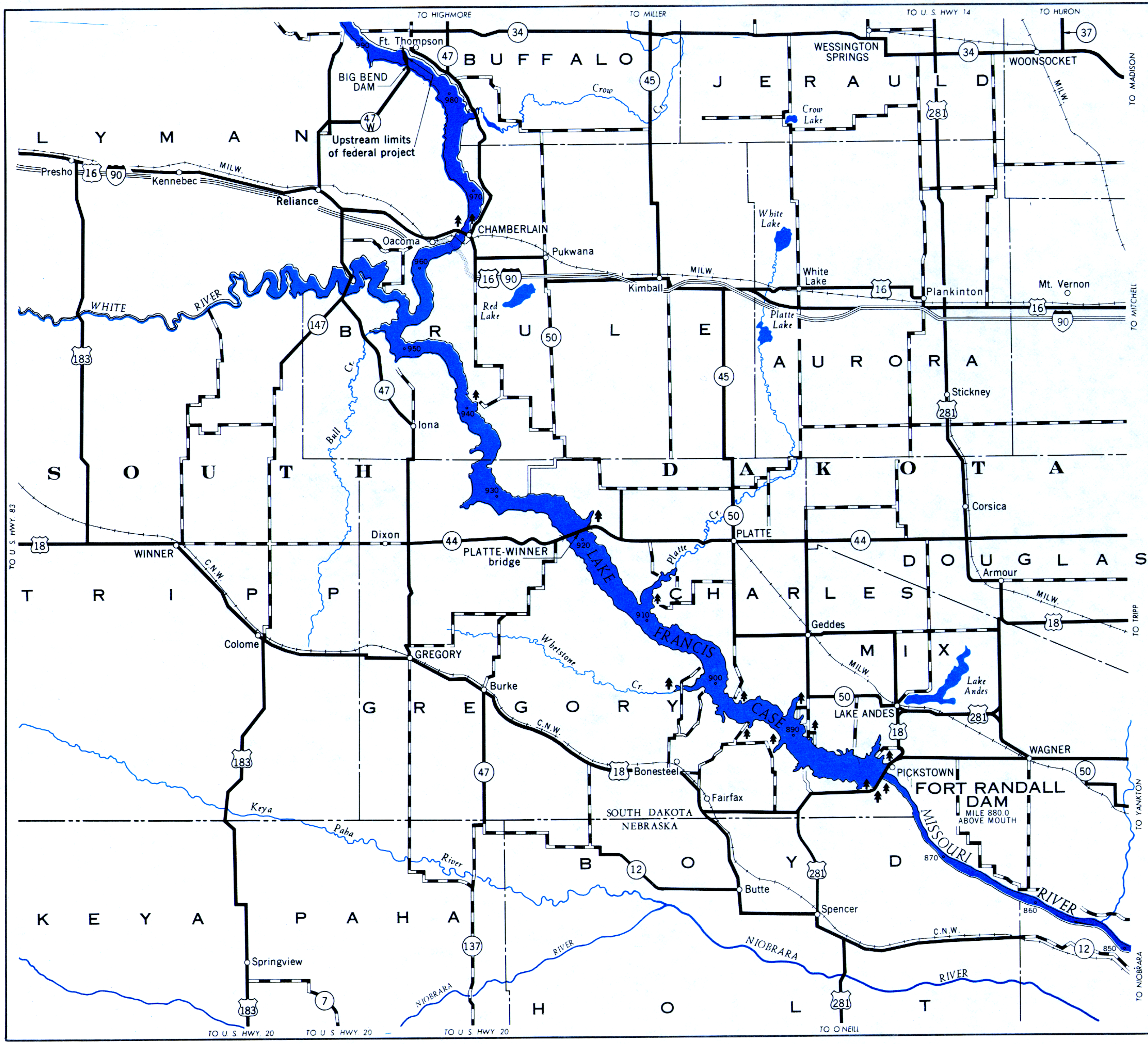
AREA IN ACRES

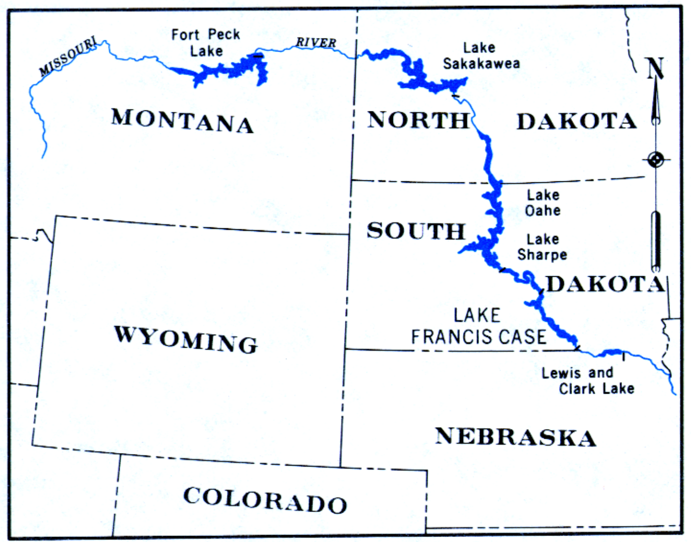
EFFECTIVE 1 JAN 1978

(1975 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1340	0	0	104	154	195	265	328	404	577	847
1350	1124	1328	1561	1918	2399	2889	3284	3718	4310	5063
1360	5906	6708	7439	8135	8796	9431	10070	10732	11419	12128
1370	12856	13582	14291	14982	15655	16326	17011	17690	18348	18986
1380	19601	20211	20846	21515	22218	22937	23644	24341	25040	25741
1390	26419	27072	27760	28523	29359	30217	31037	31854	32713	33615
1400	34506	35352	36231	37205	38275	39352	40356	41389	42545	43824
1410	45176	46501	47765	48991	50179	51346	52525	53718	54914	56113
1420	57313	58512	59711	60908	62104	63301	64497	65693	66890	68087
1430	69283									

AREA AND CAPACITY DATA
BIG BEND RESERVOIR





LOCATION MAP

↟ Recreation area

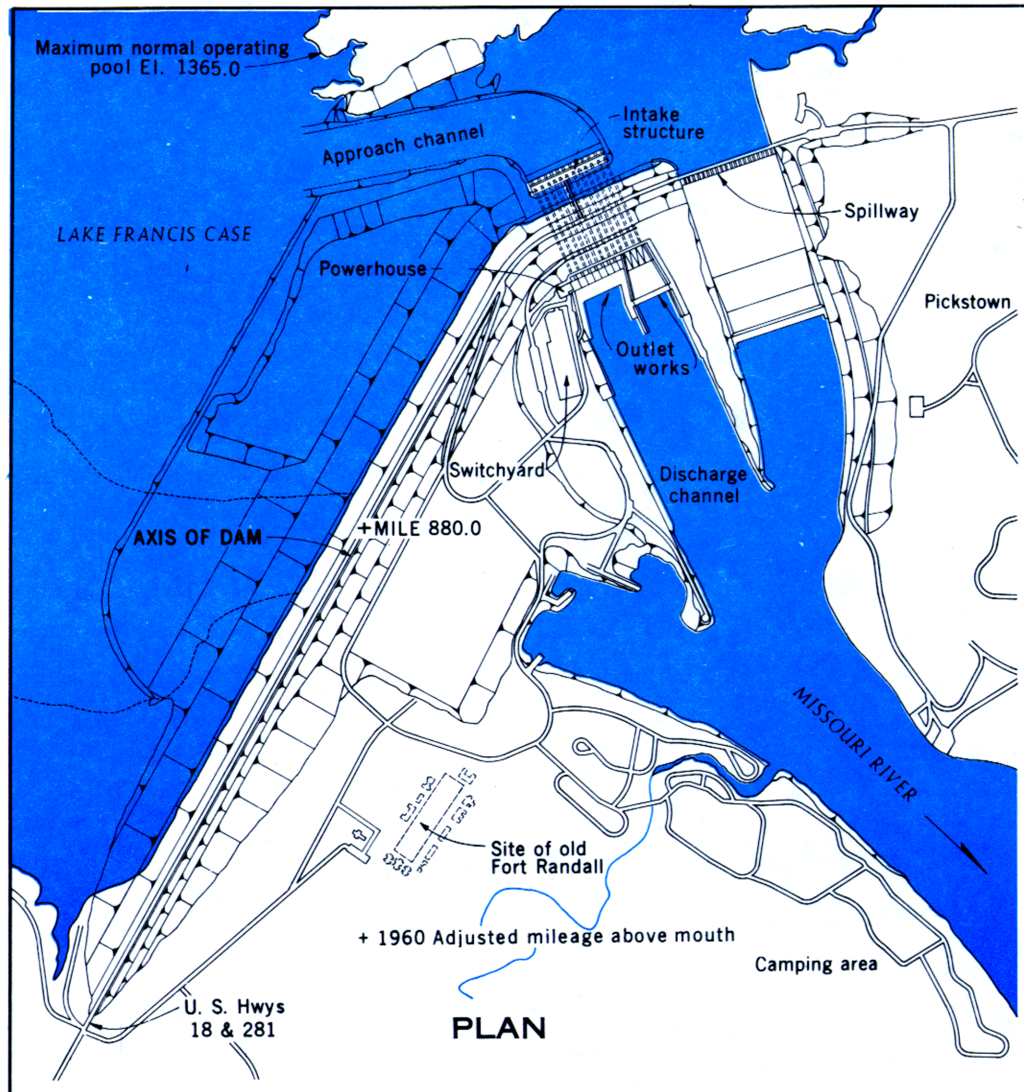
RESERVOIR CAPACITY: 5,700,000 ACRE FEET (EL.1375)

TOTAL UNITED STATES LAND ACQUIRED TO DATE:
114,373.0 ACRES

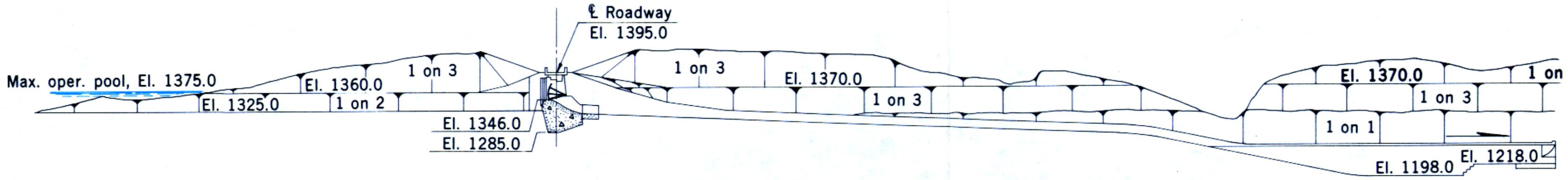
SCALE IN MILES
5 0 5 10

FLOOD CONTROL PROJECT
FORT RANDALL DAM
LAKE FRANCIS CASE
MISSOURI RIVER BASIN
SOUTH DAKOTA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

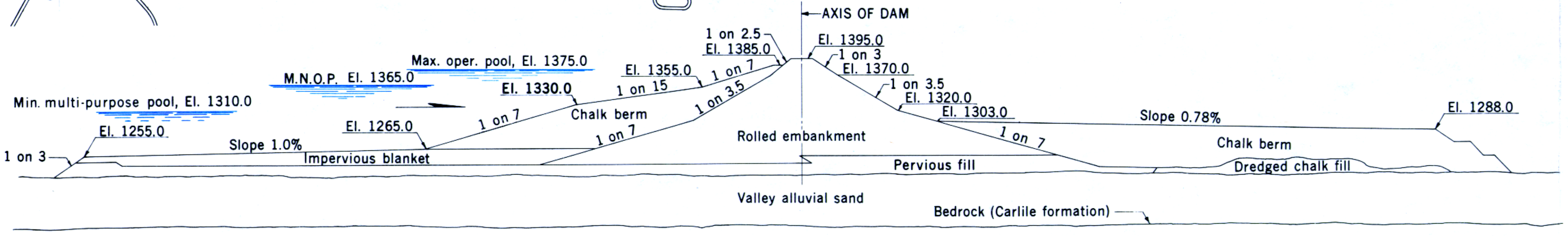
PLATE 26



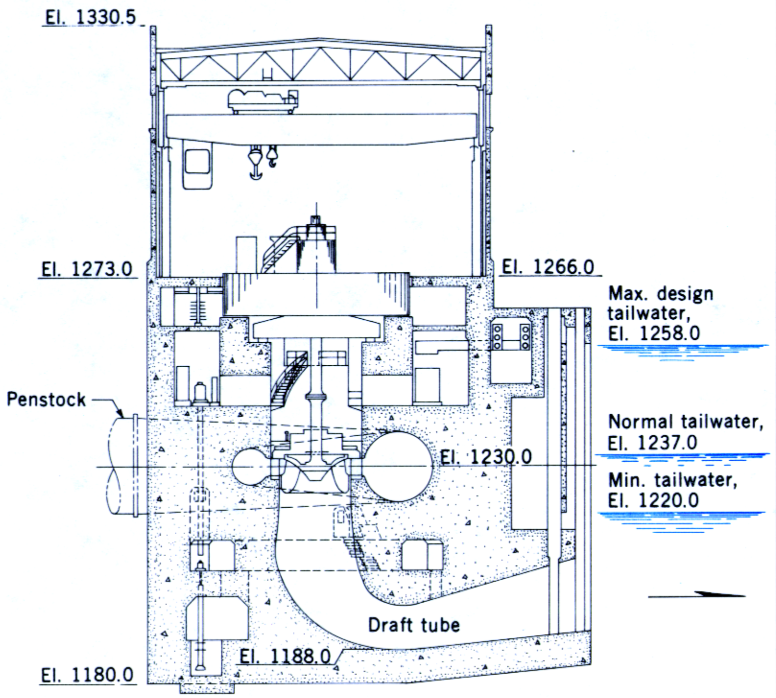
PLAN



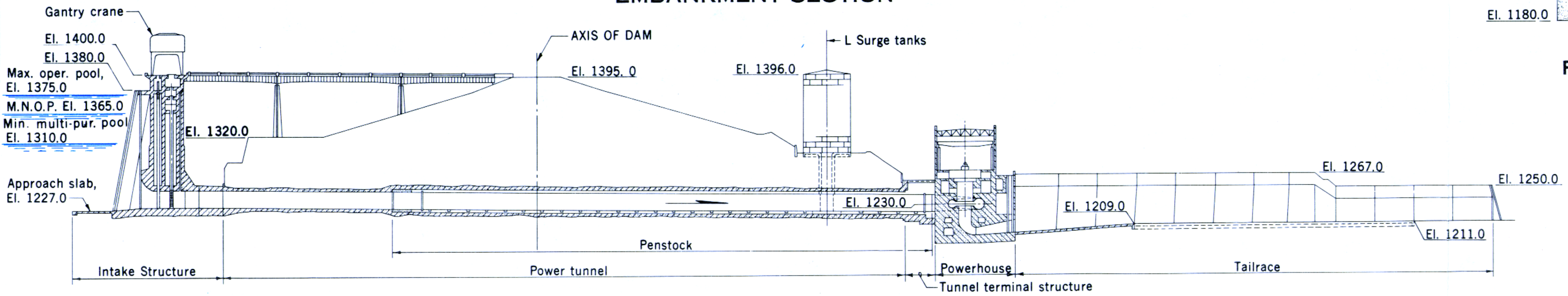
SPILLWAY PROFILE



EMBANKMENT SECTION

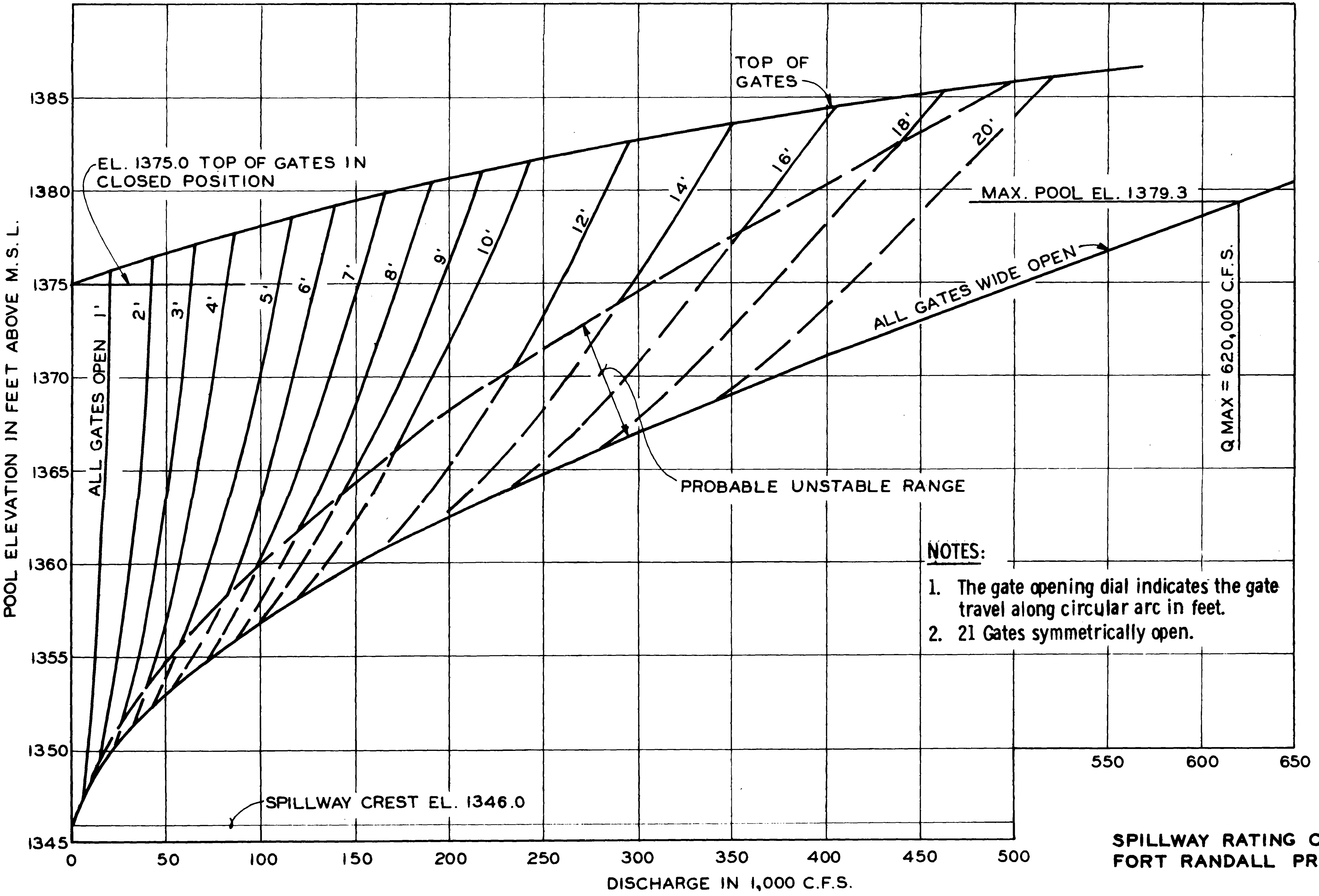


POWERHOUSE SECTION



OUTLET WORKS PROFILE

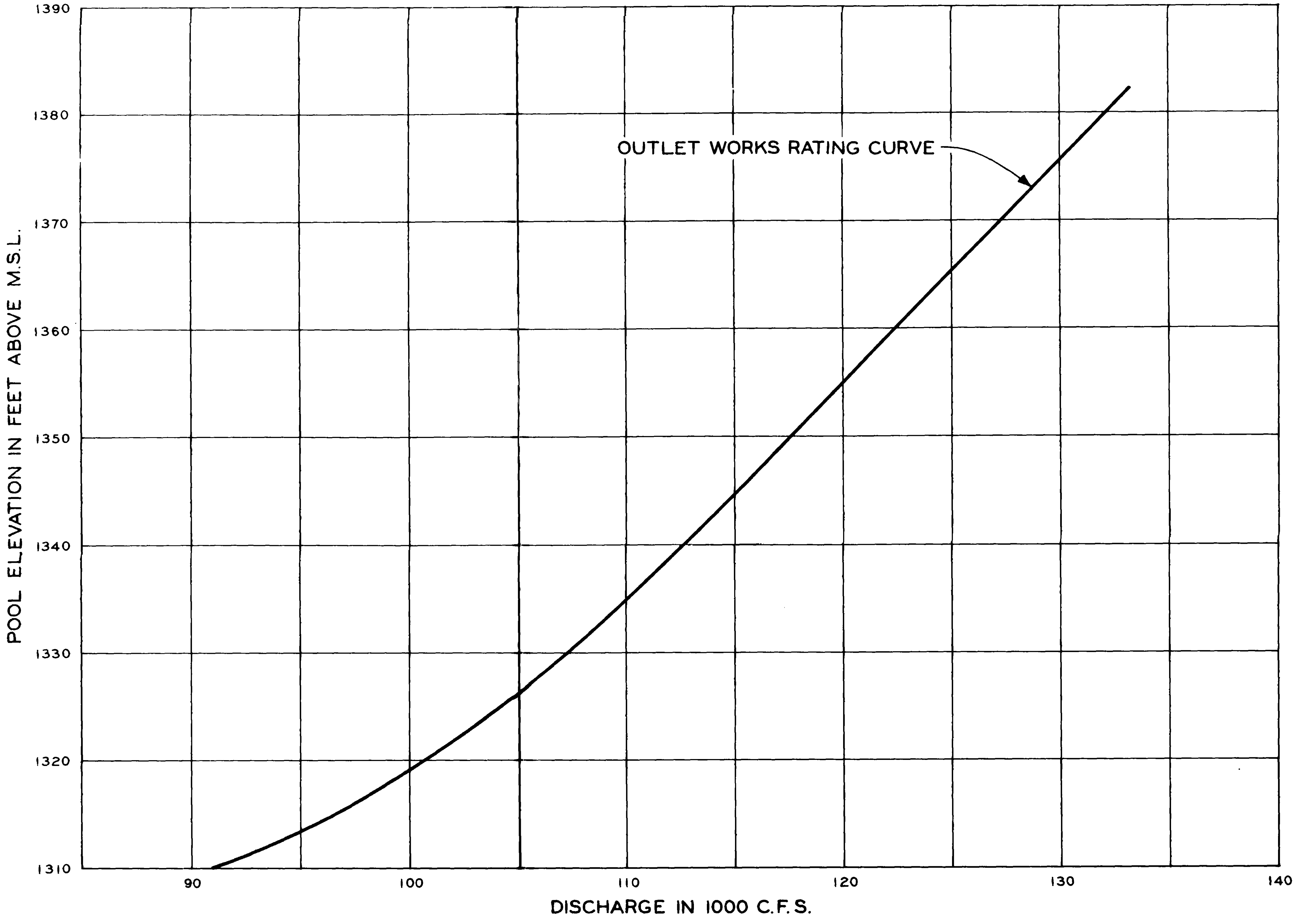
FLOOD CONTROL PROJECT
FORT RANDALL DAM
LAKE FRANCIS CASE
MISSOURI RIVER BASIN
SOUTH DAKOTA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977



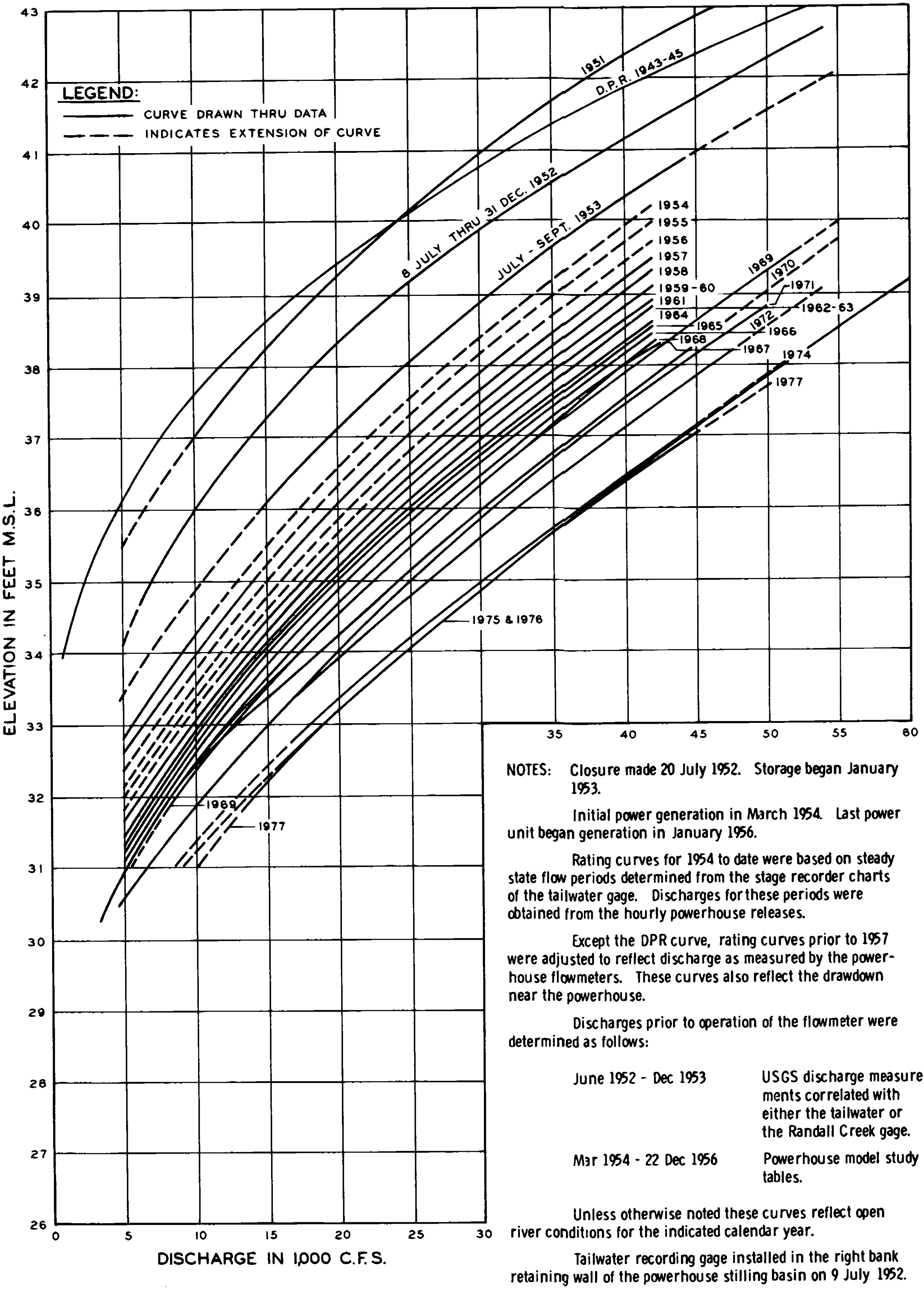
NOTES:

1. The gate opening dial indicates the gate travel along circular arc in feet.
2. 21 Gates symmetrically open.

SPILLWAY RATING CURVES
FORT RANDALL PROJECT



OUTLET WORKS RATING CURVE
FORT RANDALL PROJECT



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. Discharges for these periods were obtained from the hourly powerhouse releases.

Except the DPR curve, rating curves prior to 1957 were adjusted to reflect discharge as measured by the powerhouse flowmeters. These curves also reflect the drawdown near the powerhouse.

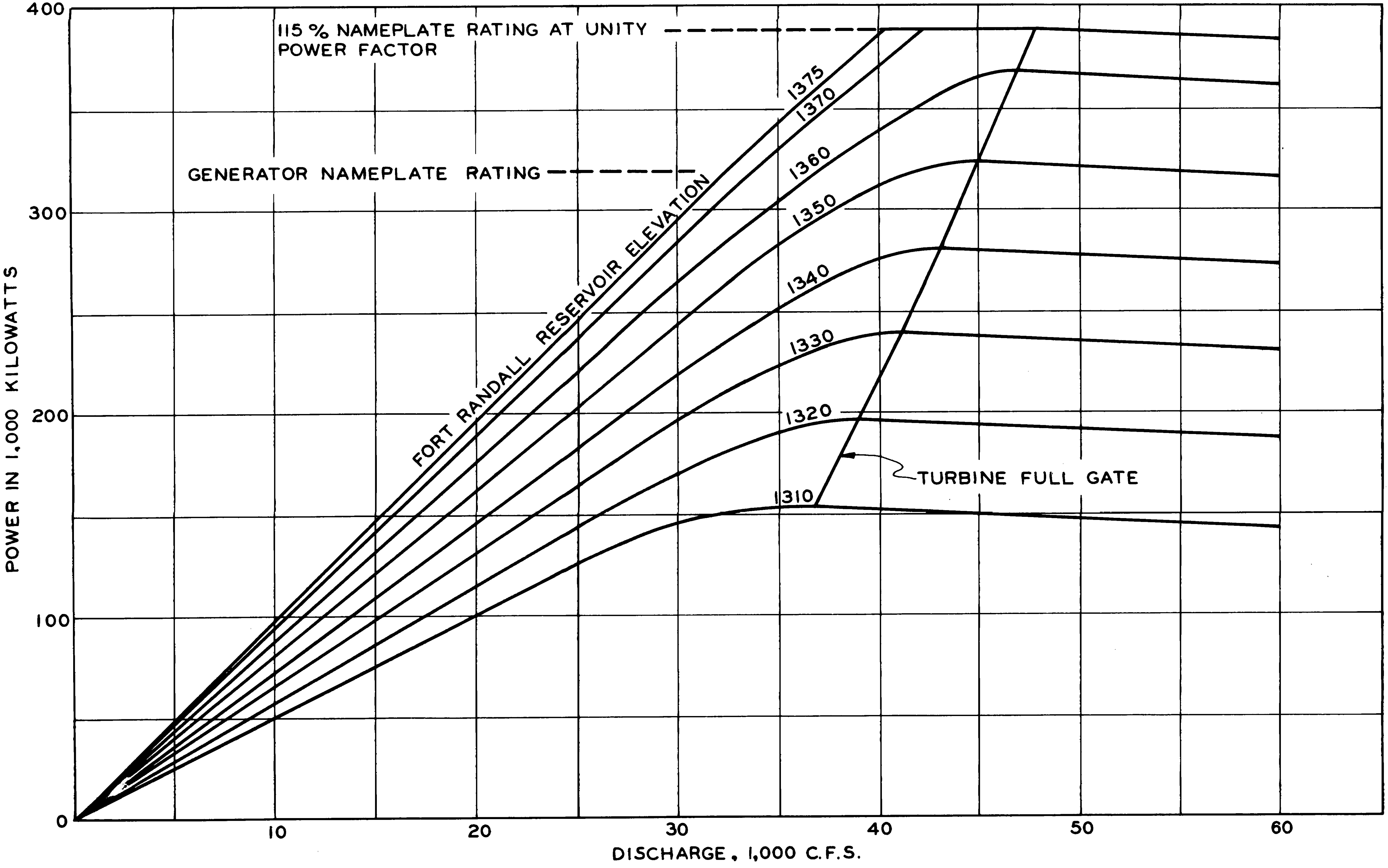
Discharges prior to operation of the flowmeter were determined as follows:

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

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

Tailwater recording gage installed in the right bank retaining wall of the powerhouse stilling basin on 9 July 1952.

TAILWATER RATING CURVES
FORT RANDALL PROJECT



POWER PLANT CHARACTERISTICS
FORT RANDALL PROJECT

PLATE 28D

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972-760

FORT RANDALL
AREA AND CAPACITY DATA

Effective 1 Jan 1978

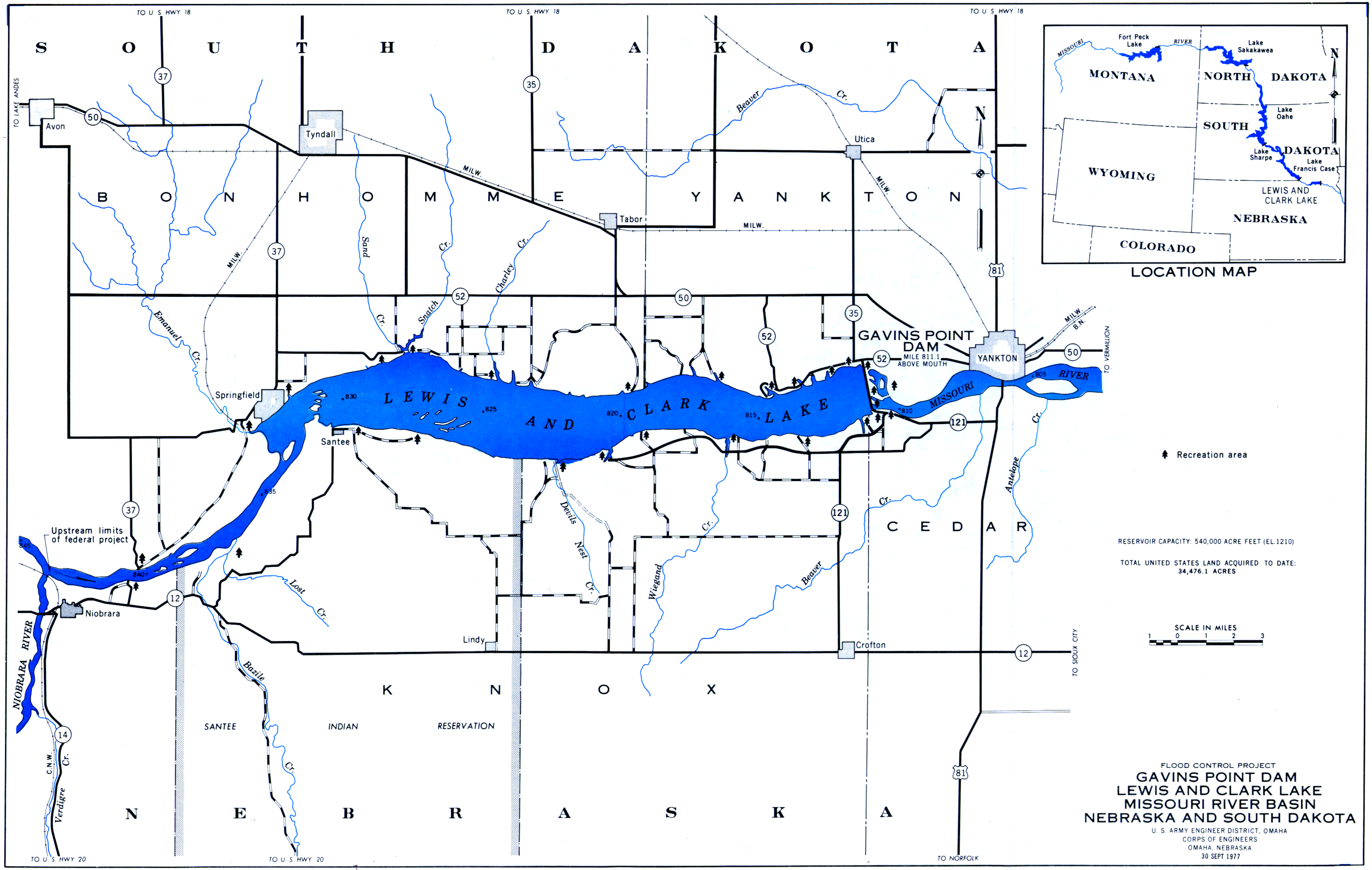
FORT RANDALL PROJECT
AREA IN ACRES
(1972 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1240	0	0	0	0	445	702	854	1003	1151	1300
1250	1794	2289	2486	2777	3164	3647	4225	4898	5667	6532
1260	7432	8265	9024	9745	10428	11073	11681	12250	12782	13276
1270	13722	14142	14596	15110	15683	16319	17008	17760	18572	19443
1280	20378	21335	22240	23068	23816	24487	25079	25593	26028	26385
1290	26779	27329	27934	28482	28973	29408	29786	30107	30371	30579
1300	30696	30745	30847	31062	31393	31839	32399	33074	33864	34296
1310	35711	36564	37328	38054	38742	39392	40004	40579	41116	41615
1320	41967	42139	42355	42764	43364	44156	45141	46318	47686	49247
1330	50777	52010	53105	54262	55481	56762	58105	59511	60978	62508
1340	64040	65495	66904	68316	69733	71153	72578	74007	75439	76875
1350	78428	80156	81868	83426	84829	86078	87173	88115	88901	89533
1360	90189	91081	92084	93039	93946	94805	95616	96379	97094	97761
1370	98420	99130	99877	100628	101384	102144	102709	103677	104450	105228
1380	106007	186779	107549	108319	109088	109858	110628	111397	112167	112937
1390	115707									

Effective 1 Jan 1978

FORT RANDALL PROJECT
CAPACITY IN ACRE-FEET
(1972 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1240	0	0	0	0	260	891	1671	2600	3677	4903
1250	6277	8492	10856	13464	16411	19793	23706	28244	33503	39579
1260	46567	54444	63098	72493	82589	93349	104736	116711	129236	142275
1270	155788	169719	184073	198912	214293	230278	246926	264295	282446	301439
1280	321333	342196	364003	386677	410139	434310	459113	484469	510300	536526
1290	563071	590084	617730	645953	674695	703900	733511	763472	793725	824215
1300	854884	885607	916375	947301	978500	1020088	1042178	1074887	1108327	1142616
1310	1179866	1214039	1250995	1288696	1327103	1306180	1405888	1446189	1487046	1528422
1320	1570277	1612356	1654555	1697067	1740083	1783792	1828396	1874078	1921032	1969450
1330	2019526	2671005	2123547	2177216	2232072	2288178	2345596	2404389	2464618	2526346
1340	2589635	2854427	2720626	2788235	2857259	2927707	2999565	3072857	3147579	3223735
1350	3302330	3380592	3461642	3544328	3828494	3713987	3800651	3888334	3976881	4066137
1360	4155948	4246515	4338110	4430683	4524188	4618574	4713799	4809809	4906558	5083998
1370	5102080	5200838	5300341	5400593	5501598	5603361	5705887	5809179	5913242	6018080
1380	6123699	6230094	6337258	6445193	6553897	6663370	6773613	6884626	6996408	7108960
1390	7222282									



RESERVOIR CAPACITY: 540,000 ACRE FEET (EL.1210)

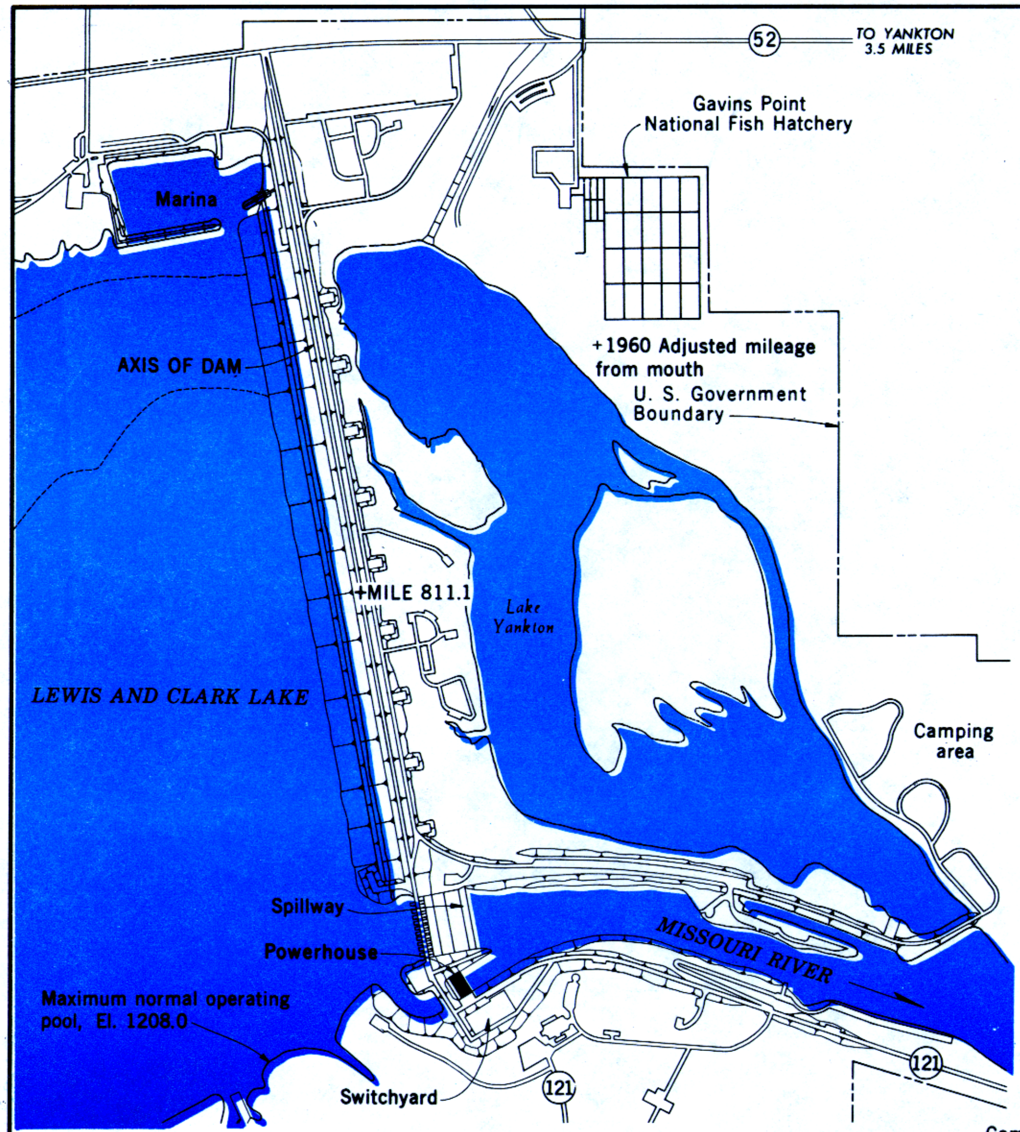
TOTAL UNITED STATES LAND ACQUIRED TO DATE:
34,476.1 ACRES

FLOOD CONTROL PROJECT

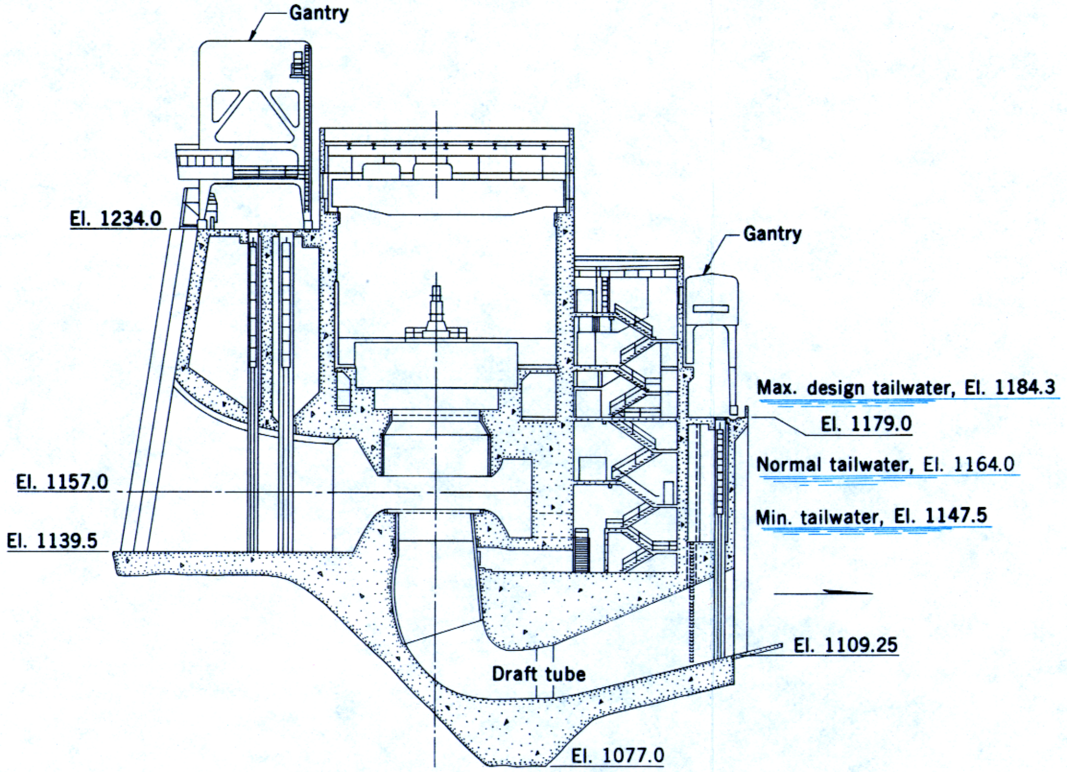
GAVINS POINT DAM
LEWIS AND CLARK LAKE
MISSOURI RIVER BASIN
NEBRASKA AND SOUTH DAKOTA

U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977

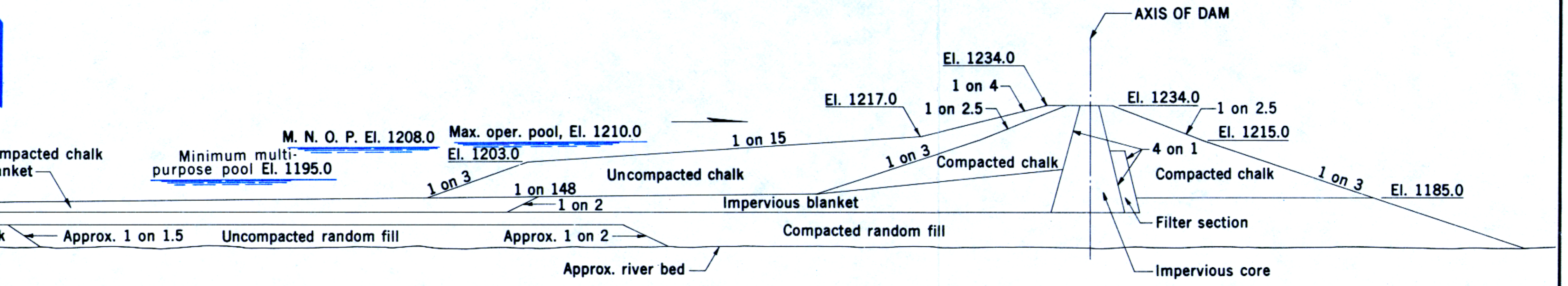
PLATE 29



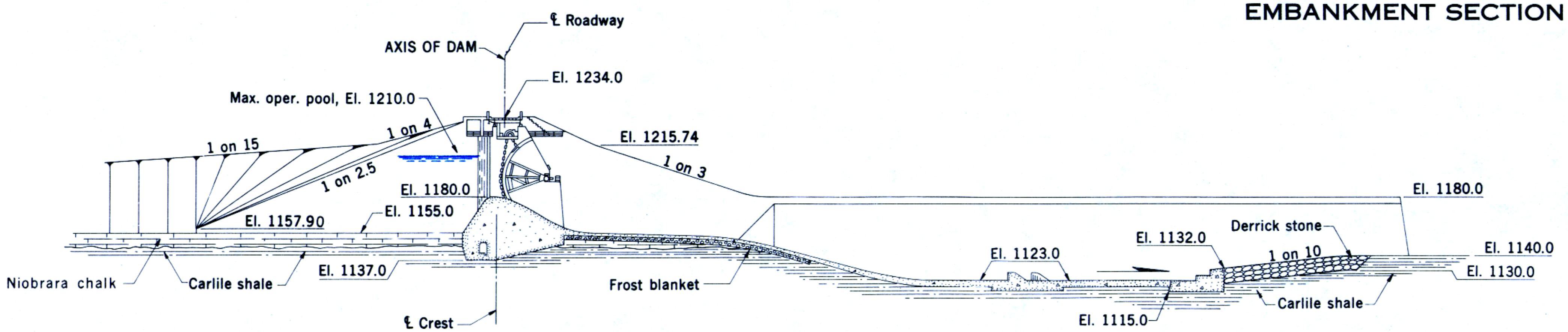
PLAN



POWERHOUSE SECTION

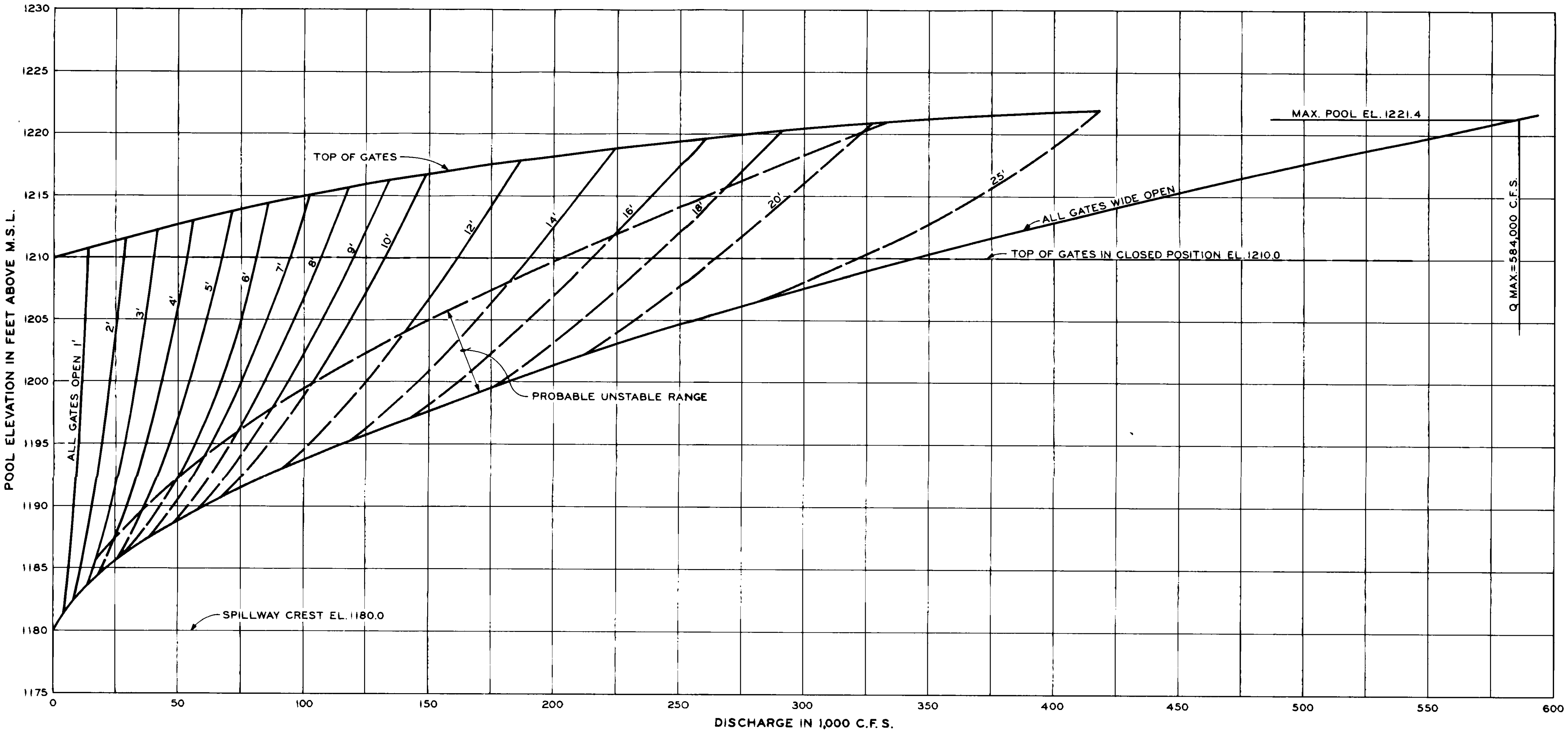


EMBANKMENT SECTION



SPILLWAY PROFILE

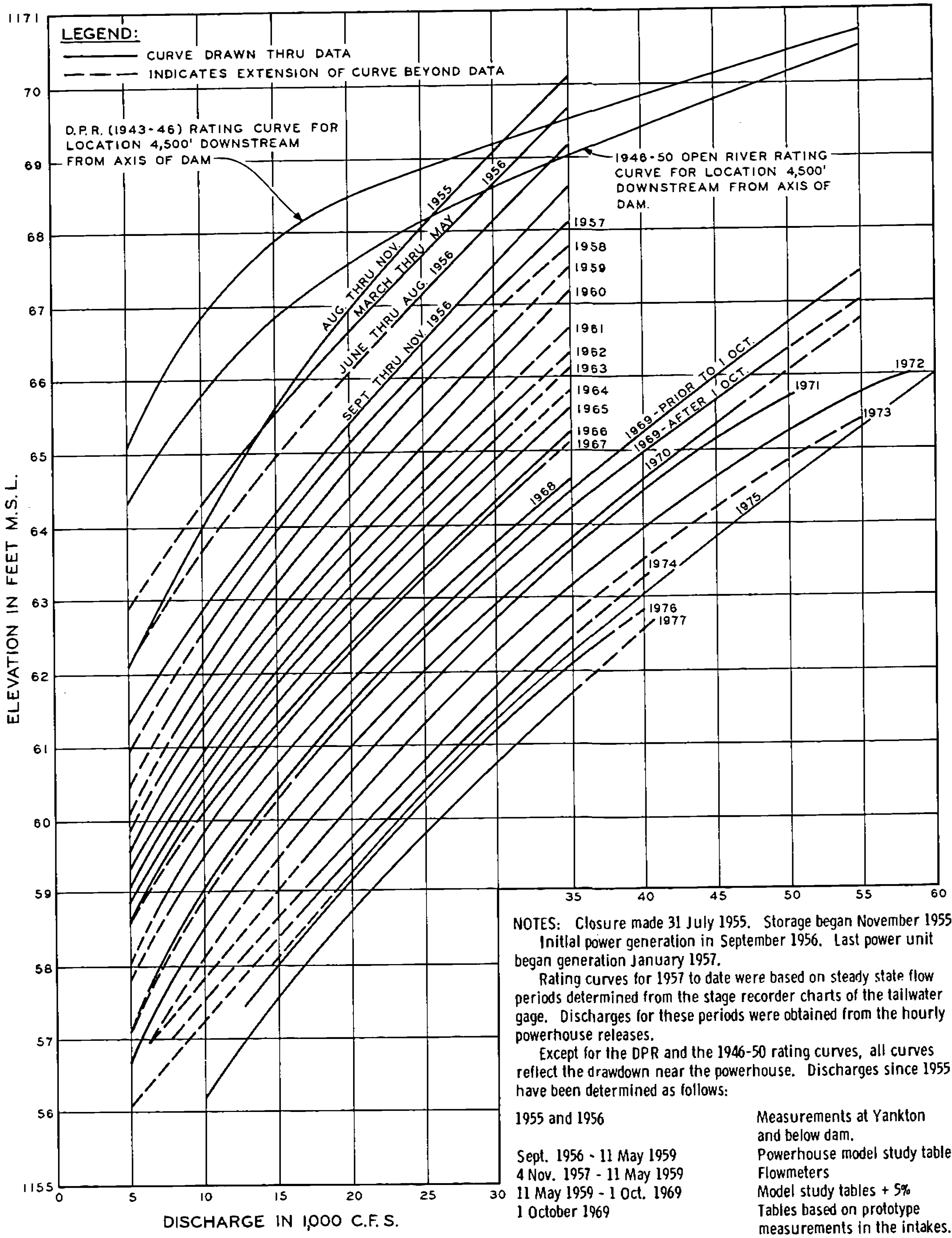
FLOOD CONTROL PROJECT
GAVINS POINT DAM
LEWIS AND CLARK LAKE
MISSOURI RIVER BASIN
NEBRASKA AND SOUTH DAKOTA
U. S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
OMAHA, NEBRASKA
30 SEPT 1977



NOTES:

1. GATE OPENING DIAL INDICATES THE GATE TRAVEL IN FEET ALONG CIRCULAR ARC.
2. 14 GATES SYMMETRICALLY OPEN.

SPILLWAY RATING CURVES
GAVINS POINT PROJECT



NOTES: 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 date were based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Discharges for these periods were obtained from the hourly powerhouse releases.

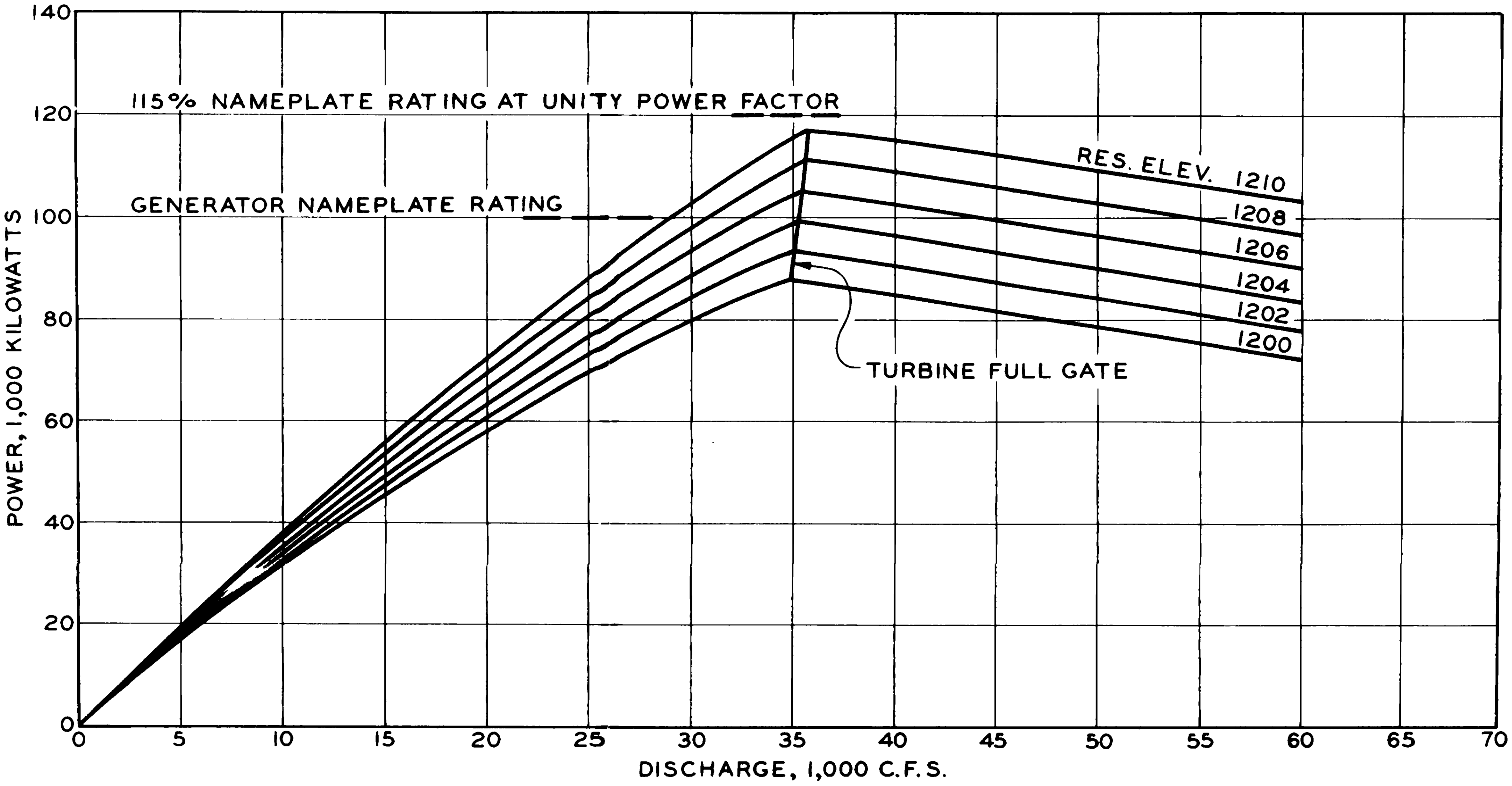
Except for the DPR and the 1946-50 rating curves, all curves reflect the drawdown near the powerhouse. Discharges since 1955 have been determined as follows:

1955 and 1956	Measurements at Yankton and below dam.
Sept. 1956 - 11 May 1959	Powerhouse model study tables.
4 Nov. 1957 - 11 May 1959	Flowmeters
11 May 1959 - 1 Oct. 1969	Model study tables + 5%
1 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 throught the downstream side of powerhouse.

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

TAILWATER RATING CURVES
GAVINS POINT PROJECT



POWER PLANT CHARACTERISTICS
GAVINS POINT PROJECT

GAVINS POINT
AREA AND CAPACITY DATA

Effective 1 Jan 1978

GAVINS POINT PROJECT
AREA IN ACRES
(1975 SURVEY)

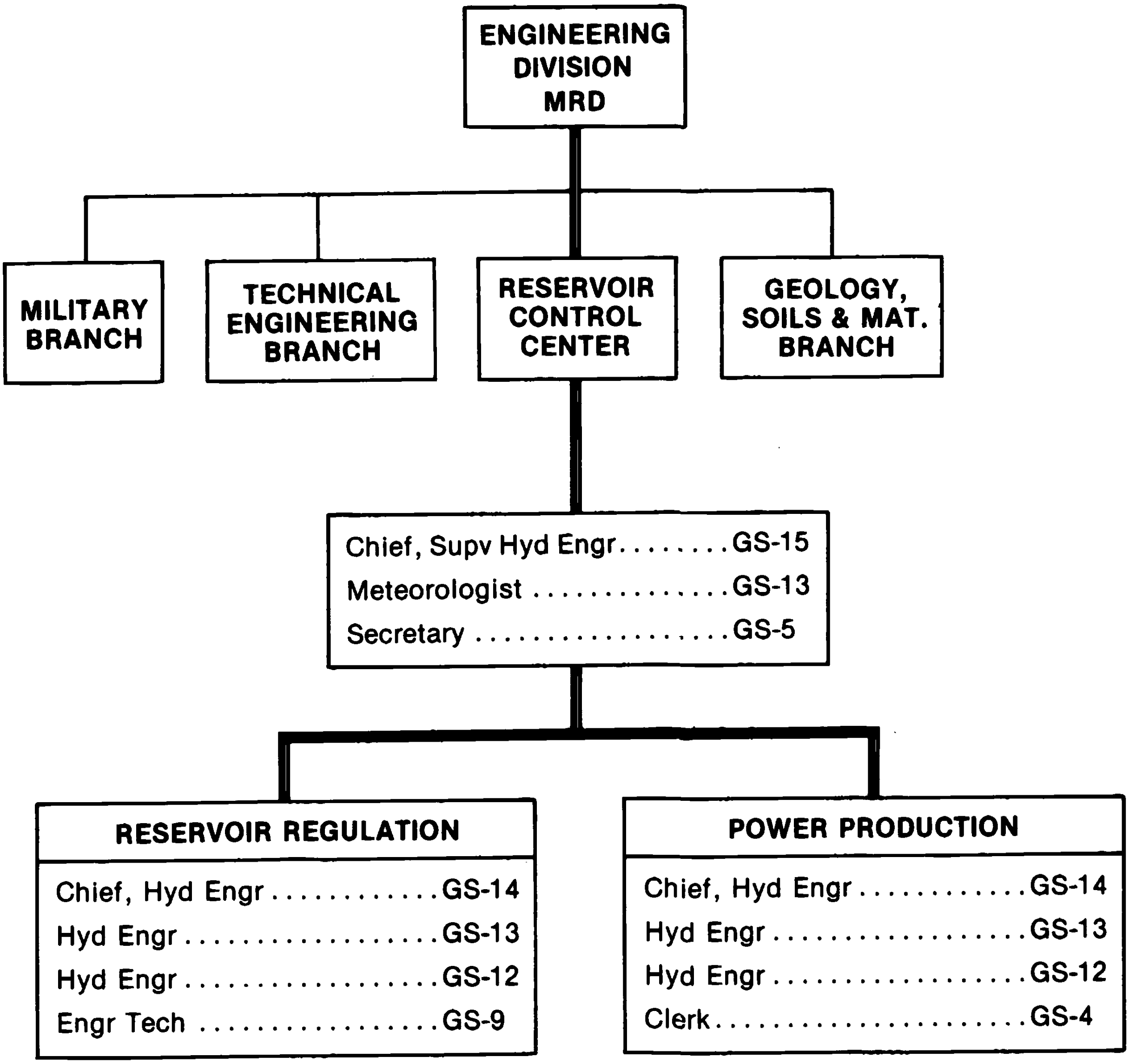
ELEV	0	1	2	3	4	5	6	7	8	9
1160	0	74	148	221	295	350	384	448	571	754
1170	933	1059	1216	1472	1828	2207	2524	2850	3260	3753
1180	4252	4686	5147	5717	6396	7091	7712	8353	9110	9982
1190	10889	11737	12578	13485	14457	15429	16346	17290	18334	19478
1200	20666	21817	22942	24079	25229	26367	27482	28620	29815	31066
1210	32356	33638	34885	36101	37285	38458	39646	40838	42015	43177
1220	44331	45488	46652	47822	48996	50172	51347	52520	53692	54866
1230	56040									

Effective 1 Jan 1978

GAVINS POINT PROJECT
CAPACITY IN ACRE-FEET
(1975 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1160	0	37	148	333	591	924	1291	1692	2187	2835
1170	3695	4701	5814	7133	8758	10790	13173	15839	18874	22359
1180	26380	30863	35753	41158	47188	53951	61371	69375	78077	87595
1190	98041	109373	121515	134530	148485	163445	179343	196137	213924	232806
1200	252880	274139	296515	320023	344674	370482	397409	425446	454650	485077
1210	516783	549790	584060	619561	656262	694131	733178	773424	814854	857454
1220	901209	946117	992186	1039422	1087830	1137414	1188174	1240108	1293214	1347493
1230	1402946									

ORGANIZATION FOR RESERVOIR REGULATION & POWER PRODUCTION



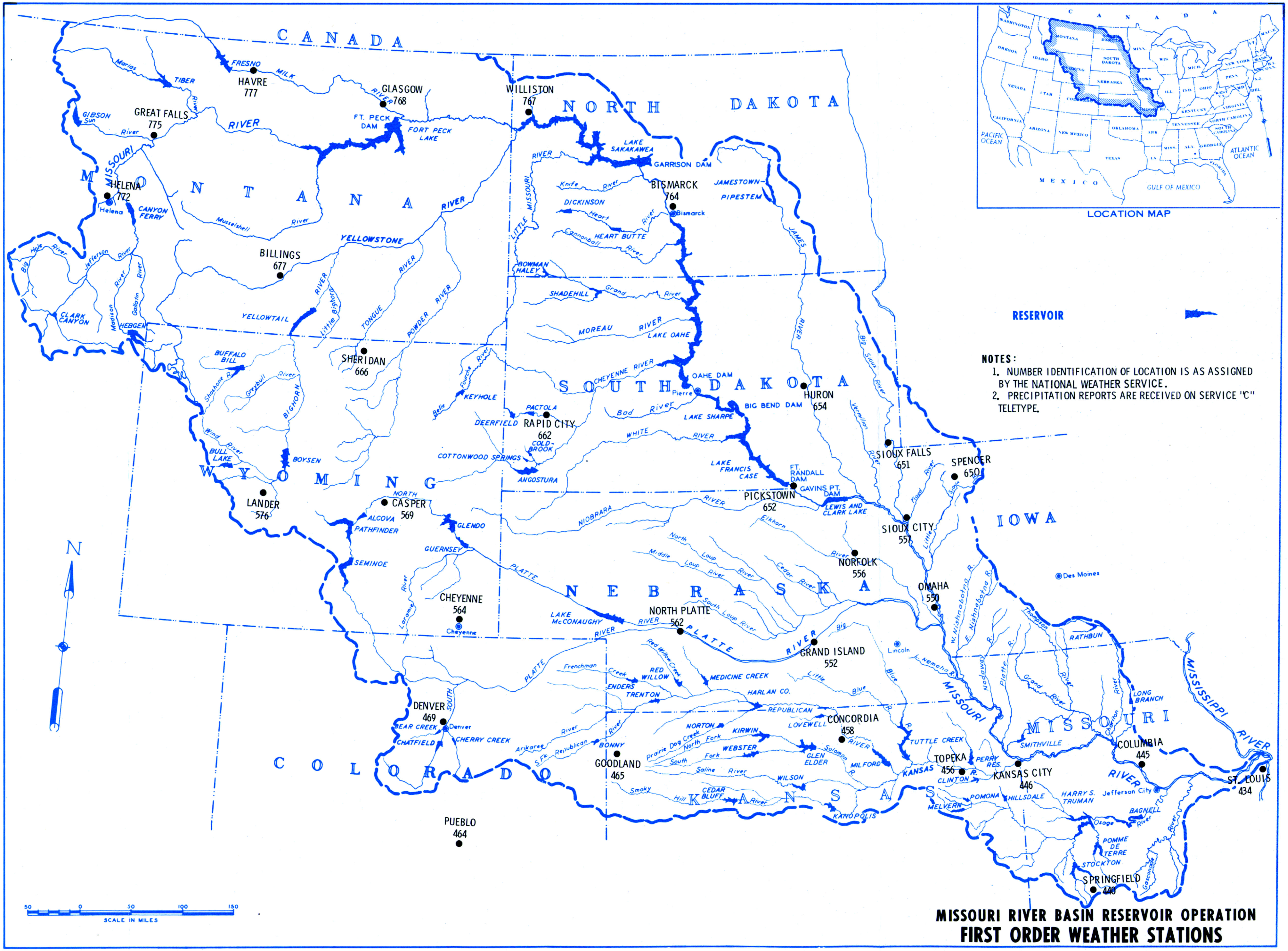
Chief, Supv Hyd Engr	GS-15
Meteorologist	GS-13
Secretary	GS-5

RESERVOIR REGULATION

Chief, Hyd Engr	GS-14
Hyd Engr	GS-13
Hyd Engr	GS-12
Engr Tech	GS-9

POWER PRODUCTION

Chief, Hyd Engr	GS-14
Hyd Engr	GS-13
Hyd Engr	GS-12
Clerk	GS-4

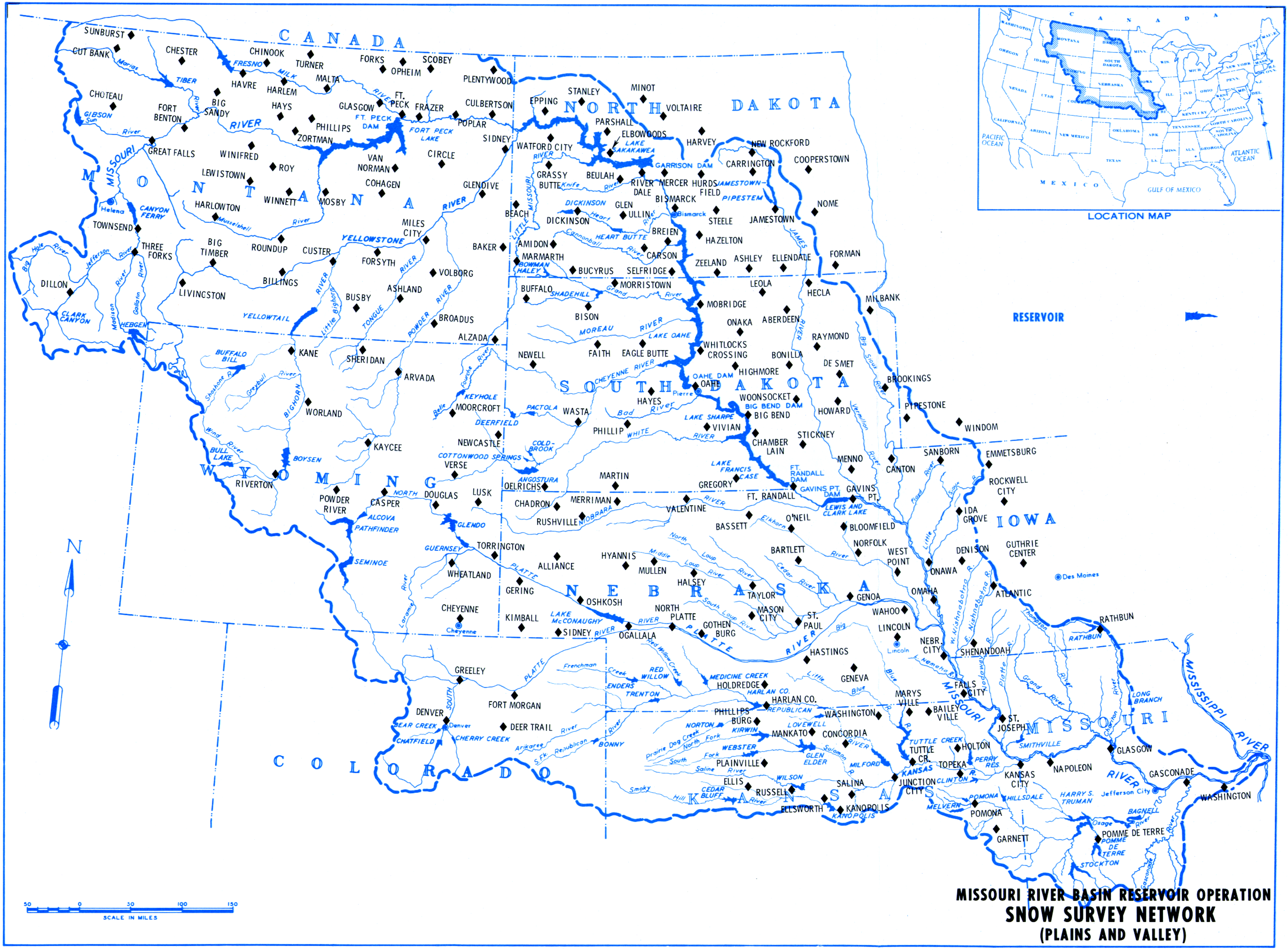


RESERVOIR

NOTES:

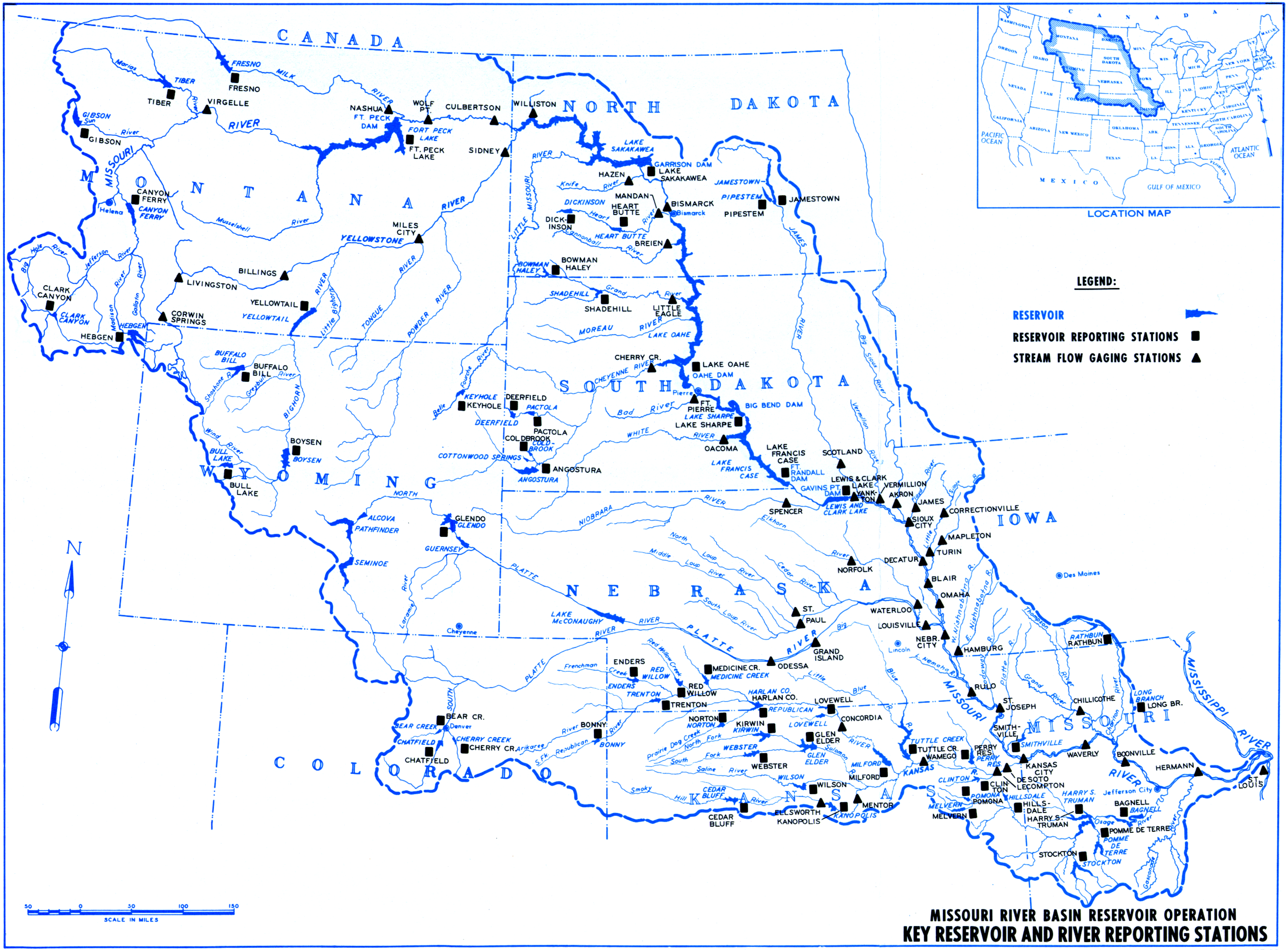
1. NUMBER IDENTIFICATION OF LOCATION IS AS ASSIGNED BY THE NATIONAL WEATHER SERVICE.
2. PRECIPITATION REPORTS ARE RECEIVED ON SERVICE "C" TELETYPE.

MISSOURI RIVER BASIN RESERVOIR OPERATION
FIRST ORDER WEATHER STATIONS



MISSOURI RIVER BASIN RESERVOIR OPERATION
SNOW SURVEY NETWORK
(PLAINS AND VALLEY)

PLATE 34



MISSOURI RIVER BASIN RESERVOIR OPERATION
KEY RESERVOIR AND RIVER REPORTING STATIONS

PLATE 35

FORMS FOR FORECASTING INFLOW BELOW GAVINS POINT

MAY 1952

FLOWS 100 CFS

SHEET 1

GVP. DATE	GAVINS POINT		SIOUX CITY	GVP.-SUX.		OMAHA	SUX-OMAHA	GVP-OMAHA
					1			
		1			2			
		2			3			
1		3			4			
2		4			5			
3		5			6			
4		6			7			
5		7			8			
6		8			9			
7		9			10			
8	510	10			11			
9	510	11			12			
10	510	12			13			
11	510	13	610		14	610		100
12	510	14	570		15	610	40	100
13	510	15	590	80	16			
14	520	16			17			
15		17			18			
16		18			19			
17		19			20			
18		20			21			
19		21			22			
20		22			23			
21		23			24			
22		23			25			
23		25			26			
24		26			27			
25		27			28			
26		28			29			
27		29			30			
28		30			31			
29		31						
30								
31								
	A		B			C		

	NEBR. CITY	OMAHA-NB.C.	GVP.-NB.C.
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12	810		300
13	850		340
14	770		260
15	670	60	160
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
	D		

	RULO	NBC-RULO
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4		
5		
6		
7		
8		
9		
10		
11		
12		
13	850	20
14	850	40
15	760	40
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
	E	

	MKC	RULO-MKC	NBC.-MKC
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15	960	110	140
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
	F		

JAMES R. SCOTLAND		
	0	1
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12	44	
13	43	
14	41	
15	40	
16		39
17		
18		
19		
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21		
22		
23		
24		
25		
26		
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28		
29		
30		
31		
	G	

BIG SIOUX RIVER AKRON				
	0	1	2	3
1				
2				
3				
4				
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12				
13	26			
14	24			
15	23			
16		21		
17			19	
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31				
		H		

VERMILLION RIVER VERMILLION				GAGED INFLOW GVP-SUX.					UNGAGED INFLOW GVP-SUX.					TOTAL INFLOW GVP-SUX.					GVP REL. SUX CONTROL		
	0	1	2		1	2	3	4	0	1	2	3	4	0	1	2	3	4		0	1
																				TARGET	
				1																610	
				2																	
1				3															1		
2				4															2		
3				5															3		
4				6															4		
5				7															5		
6				8															6		
7				9															7		
8				10															8		
9				11															9		
10				12															10		
11				13															11		
12				14					10										12		
13	2			15	71				9					80					13		
14	2			16	67					8					75				14		
15	1			17		64					7					71			15	540	
16		1		18			61					6					67		16		545
17			1	19				58					5					63	17		545
18				20															18		
19				21															19		
20				22															20		
21				23															21		
22				24															22		
23				25															23		
24				26															24		
25				27															25		
26				28															26		
27				29															27		
28				30															28		
29				31															29		
30																			30		
31																			31		
		I				J					K					L				M	

PLATE 36

FORMS FOR FORCASTING INFLOW BELOW GAVINS POINT

MAY 1952

FLOWS 100 CFS

SHEET 2

GVP DATE

GVP DATE
1
2
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29
30
31

A: LITTLE SIOUX RIV. CORRECTIONVILLE

	0	1	2	3	4
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13	11				
14	11				
15	10				
16		9			
17			8		
18				7	
19					6
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					

B: M.H. DITCH TURIN

	0	1	2	3	4	5
1						
2						
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4						
5						
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9						
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11						
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13						
14	19					
15	19					
16		18				
17			17			
18				16		
19					15	
20						14
21						
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23						
24						
25						
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27						
28						
29						
30						
31						

C: FLOYD RIVER JAMES — D: MAPLE RIVER MAPLETON

	FLOYD RIVER JAMES					MAPLE RIVER MAPLETON				
	0	1	2	3	4	0	1	2	3	4
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14	3					3				
15	3					9				
16		3					6			
17			3					4		
18				3					3	
19					3					2
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
31										

E: GAGED INFLOW SUX-OMA — F: UNGAGED INFLOW SUX-OMA — G: TOTAL INFLOW SUX-OMA — H: TOTAL INFLOW GVP-OMA

	GAGED INFLOW SUX-OMA						UNGAGED INFLOW SUX-OMA						TOTAL INFLOW SUX-OMA						TOTAL INFLOW GVP-OMA					
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
1																								
2																								
3																								
4																								
5																								
6																								
7																								
8																								
9																								
10																								
11																								
12																								
13																								
14																			100					
15	36						4						40						100					
16		41						3						44						124				
17			36						2						38						113			
18				32						1						33						104		
19					29						0						29						96	
20						26						0						26						89
21																								
22																								
23																								
24																								
25																								
26																								
27																								
28																								
29																								
30																								
31																								

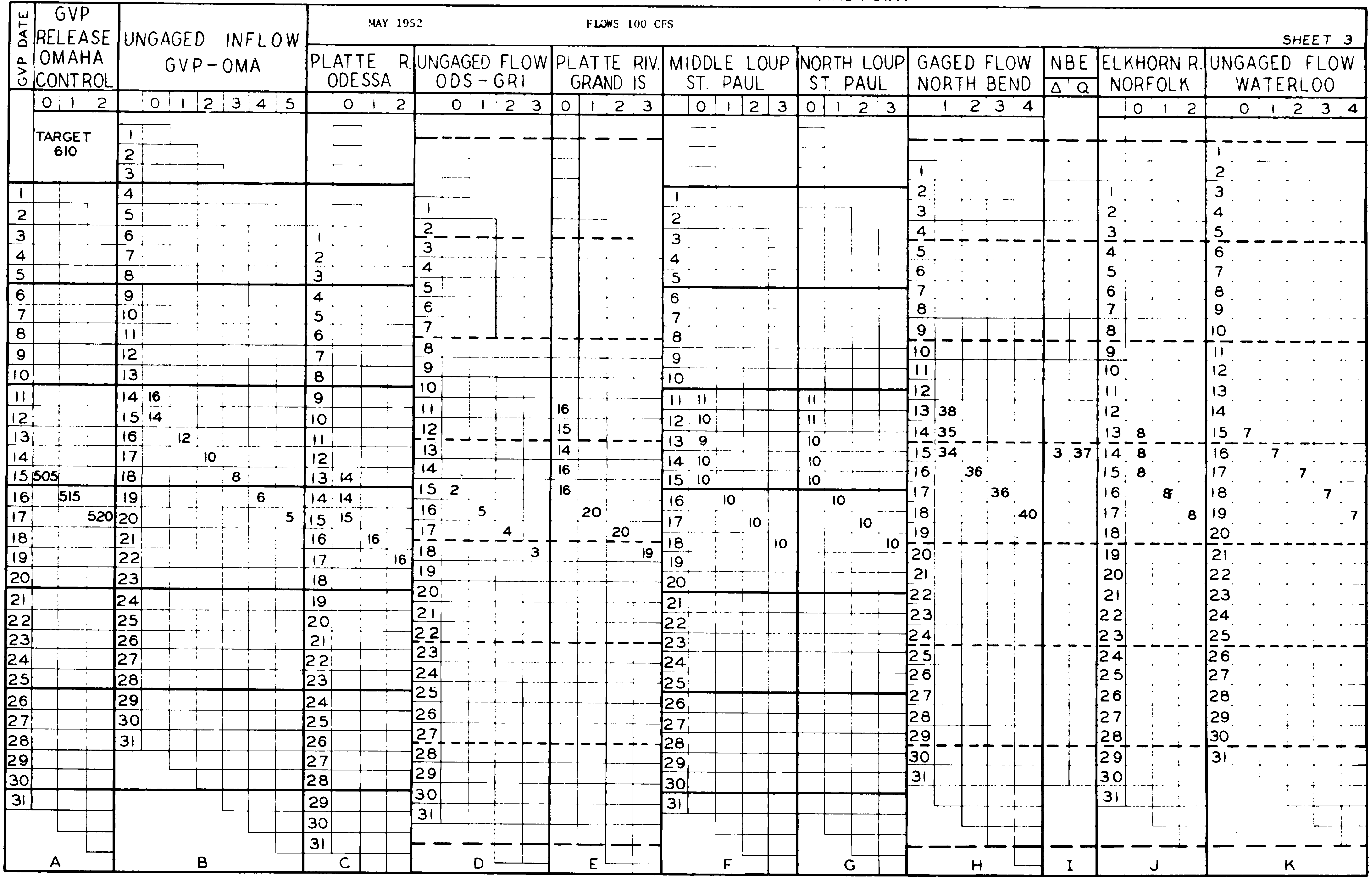
A B C D E F G H

FORMS FOR FORECASTING INFLOW BELOW GAVINS POINT

MAY 1952

FLOWS 100 CFS

SHEET 3



A. GVP RELEASE OMAHA CONTROL. TARGET 610

GVP DATE	0	1	2
15	505		
16		515	
17			520

B. UNGAGED INFLOW GVP-OMA

DATE	0	1	2	3	4	5
14	16					
15	14					
16		12				
17			10			
18				8		
19					6	
20						5

C. PLATTE R. ODESSA

DATE	0	1	2
13	14		
14	14		
15	15		
16		16	
17			16

D. UNGAGED FLOW ODS-GRI; E. PLATTE RIV. GRAND IS

DATE	D 0	D 1	D 2	D 3	E 0	E 1	E 2	E 3
11					16			
12					15			
13					14			
14					16			
15	2				16			
16		5				20		
17			4				20	
18				3				19

F. MIDDLE LOUP ST. PAUL; G. NORTH LOUP ST. PAUL

DATE	F 0	F 1	F 2	F 3	G 0	G 1	G 2	G 3
11	11				11			
12	10				11			
13	9				10			
14	10				10			
15	10				10			
16		10				10		
17			10				10	
18				10				10

H. GAGED FLOW NORTH BEND; I. NBE

DATE	H 1	H 2	H 3	H 4	I Δ	I Q
13	38					
14	35					
15	34				3	37
16		36				
17			36			
18				40		

J. ELKHORN R. NORFOLK

DATE	0	1	2
13	8		
14	8		
15	8		
16		8	
17			8

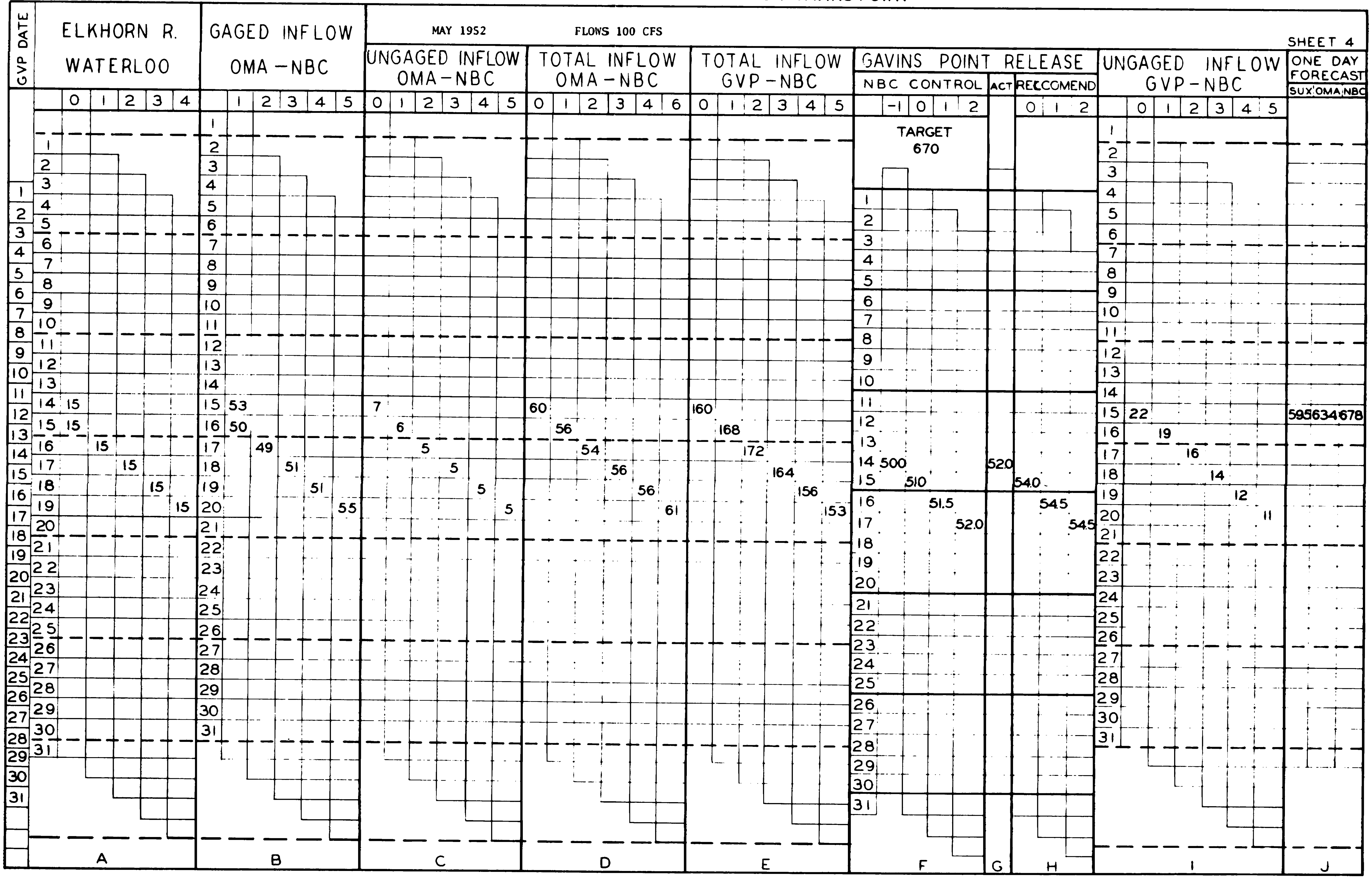
K. UNGAGED FLOW WATERLOO

DATE	0	1	2	3	4
15	7				
16		7			
17			7		
18				7	
19					7

FORMS FOR FORECASTING INFLOW BELOW GAVINS POINT

MAY 1952 FLOWS 100 CFS

SHEET 4



A. ELKHORN R. WATERLOO

	0	1	2	3	4
14	15				
15	15				
16		15			
17			15		
18				15	
19					15

B. GAGED INFLOW OMA – NBC

	1	2	3	4	5
15	53				
16	50				
17		49			
18			51		
19				51	
20					55

C. UNGAGED INFLOW OMA – NBC

0	1	2	3	4	5
7					
	6				
		5			
			5		
				5	
					5

D. TOTAL INFLOW OMA – NBC

0	1	2	3	4	6
60					
	56				
		54			
			56		
				56	
					61

E. TOTAL INFLOW GVP – NBC

0	1	2	3	4	5
160					
	168				
		172			
			164		
				156	
					153

GAVINS POINT RELEASE

F. NBC CONTROL — TARGET 670

	-1	0	1	2
14	500			
15		510		
16			51.5	
17				52.0

G. ACT: 520

H. RECCOMEND

	0	1	2
15	540		
16		545	
17			545

I. UNGAGED INFLOW GVP – NBC

	0	1	2	3	4	5
15	22					
16		19				
17			16			
18				14		
19					12	
20						11

J. ONE DAY FORECAST

SUX	OMA	NBC
595	634	678

PLATE 39

FORMS FORECASTING INFLOW BELOW GAVINS POINT

MAY 1952 FLOWS 100 CFS SHEET 5

NBC-RLO (A)

	0	1	2	3	4	5
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13	20					
14	40					
15	40					
16		30				
17			25			
18				20		
19					20	
20						20
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						

RLO-KAW (B), **KAW** (C), **NBC-MKC** (D)

	RLO-KAW 0	1	2	3	4	5	6	KAW 0	1	2	3	4	5	6	NBC-MKC 0	1	2	3	4	5	6
1																					
2																					
3																					
4																					
5																					
6																					
7																					
8																					
9																					
10																					
11																					
12																					
13																					
14																					
15	20							90							140						
16		17							88							145					
17			15							85							135				
18				15							82							125			
19					15							80							117		
20						15							80							115	
21							15							80							115
22																					
23																					
24																					
25																					
26																					
27																					
28																					
29																					
30																					
31																					

RQ'D NBC (E), **FCST NBC** (F)

KANSAS CITY TARGET
710

	RQ'D NBC 0	1	2	3	4	FCST NBC 0	1	2	3	4
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15	575					670				
16		585					678			
17			593					687		
18				595					694	
19					595					698
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
31										

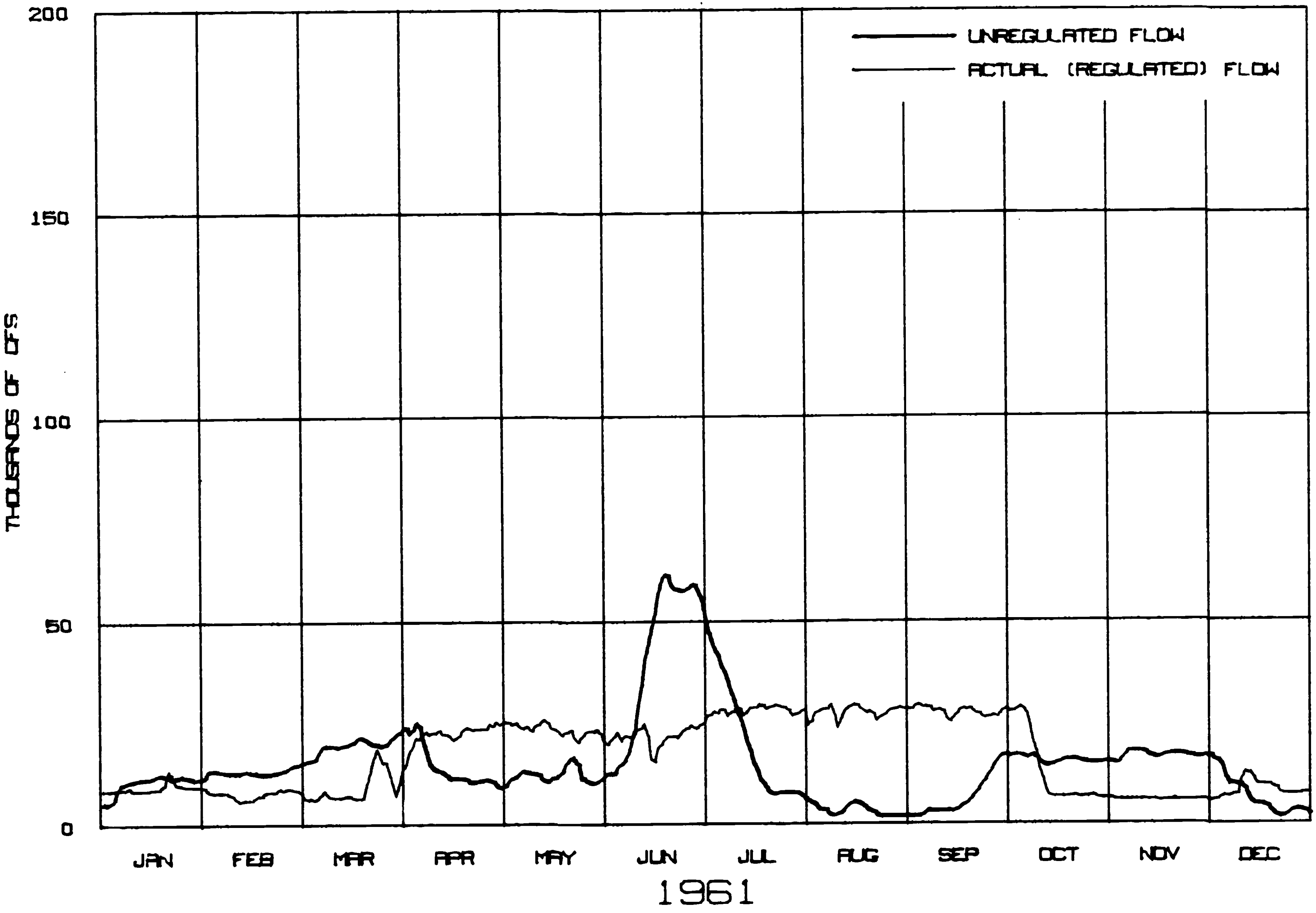
FORECASTS — GVP DATE (G), RLO (H)

GVP DATE		RLO 0	1
	1		
	2		
	3		
	4		
1	5		
2	6		
3	7		
4	8		
5	9		
6	10		
7	11		
8	12		
9	13		
10	14	850	
11	15	760	
12	16		704
13	17		708
14	18		710
15	19		716
16	20		
17	21		
18	22		
19	23		
20	24		
21	25		
22	26		
23	27		
24	28		
25	29		
26	30		
27	31		
28			
29			
30			
31			

FORECASTS — RLO-MKC (I), MKC (J)

	RLO-MKC 1	2	MKC 1	2	3
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16	105		910		
17		100		832	
18		97			803
19		95			800
20		95			808
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					

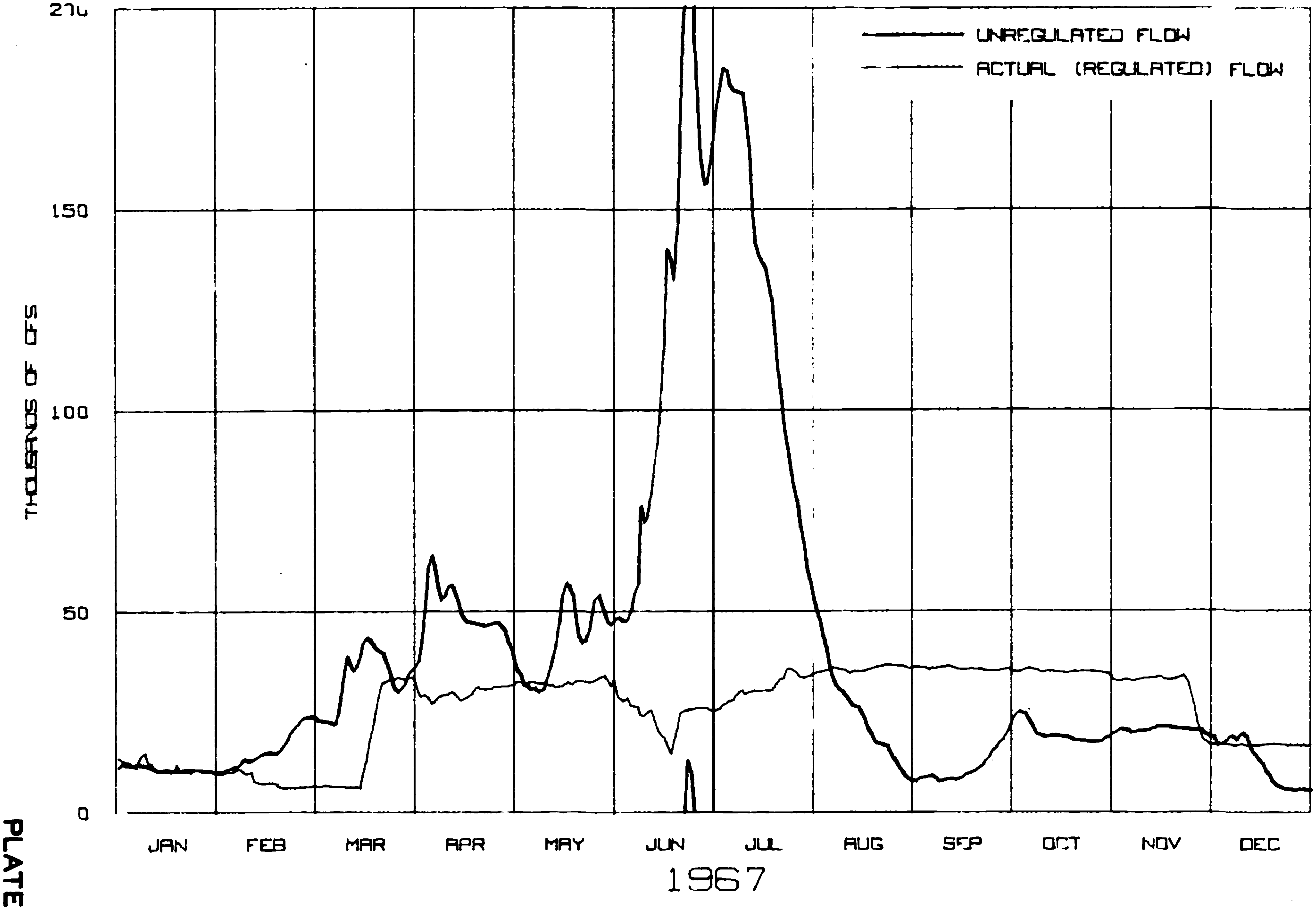
A B C D E F G H I J



ACTUAL AND UNREGULATED FLOWS

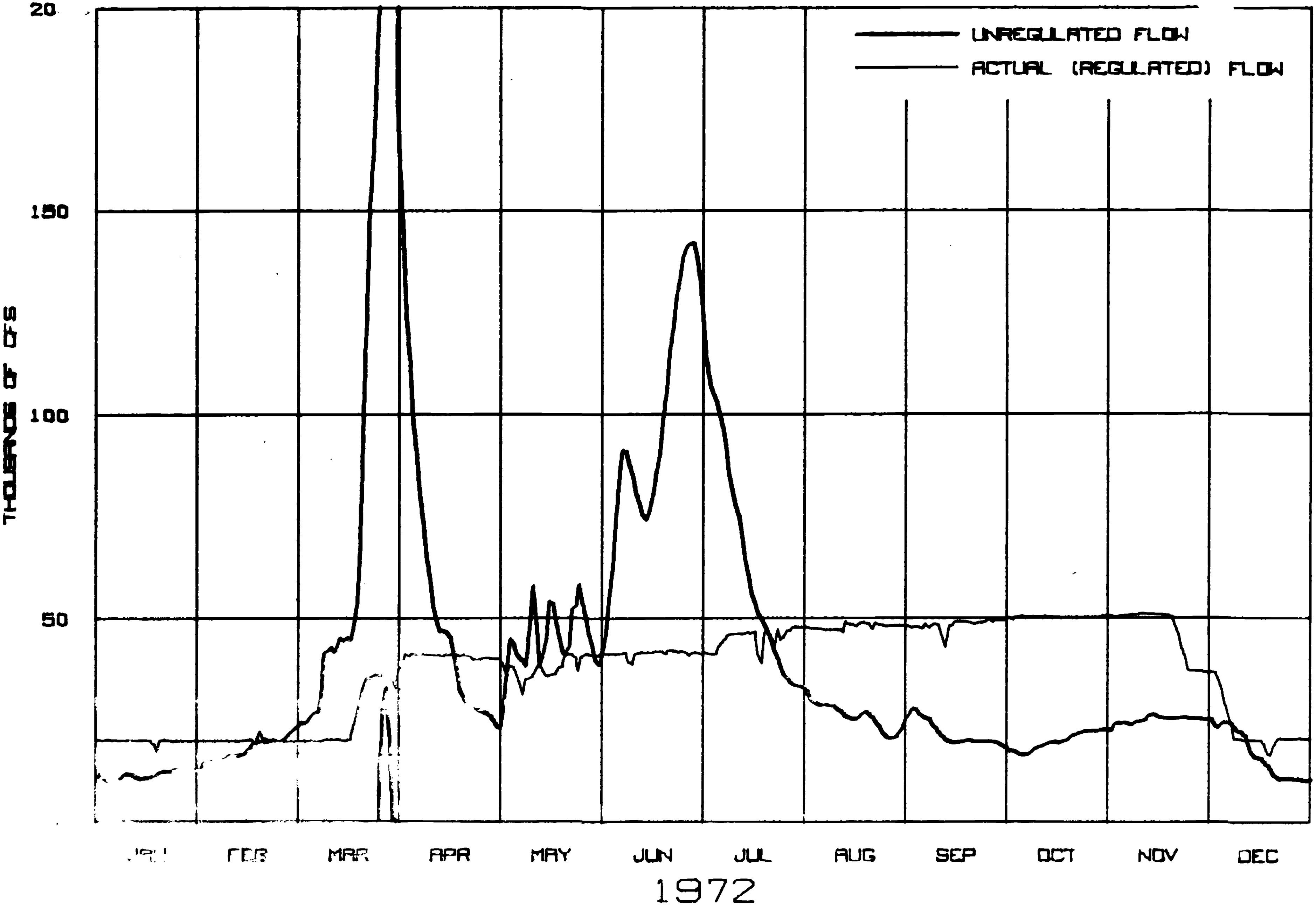
MISSOURI RIVER AT GAVINS POINT DAM

PLATE 42

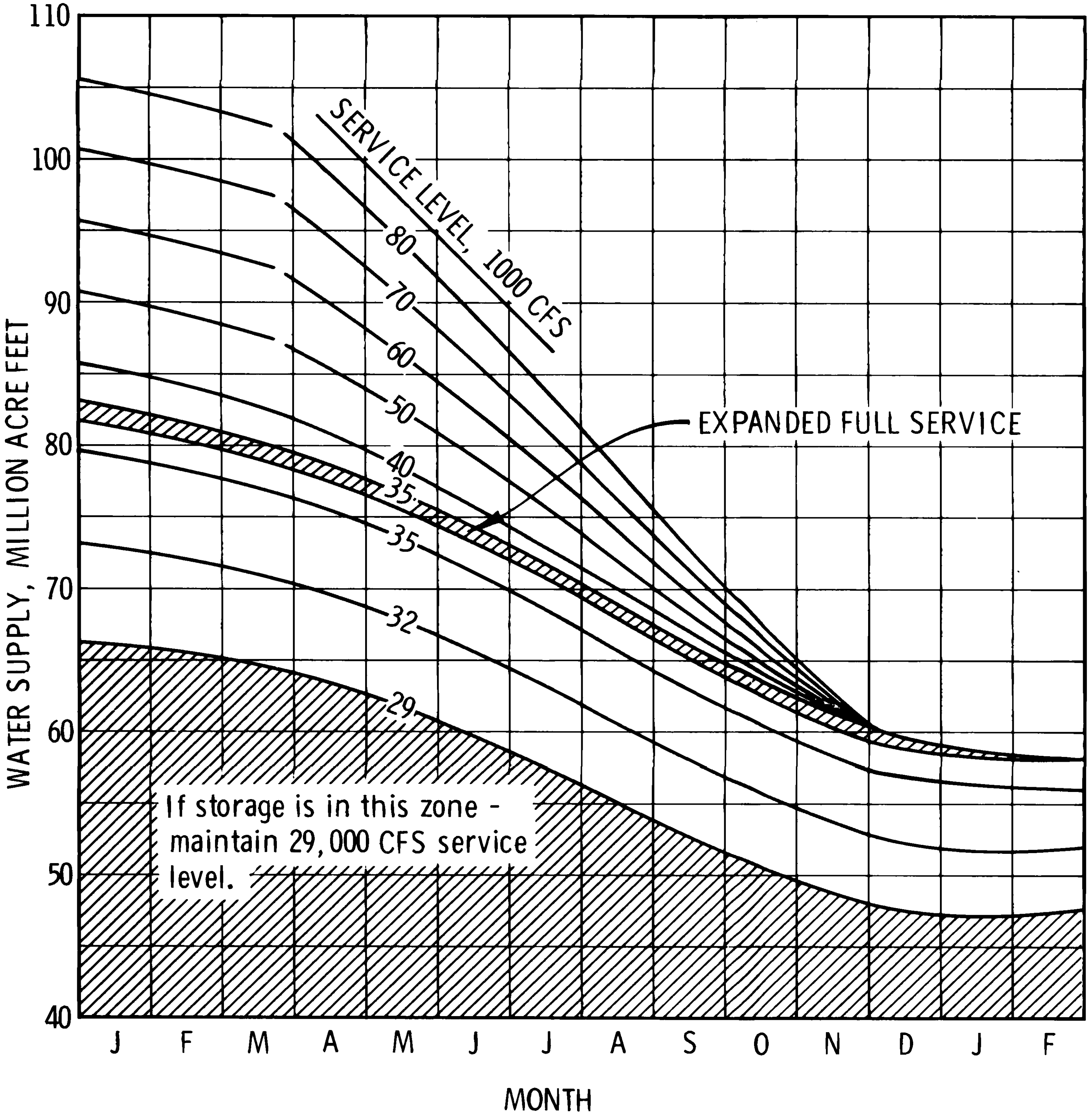


ACTUAL AND UNREGULATED FLOWS

MISSOURI RIVER AT GAVINS POINT DAM



ACTUAL AND UNREGULATED FLOWS
MISSOURI RIVER AT GAVINS POINT DAM



NOTES:

1. Water supply consists of the accumulation of the following:
   a. System storage
   b. Forecast remaining calendar year runoff (1949 basin development level) above Gavins Point Dam.
   c. Departure of total tributary storage from base level. (See text).
2. Expanded full-service consists of the following:
   a. Maintenance of 35,000 cfs service level through the navigation season.
   b. Extension of the navigation season for up to 10 days beyond the normal closing date of 1 December at the mouth of the Missouri River.
   c. Winter releases averaging 20,000 cfs from Gavins Point.
3. The relationship between the service level and target flow is as given in the table below:

Service Level 1,000 CFS	Target Flows - 1,000 CFS		
	Sioux City & Omaha	Nebraska City	Kansas City
29.0[1]	25.0	31.0	35.0
35.0[2]	31.0	37.0	41.0
40.0[3]	36.0	42.0	46.0
50.0[3]	46.0	52.0	56.0

[1] Minimum service level.

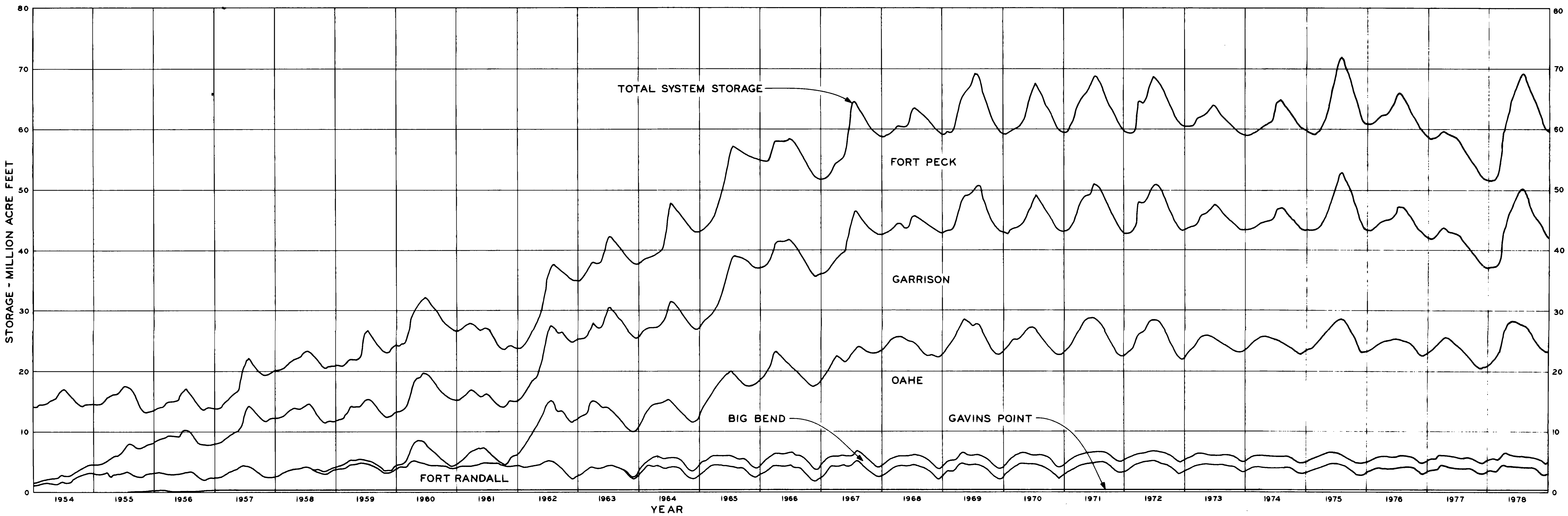
[2] Full service level.

[3] Storage evacuation service level.

MISSOURI RIVER
MAIN STEM RESERVOIR SYSTEM

SERVICE LEVELS

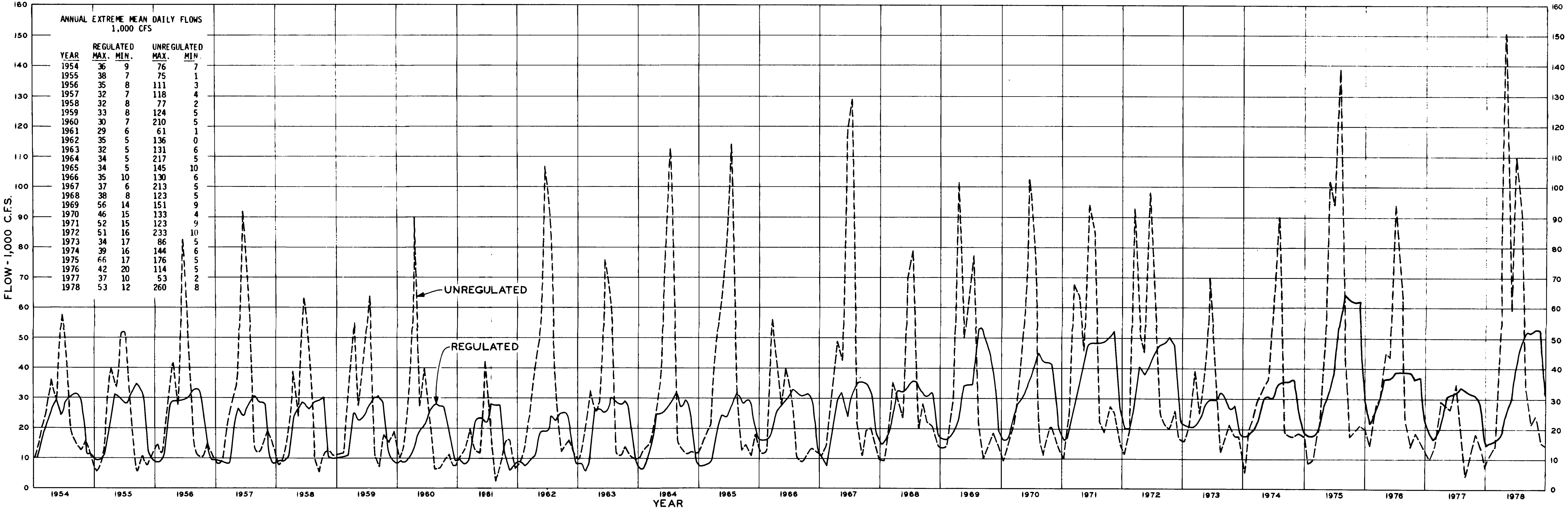
PLATE 44



HISTORICAL STORAGE ACCUMULATION

PLATE 45

☆ U.S. GOVERNMENT PRINTING OFFICE 1972 760 641



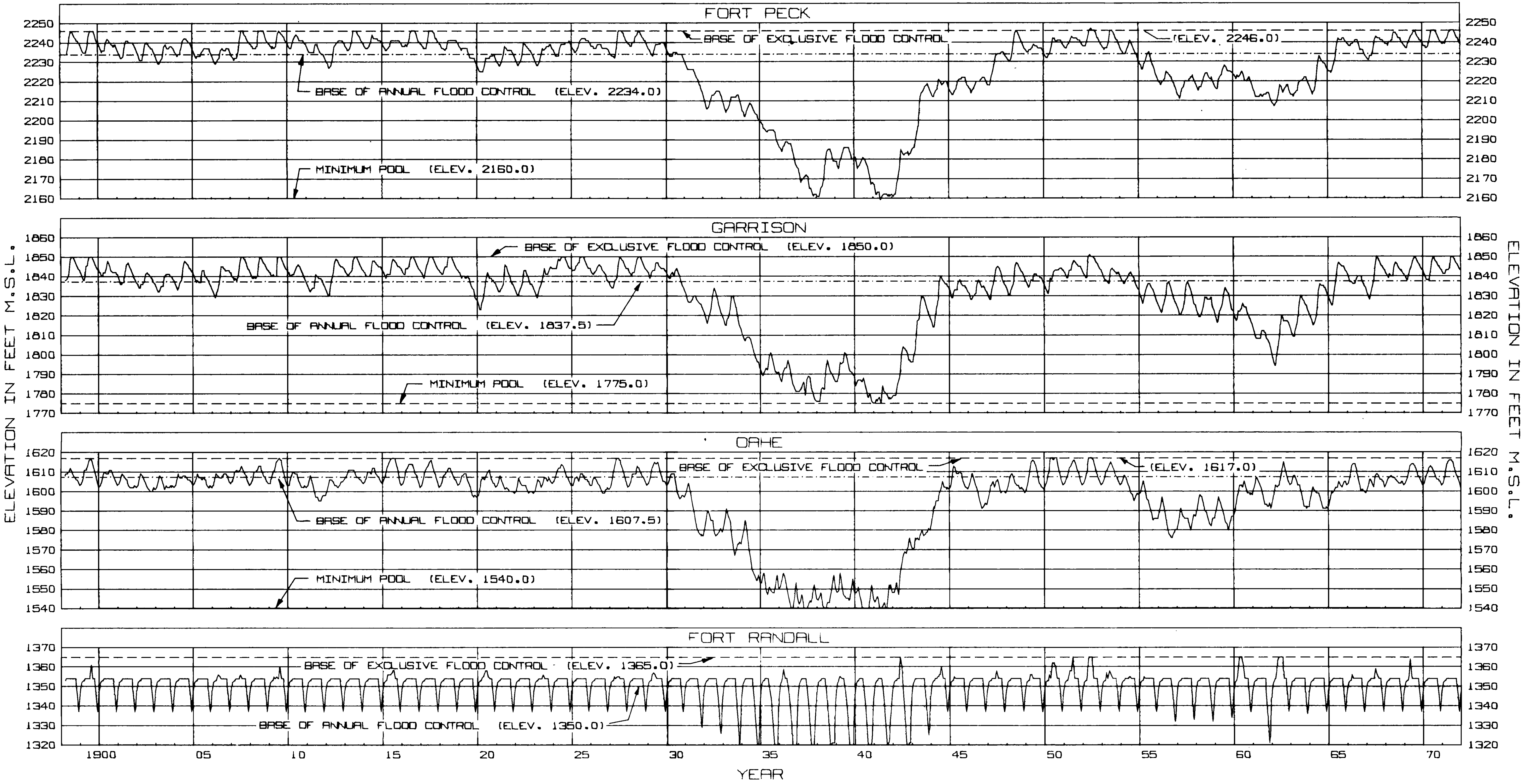
ANNUAL EXTREME MEAN DAILY FLOWS
1,000 CFS

	REGULATED		UNREGULATED	
YEAR	MAX.	MIN.	MAX.	MIN.
1954	36	9	76	7
1955	38	7	75	1
1956	35	8	111	3
1957	32	7	118	4
1958	32	8	77	2
1959	33	8	124	5
1960	30	7	210	5
1961	29	6	61	1
1962	35	5	136	0
1963	32	5	131	6
1964	34	5	217	5
1965	34	5	145	10
1966	35	10	130	6
1967	37	6	213	5
1968	38	8	123	5
1969	56	14	151	9
1970	46	15	133	4
1971	52	15	123	9
1972	51	16	233	10
1973	34	17	86	5
1974	39	16	144	6
1975	66	17	176	5
1976	42	20	114	5
1977	37	10	53	2
1978	53	12	260	8

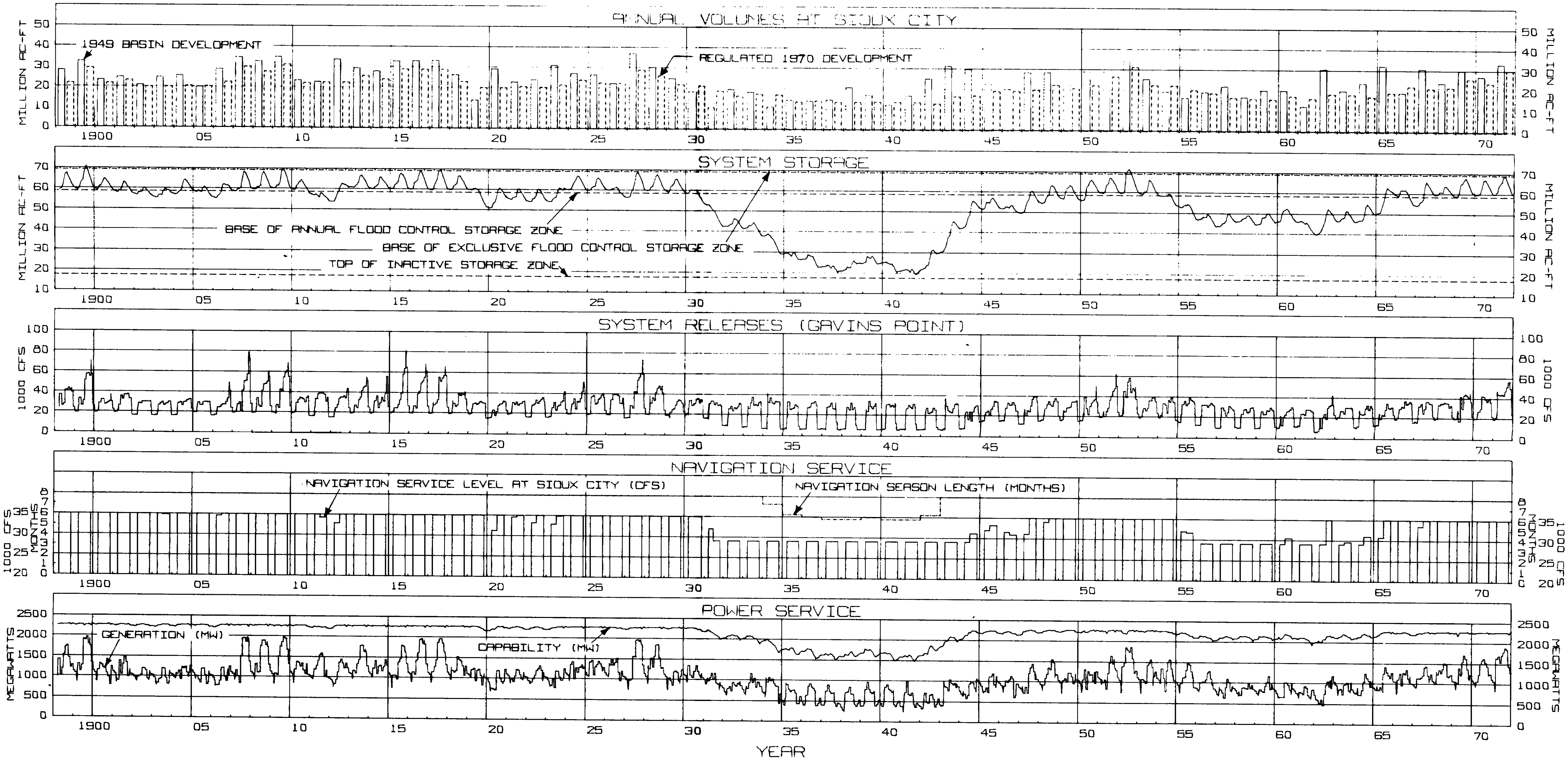
HISTORICAL MEAN MONTHLY REGULATION EFFECTS AT YANKTON, S.D.

PLATE 46

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972-760-644



MISSOURI RIVER MAIN STEM RESERVOIR REGULATION, POOL ELEVATIONS, STUDY 1-74-1970



MISSOURI RIVER MAIN STEM RESERVOIR OPERATIONS, STUDY 1-74-1970

PLATE 48

SIMULATED REGULATION FOR 1951-1952-1944-1945 FLOOD COMBINATION - SHEET 1

		1951												1952		
		22MAR	31MAR	30APR	31MAY	30JUN	31JUL	31AUG	30SEP	31OCT	15NOV	30NOV	31DEC	31JAN	28FEB	15MAR
						FORT PECK										
REACH INF,1000AF	8773	223	287	911	1499	1508	881	434	489	522	233	233	318	384	526	323
EVAP,1000 AF	481	0	0	0	33	24	93	96	90	62	28	28	24	0	0	0
INF ADJUST,1000AF	-824	13	16	3	-465	-470	-294	43	133	-71	24	24	-34	162	88	2
MOD INF,1000AF	7467	236	304	914	1000	1013	493	380	531	388	228	228	259	546	614	325
STORAGE,1000AF	15300	15453	15669	16285	16610	16969	16725	16367	16453	16534	16614	16694	16259	16036	15950	15904
POOL ELEV,FT MSL	2234.4	2235.1	2236.1	2238.8	2240.2	2241.8	2240.7	2239.2	2239.6	2239.9	2240.3	2240.6	2238.7	2237.7	2237.4	2237.2
RELEASE,1000AF	6863	83	69	297	676	654	737	737	446	307	148	148	694	768	700	371
RELEASE,1000CFS	9.5	6.0	5.0	5.0	11.0	11.0	12.0	12.0	7.5	5.0	5.0	5.0	11.3	12.5	12.5	12.5
AVERAGE POWER,MW	132	82	69	69	153	154	168	167	105	70	70	70	157	173	173	173
PEAK POWER,MW		200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
ENERGY,1000MWH	1160.1	13.9	15.0	50.4	114.3	111.0	125.1	124.8	75.6	52.4	25.4	25.4	117.5	129.3	117.6	62.4
						GARRISON										
REACH INF,1000AF	11939	187	240	1969	1374	2201	1702	1044	822	717	321	321	90	319	484	147
EVAP,1000 AF	549	0	0	0	36	26	105	112	105	70	32	33	27	0	0	0
INF ADJUST,1000AF	-606	33	43	55	-161	-492	-120	-165	-65	84	20	20	21	25	29	65
MOD INF,1000AF	17646	303	372	2321	1852	2337	2214	1504	1097	1038	456	456	778	1112	1213	585
STORAGE,1000AF	18200	18334	18261	19095	19411	20498	20868	20528	19841	20264	20423	20583	19977	19399	18931	18624
POOL ELEV,FT MSL	1837.0	1837.5	1837.2	1839.8	1840.8	1844.0	1845.0	1844.1	1842.2	1843.4	1843.8	1844.2	1842.5	1840.8	1839.3	1838.4
RELEASE,1000AF	17221	168	446	1487	1537	1249	1844	1844	1785	614	297	297	1383	1690	1681	892
RELEASE,1000CFS	23.8	12.2	25.0	25.0	25.0	21.0	30.0	30.0	30.0	10.0	10.0	10.0	22.5	27.5	30.0	30.0
AVERAGE POWER,MW	294	150	300	302	306	261	374	374	371	129	130	130	281	338	364	362
PEAK POWER,MW		446	445	455	459	460	460	460	460	460	460	460	460	459	453	449
ENERGY,1000MWH	2577.8	25.3	64.8	217.8	227.7	188.5	278.5	278.6	267.5	96.4	46.9	47.0	209.3	251.8	247.4	130.3
						OAHE										
REACH INF,1000AF	1266	53	68	933	-78	185	50	20	105	44	-54	-54	-68	-71	78	53
EVAP,1000 AF	481	0	0	0	32	23	89	96	94	66	28	27	22	0	0	0
INF ADJUST,1000AF	88	-14	-16	-39	80	-62	-37	-24	-37	-13	61	61	82	85	-22	-14
MOD INF,1000AF	18095	208	496	2381	1506	1349	1768	1744	1758	579	275	276	1375	1704	1737	932
STORAGE,1000AF	19100	18982	19122	20135	20412	20571	21110	21821	22495	21077	20249	19397	16659	18867	19610	20131
POOL ELEV,FT MSL	1607.1	1606.7	1607.1	1610.2	1611.1	1611.6	1613.2	1615.4	1617.2	1613.1	1610.6	1608.0	1605.7	1606.4	1608.6	1610.2
RELEASE,1000AF	17063	325	357	1368	1229	1190	1229	1033	1084	1998	1103	1128	2112	1497	994	411
RELEASE,1000CFS	23.6	23.4	20.0	23.0	20.0	20.0	20.0	16.8	18.2	32.5	37.1	37.9	34.4	24.4	17.7	13.8
AVERAGE POWER,MW	311	302	258	300	265	266	267	227	249	438	492	495	441	312	231	183
PEAK POWER,MW		685	685	685	685	685	685	685	685	885	685	685	685	685	685	685
ENERGY,1000MWH	2726.8	50.9	55.9	216.6	197.5	191.8	199.4	169.6	179.3	326.6	177.2	178.3	328.7	232.4	156.7	66.0
						BIG BEND										
EVAP,1000 AF	60	0	0	0	4	3	11	12	11	7	3	3	3	0	0	0
AVERAGE POWER,MW	107	106	89	100	85	84	82	69	79	155	181	185	168	116	81	61
PEAK POWER,MW		487	487	454	459	440	426	454	491	529	537	538	531	506	495	495
ENERGY,1000MWH	941.5	17.9	19.4	72.6	63.5	60.8	61.3	51.8	57.2	115.6	65.3	66.9	125.1	86.8	55.0	22.3
						FORT RANDALL										
REACH INF,1000AF	1181	33	42	103	131	218	77	23	56	100	60	60	6	24	119	128
EVAP,1000 AF	70	0	0	0	5	3	14	15	13	8	3	3	2	0	0	0
INF ADJUST,1000AF	-161	-3	-4	-21	-19	-34	-33	-17	-17	-4	0	0	-1	-1	-1	-3
MOD INF,1000AF	17953	354	394	1450	1332	1367	1248	1011	1098	2077	1155	1180	2112	1520	1112	535
STORAGE,1000AF	3700	3783	3760	4116	4072	4262	4392	4115	3746	3218	2868	2543	3184	3598	3701	3701
POOL ELEV,FT MSL	1353.0	1354.0	1354.0	1357.9	1357.4	1359.5	1360.9	1357.9	1353.6	1346.9	1342.2	1337.5	1346.5	1351.8	1353.0	1353.0
RELEASE,1000AF	17951	271	397	1115	1376	1177	1118	1288	1467	2606	1505	1505	1471	1106	1008	535
RELEASE,1000CFS	24.8	19.6	22.3	18.7	22.4	19.8	18.2	21.0	24.7	42.4	50.6	50.6	23.9	18.0	18.0	18.0
AVERAGE POWER,MW	192	161	183	157	190	170	159	181	204	322	299	277	176	143	147	148
PEAK POWER,MW		338	338	353	352	360	365	353	337	307	285	264	305	329	334	334
ENERGY,1000MWH	1684.7	27.1	39.6	113.7	141.4	122.5	118.4	134.7	147.5	240.0	107.7	100.0	131.3	107.1	100.3	53.5
1951		22MAR	31MAR	30APR	31MAY	30JUN	31JUL	31AUG	30SEP	31OCT	15NOV	30NOV	31DEC	31JAN	28FEB	15MAR
						GAVINS POINT										
REACH INF,1000AF	2363	65	84	296	235	343	19	289	242	171	13	13	63	115	171	242
EVAP,1000 AF	31	0	0	0	2	1	6	6	6	4	1	1	1	0	0	0
INF ADJUST,1000AF	-140	-4	-5	-5	-10	-24	-26	-38	-23	-14	6	6	1	1	0	-4
RELEASE,1000AF	20143	332	476	1406	1599	1494	1104	1532	1679	2758	1523	1523	1533	1222	1179	773
RELEASE,1000CFS	27.8	24.0	26.7	23.6	26.0	25.1	18.0	24.9	28.2	44.9	51.2	51.2	24.9	19.9	21.1	26.0
AVERAGE POWER,MW	75	72	79	71	77	75	56	75	83	95	92	92	75	61	64	77
PEAK POWER,MW		97	99	96	99	99	75	99	99	95	92	92	99	82	86	99
ENERGY,1000MWH	662.3	12.2	17.2	51.5	57.9	54.4	41.8	55.8	60.3	70.7	33.4	33.4	55.9	45.9	43.9	28.0
						MAIN STEM SYSTEM										
REACH INF,1000AF	29276	656	843	4999	5588	5089	3322	2092	2032	1721	562	562	431	725	1619	1044
EVAP,1000 AF	1675	0	0	0	113	82	319	339	321	219	99	98	81	0	0	0
INF ADJUST,1000AF	-1872	21	27	-40	-595	-1114	-556	-240	-40	-27	110	110	68	271	90	41
STORAGE,1000AF	58300	58721	59001	61800	62673	64469	65264	65000	64703	63261	62323	61385	60248	60068	60360	60529
AVERAGE POWER,MW	1112	876	980	1003	1078	1012	1108	1095	1093	1211	1266	1252	1300	1146	1063	1006
PEAK POWER,MW		2255	2256	2246	2255	2244	2213	2252	2272	2277	2260	2240	2280	2263	2256	2264
ENERGY,1000MWH	9753.3	147.2	211.9	722.7	802.3	729.0	824.5	815.3	787.5	901.7	455.8	451.0	967.7	853.3	720.9	362.5
SVC LVL,1000CFS		35.0	35.0	35.0	35.0	35.0	38.0	41.0	45.0	55.0	60.0	60.0				
NAV LENGTH		20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
CONTROL POINT		11	992	902	9992	9992	9992	9992	9992	994	994	994	11	11	11	11
						SIOUX CITY										
REACH INF,1000AF	3751	93	119	777	427	634	593	282	318	167	-12	-12	22	-46	241	147
INF ADJUST,1000AF	-229	-3	-4	-33	-20	-32	-46	-39	-31	-9	0	0	-1	-1	-4	-3
MOD INF,1000AF	3522	89	115	744	407	602	547	243	287	158	-12	-12	21	-47	237	143
FLOW, 1000AF	23666	422	591	2149	2005	2096	1651	1775	1966	2916	1511	1511	1554	1175	1416	917
FLOW, 1000CFS	32.7	30.4	33.1	36.1	32.6	35.2	26.9	28.9	33.1	47.4	50.8	50.8	25.3	19.1	25.3	30.8
						OMAHA										
REACH INF,1000AF	3879	132	170	755	545	392	444	552	284	28	30	30	79	90	291	54
INF ADJUST,1000AF	-33	-1	-2	-6	-6	-8	-6	-2	0	0	0	0	0	0	0	-1
MOD INF,1000AF	3846	131	168	749	539	384	438	550	284	28	30	30	79	90	291	53
FLOW, 1000AF	27485	528	751	2889	2555	2473	2115	2319	2238	2901	1531	1541	1710	1284	1689	954
FLOW, 1000CFS	37.9	38.0	42.1	48.6	41.6	41.6	34.4	37.7	37.6	47.2	51.5	51.6	27.8	20.9	30.1	32.1
						NEBRASKA CITY										
REACH INF,1000AF	8035	275	354	573	912	1331	781	562	537	496	227	227	345	406	732	276
INF ADJUST,1000AF	-947	-2	-3	7	-21	-87	-129	-129	-119	-84	-31	-31	3	-60	-182	-79
MOD INF,1000AF	7087	273	351	580	891	1244	652	433	418	412	196	196	348	346	550	197
FLOW, 1000AF	34564	792	1100	3466	3450	3714	2775	2750	2652	3299	1724	1737	2083	1636	2232	1145
FLOW, 1000CFS	47.7	57.1	61.6	58.3	56.1	62.4	45.1	44.7	44.6	53.7	58.0	58.4	33.9	26.6	39.9	38.5
						KANSAS CITY										
REACH INF,1000AF	28938	125	160	755	3153	5906	9363	2207	3460	1110	472	472	355	381	518	500
INF ADJUST,1000AF	-333	0	-1	-50	-34	-1019	-808	802	-5	684	77	77	-6	-9	-30	-10
MOD INF,1000AF	28605	124	159	705	3119	4887	8555	3009	3455	1794	549	549	349	372	488	489
FLOW, 1000AF	63134	883	1249	4159	6583	8591	11363	5751	6090	5835	2260	2286	2534	2033	2696	1613
FLOW, 1000CFS	87.1	63.6	70.0	69.9	107.1	144.4	184.8	93.5	102.4	81.9	76.0	76.9	41.2	33.1	48.1	54.2
						BOONVILLE										
REACH INF,1000AF	13785	149	192	1490	845	1035	4722	939	1215	351	355	355	562	499	452	623
INF ADJUST,1000AF	-93	-5	-7	-19	-19	-28	0	0	0	0	0	0	0	0	-9	-5
MOD INF,1000AF	13692	144	185	1471	826	1007	4722	939	1215	351	355	355	562	499	443	617
FLOW, 1000AF	76791	993	1423	5618	7423	9587	16119	6682	7288	5329	2601	2641	3199	2556	3114	2209
FLOW, 1000CFS	106.0	71.6	79.8	94.4	120.7	161.1	262.2	108.7	122.5	86.7	87.4	88.8	52.0	41.6	55.6	74.3
						HERMANN										
REACH INF,1000AF	28844	643	826	1778	1310	1440	8947	974	3993	1547	1262	1262	1326	1121	1703	710
INF ADJUST,1000AF	-89	-22	-29	-86	-88	47	74	89	150	-82	-22	-22	-20	-19	-33	-24
MOD INF,1000AF	28754	620	797	1692	1222	1487	9021	1063	4143	1465	1240	1240	1306	1102	1670	685
FLOW, 1000AF	105528	1597	2216	7304	8652	11069	25157	7741	11423	6765	3834	3881	4556	3671	4772	2883
FLOW, 1000CFS	145.7	115.1	124.1	122.8	140.7	186.0	409.1	125.9	192.0	110.0	128.9	130.5	74.1	59.7	85.2	96.9

SIMULATED REGULATION FOR 1951-1952-1944-1945 FLOOD COMBINATION - SHEET 2

		1952				1944								1945		
		22MAR	31MAR	30APR	31MAY	30JUN	31JUL	31AUG	30SEP	31OCT	15NOV	30NOV	31DEC	31JAN	28FEB	15MAR
FORT PECK																
REACH INF,1000AF	9036	283	363	1541	1693	1740	914	375	309	339	163	163	270	375	343	163
EVAP,1000 AF	518	0	0	0	34	25	101	107	99	66	29	29	24	0	0	0
INF ADJUST,1000AF	-1251	2	3	-162	-523	-540	-304	-46	136	12	25	25	-5	38	67	18
MOD INF,1000AF	7266	285	366	1379	1135	1174	508	221	345	284	159	159	240	413	410	182
STORAGE,1000AF	15644	15846	16123	17205	18033	18969	18928	18398	17799	17313	17071	16828	16374	16018	15728	15539
POOL ELEV,FT MSL	2236.0	2236.9	2238.1	2242.8	2246.4	2250.0	2250.1	2247.5	2245.4	2243.3	2242.3	2241.2	2239.2	2237.7	2236.4	2235.5
RELEASE,100CAF	7371	83	89	297	307	297	489	851	844	770	401	402	694	768	700	371
RELEASE,1000CFS	10.2	6.0	5.0	5.0	5.0	5.0	8.0	13.9	14.2	12.5	13.5	13.5	11.3	12.5	12.5	12.5
AVERAGE POWER,MW	142	83	69	70	71	71	112	195	200	176	189	189	158	173	173	172
PEAK POWER,MW		200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
ENERGY,1000MWH	1251.3	14.0	15.1	50.8	52.8	51.2	83.8	145.3	144.0	131.2	68.3	68.2	117.6	129.4	117.4	62.1
GARRISON																
REACH INF,1000AF	17222	129	166	4802	2097	4346	2469	567	395	460	214	214	250	238	365	508
EVAP,1000 AF	603	0	0	0	41	29	119	125	115	76	34	33	27	0	0	0
INF ADJUST,1000AF	-929	57	73	131	-54	-749	-345	-64	-37	18	4	4	35	1	-6	0
MOD INF,1000AF	23060	270	329	5230	2309	3864	2494	1229	1087	1171	585	586	952	1007	1059	881
STORAGE,1000AF	18861	18962	18845	21969	22102	23664	23695	22898	22101	21315	20934	20555	20124	19440	18819	18808
POOL ELEV,FT MSL	1839.1	1839.4	1839.1	1848.1	1848.5	1852.7	1852.8	1850.7	1848.5	1846.3	1845.2	1844.2	1843.0	1840.9	1839.0	1838.9
RELEASE,1000AF	23113	168	446	2106	2176	2302	2464	2025	1884	1958	965	965	1383	1690	1681	892
RELEASE,1000CFS	31.9	12.2	25.0	35.4	35.4	38.7	40.1	32.9	31.7	31.8	32.5	32.5	22.5	27.5	30.0	30.0
AVERAGE POWER,MW	393	152	303	438	447	460	460	421	402	402	406	404	281	339	364	362
PEAK POWER,MW		454	452	460	460	460	460	460	460	460	460	460	460	460	452	452
ENERGY,1000MWH	3447.0	25.6	65.7	315.6	332.8	331.2	342.2	313.3	290.0	299.1	146.4	145.7	209.5	252.3	247.2	130.4
OAHE																
REACH INF,1000AF	6456	47	60	3650	230	1299	40	145	61	30	76	76	-105	16	365	463
EVAP,1000 AF	504	0	0	0	37	26	101	106	95	61	27	27	22	0	0	0
INF ADJUST,1000AF	-529	-12	-16	-288	-18	-70	-34	-48	-18	-3	-2	-2	119	-2	-93	-41
MOD INF,1000AF	28535	203	490	5468	2351	3505	2369	2016	1831	1924	1012	1013	1374	1704	1953	1314
STORAGE,1000AF	20153	20007	20141	23506	23506	23506	23431	22010	20498	19827	19806	19762	18872	18989	19884	20797
POOL ELEV,FT MSL	1610.3	1609.9	1610.3	1620.0	1620.0	1620.0	1619.8	1615.9	1611.4	1609.3	1609.2	1609.1	1606.4	1606.7	1609.5	1612.3
RELEASE,1000AF	27890	349	357	2103	2351	3505	2443	3437	3343	2596	1033	1057	2264	1588	1058	401
RELEASE,1000CFS	38.5	25.1	20.0	35.4	38.2	58.9	39.7	55.9	56.2	42.2	34.7	35.6	36.6	25.8	18.9	13.5
AVERAGE POWER,MW	493	331	264	477	525	685	545	685	685	554	453	464	476	332	246	180
PEAK POWER,MW		685	685	685	685	685	685	685	685	685	685	685	685	685	685	685
ENERGY,1000MWH	4326.7	55.7	57.1	343.8	390.9	493.2	406.0	509.6	493.2	412.7	163.4	167.1	354.3	247.3	167.3	65.1
BIG BEND																
EVAP,1000 AF	60	0	0	0	4	3	11	12	11	7	3	3	3	0	0	0
AVERAGE POWER,MW	168	112	86	139	144	219	159	257	258	202	169	174	180	123	86	60
PEAK POWER,MW		471	459	349	410	331	491	491	491	529	537	538	531	506	495	495
ENERGY,1000MWH	1480.8	18.9	18.7	100.5	107.2	157.9	118.8	191.2	186.0	150.8	61.1	62.7	134.2	92.2	58.6	21.8
FORT RANDALL																
REACH INF,1000AF	2598	112	144	1305	139	490	179	180	54	-8	25	25	-174	-69	55	140
EVAP,1000 AF	71	0	0	0	6	3	17	13	12	8	3	3	2	0	0	0
INF ADJUST,1000AF	-187	-3	-4	-19	-28	-41	-35	-33	-18	1	-1	-1	1	1	-1	-6
MOD INF,1000AF	30169	458	497	3389	2452	3947	2559	3559	3355	2572	1049	1074	2085	1520	1112	535
STORAGE,1000AF	3701	3950	4072	5131	4549	5306	3746	3746	3746	3218	2868	2543	3184	3598	3701	3701
POOL ELEV,FT MSL	1353.0	1356.0	1357.4	1368.6	1362.6	1370.3	1353.6	1353.6	1353.6	1346.9	1342.2	1337.5	1346.5	1351.8	1353.0	1353.0
RELEASE,1000AF	30168	208	375	2331	3034	3190	4118	3559	3355	3101	1399	1399	1444	1106	1008	535
RELEASE,1000CFS	41.6	15.0	21.0	39.2	49.3	53.6	67.0	57.9	56.4	50.4	47.1	47.1	23.5	18.0	18.0	18.0
AVERAGE POWER,MW	277	126	177	340	360	360	360	336	336	322	299	277	173	143	147	148
PEAK POWER,MW		346	352	368	368	368	337	337	337	307	285	264	305	329	334	334
ENERGY,1000MWH	2430.0	21.2	38.4	245.3	267.8	259.2	267.8	250.4	242.3	240.0	107.7	100.0	129.0	107.1	100.3	53.5
1952		22MAR	31MAR	30APR	31MAY	30JUN	31JUL	31AUG	30SEP	31OCT	15NOV	30NOV	31DEC	31JAN	28FEB	15MAR
GAVINS POINT																
REACH INF,1000AF	2060	212	273	271	155	218	137	103	79	101	53	53	87	113	133	71
EVAP,1000 AF	31	0	0	0	2	1	6	6	6	4	1	1	1	0	0	0
INF ADJUST,1000AF	-152	-4	-5	-6	-9	-24	-32	-30	-22	-14	-2	-2	2	2	1	-4
RELEASE,1000AF	32045	416	643	2596	3178	3382	4216	3625	3405	3183	1448	1448	1532	1221	1142	601
RELEASE,1000CFS	44.2	30.0	36.0	43.6	51.7	56.9	68.6	59.0	57.2	51.8	48.7	48.7	24.9	19.9	20.4	20.2
AVERAGE POWER,MW	84	88	98	95	92	90	86	89	90	92	93	93	74	61	63	62
PEAK POWER,MW		99	98	95	92	90	86	89	90	92	93	93	99	82	84	83
ENERGY,1000MWH	738.5	14.8	21.2	68.8	68.9	65.3	64.3	66.9	65.2	68.8	33.7	33.7	55.8	45.8	42.7	22.5
MAIN STEM SYSTEM																
REACH INF,1000AF	41390	914	1175	12600	4915	8162	4659	1800	1124	1067	571	571	326	679	1346	1481
EVAP,1000 AF	1790	0	0	0	125	90	356	370	340	224	100	99	81	0	0	0
INF ADJUST,1000AF	-3291	36	46	-375	-652	-1430	-799	-968	-4	3	19	19	151	39	-38	-40
STORAGE,1000AF	60528	60934	61350	69979	70358	73553	71968	69121	66314	63841	62848	61856	60722	60213	60300	61013
AVERAGE POWER,MW	1559	894	1000	1562	1640	1886	1724	1984	1973	1750	1612	1604	1344	1174	1081	987
PEAK POWER,MW		2256	2247	2157	2215	2135	2259	2263	2263	2274	2260	2241	2280	2263	2252	2251
ENERGY,1000MWH	13674.3	150.3	216.1	1124.8	1220.5	1358.0	1283.0	1476.8	1420.7	1302.6	580.6	577.5	1000.4	874.1	733.6	355.4
SVC LVL,1000CFS		55.0	55.0	60.0	65.0	70.0	75.0	65.0	60.0	60.0	60.0	60.0				
NAV LENGTH		20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
CONTROL POINT		11	992	992	992	992	992	994	994	994	994	994	11	11	11	11
SIOUX CITY																
REACH INF,1000AF	4016	129	166	1031	601	69	920	430	226	145	38	38	-2	6	85	132
INF ADJUST,1000AF	-241	-3	-4	-31	-20	-6	-49	-47	-45	-11	-4	-4	-1	-1	-6	-7
MOD INF,1000AF	3775	126	162	1000	581	63	871	383	181	134	34	34	-3	5	79	125
FLOW, 1000AF	35821	542	805	3595	3758	3445	5087	4008	3586	3317	1482	1482	1529	1226	1221	727
FLOW, 1000CFS	49.4	39.1	45.1	60.4	61.1	57.9	82.7	65.2	60.3	54.0	49.8	49.8	24.9	20.0	21.8	24.4
OMAHA																
REACH INF,1000AF	1520	48	61	109	128	512	140	147	73	-1	19	19	-26	17	148	125
INF ADJUST,1000AF	-35	-1	-1	-4	-4	-8	-6	-2	0	0	0	0	0	0	0	-8
MOD INF,1000AF	1485	46	60	105	124	504	134	145	73	-1	19	19	-26	17	148	117
FLOW, 1000AF	37326	564	847	3655	3880	3959	5147	4206	3674	3335	1514	1501	1578	1258	1364	83-
FLOW, 1000CFS	51.5	40.7	47.5	61.4	63.1	66.5	83.7	68.4	61.8	54.3	50.9	50.5	25.7	20.5	24.3	28.1
NEBRASKA CITY																
REACH INF,1000AF	5708	242	311	644	886	1377	508	307	187	148	92	92	126	251	337	200
INF ADJUST,1000AF	-916	-69	-89	-131	-118	-69	-2	-110	-75	-59	-37	-37	-50	-100	23	7
MOD INF,1000AF	4792	172	222	513	768	1308	506	197	112	89	55	55	76	151	360	207
FLOW, 1000AF	42125	729	1063	4152	4648	5270	5628	4421	3791	3431	1573	1556	1679	1414	1722	1041
FLOW, 1000CFS	58.1	52.5	59.6	69.8	75.6	88.6	91.5	71.9	63.7	55.8	52.9	52.3	27.3	23.0	30.7	35.0
KANSAS CITY																
REACH INF,1000AF	12903	437	563	914	1638	1117	1596	1755	1209	549	206	206	1197	433	542	539
INF ADJUST,1000AF	-956	-9	-11	-36	-116	-402	-251	-131	0	0	0	0	0	0	0	0
MOD INF,1000AF	11946	428	551	878	1522	715	1345	1624	1209	549	206	206	1197	433	542	539
FLOW, 1000AF	54097	1124	1590	4969	6167	5998	6824	6115	5020	4005	1795	1762	2975	1867	2256	1571
FLOW, 1000CFS	74.7	81.0	89.1	83.5	100.3	100.8	111.8	99.5	84.4	65.1	60.4	59.3	48.4	30.4	40.3	52.8
BOONVILLE																
REACH INF,1000AF	5717	545	701	544	1382	-36	26	383	339	255	67	67	587	32	408	415
INF ADJUST,1000AF	-107	-5	-6	-18	-18	66	4	-38	-34	-26	-5	-5	0	0	-13	-7
MOD INF,1000AF	5610	540	695	526	1364	30	30	345	305	229	62	62	587	32	395	407
FLOW, 1000AF	59733	1632	2262	5434	7528	6041	6804	6530	5345	4259	1874	1874	3662	1918	2644	1968
FLOW, 1000CFS	82.5	117.6	126.7	91.3	122.4	101.5	110.7	106.2	89.8	69.3	63.0	61.3	59.6	31.2	47.2	66.2
HERMANN																
REACH INF,1000AF	11392	621	799	1729	1156	436	489	995	1036	893	142	142	687	400	737	1129
INF ADJUST,1000AF	-28	-21	-27	-82	-83	64	100	122	205	-112	-30	-30	-27	-26	-45	-33
MOD INF,1000AF	11364	600	771	1647	1073	500	589	1117	1241	781	111	111	660	374	692	1095
FLOW, 1000AF	71110	2216	3021	7050	8600	6548	7344	7682	6595	5053	1994	1936	4372	2302	3332	3058
FLOW, 1000CFS	98.2	159.6	149.3	118.5	139.9	110.0	119.4	124.9	110.8	82.2	67.0	65.1	71.1	37.4	59.5	102.8